SHOALHAVEN CITY COUNCIL

LAKE CONJOLA ENTRANCE STUDY

Issue No. 2
MAY 1999

Patterson Britton
& Partners Pty Ltd
consulting engineers

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INTRODUCTION AND BACKGROUND

ENTRANCE SETTING

Lake Conjola is a coastal lake located about 50 km south of Nowra on the NSW south coast. The lake has a surface area of approximately 4.3 km^2 and a catchment area of 145 km^2.

A shallow sandy inlet some 3 km long separates the main lake, which has water depths up to 10 m, from the ocean. The inlet itself is shallow with extensive intertidal muddy sand flats and an average channel depth of the order of 1 m.

At the entrance to the inlet there is a tidal delta of clean marine sand with pronounced sand lobes which are elevated up to 1 m above mean sea level. The entrance shoals constantly change due to the dynamic interchange between floods, tidal flows, storm waves, littoral sand supply and wind blown sand from Conjola Beach. The restrictive effect of the shallow inlet plus storage attenuation of the main lake, reduces tidal range in the lake to approx 20% of ocean range under typical entrance conditions.

Average tidal flows maintain a relatively small entrance channel which is typically located against the northern foreshore. The entrance is prone to periodic closures; over the last 60 years there have been 8 closures. The entrance can remain closed for years until opened by floods, usually assisted by mechanical excavation of a pilot channel.

When the entrance is closed, lake level builds up in freshes and there can be a marked decline in overall water quality.

Several villages and caravan parks line the lake shoreline and are popular tourist destinations during summer holiday periods. Some properties are flood affected resulting in inundation of septic disposal systems and dwellings. The area is subject to continuing urban growth and the lack of a modern sewerage system results in bacterial pollution during peak occupational periods and flows due to rainfall events. As a result Shoalhaven City Council has a policy of opening the lake when water levels reach 1 m AHD to principally relieve flooding, as well as water quality concerns.

STUDY SETTING

Towards the end of 1994 the entrance, having been open for approximately 5 years, closed and remained closed until the entrance was successfully opened in June 1998. Closure caused considerable hardship and concern to the local communities viz:

- loss of oyster production;
- habitat decline re mangrove and seagrass dieback;
- emergence of algae along inlet foreshores;
- public health related to elevated bacteria and viruses;
- loss of tourism income;
- degradation of foreshore habitat along inlet;
- decline in fish and crustacean catches;
- decline in sea birds;
- decline in aesthetics of lake.

The draft Estuary Management Plan *(SCC, 1998)* was amended to reflect the communities heightened concern about entrance stability and called for an investigation of the costs and benefits of various strategies to alleviate flooding and water quality concerns.

STUDY OBJECTIVES

Arising from the foregoing community concerns, the Lake Conjola Entrance Study was commissioned with the following objectives:

- to develop an understanding of existing lake processes;
- to determine the effect of existing entrance conditions on:

- lake flood behaviour;
- water quality *(particularly faecal contamination)*;

- to determine the relative impact of different entrance channel manipulation on:
  - lake flood behaviour;
  - water quality;
- discuss other options for alleviating water quality and flooding concerns;
- undertake an economic assessment of the various management options in terms of their cost, reduction in flood damages and improvements in water quality.

STUDY SCOPE

The scope of this Entrance Study includes the following tasks.

EXISTING PROCESSES

- analyse and interprět available processes data and develop a conceptual model of sediment transport processes.

EXISTING ENTRANCE

Stability

- determine reasons for the 1994 entrance closure;
- examine effects of rock walls on entrance processes, particularly erosion of entrance dune.

Flooding

- under existing entrance conditions, carry out a preliminary analysis of flooding;
- estimate the nature and extent of flooding under existing condition, using the available database of land and floor levels at risk.

Water Quality

- determine flushing characteristics of the existing estuary;
- identify possible sources and extent of pollution;
- evaluate relative contribution of pollutants from sources.

ENTRANCE MANAGEMENT POLICY

- comment on appropriateness of current entrance opening policy with reference to flooding of property and septic systems, effects on entrance closure and ability to maintain a long term open entrance;
- determine optimal time for the manual opening option, with respect to ocean level;
- discuss implications of an entrance opening policy, based on a higher lake level.

ENTRANCE IMPROVEMENT OPTIONS

- assess a range of options for their capacity to provide a sustainable opening;
- discuss risk of failure *(of each option)* associated with storms and floods;
- estimate the *relative impact* of entrance options on flooding;
- estimate the *relative impact* of entrance options on water quality.

ALTERNATIVE OPTIONS

- briefly discuss alternative entrance management options;
- discuss alternative floodplain management options;
- discuss need for and benefit of preparing and implementing a floodplain management plan.

OPTIONS BENEFIT AND COST ANALYSIS

- prepare preliminary cost estimate of options;
- undertake an economic analysis of benefits of reduced flood damages versus cost of options;
- undertake an economic analysis of benefits and costs from improved water quality;
- collate findings to allow consideration between each management option and its ability to a sustain an opening, cost and improvements to water quality and flooding;
- provide details of environmental assessments needed for approval of each option.

REPORT LAYOUT

The scope of the study embraces a considerable amount of data analysis and interpretation. In order to keep the discussion of the study findings succinct and focussed on entrance management issues, the details of data analyses and analytical methods are provided in a comprehensive list of Technical Appendices.

The Technical Appendices are extensively cross-referenced in the main text so that the interested reader can pursue further technical detail and explanation if required.

The contents of the Technical Appendices can be briefly summarised as follows:

TECHNICAL APPENDIX 1: **Aerial Photograph Analysis**	Chronological presentation of available photography to an approx common scale with annotated process interpretations.
TECHNICAL APPENDIX 2: **Photogrammetry**	Photogrammetric analysis of aerial photographs 1964, 1981, 1993/94 was used to estimate gross volumetric changes of the entrance tidal delta and entrance sand spit over the last 30 years or so.
TECHNICAL APPENDIX 3: **Analysis of Entrance Surveys**	Analysis of hydrographic surveys taken immediately before *(3 Aug)* and after *(16 Sept)* the flood of August 1998, to determine channel erosion and high dune erosion caused by the flood.
TECHNICAL APPENDIX 4: **Wind Transport Regime**	Analysis of hourly wind records from Ulladulla to determine the annual sand drift potential across the entrance sand spit.
TECHNICAL APPENDIX 5: **Longshore Transport Regime**	Analysis of offshore wave data to generate estimates of longshore sand transport within the surf zone of Conjola Beach.
TECHNICAL APPENDIX 6: **Tidal Hydrodynamics**	Analysis of results of hydrodynamic modelling of tidal flows and bed shear stress under 1993 shoaled and existing condition.
TECHNICAL APPENDIX 7: **Flow Gauging Report**	Results of gauging of full ebb and flood tide cycle on 22 September 1988, representing post flood conditions. Results of freshwater flow measurement of Conjola Creek and Jerrawangala Creek.
TECHNICAL APPENDIX 8: **Tidal Delta Sediment Transport Processes**	Analysis and interpretation of field bedform measurements, diver measurements and observations and sediment transport calculations. Development and discussion of conceptual model of sediment transport pathways.
TECHNICAL APPENDIX 9: **Analysis of Entrance Stability**	Analysis of history of entrance behaviour and correlations with rainfall data, data on occurrence of major storms and anecdotal information.
TECHNICAL APPENDIX 11: **Analysis of 1994-1998 Entrance Closure**	Discussion of reasons for entrance closure between the end of 1994 and July 1998 including detailed analysis of lake water level data and rainfall data.
TECHNICAL APPENDIX 12: **Assessment of Pipeline Crossing**	Assessment of the impact of the 1986 water supply pipeline crossing on entrance stability.
TECHNICAL APPENDIX 13: **Hydrologic Modelling**	Description and results of catchment runoff modelling to determine stream hydrographs for "major" and "minor" flood scenarios.
TECHNICAL APPENDIX 14: **Flood Assessment**	Results of hydraulic modelling of flood behaviour of existing entrance conditions including assessment of flood damages.

TECHNICAL APPENDIX 15: **Water Quality Loadings**	Analysis of available water quality data and discussion of relative water quality loadings at various points around the inlet and main lake.
TECHNICAL APPENDIX 16: **Ecological Assessment**	Provides overview of the variability of seagrass coverage with entrance conditions and likely effect of a permanent entrance.
TECHNICAL APPENDIX 17: **Entrance Scour and Opening Protocol**	Results of analysis of current entrance opening protocol *(ie. 1 m AHD)* using a dynamic entrance scour model to optimise scour in relation to the state of the tide at the time of opening and dimensions of the pilot channel.
TECHNICAL APPENDIX 18: **Entrance Options Assessment**	Results of hydraulic modelling and economic assessment of the relative benefits of entrance management options in respect of flood behaviour and water quality.
TECHNICAL APPENDIX 19: **Benefits and Costs of Entrance Options**	Comparative discussion of entrance option stability and present value analysis of time varying costs and benefits.

ENTRANCE PROCESSES

PAST ENTRANCE PROCESSES STUDIES

Entrance processes were examined in the Lake Conjola Entrance Processes Study *(SCC, 1996)*.

Lake Conjola was identified as an immature barrier estuary. It was noted that it has steep valley sides and a central deep basin which was formed when sea level rose *(some 6000 years ago)* to drown the pre-existing river valley. Infilling of the basin by catchment derived sediment has been minor because the catchment consists largely of slowly weathering grits and conglomerates.

The inlet is referred to as a "terminal delta" which has been built up over the eons by marine sand transported in on the flood tide from Conjola Beach under net landward transport by tidal currents and a significant south to north littoral drift of sand. Floods periodically reverse the process causing sand to be carried offshore and deposited in the nearshore zone as shallow sand bars.

The entrance shoals were considered to be growing at an annual rate in the order of 2000m^3 p.a. This trapping of marine sand was considered to occur mainly through tidal action. Winds were considered to transport relatively large quantities of sediment across unvegetated subaerial areas but the relative significance of aeolian transport at the entrance was not quantified. *(N.B. as will be shown later, sand drift is quite significant at the entrance).*

It was noted that the entrance channel has been for the great majority of time located against rocks at the northern extremity of the entrance. It was considered that the entrance was "very stable" compared to other similar tidal inlets on the NSW coast. This perceived stability was attributed in part to the rocky northern shoreline.

It was noted that Hranisavljevic and Nittim *(1992)* found that closure of the Shoalhaven River entrance was directly related to the occurrence of large coastal storms. Unfortunately, the possibility of a similar nexus between entrance closure and storms was not investigated in respect of Lake Conjola because of the perceived stability of the entrance.

As will be shown later, washover fans associated with major to severe storms are a necessary precursor to closure of the Lake Conjola entrance.

Analysis of aerial photographs showed that in the vicinity of the caravan park and southern boat ramp, the main channel has never moved south of its present day location. The channel has temporarily moved northwards due to flood scour across the entrance shoals. Downstream of the boat ramp, it was noted that the high dunes are eroded periodically when the channel is forced against the dunes by the extensive build-up of the entrance shoals.

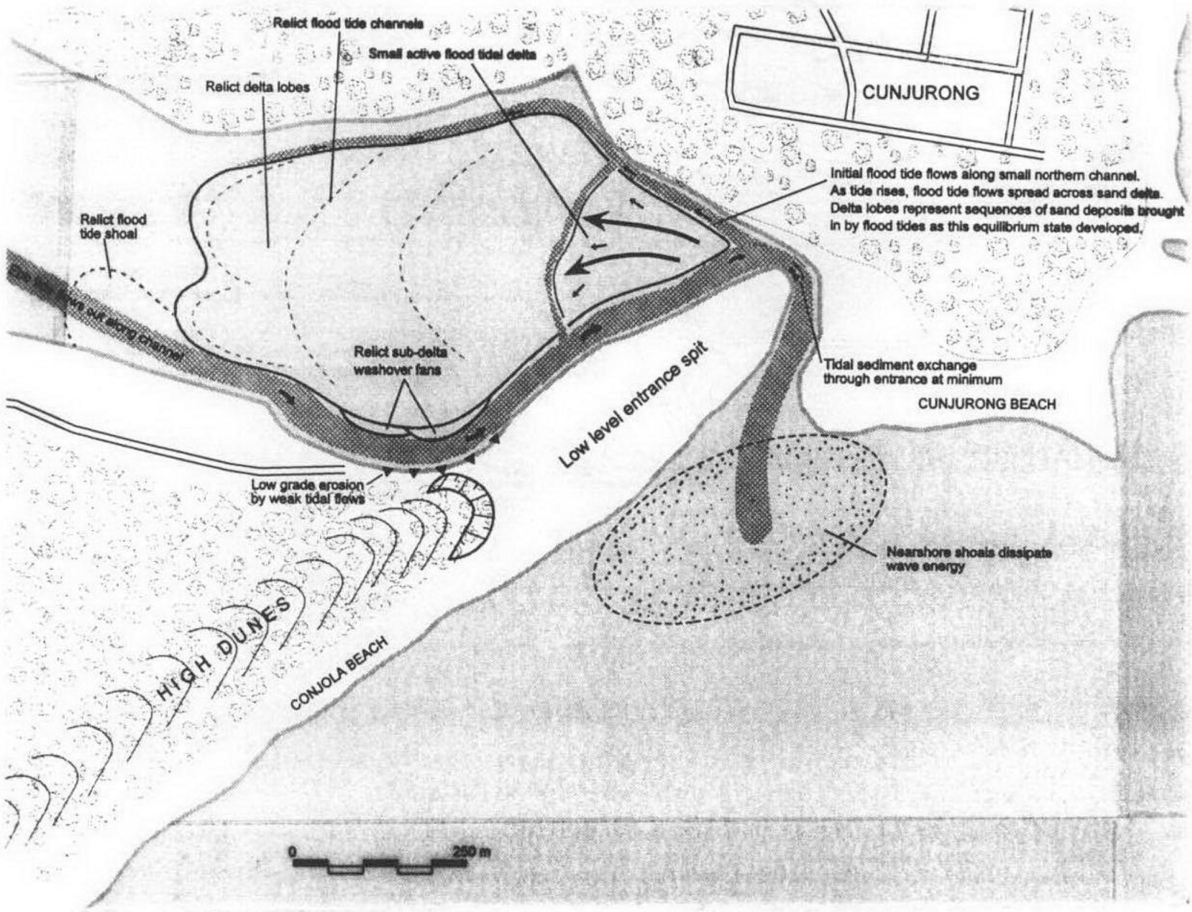
AERIAL PHOTOGRAPH ANALYSIS

An annotated interpretation of aerial photographs is provided in Technical Appendix 1. Apart from entrance closure *(discussed below)*, four basic characteristic entrance states can be recognised.

REGIME STATE	the steady end state that the entrance naturally and gradually establishes in the absence of any sudden changes caused by major floods and storms. This is a state of near equilibrium and should be the aim of any sustainable management plan.
FLOOD SCOURED	sudden change caused by a significant flood leading to a net loss of sand from the entrance shoals and widening of the entrance.
INTERMEDIATE	characterised by relatively rapid infilling of entrance shoals after a major flood and before reaching regime conditions. The intermediate state gradually progresses to the regime state over a period of 1

– 2 years.

STORM WASHOVER sudden change caused by major to severe storm waves washing over the entrance spit leading to blocking of the entrance channel. Entrance closure is likely to ensue.

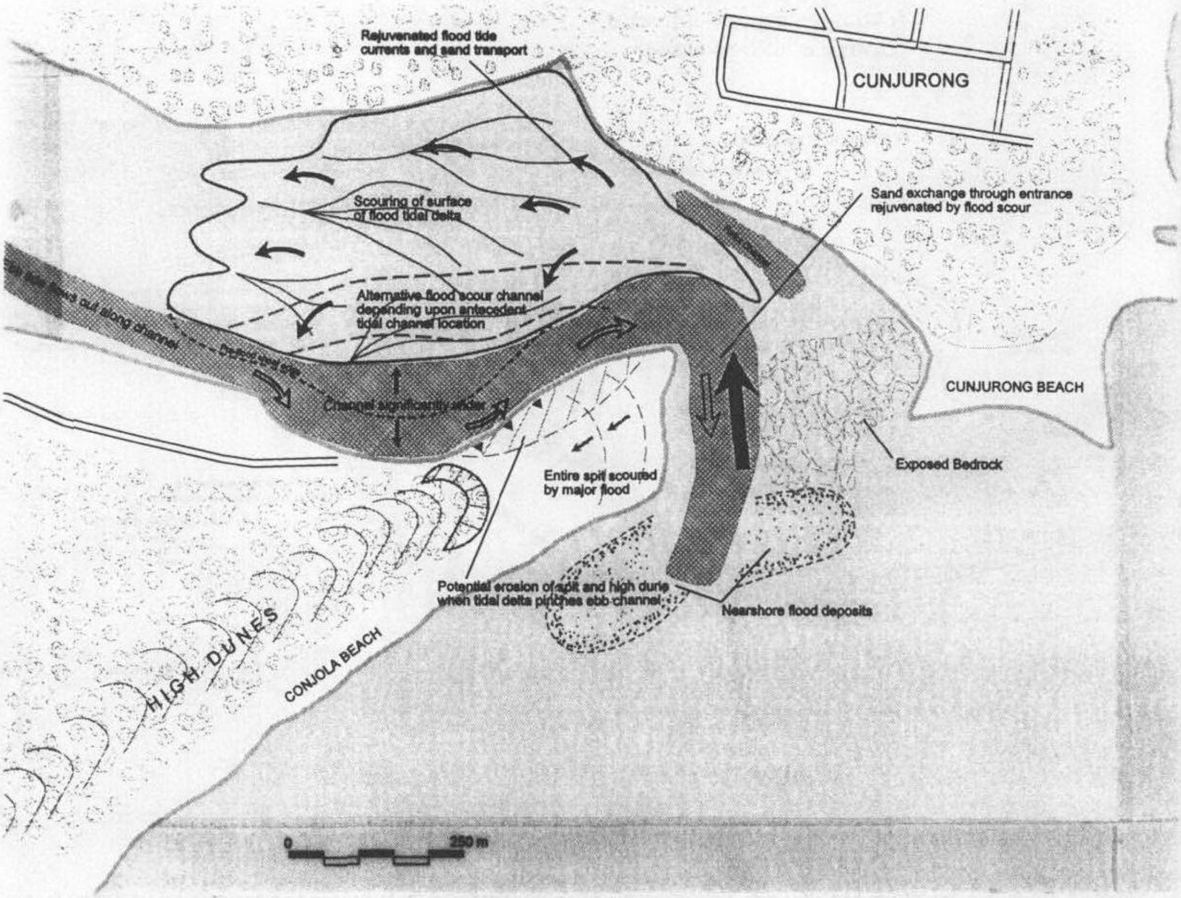


REGIME ENTRANCE STATE

The broad features of the *Regime* entrance state are:

- Entrance is hard against the northern shoreline and channel is quite small;
- Small tidal exchange with limited tidal range in lake – average lake level is elevated well above mean sea level;
- Flood tide delta and low level entrance spit relatively stable but prone to instability from:

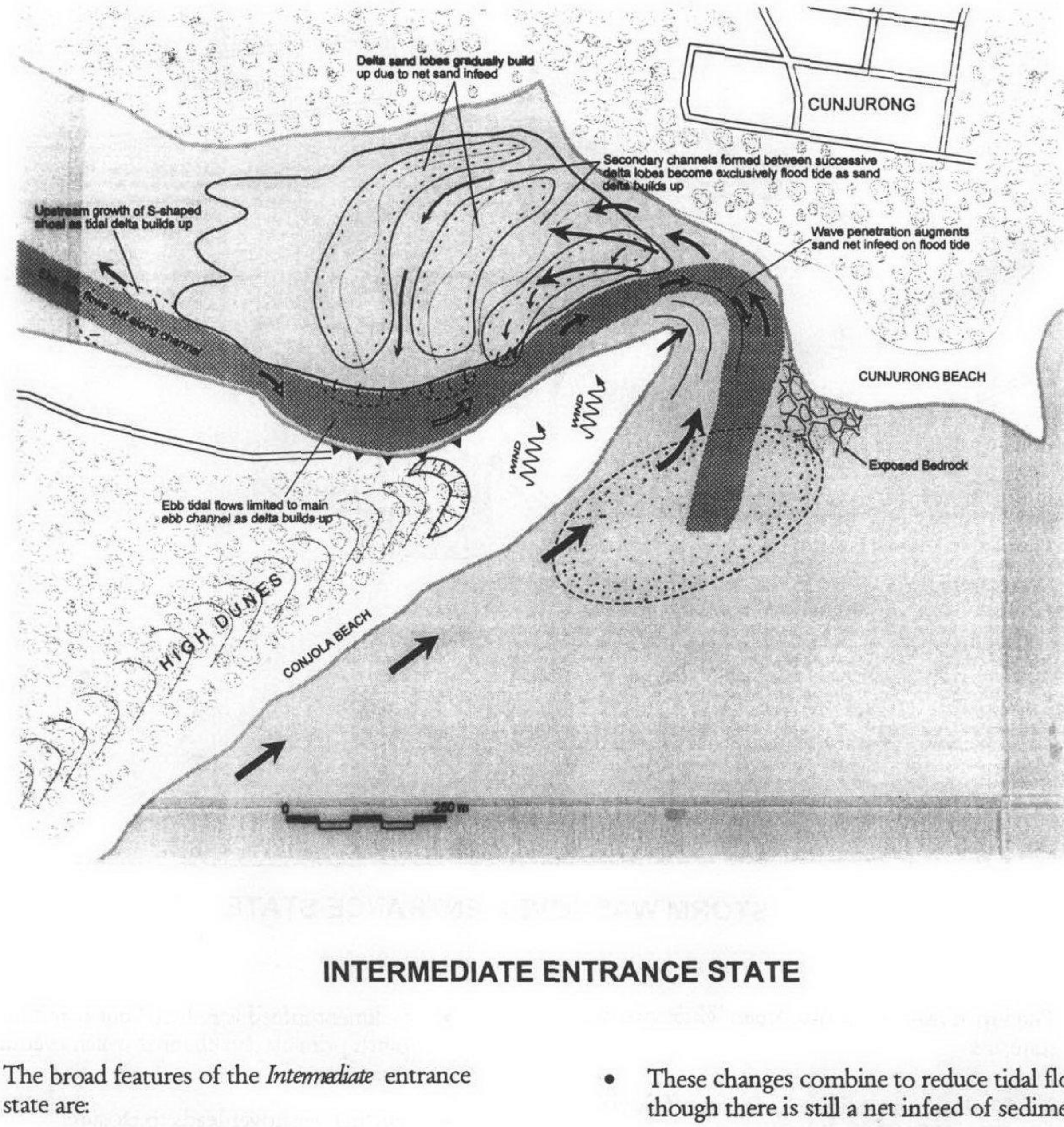
1. Floods cutting through spit and opening up lake and rejuvenating tidal exchange;
2. Severe coastal storm overtopping the entrance sand spit and pushing large deposits of sand westwards and potentially closing the entrance;
3. Lengthy dry spell *(several years)* allowing wind-blown sand to slowly close off the narrow entrance channel.



FLOOD SCOURED ENTRANCE STATE

The broad features of the *Flood Scoured* entrance are:-

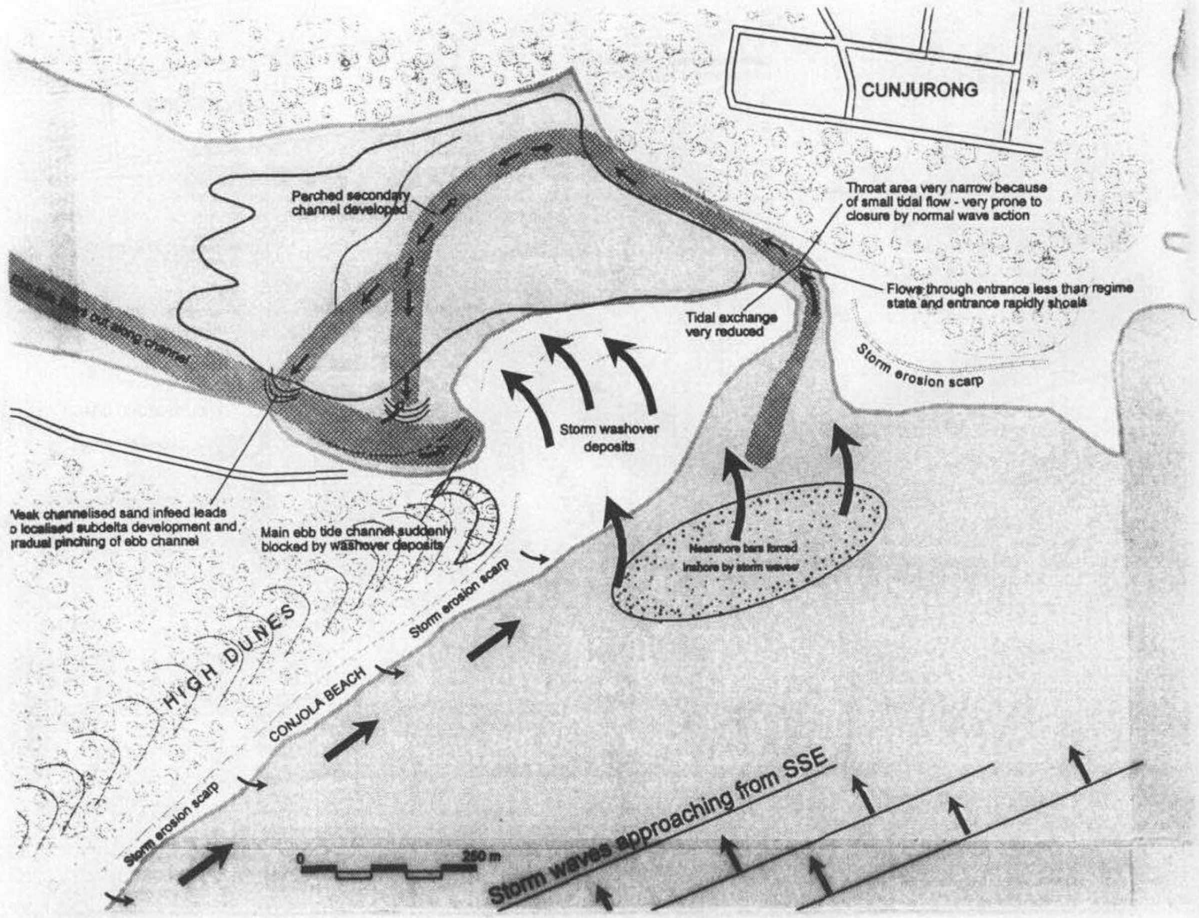
- Scour expands entrance throat, enlarging channel more to the south;
- Flood tide delta scoured at southern edge and over entire surface *(evidenced by channeling pattern)*;
- Flood scour deposits placed in nearshore zone as large shallow bar;
- Due to proximity of flood sediment deposits and increased tidal flows, the entrance is primed for:
  1. Rapid onshore movement of previously flood scoured deposits combined with normal longshore transport of sand from Conjola Beach into the entrance area.
  2. Pronounced net infeed of sediment thereby increasing shoal build-up across flood tidal delta.



INTERMEDIATE ENTRANCE STATE

The broad features of the *Intermediate* entrance state are:

- Sediment has mobilised into entrance via *onshore movement* of flood deposits as well as longshore and wind transport, viz:
    1. Entrance spit has migrated northwards;
    2. Flood tidal delta lobes have built up significantly;
- These changes combine to reduce tidal flows, though there is still a net infeed of sediment;
- Entrance will gradually reduce unless reopened by flood;
- Closure may be catalysed by storm supply of large amount of sediment.



STORM WASHOVER ENTRANCE STATE

The broad features of the *Storm Washover* entrance state are:-

- Washover deposits ie 'fans' cut off fluvial channel/primary ebb channel;
- Ebb channel becomes perched on flood delta lobes leading to suddenly and substantially diminished tidal flows;
- Flood tide tends to re-establish northern perimeter channel;
- Sediment infeed is reduced but continues to pinch primary ebb channel which eventually disappears;
- Further washover leads to closure.

PHOTOGRAMMETRY

A photogrammetric analysis of selected aerial photos of the entrance was carried out by DLWC *(Coastal Branch)*. Detailed cross sections of the entrance spit and flood tidal delta are provided in Technical Appendix 2. It is interesting to note that a very high entrance spit, which had been identified by earlier photogrammetric analysis of 1940's photography *(T. Roper, pers. comm.)*, has been shown not to have existed.

Analysis of the cross sections shows that the volume of sand in the tidal delta has increased by approx 330,000 m³ over the period 1964 to 1997 i.e. an average infilling rate of approx 10,000 m³ pa.

The volume of sand in the entrance spit has decreased by approx 60,000 m³ over the period 1964 to 1993 ie. an average erosion rate of approx 2,000 m³ pa.

ANALYSIS OF ENTRANCE SURVEYS

Analysis of entrance surveys taken before and after the August 1998 flood *(Technical Appendix 3)* shows that the flood scoured a horizontal distance into the high dunes of up to 30 m. Volume calculations found that the flood caused 35,500 m³ of dune erosion and 17,000 m³ of channel scour i.e. total erosion of 52,500 m³.

WIND TRANSPORT REGIME

The entrance to Lake Conjola is characterised by high dunes both north and south of the entrance. The foreshore coastal heath shows a strong south-easterly growth habitat which indicates a predominant wind direction. Early photography of the entrance shows the entrance spit as having a large build up of sand in the form of extensive incipient foredunes covered with spinifex. The construction of sand fences in the 1970's trapped considerable quantities of wind blown sand before the fencing was destroyed by coastal storms and flood scour.

Hence there is evidence that there is a strong sand drift regime which is likely to be significant to entrance stability, particularly during those years when the entrance spit is undisturbed by floods and a considerable volume of sand can drift from Conjola Beach and build foredunes and sandhills on the entrance spit and add to the build up of the tidal delta.

Detailed analysis of wind data *(Technical Appendix 3)* found that there is a very strong sand transport potential along Conjola Beach and onshore at a resultant transport direction of 15 degrees east of north. The wind blown sand supply to the entrance can vary from less than 4500 m³ p.a. when Conjola Beach is heavily scarped to 13,500 m³ p.a. when Conjola Beach is in an accreted state with an extensive width of dry, unvegetated, subaerial beach.

LONGSHORE TRANSPORT REGIME

Detailed analysis of wave data *(Technical Appendix 5)* found that there is an average net transport mid way along Conjola Beach, of 120,000 m³ pa. to the north. Towards the entrance, the net annual transport reduces to 70,000 m³ implying an average build up of 50,000 m³ pa in the northern half of Conjola Beach.

At the northern end of the coastal compartment *(Cunjerong Beach)*, it was found that there is a northerly leakage of the order of 9,000 m³ pa. which was corroborated by preliminary assessment of aerial photographs of beaches to the north which display periodic signs of northerly moving sand slugs.

Whilst a comprehensive coastal processes study would be required to confirm these longshore transport estimates, the analysis in Technical Appendix 5 confirms that a net littoral sand supply to the entrance of the order of 50,000 m³ pa. is compatible, from a sediment budget viewpoint, with annual "losses" from the beach compartment associated with the northerly littoral leakage, infilling of entrance tidal delta, wind transfer of sand and beach and nearshore shoal build-up.

TIDAL HYDRODYNAMICS

Detailed plots of velocity patterns throughout the inlet are provided in Technical Appendix 6 in relation to 1993 entrance shoaled conditions and 1998 post flood conditions. The 1998 tidal simulations compared very well with tidal flows measured in September 1998 *(refer Technical Appendix 7)*.

Tidal range reduction occurs almost exclusively across the inlet reach between the surf zone and the upstream end of the tidal delta. The tidal range in Berringer Lake is heavily constricted by the extensive shallow sand flats leading into it.

Table 1 Tidal Range Variation

Location	Simulated 1993 Conditions	Simulated 1998 Conditions
A. Ocean	1.3	1.3
B. Tide Guage	0.3	0.34
C. Yooralla	0.25	0.27
D. Sunny Hills	0.25	0.27
E. Berringer Lake	0.07	0.10

Velocity plots show that under relatively shoaled entrance conditions, peak tidal velocities do not exceed 0.5 m/sec, except in the vicinity of the boatramp and the entrance throat where peak velocities of 1 m/sec and 1.4 m/sec occur during the flood and ebb tide, respectively.

Hydrodynamic model results show that during the ebb tide, the majority of flow is confined to the main entrance channel. During the flood tide, however, tidal flows can access the minor channels which separate the various lobes of the entrance delta surface. Under September 1998 conditions, 70% of the flood tide occupied the main channel. The remaining 30% was split 60/40 into the most easterly and westerly channels, respectively.

The significantly more constricted flow path of the ebb tide causes the ebb tide to have a much greater duration *(approx 7-7½ hrs)* as compared to the flood tide *(typically 5-5½ hrs)*. This was borne out by field measurements as shown in **Figure 2** of Appendix 7. As can be seen this produces a distortion in the shape of the tidal curves which enhances the peak flood tide flow rate.

TIDAL DELTA SEDIMENT TRANSPORT PROCESSES

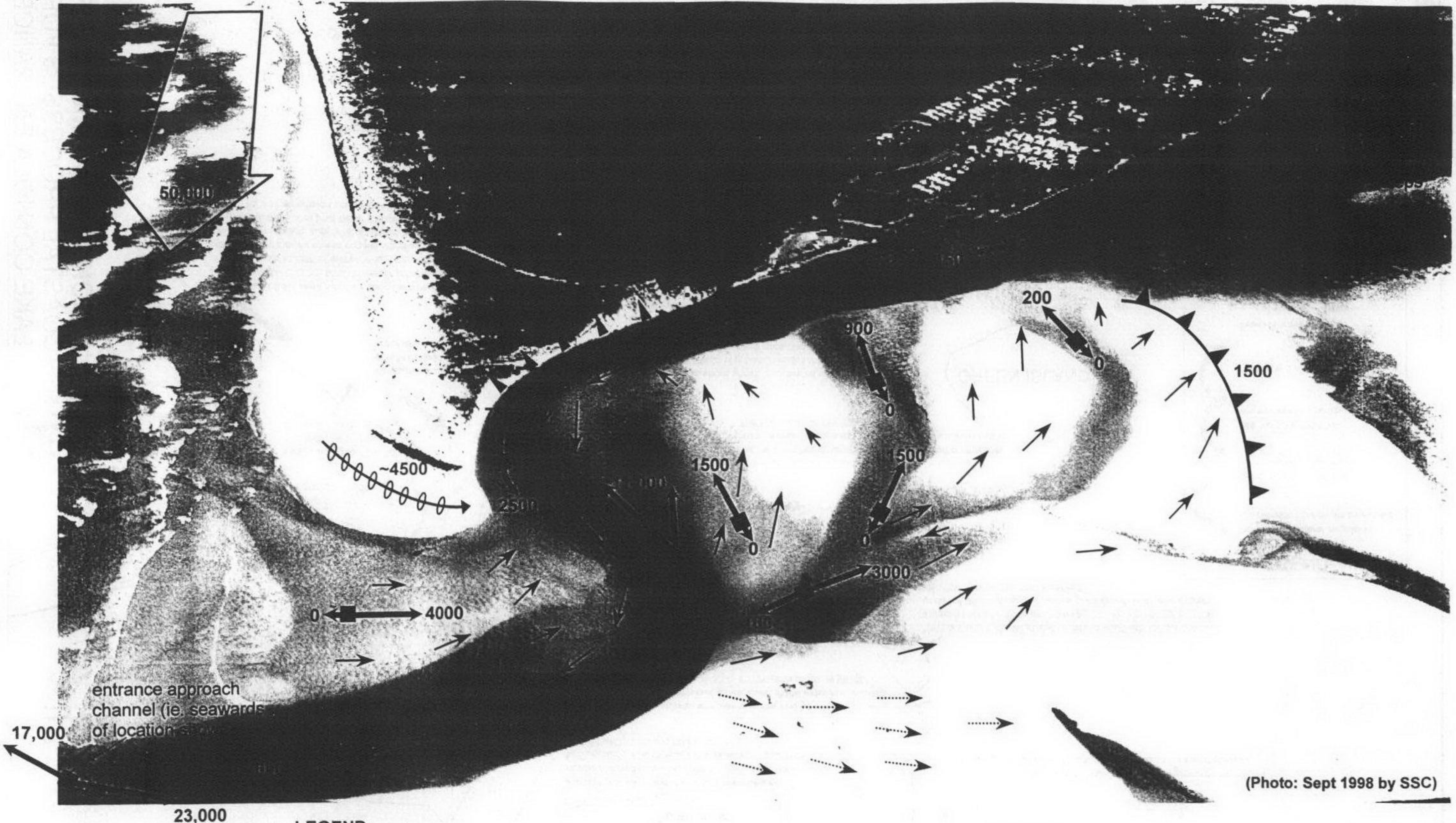
Figure 1 *(shown overleaf)* shows the main sediment pathways across the tidal delta which was developed from field measurements and sediment transport calculations. Investigation methods and detailed findings are provided in Technical Appendix 8; Tidal Delta Sediment Transport Processes. Key findings are described below:

- the average annual gross tidal sand transport reduces from 40,000 m^3 pa at the entrance to 50 m^3 pa at The Steps;
- the present annual growth of the tidal delta is approx 10,000 m^3 pa;
- wind blown sand accounts for approx 50% of the annual growth of the entrance tidal delta;
- contemporary erosion of the high dune by tidal scour is adding an additional 2,500 to 5,000 m^3 pa to the growth of the entrance tidal delta;
- tidal velocities are insufficient to cause significant scour of the bed and banks of the estuary upstream of the boat ramp;
- the depth of the bends in the main channels, upstream of Chinamans Island, are caused by periodic flood flows. A shell armour layer beneath the sand surface attests to the morphological role of flood flows in this area;
- the channels leading into Berringer Lake have built up by biogenic activity *(shell beds)* and there is no significant transfer of sand from the entrance delta under present day processes;
- the western edge of the flood tide delta is currently advancing upstream at 10-30 m pa.

ANALYSIS OF ENTRANCE STABILITY

A detailed analysis of entrance states, monthly rainfall and the occurrence of storms is provided in Technical Appendix 9; Analysis of Entrance Stability. The detailed analysis established the following:

- since 1937, the entrance has closed 8 times;
- in every case, closure was triggered by a severe storm ie. due to storm washover deposits which block the entrance channel;
- entrance closures often last for several years until a large flood scours a substantial entrance channel;
- over the last 62 years, the cumulative duration of various entrance states have been:
  closed - 9.5 years ie. 15%
  open - 38.5 years ie. 62%
  (ie. Regime, Flood Scoured or Intermediate State)
  Shoaled - 14.0 years ie. 23%
  (ie. Heavily Shoaled or Storm Washover State)
- the largest continuous period where the entrance was either closed or heavily shoaled *(ie. almost closed)* was the period from January 1965 to February 1971, a period of 7 years. This period was characterised by 4-5 dry years



LEGEND:

800 / 2000 — average annual sand transport in absence of floods, ebb tide and flood tide, m^3 p.a.

net annual longshore transport supply, m^3 p.a.

annual average wind transport, m^3 p.a.

indicative ebb and flood tide sand transport vectors

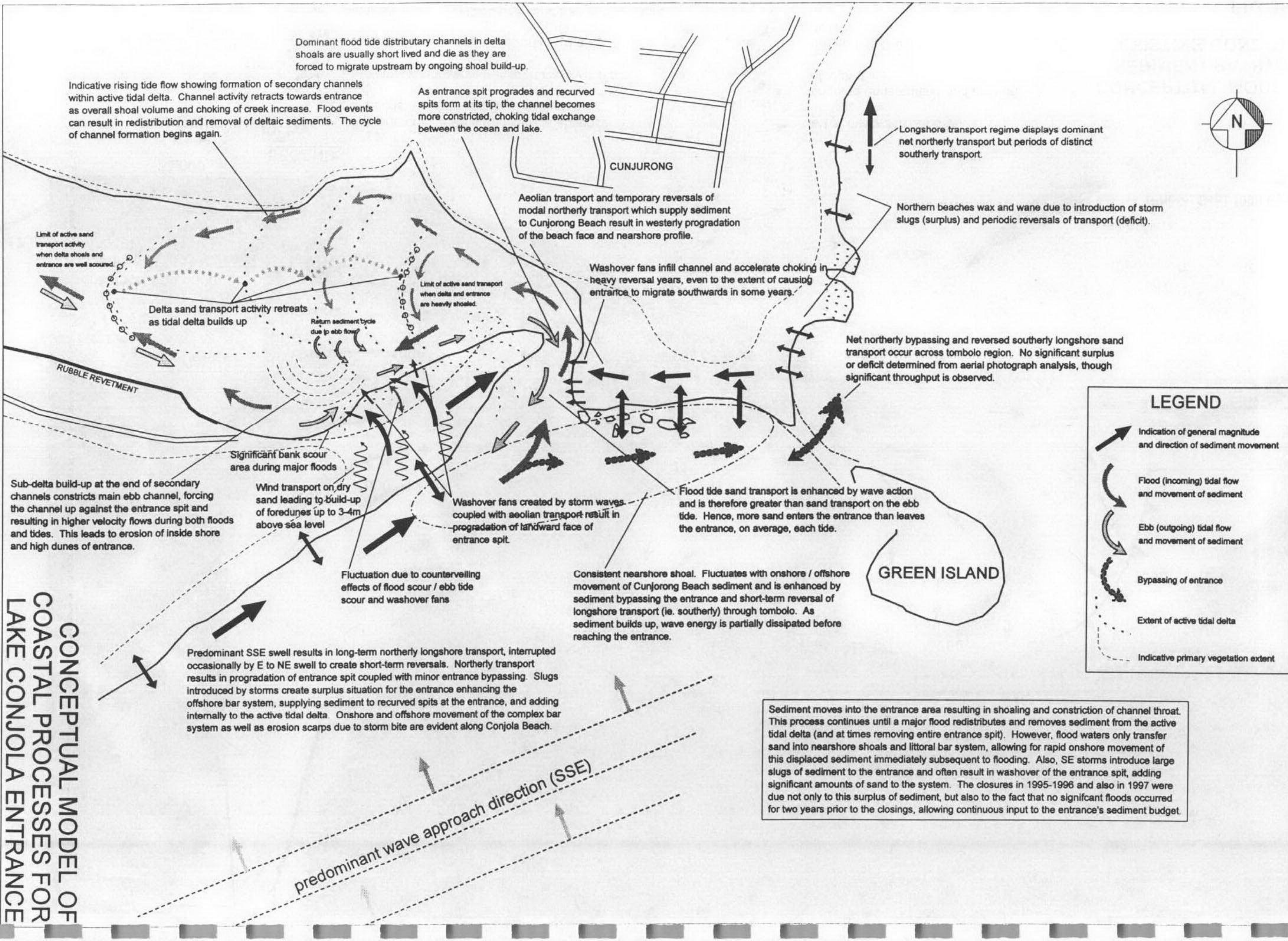
wave overwash deposits

ongoing undercutting and erosion of high dune

prograding limit of active tidal delta sands

CONCEPTUAL MODEL OF SEDIMENT PATHWAYS: EXISTING CONDITIONS

FIGURE 1



CONCEPTUAL MODEL OF COASTAL PROCESSES FOR LAKE CONJOLA ENTRANCE

FIGURE 2

and 11 severe or major storms. Because of dune buildup on the entrance spit, the highest flood on record *(February 1971)* was required to scour the entrance;

- the longest continuous period of good entrance conditions *(ie. good entrance stability)* was the period from February 1971 to August 1986, a period of 15.5 years. This period was characterised by very quiet sea conditions; there were 9 years of no major storms. The only year with a severe storm *(1974)* corresponded with the second wettest year *(ie. in period 1937 to 1998)* during which numerous floods and freshes occurred. This period of prolonged entrance stability was ended by a severe storm in August 86 which occurred in a dry year;
- Typically, the entrance remained open for 3-4 years.

The above analysis leads to the following conclusions:

1. entrance closures are caused by severe storms;
2. periods of entrance stability correspond with periods of little storm activity; and
3. the key to improving entrance stability is reducing the destabilising impact of severe storms ie. preventing storm washover deposits.

CONCEPTUAL MODEL OF ENTRANCE PROCESSES

Figure 2 *(shown overleaf)* is a conceptual model of the hydraulic and sedimentary processes operating at the existing entrance. The model draws together the aerial photograph interpretations and sediment transport analyses carried out in Technical Appendices 1-9. The conceptual model is self-explanatory. Key findings are provided below:

- Northerly net longshore transport along Conjola Beach drives northwards growth of the entrance spit and forces the entrance channel against the northern shoreline *(TA5)*.
- Because of the net northerly longshore transport, there are always extensive nearshore shoals opposite the entrance spit and entrance channel. These shoals produce a wide surf zone and considerable dissipation of wave energy opposite the entrance spit *(TA1)*.
- The northern shoreline has reduced exposure to waves due to the waveshadow of Green Island and the dissipative effects of the nearshore shoals *(TA5)*.
- There is a northerly leakage of longshore transport between Green Island and Cunjurong headland, occurring as sand slugs during southerly storms *(TA5)*.
- The entrance spit is always low and therefore susceptible to storm washover. Storm washover fans are the trigger for entrance closure *(TA9)*.
- Wind blown sand from Conjola Beach is a significant supply for the buildup of the entrance spit, entrance dunes and tidal delta shoals. Wind blown sand can buildup the entrance to 3-4 m above sea level, requiring a major flood to scour a closed entrance *(TA4)*.
- Significant reversals in longshore transport are rare but are evident in the photographic records. These can add additional sand infilling *(TA1)*.
- Wave stirring of the bed enhances flood tide transport so that there is a net infeed of sand every tide *(TA8)*.
- When the entrance is well scoured, tidal range is greatest and tidal flows are strong causing sand to be transported to the western extremity of the delta shoals *(TA1, 6 & 8)*.
- As the entrance shoals buildup, tidal range and tidal flows reduce and the area of active sand transport retreats towards the entrance *(TA1, 6 & 8)*.
- Floods periodically scour the surface of the tidal delta and expand the entrance channel, thereby rejuvenating tidal flows and sediment infeed *(TA3)*.
- Secondary flood tide channels convey sand towards the southern edge of the tidal delta, in the vicinity of the boat ramp *(TA8)*. Southerly progradation of the delta in this area deflects ebb tide and flood flows against the high dunes, causing bank erosion.

- o The indented shoreline, in the boat ramp area, including the large bay and beach to the east in the vicinity of the timber walkway, is present in the earliest photos of the area. It has evolved due to repeated southerly progradation of the tidal delta during periods of sustained delta buildup *(TA6)*.

1994-1998 ENTRANCE CLOSURE

In Technical Appendix 11; Analysis of 1994-1998 Entrance Closure, it is demonstrated that the entrance closure was triggered by an extensive washover fan which occurred during the severe storm of March 1994.

FIGURE 3 - LAKE CONJOLA ENTRANCE, JULY 1994

Figure 3 shows the main entrance channel completely infilled by the storm washover fan. Tidal flows through the shallow, choked secondary channel were insufficient to maintain the entrance which closed towards the end of 1994.

The extended duration of the closure was caused by the absence of any significant floods and the occurrence of 5 severe storms and 3 major storms over the period *(refer TA9)*.

Detailed analysis of lake water levels shows that the average lake level was superelevated approx 0.3 m above normal levels for a period of 2½ years. During this period seagrass extensively colonised the lake margins. Between November 1997 and April 1998, evaporation caused lake levels to drop below normal levels and extensive die-back of these lake margin seagrasses occurred along with a decline in water quality.

ASSESSMENT OF 1986 PIPELINE CROSSING

A water supply pipeline was constructed under the sand shoals within the inlet of Lake Conjola in mid 1986. The pipeline is located approximately at the upstream end of the Council Caravan Park.

A detailed assessment of the impact of the pipeline construction on entrance stability is provided in Technical Appendix 12; Assessment of Pipeline Crossing. The assessment demonstrates that the poor entrance conditions between 1986 and 1989 were not the result of the construction of the water supply pipeline. The construction of the pipeline merely coincided with a substantial washover fan caused by the severe storm of August 1986.

Figure 3A shows that the washover blocked the main ebb channel. These heavily shoaled entrance conditions persisted through 1987 and 1988 which were relatively dry years until several floods in the wet year of 1989 re-established the entrance.

TA12, concludes that any future pipeline crossings in a similar location, or further upstream, should be considered in the context that they will not have any significant impact on entrance stability.

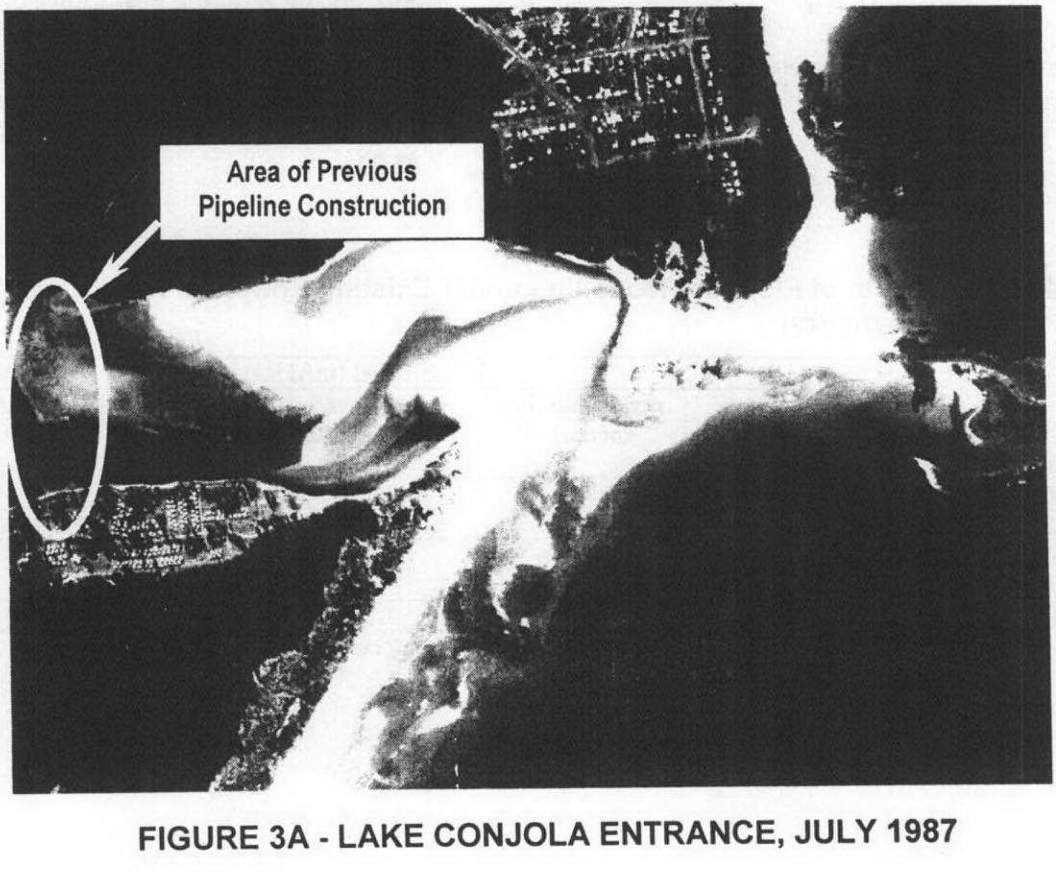


FIGURE 3A - LAKE CONJOLA ENTRANCE, JULY 1987

EXISTING FLOOD BEHAVIOUR

HYDROLOGIC MODELLING

Hydrographs of the main creeks flowing into the lake and lateral inflows were determined for "major" and "minor" catchment runoff events using the catchment runoff model RAFTS. Details are provided in Technical Appendix 13; Hydrologic Modelling.

The major and minor events were based on 1 in 100 yr and 1 in 5 yr probabilities of occurrence, respectively. The major and minor descriptors have been used throughout this report to emphasise that a rigorous flood study has not been carried out and that the hydrology and flood behaviour assessments are suitable for comparing the relative performance of entrance options only.

The hydrologic analysis found that the critical storm duration for the Conjola Catchment is 9 hours.

Peak outflow discharges were found to be:

- o minor flood - 1,000 m^3/sec
- o major flood- - 2,100 m^3/sec

FLOOD ASSESSMENT

The results of flood simulations for major and minor flooding scenarios for existing conditions *(1993 bathymetry)* are provided in Technical Appendix 14; Flood Assessment. The flood behaviour of the existing entrance is summarised in **Table 2**.

The major flood scenario involves maximum flood levels in the lake proper of about RL 4.0 m AHD, RL 2.9 m AHD at the Post Office and RL 2.2 m AHD at the entrance.

The minor flood scenario involves maximum flood levels in the lake proper of about RL 2.9 m AHD, RL 2.3 m AHD at the Post Office and RL 2.2 m AHD at the entrance.

A 1 in 5 year storm surge on its own produces a peak flood level at the Post Office of RL 1.5 m AHD. This is consistent with local observations, which indicate storm surges in the past have caused water to inundate low lying areas of the town which have ground levels of about RL 1.0 to 1.2 m AHD.

Table 2 Results of Flooding Modelling under Existing Entrance Conditions (1993 Bathymetry)

Location	Flood Level (mAHD)				
	storm surge only[1]	major flooding scenario[2]	1 in 100 yr flood with no storm surge	minor flooding scenario[3]	1 in 5 yr flood with no storm surge
Ocean Tailwater	2.2	2.2	0.6	2.2	0.6
d/s Caravan Park	1.5	2.6	1.7	2.2	1.3
Lake Conjola post office	1.5	2.9	2.0	2.3	1.4
Conjola Lake	1.5	4.0	3.1	2.9	1.9

1 1 in 5 year storm surge of 1.6 m superimposed on a tide of mean spring range ie. peak ocean level of 2.2 m AHD.
2 1 in 100 year freshwater flow coinciding with 1 in 5 yr storm surge.
3 1 in 5 freshwater flow coinciding with 1 in 5 yr storm surge.

COMPARISON WITH FLOOD OF RECORD

The flood of record is the February 1971 flood which reached levels of RL 2.4 m AHD in the centre of town *(J Downey pers. comm)*. Councils current minimum floor level requirement of RL 3.0 m AHD is based on this historical flood level and an isolated recording further upstream of 2.9m AHD.

Preliminary flood modelling carried out for this study has shown that there is a significant flood gradient between the centre of Lake Conjola township and the main lake *(ie. as much as one metre)*. Hence the adopted flood level may afford a reasonable risk against flooding in the township but may seriously underestimate the risk of flooding around the perimeter of the main lake.

FLOOD DAMAGE POTENTIAL

Table 3 shows a profile of flood damages based on Council's database of floor levels and septic tank levels of residential areas around Lake Conjola.

Table 3 Tangible Flood Damages

Flood Event	Number of Dwellings Flooded		Number of septic tanks flooded	Flood Damage
	less than 0.3m above floor level	greater than 0.3m above floor level		
major flood scenario[1]	133	112	187	$1,430,000
minor flood scenario[2]	73	41	145	$670,000
1 in 100yr freshwater flow with no storm surge	46	27	81	$400,000
1 in 5yr freshwater flow with no storm surge	12	1	24	$70,000

1. 1 in 100 yr flood flow coinciding with 1 in 5 yr storm surge.
2. 1 in 5 yr flood flow coinciding with 1 in 5 yr storm surge.

These flood damages were converted to an average annual damage by integrating the above damages with the probability of occurrence of the major and minor flood scenarios. The avreage annual damage was calculated to be $302,000 (*T.A. 14*). When discounted over a 50 year planning period, the present value of the flood damages was calculated to be $4.2 million..

The $4.2 million relates to tangible flood damage. Based on recent research for the Hawkesbury Nepean Floodplain Management Plan the total damages, after accounting for the costs associated with trauma and public health, could be as much as $5-$6 million.

NEED FOR FLOODPLAIN MANAGEMENT PLAN

The preliminary flood assessment suggests that the current flood policy in the Lake Conjola area may underestimate the flood risk facing the community. Due to the absence of substantial floods in recent decades, it is probably reasonable to assume that the community is unprepared for the potentially devastating effect of a major flood.

This study has shown that flood behaviour is quite complex because storm surge has a significant role in the flooding of the lake, which is complicated further by the difference in flood levels caused by entrance conditions.

Hence a Floodplain Management Plan is needed to accurately dimension the full range of flood hazards. Such a plan would bring the following benefits:

- rigorous assessment of the full range of flood levels and risks and potential damages, both tangible and intangible;
- improved flood awareness and preparedness re. minimise avoidable flood damage;
- improved emergency response planning;
- identify need for improved evacuation infrastructure;
- prevent escalation of the flood damage potential;
- identify pros and cons of a formal house raising program;
- identify possible flood mitigation works.

EXISTING WATER QUALITY

WATER QUALITY DATA

Technical Appendix 15: Water Quality Loadings provides a brief review of water quality data and past studies. The review found that:

- median faecal coliforms levels between 1989 and 1998 within the lake generally meet ANZECC primary contact recreation guidelines;
- during 1996/97 *(entrance closed)* elevated faecal coliform counts were recorded in swimming areas at the boat ramp near the lake inlet and adjacent to Edwin Ave, Lake Conjola. These elevated coliform counts correlated to rainfall events;
- sample sites adjacent to the boat ramp and the outlet from Pattimores Lagoon recorded high enterococci values *(1996/97)* particularly after rainfall events;
- recent viral analysis commissioned by the local community detected adenovirorus, enterovirus and reovirus in 1 of 3 water samples and 3 of 5 sediment samples. The presence of viruses in these samples indicates that sewage effluent has found its way into the lake;
- elevated phosphorus values are reported around urban and agricultural areas *(eg. boat ramps Pattimores Lagoon, Yooralla Bay, Kidgee Point and Conjola Creek downstream of Fisherman's Paradise).*

It was determined that the relative weighting *(ie. magnitude)* of pollutant inputs around the lake can be apportioned as follows:

- d/s Caravan Park - 12%
- Post Office/Canal Entrance - 50%
- Adjacent to Edwin Ave - 1%
- Killarney - 5%
- Conjola West - 12%
- Fisherman's Paradise - 20%

NATURAL FLUSHING TIMES

Technical Appendix 6 demonstrates that under existing open entrance conditions *(1993 bathymetry)* the dry weather natural tidal flushing time at various locations is as follows:

- Post Office - 1 day
- Edwin Ave - 1 day
- The Steps - 5-10 days
- Killarney - 20-30 days
- Lake Conjola West - 30-40 days
- Fisherman's Paradise - >70 days
- Berringer Lake - 10-20 days

TIDAL FLUSHING

Technical Appendix 18; Entrance Options Assessment and Technical Appendix 6; Tidal Hydrodynamics, examine the natural tidal flushing characteristics of the waterway and its ability to flush distributed bursts of pollution *(bacteria)* associated with storm water runoff.

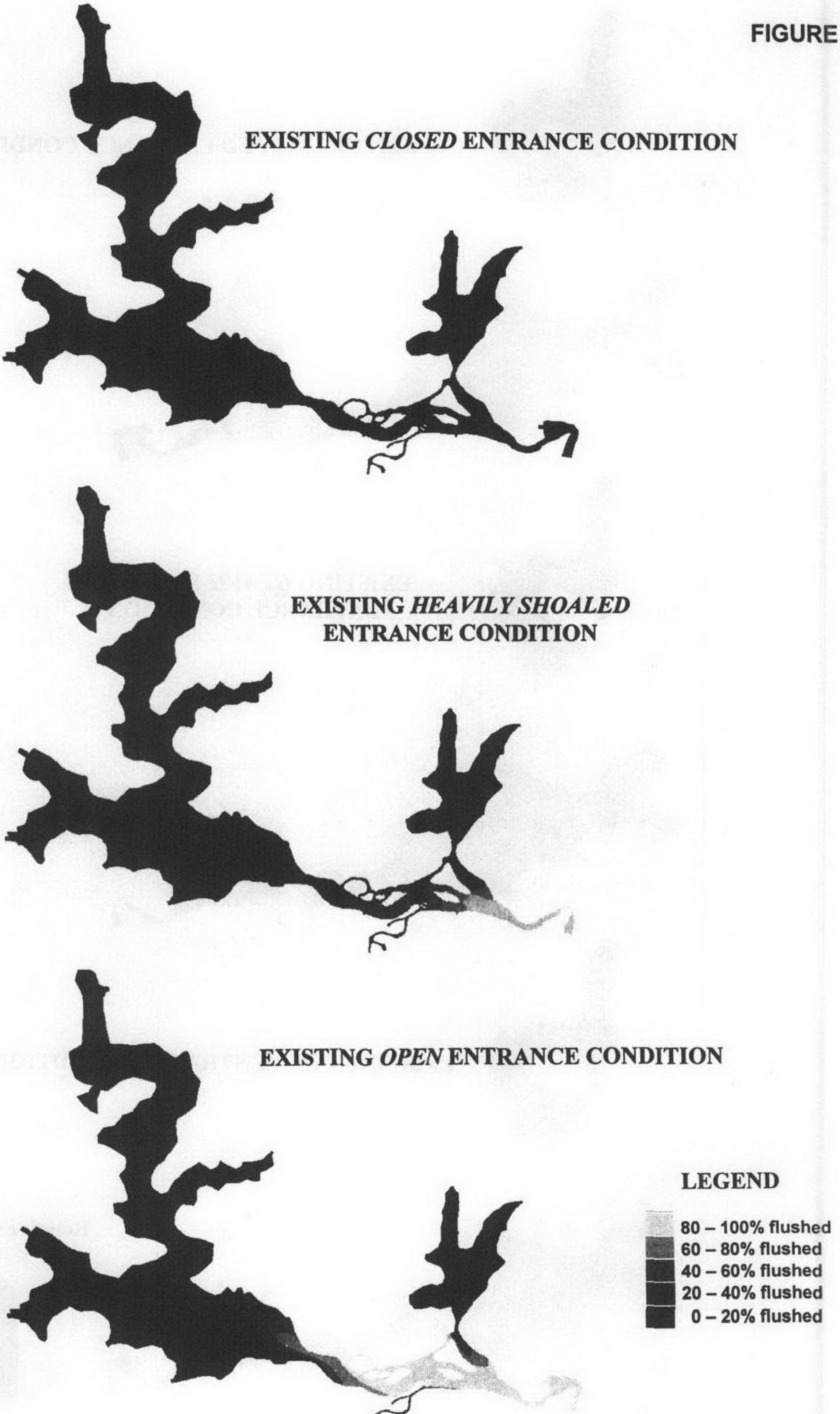
Variability of Entrance Flushing

The existing entrance was considered as a time varying amalgam of three entrance states based on analysis of entrance stability, viz:

- closed - 15% of time
- heavily shoaled - 23% of time
- open - 62% of time

Figure 4 *(overleaf)* shows the different flushing characteristics of each of these existing entrance states in relation to the flushing of an initial, uniformly distributed reference concentration of pollutant, after 8 tidal cycles.

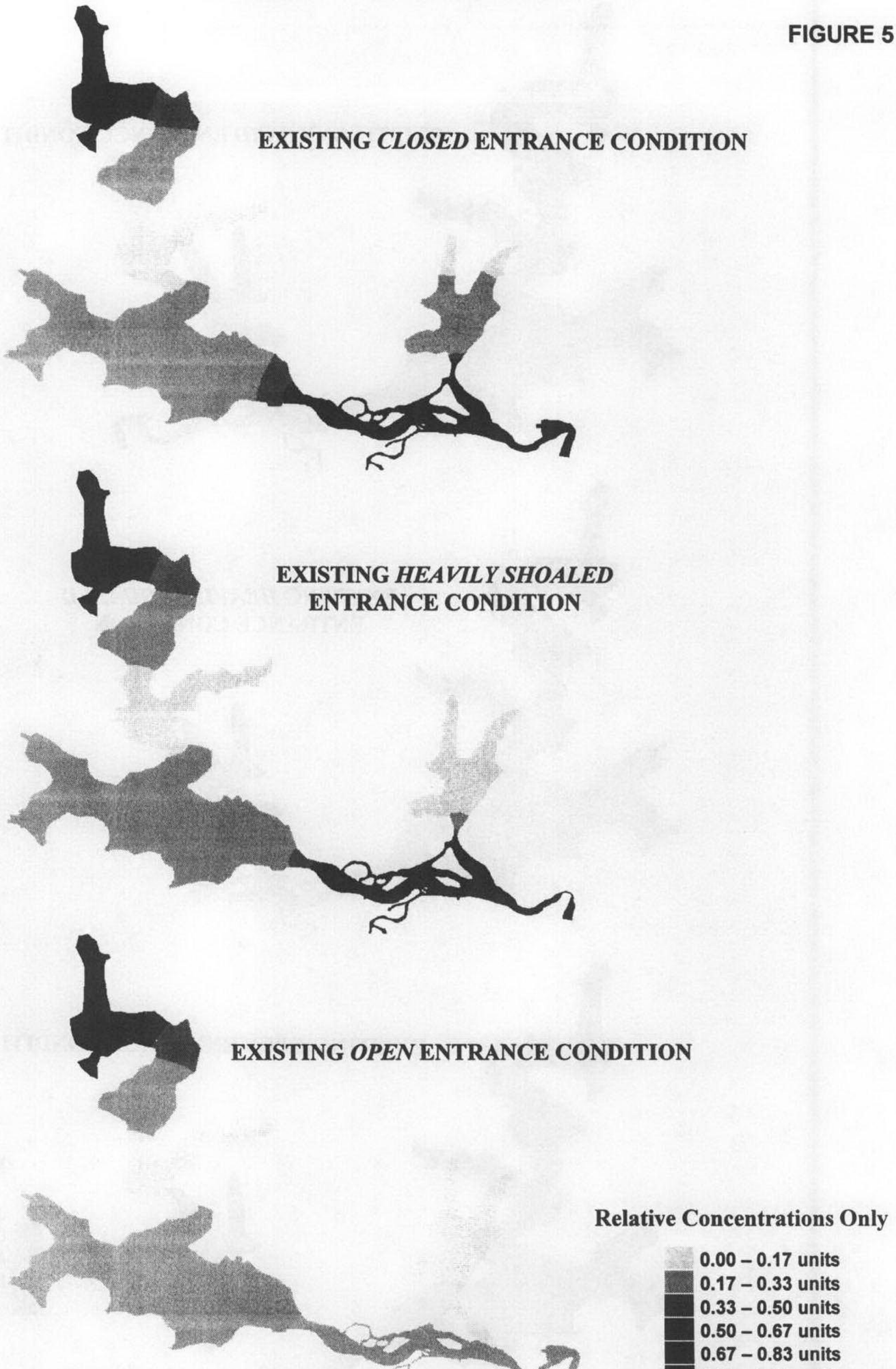
When the entrance is open, the inlet from the mouth to Conjola Island is 80-100% flushed and 60-80% from Conjola Island to "the steps". Lake Berringer is approx 30 -40% flushed. Apart from a tongue extending along the northern shore to Station Point, the main body of Lake Conjola is



LAKE CONJOLA ENTRANCE STUDY

FLUSHING CHARACTERISTICS OF EXISTING ENTRANCE

FIGURE 5



LAKE CONJOLA ENTRANCE STUDY

DISPERSION OF STORM POLLUTION FOR EXISTING CONDITIONS

flushed less than 10%. The minimal evacuation of the reference pollutant from the majority of the main lake *(in 8 tide cycles)* reflects the long flushing times noted above.

When the entrance is heavily shoaled, the area of 80-100% flushing is limited to downstream of Chinamans Island. Berringer Lake is flushed less than 10% and the western half of Lake Conjola is not flushed at all.

Dispersion of Storm Pollutants

Figure 5 *(overleaf)* shows the net flushing and dispersion of unit 6 hour storm loads input at 6 locations representing the main population nodes around the lake; ie. Downstream of boat ramp, post office/canal entrance, Edwin Ave, Killarney, Conjola West and Fisherman's Paradise. The relative weightings *(ie. magnitude)* of the pollutant loadings *(TA15)* were used to identify the relative contribution of each pollutant source to the ambient pollution level at any location around the lake *(TA18)*.

The comparison relates to 24 hours after the storm which is usually the critical time in relation to public health risks to swimmers and contact users.

When the existing entrance is open, good flushing of the inlet *(ie., up to, "the Steps")* prevents any significant buildup of pollutants in the Lake Conjola township area.

Berringer Lake has no pollution because it is relatively isolated from the pollution sources in the short time available for them to disperse. This is consistent with the results of testing of oysters which have shown high bacteria counts in the flesh of oysters growing in the main channel after runoff producing rainfall but negligible bacteria in the oysters of Berringer Lake *(S Tierney, pers. comm)*.

Even with an open entrance, pollutants are not dispersed from the Fisherman's Paradise area due to the shallow water depth, which restricts dilution, and the small tidal exchange. Pollutant inputs at Conjola West and Killarney are dispersed and diluted rapidly within 24 hours after a storm event. It should be noted, however, that the analysis assumes vertical mixing in the water column and therefore there could be some potential for concentration of bacteria in surface water depending upon ambient salinity levels in the lake.

When the entrance is heavily shoaled, high bacteria levels could occur in the canal leading to Pattimores Lagoon, justifying the general warning from Council that the public should not swim in the area for two days after runoff producing rain *(W. Papworth, pers. comm)*.

When the entrance is closed pollutant concentration increases between the entrance and "The Steps" and there is a tendency for pollutant levels to be slightly elevated in Berringer Lake.

Table 4 Proportion of Total Load Contributed by Each Pollutant Input Location

Location	Pollution Load (%)*					
	1	2	3	4	5	6
d/s Carav. Park	15.9	81	1.4	1.0	0.7	0.0
Post Office	12.6	83.7	1.6	1.2	0.9	0.0
Canal Entrance	11.0	85.1	1.8	1.2	0.9	0.0
Edwin Ave	10.3	84.1	1.9	2.1	1.7	0.0
"The Steps"	2.5	47.9	2.5	22.3	24.2	0.6
Main Lake *(500m u/s of The Steps)*	1.3	29.9	1.9	24.0	41.2	1.6

Legend:
1. d/s Caravan Park
2. Post Office/Canal Entrance
3. Edwin Ave
4. Killarney
5. Lake Conjola West
6. Fisherman's Paradise

When the relative contribution of loads, is considered, **Table 4** shows that under existing open entrance conditions, the majority of pollution within the inlet, which is the main swimming and primary contact area, comes from the input load at the Post Office/Canal Entrance area. It can be seen that the water quality in the main lake is relatively less sensitive to pollutant sources from Lake Conjola township than it is to inputs from the areas of Killarney, Lake Conjola West and Fisherman's Paradise.

Table 4 can be used to identify where effort should be applied to particular pollutant sources to improve the ambient water quality at any location around the lake.

ECOLOGICAL ASSESSMENT

Technical Appendix 16: Ecological Assessment provides an overview of the endemic variability of seagrasses in response to entrance regime.

The seagrass communities of Lake Conjola are made up of *Zostera* and *Halophila*. The extent of these seagrasses is directly correlated to the state of the inlet -whether it is open, closed or intermediate. Opportunistic growth and spreading of seagrasses can occur when elevated water levels result from a closed entrance, while subsequent dieback can occur if tidal ranges return to normal after a flood reopens the entrance. Variations on this growth and dieback can occur based on the input of many variables including rainfall, sediment and nutrient input, boat traffic, current velocities, etc.

Airphoto analysis of seagrass extent covering the years 1945, 1959,1971, 1985, 1993 and 1997 indicates the following:

- there is a strong correlation between lake closures and increased extent of seagrasses (refer **Figure 3B**);
- 1997 saw twice the amount of seagrasses present than in 1985;
- there does not appear to be a decline in seagrasses, rather a cyclical pattern of opportunistic growth and dieback resulting from entrance conditions.

Analysis of the general health of the seagrass communities of Lake Conjola was undertaken by members of the PBP study team in September of 1998. Snorkelling and diving in several areas of the lake revealed the variable nature of the health of seagrasses. In particular, the following was noted:

- increased tidal ranges (*ie. overexposure at low tide*) due to an open inlet resulted in dieback / bleaching of grasses in the shallows;
- seagrasses consistently in 0.5m to 2m of water at low tide exhibit dense growth;
- increased tidal flushing due to an open inlet would tend to maintain a system with better water quality and increase accessibility to a larger number of marine organisms which rely upon seagrass environments as a nursery.

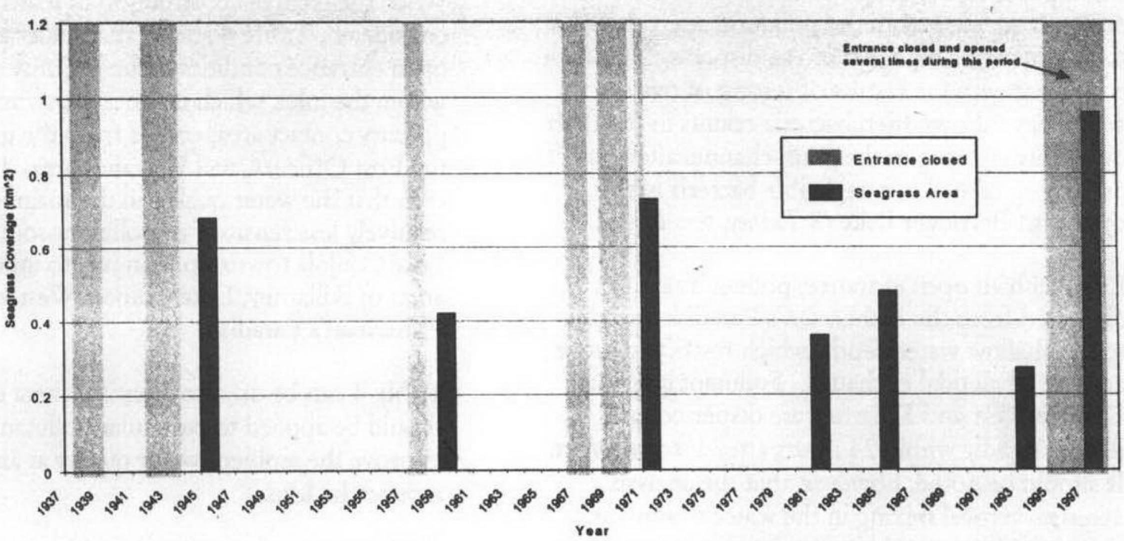


Figure 3B - Correlation between Entrance State and Seagrass Extent

ENTRANCE MANAGEMENT OPTIONS

ENTRANCE IMPROVEMENT STRATEGIES

Based on the entrance process studies and investigation of the causes of past entrance closures of the previous sections, any options for improving entrance stability must utilise as many of the following strategies as possible:

- *Reduce susceptibility to storm washover* - this is the dominant factor in all previous entrance closures.
- *Manage and contain wind blown sand* - wind blown sand can contribute half of the sand supply to the entrance shoals unless effectively trapped.
- *Reduce Littoral Sand Infeed* - there is a strong northerly longshore sand supply which enhances flood tide transport into the entrance.
- *Locate Entrance to the North* - the northern foreshore has least exposure to wave energy because of the Green Island waveshadow and the wave energy dissipation caused by the nearshore shoals.
- *Reduce or modify wave penetration of entrance* - wave stirring enhances ability of flood tide to transport sand across tidal delta surface.
- *Don't let entrance close* - once the entrance closes, subsequent sand buildup across the delta surface necessitates high lake levels to effectively re-open the entrance.
- *Nullify effect of storm washover*
  - in the event of a storm washover which cripples the entrance, by perching the main channel, immediately cut a new channel through or around the washover. Otherwise the entrance will close and subsequent sand build up will necessitate a substantial rise in lake level to cause scouring of a new entrance;
  - requires channel cut to be of sufficient size to effectively re-open the entrance. The new channel should be cut as far to the North as is practicable.

IDENTIFICATION OF MANAGEMENT OPTIONS

Six (6) basic options for the long term management of the entrance to Lake Conjola are identified:

1. Entrance Breakwaters
2. Stub Groyne and Internal Training Wall
3. Stub Groyne and Internal Groyne Field
4. Stub Groyne with Partial spit Stabilisation
5. Managed Entrance
6. Existing Opening Policy

The salient features of each option are shown schematised in **Figure 6**, overleaf. Further details are provided in Technical Appendix 18 ; Entrance Options Assessment.

An optional feature which can be included in any of the options is a wave trap/sand trap. This comprises a deepened basin of designed shape which will direct a significant portion of the flood tide away from the main ebb channel and dissipate wave energy, thereby capturing marine sand feeding in through the entrance.

Because of the shape of the breakwaters in Entrance Breakwater Option, wave energy penetration would be minimised and a wave trap would be created naturally.

SUSTAINABILITY OF ENTRANCE OPTIONS

The sustainability of the entrance options is impossible to predict because it will depend upon the occurrence of floods and severe storms. Analysis of entrance stability has shown that there can be prolonged periods of frequent occurrences and absence of both.

Table 5 provides an approximate guide as to the likely time between corrective dredging of each entrance option taking into account the current condition of the entrance and analysis of past entrance behaviour *(TA's 1-11)*.

Table 5 Dredging Frequency to Maintain Entrance Stability

Entrance Option	Approximate frequency for corrective dredging works
Entrance Training Walls	>> 20 years
Stub Groyne and Internal Training Wall *(without wave/sand trap)*	≈ 15 years
Stub Groyne and Internal Training Wall *(with wave/sand trap)*	15-20 years
Stub Groyne and Internal Groyne Field *(without wave/sand trap)*	≈ 15 years
Stub Groyne and internal Groyne Field *(with wave/sand trap)*	15-20 years
Stub Groyne with Partial Spit Stabilisation *(without wave/sand trap)*	≈ 10 years
Stub Groyne with Partial Spit Stabilisation *(with wave/sand trap)*	≈ 10 years
Managed Entrance *(without wave/sand trap*	> 10 years
Managed Entrance *(with wave/sand trap)*	10-15 years
Maintain existing protocol	≈ 5 years

EXISTING ENTRANCE OPENING POLICY

The behaviour of an artificial entrance opening was modelled by means of a dynamic entrance scour model. A discussion of the model and the detailed findings are provided in Technical Appendix 17; Entrance Scour and Opening Protocol.

Model results show that the behaviour of the entrance breakout is a complex interaction between the cross-section of the initial pilot channel, the length of the pilot channel, the length of the entrance sand berm, the timing of the initial cut in relation to ocean tides and the actual water level in the lake.

The model results demonstrate that the unsuccessful attempts to open the entrance during 1995-1998 stem from the mismatch between the very large entrance berm *(≈300 m)* and the dimensions of the pilot channel, which were too small.

The model results demonstrate that the current entrance opening policy is capable of creating a thorough entrance breakout provided:

- the "point of breakout" is timed to coincide with low tide NB. the "point of breakout" is the time at which the opening is scouring vertically and horizontally at its greatest rate;
- the pilot channel dimensions are appropriately sized to reflect the width of the entrance berm eg. a pilot channel 200 m long would need to be no smaller than about 10 m wide and have a bed at RL 0.0, assuming a lake level of RL 1.0 m AHD.

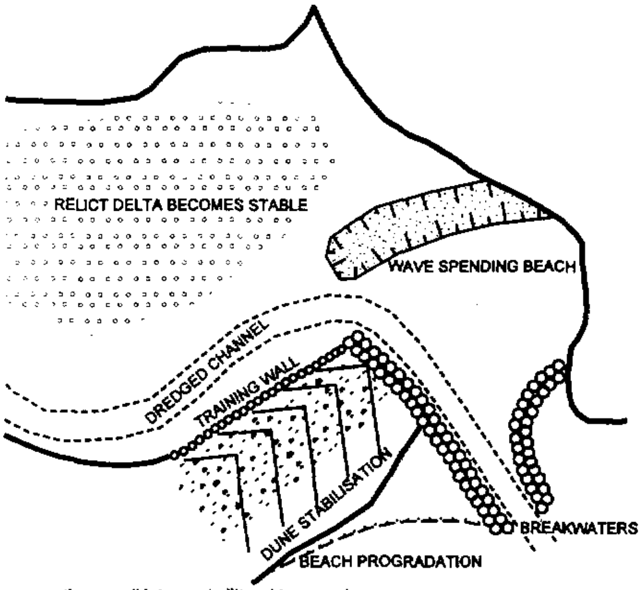
It was found that delaying the artificial opening until the lake reaches a higher level *(RL 1.5 m say)* would result in a larger entrance being formed. However, this larger entrance would not stay open any longer than a smaller entrance *(ie. 12 months depending on flood events)* as the rate of sand infeed into the entrance would be higher for longer. The final entrance dimensions after 12 months would be no different. This is clearly demonstrated in the aerial photograph analysis *(TA 1)* which shows that the scoured entrance caused by the February 1971 flood of record had infilled and was hard against the northern foreshore within 18 months of that event.

The 1.0 m AHD opening level was selected because it was a safe level which did not inundate septic tanks or dwellings. If the opening of the lake, under the existing policy, was delayed until a level of say RL 1.5 m AHD, eight (8) houses would be flooded above floor level and thirteen (13) septic tanks would be inundated *(ref: Council database)*.

As a corollary to the above, the existing entrance opening policy has no bearing on the duration of entrance opening. Analysis of entrance stability *(refer to earlier discussion on Analysis of Entrance Stability)* shows that the duration of entrance stability is related to the occurrence of severe storms *(which close the entrance)* and the frequency of freshes/floods *(which maintain/scour the entrance)*, provided that the artificial opening produces a complete and comprehensive "breakout". The transient nature of the artificial openings during 1996/1998, reflect the fact that full breakout was not achieved.

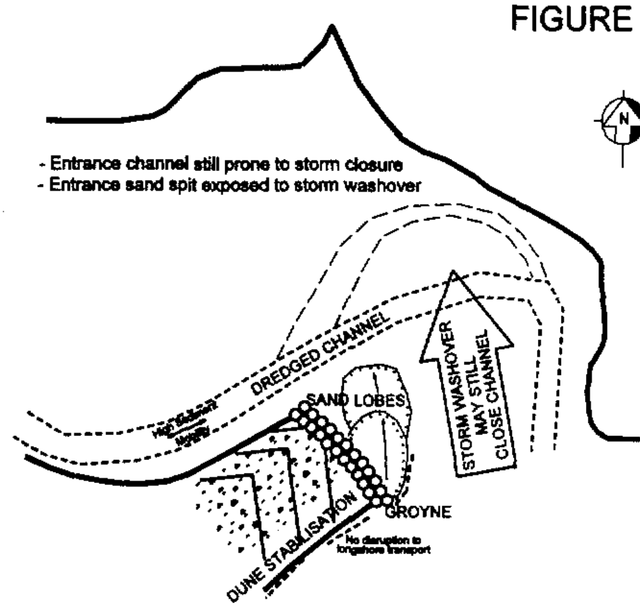
The entrance scour modelling demonstrates that the existing entrance opening policy is capable of generating a fully scoured entrance provided that the pilot channel dimensions and timing of the opening, relative to low tide, is optimised. The

FIGURE 6

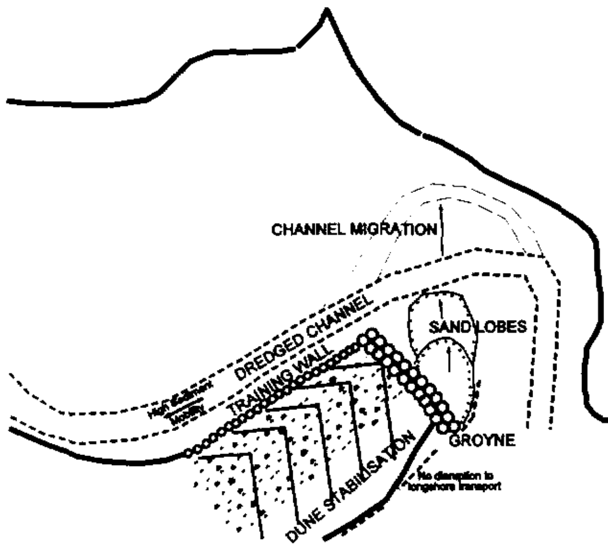


- southern wall intercepts littoral transport
- twin walls to reduce wave penetration
- entrance spit built-up to eliminate closure by storm washover
- channel dimensions maintained as per past flood scour

ENTRANCE WALLS

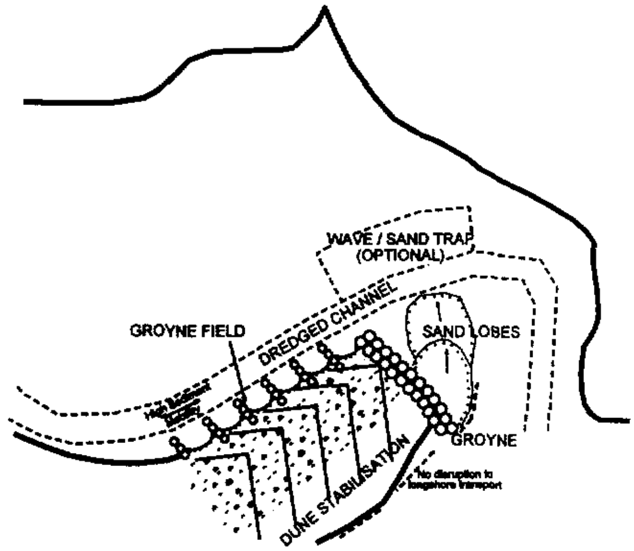


STUB GROYNE AND PARTIAL SPIT STABILISATION



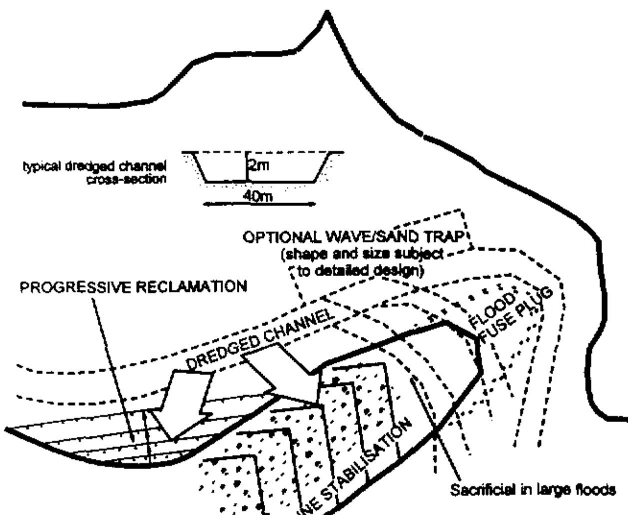
- *Construct minimal groyne to provide hard point to support elevated entrance spit*
- Stabilised entrance spit prevents storm washover
- Main channel could still choke tidally under prolonged dry spells and entrance storm slugs

STUB GROYNE AND INTERNAL TRAINING WALL



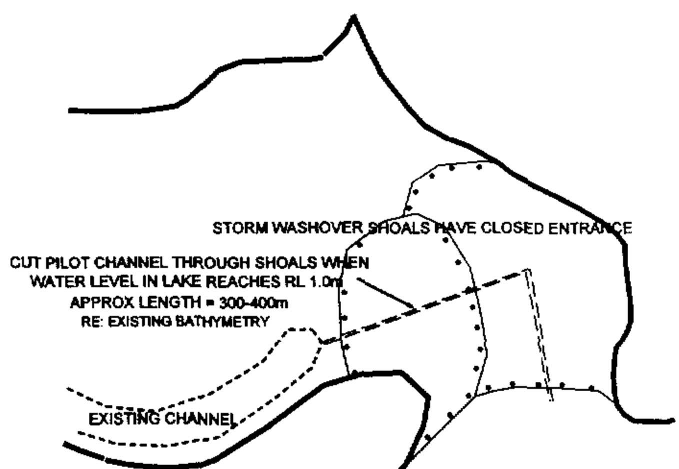
- Stabilise spit with groyne field
- Build up entrance spit to prevent storm washover
- Utilise sand from sand trap in spit stabilisation
- Extract sand from wave / sand trap (optional)

STUB GROYNE AND INTERNAL GROYNE FIELD



- Stabilise entrance spit to reduce storm washover
- Maintain fuse plug at northern tip of spit to suit flood flows (1.0 - 1.5m AHD)
- When close to closure according to a new Entrance Management Policy, dredge new channel along path of historic flood cuts to substantial dimensions, ie 40m x 2m deep
- Monitor entrance conditions

MANAGED ENTRANCE



EXISTING PROTOCOL

0 100 200 m

LAKE CONJOLA ENTRANCE STUDY
ENTRANCE MANAGEMENT OPTIONS

results of the entrance scour modelling *(T.A. 17)* can be used to optimise future lake openings to achieve maximum entrance breakout results.

ASSESSMENT OF ENTRANCE OPTIONS

Hydraulic Grouping Of Options

In recognition of the similar hydraulic performance of the three Stub Groyne options *(ie. options 2, 3 & 4 above)*, entrance options were categorised into the following groups to simplify flooding and water quality comparisons:

ENTRANCE WALLS	1.	Entrance Training Walls options
ENTRANCE STUB WALL	2.	Stub Groyne and Internal Training Wall
	3.	Stub Groyne and Internal Groyne Field
	4.	Stub Groyne and Partial Spit stabilisation
MANAGED ENTRANCE	5.	Managed Entrance
EXISTING CONDITION		Existing Opening Policy with following subsets:

- Existing Closed Condition - 15% of time;
- Existing Heavily Shoaled - 23% of time;
- Existing Open Condition - 62% of time.

Details of the dimensions of each of these groupings and subsets is provided in TA18; Entrance Options Assessment.

Flooding Assessment

Table 6 summarises flooding impacts for the major and minor flood scenarios adopted for the study. It also shows flooding due to storm surge only.

Table 6 Flood Level Comparisons

Location	Existing Closed Condition	Existing Heavily Shoaled	Existing Open Condition	Entrance Walls	Stub Wall	Managed Entrance
d/s Caravan Park	2.97 **2.59** (-)	2.81 **2.41** (0.48)	2.62 **2.24** (1.45)	4.00 **2.48** (1.70)	2.90 **2.47** (1.45)	2.62 **2.24** (1.45)
Post Office	3.22 **2.69** (-)	3.06 **2.51** (0.48)	2.87 **2.34** (1.45)	4.20 **2.58** (1.70)	3.15 **2.57** (1.45)	2.87 **2.34** (1.45)
Canal Entrance	3.52 **2.79** (-)	3.36 **2.61** (0.48)	3.17 **2.44** (1.45)	4.45 **2.68** (1.70)	3.45 **2.67** (1.45)	3.17 **2.44** (1.45)
Edwin Ave	3.67 **2.94** (-)	3.51 **2.76** (0.48)	3.32 **2.59** (1.45)	4.60 **2.83** (1.70)	3.60 **2.82** (1.45)	3.32 **2.59** (1.45)
Main Lake	4.37 **3.24** (-)	4.21 **3.06** (0.48)	4.02 **2.89** (1.45)	5.20 **3.13** (1.70)	4.30 **3.12** (1.45)	4.02 **2.89** (1.45)
Berringer Lake	3.17 **2.69** (-)	3.01 **2.51** (0.48)	2.82 **2.34** (1.45)	4.15 **2.58** (1.70)	3.10 **2.57** (1.45)	2.82 **2.34** (1.45)

Legend:
2.97 major flood scenario involving 1 in 100 yr freshwater flow coinciding with 1 in 5 yr storm surge.
2.59 minor flood scenario involving 1 in 5 yr freshwater flow coinciding with 1 in 5 yr storm surge.
(-) flood level due to 1 in 5 yr storm surge only.

Major Flood Scenario

It can be seen that during a major flood scenario, the Entrance Walls increase flood levels generally by more than 1 metre compared to the Existing Condition. This is because the entrance walls do not allow the entrance to increase its flood discharge capacity by widening. The Stub Wall group of options cause an increase in flood level of approx 0-0.3 m depending upon whether the existing entrance is closed or open. This reflects the ability of the stub groyne options to accommodate significant lateral entrance scour.

The Managed Entrance is identical to the Existing Open Condition. Hence it provides a reduction in flood levels of approx 0-0.35 depending upon whether the existing entrance is open or closed, at the time of flooding.

Minor Flood Scenario

During a minor flood scenario, the flood impacts of the Entrance Wall and Stub Wall are similar and vary from a reduction of approx 0.1 m to an increase of 0.24 m depending on whether the existing entrance is closed or open at the time of flooding.

The Managed Entrance is again identical to the Existing Open Condition, hence it provides a reduction in flood levels of approx 0-0.35 depending on whether the existing entrance is open or closed at the time of flooding.

Storm Surge Flooding

In relation to storm surge penetration, the Entrance Walls allow the main lake to buildup significantly higher than the existing entrance condition by providing an efficient entrance for storm surge inflow.

FLOOD DAMAGES

Table 7 shows the number of dwellings and septic tanks affected by flooding for major and minor flood scenarios and for storm surge only, based on Council's database of floor levels and septic tank levels.

Table 7 Impact of Options on Flooding of Dwellings & Septic Tanks

Impact	Existing Closed Condition	Existing Heavily Shoaled	Existing Open Condition	Entrance Walls	Stub Walls	Managed Entrance
no of dwelling flooded above floor level	138/138 118/138 (0/138)	138/138 89/138 (0/138)	133/138 73/138 (5/138)	138/138 103/138 (14/138)	138/138 102/138 (5/138)	133/138 73/138 (5/138)
no of dwellings where flooding exceeds 0.3m above floor level	135/138 76/138 (0/138)	130/138 63/138 (0/138)	112/138 41/138 (1/138)	138/138 69/138 (3/138)	133/138 68/138 (1/138)	112/138 41/138 (1/138)
no of septic tanks flooded	187/187 177/187 (0/187)	187/187 160/187 (0/187)	187/187 145/187 (9/187)	187/187 169/187 (28/187)	187/187 168/187 (9/187)	187/187 145/187 (9/187)

Legend:
138/138 no of dwellings/septics flooded in Major Flood Scenario.
118/138 no of dwellings/septics flooded in Minor Flood Scenario.
(0/138) no of dwellings/septics flooded due to 1 in 5 yr storm surge only.

Table 8 shows the sum of direct and indirect tangible damages associated with the major and minor flood scenarios. The flood damages are based on flood damage curves published by ANU (Smith, 1992).

Table 8 Tangible Flood Damages

Flooding Event	Existing Condition[1]	Entrance Walls	Stub Wall	Managed Entrance
Major Flood Scenario	$1,425,000	$1,553,000	$1,522,000	$1,368,000
Minor Flood Scenario	$667,000	$953,000	$940,000	$627,000

1 value for existing condition is based on proportion of time entrance is in different states ie. 15% closed, 23% heavily shoaled and 62% open.

As discussed above, the managed entrance is the only option which reduces flood levels and hence flood damages compared to the existing entrance condition. The flood benefit for the managed entrance is approximately $40,000 during minor floods and $57,000 during major floods.

Alternative Floodplain Management Options

The flood damage potential faced by the community is estimated to have a present worth of $4.2 to $6.0 million, depending upon whether public health is factored in or not *(refer previous discussion on Existing Flood Behaviour)*. This damage potential could be reduced by a number of floodplain management options:

House Raising

Dwellings with low floor levels could be raised to give greater protection against flooding. House raising is not applicable to slab on ground dwellings. The cost of raising is of the order of $20,000 to $25,000 per dwelling irrespective of whether it is raised a little or a lot.

The overall cost of house raising would depend upon the number of houses raised which in turn would depend upon the level of protection selected and the number of houses which are not amenable to raising.

If flood damage was to be avoided in floods up to a major flood scenario, 110-130 dwellings would need to be raised at a total cost of $2.2 million to $3.3 million.

If flood damage was to be avoided in floods up to a minor flood scenario, 40-70 dwellings would need to be raised at a total cost of $0.8 million to $1.8 million.

These costs are comparable to the estimated present worth of flood damages. Hence, there would appear to be merit in having a comprehensive look at house raising as part of a Floodplain Management Plan *(refer earlier discussion)*.

House Relocation

House relocation is usually only considered in relation to a minor proportion of the dwellings within a town which are exposed to high flood hazards, usually on the floodways of a swiftly flowing river. This is not considered applicable to Lake Conjola.

Voluntary Purchase

The voluntary purchase of dwellings, at market rates, is similarly applied only to assist residents exposed to high flood hazard. Again, this is not considered applicable to Lake Conjola. However, voluntary purchase of key areas could be considered as part of a Floodplain Management Plan with a wider context of environmental and ecological considerations.

Emergency Response Planning

The flood damages referred to above are *potential* flood damages. The extent to which these damages are fully realised in any flood *(ie. actual damages)* depends upon damage avoidance measures taken by occupants. The effectiveness of any such measures depends upon the flood awareness and preparedness of the community.

Good emergency response planning involving regular community education, awareness activities and comprehensive flood warning can reduce actual flood damage to 50% of the damage potential. The extent to which this is truly achievable will depend upon the specific profile of the flood affected communities eg. percentage of holiday homes, percentage of elderly etc.

WATER QUALITY ASSESSMENT

Tidal Flushing

Figure 7 *(overleaf)* shows the flushing characteristics of all options in response to an initial uniformly distributed reference pollutant concentration.

The Managed Entrance and Stub Wall group of options are identical in their tidal response and tidal flushing characteristics to the existing entrance in an open condition. The characteristics of the existing open condition have been discussed earlier.

The Entrance Walls option allows greater tidal penetration. **Figure** 7 shows that this increases the flushing of the southern half of the main lake from 10%, under existing entrance conditions, to 40%. Along the northern portion of the southern half of the lake, between The Steps and Station Point, flushing increases up to 80%.

The Entrance Walls increase the flushing of Berringer Lake from 0% to 10%, under existing entrance conditions, to approx 30%.

It is interesting to note that the Entrance Walls appear to decrease flushing between Conjola Island and Chinamans Island. This reflects the better flushing of the upper lake and the consequential time dependent increase in pollutant transport through the inlet. The apparent decrease in flushing would disappear if the computer run exceeded 100 hrs.

The increased exchange of pollutants between the upper lake and the inlet, when entrance tidal flows are increased, is discussed below.

Pollutant Dispersion

In terms of the evacuation of point source pollutants, it was shown that under existing open entrance conditions, tidal flushing is strong enough to avoid high concentrations in the inlet area. Fisherman's Paradise area is prone to higher concentrations 24 hours after a storm burst and entrance conditions have no impact on reducing these. The various entrance improvement options, therefore, cannot improve upon the existing entrance open condition - refer plots of pollutant evacuation in TA18.

Table 9 shows the predicted relative concentration of pollutants around the lake, 24 hours after a pollutant burst caused by a 6 hour storm and taking into account the relative magnitudes of point source loadings to the lake. The concentrations have been normalised by setting the concentration at the downstream caravan park, under existing conditions, equal to 100%.

Table 9 Predicted Relative 24 hr Pollutant Concentrations

Location	Existing[1] Condition	Entrance Walls	Stub Wall	Managed Entrance
d/s caravan park	100%	5%	5%	5%
post office	101%	5%	6%	6%
Canal Entrance	99%	5%	6%	6%
Adjacent to Edwin Ave	71%	5%	6%	6%
At "The Steps" (u/s end of delta)	8%	6%	6%	6%
Main Lake (500 u/s of "The Steps"	7%	6%	7%	7%

1 existing condition based on proportion of time entrance is in different states ie. 15% closed, 23% heavily shoaled and 62% open.

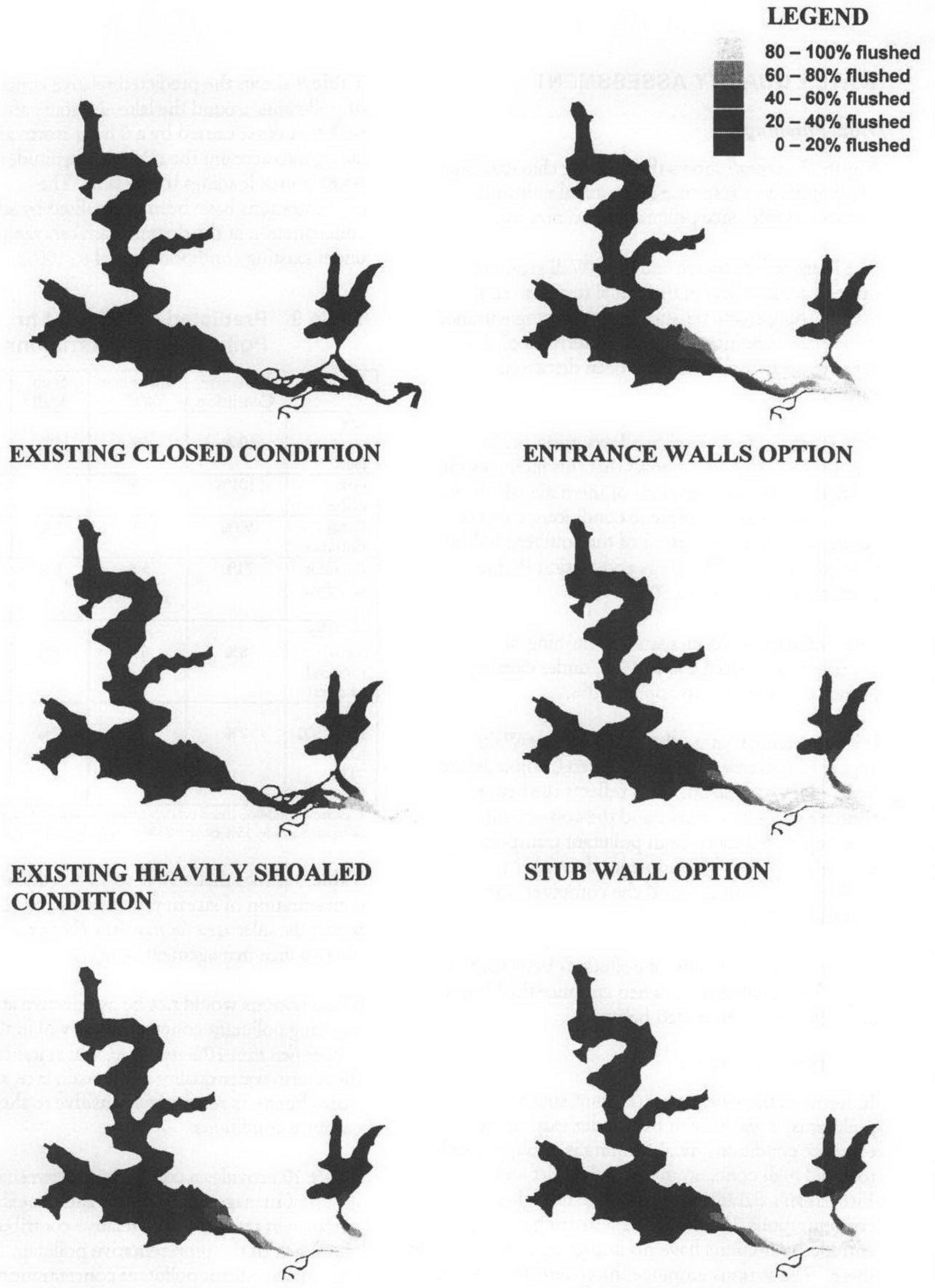
Table 9 shows that a 90% to 95% reduction in the concentration of storm pollutant can be achieved within the inlet area *(ie. mouth to The Steps)* by all of the entrance management options.

These options would not be as effective at reducing pollutant concentrations within the lake proper *(less than 10% reduction)*, which indicates that short term water quality in the main lake, related to storm bursts, is relatively insensitive to the lake entrance conditions.

Table 10 provides a comparison between each group of management options and the existing entrance in respect of the relative contribution from each of the representative pollutant loads to the ambient storm pollutant concentration at locations around the lake.

Table 10 shows that under existing conditions, the majority of pollution within the inlet area *(main*

FIGURE 7



LAKE CONJOLA ENTRANCE STUDY

FLUSHING CHARACTERISTICS OF EXISTING CONDITIONS AND ENTRANCE MANAGEMENT OPTIONS *swimming and primary contact area)* comes from the input load at the Post Office/Canal Entrance. When the entrance delta is well flushed, due to a variety of entrance management options, the pollutant inputs into the more upstream portions of the lake *(ie. Killarney and Lake Conjola West)* become relatively more significant to pollutant concentrations.

Pollution levels due to storm bursts within the main portion of Lake Conjola are relatively insensitive to the entrance conditions.

Alternative Water Quality Improvement

An equivalent reduction in water quality pollutants in the inlet area could be obtained if 95% of the septic systems with infiltration trenches in Lake Conjola were converted to pump out systems *(assuming that the existing pumpout systems do not contribute to the pollutant loads).* Given that there is 193 registered septic systems with infiltration trenches in Lake Conjola, 184 of these would need to be pumped out, on average every three months *(depending on the size of the tank)* for a typical cost of $200 per dwelling ie. an average annual cost of the order of $147,000.

Current planning indicates that the residential areas of Lake Conjola are likely to be connected to town sewerage in the next 5 years. Hence any alternative action based on regular pumpout would need to operate for only 5 years.

Over a five year period, the foregoing average annual pump out cost would have a present net worth of approximately $600,000.

Table 10 Proportions of Total Load Contributed by Each Pollutant Input Location

Location	Load 1 d/s Caravan Park (%)	Load 2 Post Office/ Canal Ent (%)	Load 3 Adj to Edwin Ave (%)	Load 4 Killarney (%)	Load 5 Lake Conj. West (%)	Load 6 Fisherman's Paradise (%)
d/s Caravan Park	15.9	81.0	1.4	1.0	0.7	0.0
	1.6	*45.7*	*2.5*	*27.6*	*22.2*	*0.4*
	2.3	*39.2*	*1.8*	*28.8*	*27.4*	*0.5*
	2.3	39.2	1.8	28.8	27.4	0.5
Post Office	12.6	83.7	1.6	1.2	0.9	0.0
	1.5	*43.3*	*2.7*	*28.1*	*24.0*	*0.4*
	2.2	*37.9*	*1.7*	*28.9*	*28.9*	*0.4*
	2.2	37.9	1.7	28.9	28.9	0.4
Canal Entrance	11.0	85.1	1.8	1.2	0.9	0.0
	1.5	*47.4*	*3.3*	*25.9*	*21.5*	*0.4*
	2.4	*43.9*	*2.8*	*26.1*	*24.5*	*0.4*
	2.4	43.9	2.8	26.1	24.5	0.4
Edwin Avenue	10.3	84.1	1.9	2.1	1.7	0.0
	1.5	*40.9*	*2.2*	*28.3*	*26.8*	*0.4*
	2.1	*36.3*	*1.7*	*28.8*	*30.8*	*0.4*
	2.1	36.3	1.7	28.8	30.8	0.4
At "The Steps"	2.5	47.9	2.5	22.3	24.2	0.6
	1.1	*37.5*	*2.2*	*27.4*	*31.0*	*0.7*
	2.0	*33.9*	*1.6*	*27.9*	*33.9*	*0.8*
	2.0	33.9	1.6	27.9	33.9	0.8
Main Lake (500m u/s of The Steps)	1.3	29.9	1.9	24.0	41.2	1.6
	1.0	*28.3*	*1.7*	*24.2*	*43.1*	*1.7*
	1.4	*26.0*	*1.1*	*24.2*	*45.6*	*1.8*
	1.4	26.0	1.1	24.2	45.6	1.8

Legend:

15.9 Existing Conditions *(ie. 15% closed, 23% heavily shoaled and 62% open).*

1.6 Entrance Walls Option.

2.3 Entrance Stub Wall Option.

2.3 Managed Entrance Option.

BENEFITS AND COST OF OPTIONS

The benefits and cost of each option are set out in **Table 11**. All benefits and costs have been reduced to a common base by discounting costs and benefits which are distributed over the nominal life of the option *(adopted as 50 years)* using the *Present Value* technique and a discount rate of 7% pa.

Table 11 Present Value Benefit/Cost Analysis of Entrance Management Options

ENTRANCE MANAGEMENT OPTION	Benefit due to flood mitigation	Benefit due to improved water quality	Cost	B/C ratio
1. Entrance Training Walls	-$1.2 mil	$0.6 mil	$6.8 mil	-0.09
2. Stub Groyne and Internal Training Wall *(with Wave/Sand Trap)*	-$1.0 mil	$0.6 mil	$5.3 mil	-0.08
3. Stub Groyne and Internal Training Wall *(with Wave/Sand Tap)*	-$1.0 mil	$0.6 mil	$6.5 mil	-0.06
4. Stub Groyne and Internal Training Wall *(with Wave Trap and Comm. Extraction)*	-$1.0 mil	$0.6 mil	$5.5 mil	-0.07
5. Stub Groyne and Internal Groyne Field *(without Wave/Sand Trap)*	-$1.0 mil	$0.6 mil	$3.8 mil	-0.11
6. Stub Groyne and Internal Groyne Field *(with Wave/Sand Trap)*	-$1.0 mil	$0.6 mil	$5.0 mil	-0.08
7. Stub Groyne and Internal Groyne Field *(with Wave trap and Comm. Extraction)*	-$1.0 mil	$0.6 mil	$4.1 mil	-0.10
8. Stub Groyne with Partial Spit Stabilisation *(without Wave/Sand Trap)*	-$0.8 mil	$0.6 mil	$2.6 mil	-0.08
9. Stub Groyne with Partial Spit Stabilisation *(with Wave/Sand Trap)*	-$0.8 mil	$0.6 mil	$3.8 mil	-0.05
10. Stub Groyne with Partial Spit Stabilisation *(with Wave Trap and Comm. Extraction)*	-$0.8 mil	$0.6 mil	$2.8 mil	-0.07
11. Managed Entrance *(without Wave/Sand Trap)*	$0.2 mil	$0.6 mil	$0.7 mil	1.14
12. Managed Entrance *(with Wave/Sand Trap)*	$0.2 mil	$0.6 mil	$1.9 mil	0.42
13. Managed Entrance *(with Wave Trap and Comm. Extraction)*	$0.2 mil	$0.6 mil	$0.9 mil	0.89
14. Maintain Existing Protocol	0	0	$0.2 mil	0.0

Note: Negative numbers represent a disbenefit.

COSTS

Costs include initial capital costs *(ie immediate works such as breakwaters, channel dredging etc, and periodic maintenance costs, distributed over a 50 year period).*

A contingency of 25% was used in all cost estimates.

Coastal structures are always very costly because of the sheer volume and size of the components required to resist storm waves as well as, in this case, flood scour. Maintenance costs to keep the structures safe for public access is also significant. It can be seen that the cost of structural options varies from $2.6 million for the Stub Groyne with Partial Spit stabilisation to $6.8 million for entrance training walls.

The Managed Entrance, however, has no structural components and requires application of resources only when entrance conditions have deteriorated and entrance closure is imminent. Hence there is very little "upfront" cost. This means that the Managed Entrance is cost effective, having an estimated cost, expressed as a present value over 50 years, of $700,000 without sand trap. The comparison of this cost with the $200,000 for the current entrance policy, reflects the greater magnitude of channel excavation required to re-establish a stable channel *(refer Technical Appendix 17; Entrance Scour and Opening Protocol).*

SAND EXTRACTION OPPORTUNITY

The options in **Table 11** include the possibility of an optional wave/sand trap being maintained by a commercial sand extraction operator. Sand extraction is currently conducted in the hind dunes of Conjola Beach, south of Conjola Township. Hence, there would appear to be a viable local market.

For the purpose of costing the options in **Table 11,** it was assumed that the commercial extraction would apply only to maintenance of the sand trap. It was considered that the initial formation of the wave trap would need to be an integral component of the capital works. It was assumed that there would be no costs involved with maintenance of the wave trap by commercial extraction.

It was beyond the scope of this study to examine the feasibility of commercial sand extraction. The environmental implications of a commercial sand extraction operation designed to maintain the sand trap would need to be investigated further, and would need to consider local demand and markets for marine sands *(ie economic analysis)*, as well as the environmental impacts of regular dredging and onshore stockpiling and processing.

BENEFITS

The benefits of the entrance works were assessed in terms of flood mitigation potential, and water quality improvement potential. The flooding and water quality capabilities of the different entrance options are quantified in *Technical Appendix 18; Entrance Options Assessment.*

Flood mitigation benefits were calculated as a reduction in the average annual damages over the next 50 years, discounted at 7% pa. to give a net present worth. Water quality benefits were determined by equating the level of water quality improvement in the lake, generated by each option, to an equivalent reduction in pollutant loading through pumpout of septic systems in Lake Conjola township *(refer Technical Appendix 18; Entrance Options Assessment).* As a sewerage system is planned for Lake Conjola within the next 5 years, the costs associated with the equivalent pumping out of septic systems was calculated over a 5 year period only, and discounted at 7% p.a. to give a net present worth.

Table 11 shows that the flood mitigation benefits of the training walls and stub groyne options are negative because they increase peak flood levels associated with major and severe flooding. These options therefore would have a detrimental effect on flooding. Alternatively, additional costs would be involved in addressing the increased flood risk (ie house raising, levees etc). For most of these options, the negative benefit of flooding is counterbalanced by the positive benefit of water quality improvement, resulting in approximately no net monetary benefit from carrying out the works. House raising would cost between $0.8million - $3.3million depending on the level of protection sought (refer *house raising, Entrance Management Options*).

The managed entrance option, which has a relatively low cost, and a positive flood mitigation benefit, is the only option which potentially returns a net benefit within the terms and parameters of this study, ie the managed entrance option is the only option which has a Benefit : Cost ratio greater than 1.0.

It was beyond the scope of this study to carry out an economic assessment of the impact of entrance options on the tourist income of the area.

Discussions with the local community, in particular present and past caravan park operators, indicated that sustained entrance closure leads to a loss in annual tourist income of the order of 30%.

The structural options are likely to have both positive and negative influences in terms of maintaining tourism/holiday maker contribution to the local economy. The managed entrance is not likely to have a negative influence in this regard.

On balance, it is considered that potential benefits associated with maintaining or increasing tourism income would push the benefit cost ratio of the Managed Entrance well over 1.0 but would be unlikely to substantially alter the B/C of the structural options.

ENVIRONMENTAL APPROVAL COSTS

Entrance openings by Council are carried out under the provisions of State Environment Planning Policy (SEPP) Nº. 35 – Maintenance Dredging of Tidal Waters and in accordance with Council's current policy on opening the lake. Council's current policy serves as an Interim Lagoon Opening Strategy under SEPP Nº. 35. As this activity is considered to be of a minor and routine nature a Review of Environmental Factors (REF) is the appropriate level of assessment.

The Managed entrance option (without wave/sand trap) is not inconsistent with the current entrance policy. Adoption of this option would require revision of the policy and preparation of an REF under the provisions of SEPP Nº. 35.

The buildup and stabilisation of the entrance spit would require an environmental study (either REF or SEE depending on whether this work requires development consent under Council's LEP). Such a study, however, would not be onerous because dune stabilisation has been carried out by the Department of Land and Water Conservation numerous times in the past.

A commercial sand extraction operation to maintain a wave/sand trap however, would constitute designated development and an EIS would be required.

All the structural options would be considered to have the potential to significantly impact on the environment. Consequently, a necessary pre-requisite for development consent of any of the structural options would be the preparation of a comprehensive Environmental Impact Statement *(EIS).*

Table 12 summarises the broad scope and order of cost associated with the environmental assessments which would be needed to obtain development consent for the various entrance options.

Table 12 Review of Environmental Assessments Required for Implementation of each Entrance Option

Entrance Option	Level/Type of environmental Assessment Required	Broad Scope	Estimated Cost
Existing Protocol	REF under SEPP 35	In-house Council review of environmental factors and advice to State Government concurrence authorities	Negligible
Managed Entrance *(without Wave/Sand Trap)*	REF under SEPP 35	REF to formalise long term disposal to spit entrance stabilisation and possible reclamation against base of high dunes covering issues related to: • beach access • recreational amenity • endangered fauna (may require SIS*) • aesthetics	$10,000 to $20,000 not including SIS
Managed Entrance *(with Wave/Sand Trap)*	SEPP 35 and REF	As above but extended to include issues related to creation and maintenance of Wave/Sand Trap • wave action • sedimentation pattern • fauna impact *(wading birds)* – (may require SIS*) • fisheries impact • public safety • aesthetics	$15,000 to $25,000 not including SIS
Managed Entrance *(with Wave/Sand Trap and Comm extraction)*	EIS	As above but extended to include issues related to regular commercial sand extraction • fauna Impact *(wading birds)* – (may require SIS*) • fisheries impact • public safety • aesthetics • trucking impacts • noise • recreation amenity • lake ecology	$50,000 to $75,000
Stub Groyne Options	EIS	Comprehensive assessment of construction impacts and long term ecological impacts involving: • nearshore marine fauna • fisheries impact including fish migration patterns • fish habitat • water quality • flooding • noise • aesthetics • endangered flora and fauna generally (may require SIS*) • fauna impact *(wading birds)* • recreation and public safety • wave action • sedimentation patterns • tourism	$100,000 to $150,000
Entrance Training Walls	EIS	As above *(re Stub Groyne)* but including additional coastal and environmental impacts relating to: • behaviour of Conjola Beach • coastal sediment budget impacts • boating safety • nearshore marine ecology • tourism	$100,000 to $150,000

* SIS – Species Impact Statement

SUMMARY OF OPTIONS

Several factors need to be considered when assessing the overall effectiveness of the different entrance options. The most important factor would be the long term sustainability and stability of the entrance. However, other considerations would include the impacts of the works on flooding, the impacts on water quality within the lake, the cost of the works and their ease of implementation. In respect of the latter, those options which have significant environmental drawbacks *(eg. flooding impacts)* and would require an EIS, would be more difficult to obtain development consent.

Table 13 Assessment of Entrance Management Options for Different Selection Criteria

	Assessment of Options				
	Entrance Stability	Flooding	Water Quality	Benefit/ Cost	Ease of Implementation
Entrance Training Walls	✓✓✓	✗✗✗	✓✓✓	✗✗	✗✗✗
Stub Groyne and Internal Training Wall *(Without Wave/Sand Trap)*	✓✓	✗✗	✓✓✓	✗	✗✗
Stub Groyne and Internal Training Wall *(With Wave/Sand Trap)*	✓✓	✗✗	✓✓✓	✗	✗✗
Stub Groyne and Internal Training Wall *(With Wave Trap and Comm Extraction))*	✓✓	✗✗	✓✓✓	✗	✗✗
Stub Groyne and Internal Groyne Field *(With Wave/Sand Trap)*	✓✓	✗✗	✓✓✓	✗	✗✗
Stub Groyne and Internal Groyne Field *(With Wave Trap and Comm. Extraction)*	✓✓	✗✗	✓✓✓	✗	✗✗✗
Stub Groyne and Internal Groyne Field *(Without Wave/Sand Trap)*	✓✓	✗✗	✓✓✓	✗	✗✗
Stub Groyne with Partial Spit Stabilisation *(Without Wave/Sand Trap)*	✓	✗	✓✓✓	✗	✗
Stub Groyne with Partial Spit Stabilisation *(With Wave/Sand Trap)*	✓✓	✗	✓✓✓	✗	✗
Stub Groyne with Partial Spit Stabilisation *(With Wave Trap and Comm. Extraction)*	✓✓	✗	✓✓✓	✗	✗✗
Managed Entrance *(Without Wave/Sand Trap)*	✓	✓	✓✓✓	✓✓✓	✓✓
Managed Entrance *(With Wave/Sand Trap)*	✓✓	✓	✓✓✓	✓	✓
Managed Entrance *(with Wave Trap and Comm. Extraction)*	✓✓	✓	✓✓✓	✓✓	✗
Maintain Existing Protocol	-	-	-	-	-

Legend ✓ Favourable
✗ Unfavourable