GOSFORD CITY COUNCIL

draft

PART W
WAMBERAL LAGOON
ESTUARY PROCESSES STUDY

JULY, 1994

WEBB, McKEOWN & ASSOCIATES PTY. LTD.
CONSULTING ENGINEERS
# WAMBERAL LAGOON

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PART W - WAMBERAL LAGOON

W1. GENERAL

This report is that part of the Gosford Coastal Lagoons Estuary Processes Study which covers Wamberal Lagoon. The references and appendices referred to in this report are contained in the general document "Gosford Coastal Lagoons, Estuary Processes Study". The other lagoons area also found in separate parts:
- Part T - Terrigal Lagoon Estuary Processes Study,
- Part A - Avoca Lake Estuary Processes Study,
- Part C - Cockrone Lake Estuary Processes Study.

Wamberal Lagoon is the most northerly of the four Gosford Coastal Lagoons, and a small part of the catchment extends into neighbouring Wyong Council area (see Figure W1). The lagoon has a surface area of approximately 0.57 square kilometres and a catchment area of approximately 6.6 square kilometres. The area of the lagoon is therefore around 9% of the catchment.

The majority of the catchment lies to the north of the lagoon and is largely undeveloped rural land. South and west of the lagoon is the residential area of Wamberal. The north-eastern part of the catchment consists of part of the suburb of Forresters Beach. Wamberal Lagoon Nature Reserve and Wamberal Park encompass the lagoon and the lagoon foreshore area as well as the coastal sand barrier to the east of the lagoon adjoining Wamberal Beach. The Nature Reserve contains diverse flora and fauna which is of major conservation value.

The main tributary to the lagoon is the "North Arm" which drains 2.6 square kilometres of the northern catchment. Other tributaries all have catchments areas less than 50 hectares. The two largest enter the lagoon through Wamberal Park from near Winston Street and Loxton Avenue (see Figure W2).
The average bed level of the lagoon varies from +0.3m to +0.7m AHD although there are areas down to -1.5m AHD. The outlet to the ocean through Wamberal Beach is generally closed by the beach berm, and water levels inside the lagoon are not usually influenced by ocean tides. The available historical record of lagoon levels is limited, so a rigorous analysis of average lagoon levels cannot be undertaken. However, an estimate of 2.0m AHD has been adopted for this Processes Study based on the available data. The volume of water retained in the lagoon at this level is approximately 760ML.

The lagoon is an attractive feature in the local area and of high environmental significance. No commercial tourist operators use the lagoon. However, it is used by the local residents for fishing and boating. It is generally not used for swimming except near the outlet. There are no known references to any significant filling or dredging activities which have occurred within the lagoon.

A number of properties surrounding the lagoon are relatively low lying and flooding, in the past, has caused damage and loss of property. To minimise property flooding the entrance berm is mechanically opened by Council when lagoon levels reach 2.4m AHD. Artificially opening the lagoon affects the lagoon water balance, lagoon water quality, and the lagoon ecological system. An examination of entrance opening procedures is therefore a major consideration for this study. Other major issues examined for the study include:

- nutrient and other pollutant input and assimilation,
- sedimentation and infilling of the lagoon by catchment runoff and ocean sediment infeed,
- nature conservation (within the lagoon and the immediate foreshores) and increased urbanisation, including requirements such as:
  - recreational use,
  - visual quality,
  - odour control,
  - flooding control.
W2. PHYSICAL PROCESSES

W2.1 Water Level Analysis

W2.1.1 Historical Record of Lagoon Opening & Closure

Council's "Lagoon Book" (Reference 1) has recorded a history of conditions at the lagoon and entrance since 1970. Prior to 1977 only openings were recorded. Subsequently, a more detailed record has been kept including:

- the time and date of observation,
- the tide,
- the height of the lagoon above the opening level,
- the height of the beach berm above the opening level,
- wind direction and strength,
- direction of ebb flow,
- movement of channel,
- days remaining open,
- result of opening/comments.

Predominantly the entrance has opened naturally or has been opened by Council to minimise possible flooding. However, the records show that it has been opened for a range of other reasons including by private individuals for recreational purposes, and by Council for construction/environmental consideration such as the construction of sewerage works or to empty lagoon waters which have become deoxygenated, overheated or discoloured, etc.

The only other available records of entrance conditions are historical photographs and various reports held by Council or by local residents. The entrance data are presented graphically in the Gosford Coastal Lagoons Compendium of Data (Reference 2) and summarised in Table W1 below.
### TABLE W1
Summary of Entrance Condition Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Openings (1974-1993)</td>
<td>55</td>
</tr>
<tr>
<td>Average per year</td>
<td>2.8</td>
</tr>
<tr>
<td>Number of Openings (1974-1983)</td>
<td>25</td>
</tr>
<tr>
<td>Number of Openings (1984-1993)</td>
<td>30</td>
</tr>
<tr>
<td>Most openings per month:</td>
<td>June</td>
</tr>
<tr>
<td></td>
<td>10 times in 20 years</td>
</tr>
<tr>
<td>Least openings per month:</td>
<td>October</td>
</tr>
<tr>
<td></td>
<td>1 time in 20 years</td>
</tr>
<tr>
<td>Reasons for Opening:</td>
<td>Council</td>
</tr>
<tr>
<td>(1984-1993)</td>
<td>55%</td>
</tr>
<tr>
<td></td>
<td>Natural</td>
</tr>
<tr>
<td></td>
<td>23%</td>
</tr>
<tr>
<td></td>
<td>Private</td>
</tr>
<tr>
<td></td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>Environmental</td>
</tr>
<tr>
<td></td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Construction</td>
</tr>
<tr>
<td></td>
<td>2%</td>
</tr>
<tr>
<td>Duration of Opening:</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>Up to 26 days</td>
</tr>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>6.5 days</td>
</tr>
<tr>
<td></td>
<td>6.5 days Artificial</td>
</tr>
<tr>
<td></td>
<td>6.6 days Natural</td>
</tr>
<tr>
<td></td>
<td>27% closed within 2 days</td>
</tr>
<tr>
<td></td>
<td>89% closed within 14 days</td>
</tr>
<tr>
<td>Opening Lagoon Levels:</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>1.4m AHD to 2.7m AHD</td>
</tr>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>2.4m AHD</td>
</tr>
<tr>
<td>Opening Height of Beach Berm:</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>1.4m AHD to 3.9m AHD</td>
</tr>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>2.9m AHD</td>
</tr>
<tr>
<td>Duration of Closure:</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>Up to 20 months</td>
</tr>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>123 days</td>
</tr>
</tbody>
</table>
2.1.2 Lagoon Tidal Response

An automatic water level recorder was installed in Wamberal Lagoon in July 1993 by NSW Public Works (PW) and continuous water level data are available from that date. The data includes one lagoon opening, on 12 September 1993. Figure W3 shows a plot of the lagoon water level and ocean tide level (Fort Denison) for the period from July 1993 to the end of March 1994.

The RUBICON hydrodynamic numerical model (Appendix D) was used to replicate lagoon opening and subsequent tidal flows. The available tidal data were used to calibrate the breakout model. The model was then used to quantify the impacts of natural openings, as well as artificial opening of the lagoon at set levels. Details of the entrance dynamics investigation are given in Section W2.3. The modelling examined a "typical" breakout event with the initial lagoon water level at 2.4m AHD, a berm level around 3.0m AHD, and an excavated channel sufficiently large to initiate breakout. Under these conditions, and with only limited catchment runoff, some 6000m$^3$ of sand would be moved from the entrance, creating a channel approximately 50m wide to a maximum depth of between zero and +0.4m AHD.

After a breakout under the adopted "typical" conditions the entrance behaviour is such that the tidal response of the lagoon is substantially modified by shallow water effects. These effects distort the shape of the tide making the outgoing ebb tide longer and the incoming flood tide shorter and hence faster. The shallow water through the entrance also makes numerical modelling of tidal flows difficult. A comparison of averaged tidal conditions with the recorded lagoon response to actual tidal conditions was therefore used to assist analysis of the lagoon tidal response (see Figure W3).

On this basis, the response of Wamberal Lagoon following a "typical" opening (without a significant flood event) to an average ocean tidal range of 1.0m was estimated to be 0.2m, with the lagoon water level elevated to +0.4m AHD. The average tidal prism under these conditions was calculated to be 60ML. Table W2 sets out the estimated tidal
response of the lagoon after "typical" opening for a range of tidal conditions. Note, although modelled, the lagoon entrance rarely remains open through neap tides (see Section W2.3).

**TABLE W2**

<table>
<thead>
<tr>
<th>Tidal Phase</th>
<th>Ocean Tidal Range (m)</th>
<th>Lagoon Tidal Range (m)</th>
<th>Lagoon Elevation (m AHD)</th>
<th>Lagoon Tidal Prism (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Neap</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
<td>20</td>
</tr>
<tr>
<td>Mean</td>
<td>1.0</td>
<td>0.2</td>
<td>0.4</td>
<td>60</td>
</tr>
<tr>
<td>High Spring</td>
<td>1.8</td>
<td>0.4</td>
<td>0.6</td>
<td>140</td>
</tr>
</tbody>
</table>

**W2.1.3 Water Balance**

The annual water balance for Wamberal Lagoon is a function of:
- tidal flows (in and out),
- flood flows (out),
- breakout prism,
- surface water/ground water runoff,
- direct precipitation,
- evaporation,
- seepage,
- wave overtopping.

The information presented in Table W1 shows that on average the lagoon opens 2.8 times per year and remains open with progressively decreasing flows for a period of around 6.5
days. Immediately after opening, the average tidal prism for the lagoon is of the order of 60ML, and assuming a flow regression similar to that shown in Figure W3, the annual average tidal flow (flood or ebbs) would be around 1400ML.

The breakout prism is the difference between the lagoon volume before and after a breakout event. The flood flow is the additional volume of catchment runoff which enters the lagoon after entrance breakout (while the entrance is open). The RUBICON model (Appendix D) was used to calculate the average breakout prism and flood flow for a "typical" opening assuming limited catchment runoff and a range of flood events. The No Flood, 10% and a 1% annual exceedance probability flood results are shown in Table W3.

![Table W3](attachment:image.png)

The results show that the storage volume of the lagoon up to +2.4m AHD (i.e. the breakout prism) is approximately equal to the runoff volume of a 10% AEP event. This means that breakout rarely occurs due to a single storm event but rather as the cumulative result of several rainfall events. The flood flow volume (after opening) is therefore very small in relation to the breakout prism.

Analysis of the results shows that for a normal opening the breakout prism would be approximately 750ML and the flood outflow would average around 50ML (depending on
the rainfall occurrence immediately before and while the entrance is open). On an annual average basis the breakout prism would be 2100ML and the flood flow would be around 150ML.

The average annual direct precipitation into the lagoon was determined by the analysis of 20 years of rainfall data from the gauge at Avoca Beach Bowling Club (Reference 2). Of the available rainfall records this gauge best covers the catchment area both in terms of proximity and duration. An estimate of the average annual surface water/ground water inflow to the lagoon was also made using the rainfall data and the DUPLE model (see Appendix B). This model also provides estimates of pollutant runoff (see Sections W2.2.5 and W2.2.6). The analysis showed that average annual direct precipitation into the lagoon for the period examined was 1320mm or 750ML. The analysis also showed that annual surface water/ground water inflow would be of the order of 2200ML.

Monthly average annual evaporation from a standard Class A pan with bird guard are available from the Bureau of Meteorology (Reference 3). These evaporation rates are generally considered applicable for exposed locations away from significant water bodies. Local meteorological effects (mainly humidity) near coastal inlets cause reductions of 5 to 10 percent.

These evaporation rates also do not include an allowance for heat loss due to water exchange with the ocean and other localised effects such as sheltering, radiation from the bed and water depth. The values therefore are only indicative of the order of evaporation which occurs from the lagoon.

Assuming an adjustment of 20% for Wamberal Lagoon, the monthly average annual evaporation rates are as shown on Table W4. The table shows that the volume of evaporation from the lagoon is approximately 800ML per annum.
TABLE W4

Estimated Evaporation
Wamberal Lagoon

<table>
<thead>
<tr>
<th>Month</th>
<th>Class A Pan (mm)</th>
<th>Wamberal (mm)</th>
<th>Wamberal (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>205</td>
<td>165</td>
<td>95</td>
</tr>
<tr>
<td>February</td>
<td>170</td>
<td>135</td>
<td>80</td>
</tr>
<tr>
<td>March</td>
<td>145</td>
<td>115</td>
<td>65</td>
</tr>
<tr>
<td>April</td>
<td>110</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>May</td>
<td>85</td>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td>June</td>
<td>80</td>
<td>65</td>
<td>35</td>
</tr>
<tr>
<td>July</td>
<td>80</td>
<td>65</td>
<td>35</td>
</tr>
<tr>
<td>August</td>
<td>105</td>
<td>85</td>
<td>50</td>
</tr>
<tr>
<td>September</td>
<td>130</td>
<td>105</td>
<td>60</td>
</tr>
<tr>
<td>October</td>
<td>165</td>
<td>130</td>
<td>75</td>
</tr>
<tr>
<td>November</td>
<td>170</td>
<td>135</td>
<td>80</td>
</tr>
<tr>
<td>December</td>
<td>255</td>
<td>205</td>
<td>115</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1700</td>
<td>1365</td>
<td>780</td>
</tr>
</tbody>
</table>

Analysis of lagoon water level data from the automatic recorder shows good correlation between estimated monthly evaporation and the observed drop in lagoon level during periods of little or no rainfall.

Seepage from Wamberal Lagoon through the beach berm is not a major component of the overall budget. Work undertaken by PW on several NSW beach berm ground water levels indicates that the average water level at the wave runup limit for Wamberal Lagoon entrance would be between +1.0m and +0.5m AHD (Reference 13). The gradient between the lagoon and the berm groundwater is therefore around 0.012. Adopting typical permeability rates for medium beach sand and assuming reasonable width and depth conditions, the estimated seepage rate would only be $1.2 \times 10^{-3} \text{m}^3/\text{s}$ or around 30ML per annum.
Wave overtopping of the entrance berm occurs during periods of large waves, elevated ocean levels and low berm heights. At Wamberal Lagoon entrance the beach is fully exposed to the south east and the estimated wave height in the above beach zone during an extreme event could be around 2m (Reference 4). By assuming a berm height of 3m AHD and by adopting a series of maximum outcomes (including wave setup at the entrance of 1.0m and an ocean water level up to 2.5m AHD), wave overtopping of the berm was estimated to be 400ML for an extreme event (Reference 5). However, the average annual volume of wave overtopping would be far more dependent on frequent storm events with lower berm levels.

The development of a berm across the entrance (following initial closure) is substantially dependent on wave activity. This process is inevitably associated with a degree of wave overtopping. From the available water level record (see Figure W3) the volume of water entering the lagoon due to wave overtopping following closure of the entrance increases water levels by around 200mm. Based on this assessment the estimated volume of water entering the lagoon annually due to wave overtopping would be of the order of 150ML.

Based on the above assessment an average annual water balance has been determined for Wamberal Lagoon as shown on Table W5.
TABLE W5

Average Annual Water Balance
Wamberal Lagoon

<table>
<thead>
<tr>
<th></th>
<th>Volume In (ML)</th>
<th>Volume Out (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Flows</td>
<td>1400</td>
<td>1400</td>
</tr>
<tr>
<td>Flood Flow</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Breakout Prism</td>
<td></td>
<td>2100</td>
</tr>
<tr>
<td>Surface/Groundwater</td>
<td>2200</td>
<td></td>
</tr>
<tr>
<td>Direct Precipitation</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Wave Overtopping</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Evaporation</td>
<td></td>
<td>800</td>
</tr>
<tr>
<td>Seepage</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4500</strong></td>
<td><strong>4500</strong></td>
</tr>
</tbody>
</table>

W2.1.4 Water Level Fluctuations

When the lagoon entrance closes and wave overtopping substantially ceases, the water level inside the lagoon is generally around 0.5m to 0.7m AHD. The level then fluctuates, with upward steps due to rainfall and catchment runoff and a gradual downward trend due to evaporation and seepage through the berm. Analysis of the "Lagoon Book" data (Reference 1) indicates that, on average, inflow exceeds outflow by around 15mm per day, assuming the lagoon is closed for all but 20 days per year.

However, changes in water level are a complex relationship between rainfall occurrence, evaporation, wave overtopping and lagoon level/surface area. Analysis of rainfall records shows that the average monthly rainfall on the Central Coast is reasonably evenly distributed throughout the year. The average annual rainfall is 1320mm varying between 130mm and 80mm per month with the wettest period between February and July. However, actual monthly rainfalls vary significantly from year to year. The rainfall in
any one month can range from zero to over 400mm (and the standard deviation approximately equals the average).

Wave overtopping affects lagoon water levels immediately after entrance closure, but decreases in importance as the berm level (and hence the potential lagoon level) rises. Further, as the lagoon fills, the water surface area increases allowing greater evaporation and requiring a greater inflow per millimetre increase in depth. Ground water seepage through the beach berm also increases. During summer months, particularly December, the estimated rate of evaporation loss averages over 160mm per month but can increase significantly above this level (Council records). By comparison, evaporation rates during winter average 70mm. During a 12 month drought, losses could be of the order of 1.5m.

On the basis of the above there is a tendency for lagoon water levels to increase after opening. This increase is largely dependent on the level of rainfall in the catchment. Increases in water level per unit volume of inflow are more rapid at low lagoon levels, dropping off as levels increase. During summer months the level of evaporation from the lagoon when reasonably full corresponds on average with catchment inflow. However in autumn, as evaporation rates decrease and the rainfall levels increase somewhat, lagoon water levels generally increase. As a result, lagoon levels tend to reach the 2.4m AHD "pin" opening level in late autumn or early winter. This tendency is confirmed by the "Lagoon Book" which shows June as the month with the largest number of openings.
W2.2 Sediment Processes

W2.2.1 Sedimentary Geology

Wamberal Lagoon was formed during the Holocene Epoch some 6000 years ago, following the last marine transgression (Reference 6). During this period the dune system along the south-eastern foreshore of the lagoon (see Figure W4) developed as part of a "coastal sand barrier" or "bay barrier" between the rocky headlands of Wamberal Point and Broken Head. This barrier system enclosed two small waterways/estuaries creating both Wamberal and Terrigal Lagoons.

The basic shape of the lagoon foreshore (other than the sand barrier) was determined by the stratigraphy of the underlying Triassic rock of the Narrabeen Group, particularly the sandstones/silt stones of the Terrigal Formation and to a lesser extent Patonga Claystones (Reference 7). Sea level changes as a result of glaciations during the Pleistocene Epoch have contributed to the formation of alluvial and estuarine deposits around the lagoon foreshore.

W2.2.2 Lagoon Surface Sediments

Extensive bed sediment sampling was undertaken in 1975 as part of an earlier investigation of Gosford Lagoons (Reference 7). This information was examined and additional sampling and analysis undertaken for this study (see Figure W4). Historical aerial photographs dating back to 1941 were also analysed for localised changes in morphology.

The lagoon bed sediments are derived from three separate sources. Beach and nearshore marine sands are found in the lagoon entrance extending upstream approximately 500m from the beach berm. Along the western face of the coastal sand barrier the sediments are largely reworked marine sands from the barrier. Beyond this line the surface sediments are a mixture of barrier sands and material derived from erosion of the catchment. These sediments range from silty sands through to silty clays.
The marine sands in the entrance area consist of more recent sediments moved in from the beach littoral zone by a combination of tide, wave and wind action plus some reworked original Holocene barrier deposits. The sands are mainly quartzose of medium grain size, well sorted and well rounded to sub-rounded. The sands have low lithic content with some shell fragments. Some grains, probably the original barrier deposits have iron staining giving the sands a golden/orange appearance. A grain size analysis of the sediments from the entrance/beach berm area was undertaken (see Figure W5) which showed that over 90% of the grains were between 0.3mm and 0.6mm in diameter and the D₃₅ (35th percentile) grain size is 0.4mm.

The reworked barrier sands are similar to the beach sands but are light grey to light brown in colour with traces of dark brown humic coating on some grains. Occasional shell fragments occur from estuarine species and the clay and silt content tends to increase away from the foreshore. The sands at or above normal water level are bleached and sorted by wave activity and are very similar in appearance to the beach sands.

The sediments derived from the catchment are also predominantly quartzose but have a finer grain size, are poorly sorted and sub-rounded to sub-angular. The percentage of clay within the sediments increases towards the centre of the lagoon (over 40%) and the percentage of the sand sized fraction increases towards the lagoon margin (over 60%). This grain size variation is related to differential settling of the particles when they are washed into the lagoon from the catchment, or when re-mobilised by wave action. This differential settlement leaves the larger grains near the foreshore but allows the finer silts and clays to be transported into deeper water.

Historical aerial photography shows that deposition of larger grain size particles is occurring near the outlet to channels draining into the western foreshore of the lagoon through Wamberal Park (from the Winston Street/Loxton Avenue area). Delta
formations which have built up around the drainage channel outlets contain roadbase, gravel and sand which has clearly originated from (past) development activities.

By comparison, there is little evidence of a significant recent deposition in the northern portion of the lagoon "North Arm", near the main catchment drainage outlet. The lack of mobile sand shoals in the North Arm channel supports the conclusion that this is not presently a major source of sand sized sediment infeed.

W2.2.3 Catchment Soil Landscapes

Seven different soil landscapes have been identified in the Wamberal Lagoon Catchment (Reference 8). These landscapes, their broad description and approximate percentage of the catchment are as follows:

- Watagan (wn) - colluvial - rolling hills, complex soils 10%
- Erina (er) - erosional - low hills, yellow Podsols 25%
- Wyong (wy) - alluvial - coastal lowlands, yellow/brown Podsols 25%
- Woodburys Bridge (ws) - residual - low hills, red Podsols 15%
- Norah Head (nr) - aeolian - elevated sandsheets, Podsols 15%
- Tuggerah (tg) - aeolian - coastal dunes, Podsols 4%
- Narrabeen (na) - beach - coastal foredunes, sands 1%

The locations of these landscapes are shown on Figure W6 and more detailed descriptions including soil types is provided in Appendix A (or see Reference 8). A summary of general soil properties, and landscape limitations and capacities has been provided in Table W6.
TABLE W6
General Properties of Soil Landscapes
Wamberal Lagoon Catchment

<table>
<thead>
<tr>
<th>Soil Landscape</th>
<th>Watagan</th>
<th>Eriaa</th>
<th>Wyong</th>
<th>Woodburnys Bridge</th>
<th>Nora Head</th>
<th>Tuggerah</th>
<th>Narrabeen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOIL PROPERTIES:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erodibility</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Permeability</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Acidity</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>L</td>
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<tr>
<td>Fertility</td>
<td>M</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td><strong>LANDSCAPE PROPERTIES:</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steep Slope</td>
<td>W</td>
<td>S</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Flooding</td>
<td>L</td>
<td>L</td>
<td>W</td>
<td>L</td>
<td>L</td>
<td>S</td>
<td>W</td>
</tr>
<tr>
<td>Waterlogging</td>
<td>L</td>
<td>L</td>
<td>S</td>
<td>L</td>
<td>L</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>High Runoff</td>
<td>L</td>
<td>S</td>
<td>W</td>
<td>S</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
</tbody>
</table>

**NOTES:**
- Soil Properties
  - L - low
  - M - moderate
  - H - high
- Landscape Properties
  - W - widespread
  - S - some occurrence
  - L - little occurrence

**W2.2.4 Soil Erosion Hazard**

The erosion hazard of an area is related to factors such as climate, topography, soil erodibility, soil runoff and landuse. Figure W11 sets out the existing catchment zoning categories.

Each specific landuse has its own erosion hazard. For land under cultivation and pasture the erosion hazard relates to continuing long term effects, where as the effects of urbanisation are short term, during the initial construction phase (until good ground cover and drainage controls are established).
Table W7 sets out the erosion hazard for soil landscape in the Wamberal Lagoon catchment for land being urbanised as well as for continuing cultivation and pasture (Reference 8). An assessment for non-concentrated flows, concentrated flows and wind erosion is given.

**TABLE W7**

Assessment of Erosion Hazard
Wamberal Lagoon Catchment

<table>
<thead>
<tr>
<th>Erosion Hazard</th>
<th>Watagan</th>
<th>Erina</th>
<th>Wyong</th>
<th>Woodburns Bridge</th>
<th>Nora Head</th>
<th>Tuggerah</th>
<th>Narrabeen</th>
</tr>
</thead>
<tbody>
<tr>
<td>URBAN DEVELOPED:</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Non-concentrated</td>
<td>E</td>
<td>V</td>
<td>S</td>
<td>M</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Concentrated</td>
<td>E</td>
<td>V</td>
<td>M</td>
<td>V</td>
<td>V</td>
<td>M</td>
<td>E</td>
</tr>
<tr>
<td>Wind</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>V</td>
<td>V</td>
<td>E</td>
</tr>
<tr>
<td>CULTIVATION:</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Non-concentrated</td>
<td>E</td>
<td>V</td>
<td>S</td>
<td>M</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Concentrated</td>
<td>E</td>
<td>V</td>
<td>M</td>
<td>E</td>
<td>H</td>
<td>M</td>
<td>E</td>
</tr>
<tr>
<td>Wind</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>E</td>
<td>V</td>
<td>E</td>
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<tr>
<td>GRAZING:</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Non-concentrated</td>
<td>V</td>
<td>M</td>
<td>S</td>
<td>M</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Concentrated</td>
<td>V</td>
<td>M-H</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>S</td>
<td>E</td>
</tr>
<tr>
<td>Wind</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>V</td>
<td>H</td>
<td>E</td>
</tr>
</tbody>
</table>

NOTES: Erosion Hazard

- S - Slight
- M - Moderate
- H - High
- V - Very High
- E - Extreme

Estimated soil losses during the first year of residential development are as follows (Reference 8):

- Slight - 0-10 t/ha,
- Moderate - 10-30 t/ha,
- High - 30-50 t/ha,
- Very High - 50-80 t/ha,
- Extreme - > 80 t/ha.
W2.2.5 Sediment Export

As part of this Processes Study a DUPLE model was set up to examine the export of suspended and bedload sediments from the catchment (as well as nitrogen and phosphorous loads). Details of the DUPLE model are given in Appendix B. There are no suitable data on sediment export available for the Gosford Lagoons. Therefore sediment/pollutant load equations based on data collected for Canberra, Lake Macquarie and Merimbula Lake were reviewed. Information relating to the operation of a Gross Pollutant and Sediment Trap from the Botany Wetlands catchment in Sydney was also examined (Reference 10) and the sediment/pollution load equations modified to suit the soil and development conditions in the Wamberal Lagoon catchment.

Table W8 sets out the estimated sediment export from the catchment based on generalised assumptions as to the level of catchment development and hence impervious area runoff. The model has been run for existing development levels, development levels applicable during the 1970's and levels assuming a substantial increase in urban development plus consolidation of existing urban areas.

**TABLE W8**

<table>
<thead>
<tr>
<th>Development Level</th>
<th>Impervious Area (%)</th>
<th>Sediment Load (t)</th>
<th>Suspended Solids (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970's</td>
<td>5</td>
<td>160</td>
<td>120</td>
</tr>
<tr>
<td>Existing</td>
<td>17</td>
<td>430</td>
<td>320</td>
</tr>
<tr>
<td>Projected ?</td>
<td>30</td>
<td>770</td>
<td>550</td>
</tr>
</tbody>
</table>
Based on the above assessment of sediment export and the previous review of catchment sediment characteristics, it is reasonable to assume that most sand sized sediments entering the lagoon are coming from areas recently disturbed by urban development, particularly those areas to the immediate west of the lagoon. The total volume of sediments deposited in delta formations along the western foreshore between 1941 and the present is estimated to be of the order of 5 000 to 10 000m$^3$ or an average rate of around 150 tonnes per annum.

Much of the finer sand size particles plus the silts and clays are originated from both urban development and continuing grazing and cultivation of the catchment. These sediments enter the lagoon during major runoff events and tend to be distributed over much of the lagoon bed.

Based on the above assessment of sediment infeed, both bedload and suspended load, the lagoon is receiving some 750 tonnes of sediment from the catchment per annum. This represents around half a millimetre of sediment per year averaged over the lagoon bed. A proportion of the fine sediments would be flushed from the system during breakout/flood events. Therefore, the average rate of sedimentation should be less than half a millimetre per year, although, some areas would accrete at a much faster rate than other areas.

W2.2.6 Sediment Budget

A conceptual model of sediment movement in the lagoon has been prepared and is presented on Figure W7. The model indicates that the entrance area of the lagoon is the area of greatest sediment movement and that the remainder of the lagoon is subject to limited, ongoing accretion.

Marine sands are moved out of the entrance into the beach littoral zone during lagoon breakout/flooding. The estimated quantity of sand moved out is of the order of 6 000m$^3$ per breakout event, or 17 000m$^3$ per annum. (A quantity of catchment derived silts and
muds would also be moved out, particularly during larger flood/breakout events.) Following breakout marine sands move back into the estuary from the beach littoral zone due to the action of:

- waves and tides while the entrance is open,
- waves overtopping the beach berm,
- wind (aeolian) transport from the beach.

Historical aerial photographs show major depositional and erosional changes in the entrance area. The most active area is the entrance/beach berm. Changes beyond the berm are dependent on the entrance closure mechanism and subsequent wave overtopping/wind activity. There is no evidence to suggest that significant marine sediment movement occurs beyond the entrance channel area (or approximately the landward extent of the Holocene sand barrier).

There is also no evidence to suggest that substantial quantities of sediments are being eroded from the catchment and deposited into the lagoon. The only identifiable morphological changes (within the lagoon other than at the entrance) over the past 50 years are the buildup of deltas at the outlet of drainage channels along the western foreshore. As discussed in the previous Section, the estimated quantity of sediment from this source is of the order of 5 000 to 10 000 m$^3$, or around 150 tonnes per annum and the estimated export from the remainder of the catchment is around 600 tonnes per annum (mainly fine sediments entering the lagoon at the northern end).

When the lagoon entrance is closed, water circulation in the lagoon is almost entirely dependent on wind generated currents. During storms small wind waves rework foreshore and shallow water sediments, mobilising the clay and silt fractions. Currents then carry the silts and clays into deeper water where they settle. This winnowing process reduces the percentage of very fine sediments in foreshore areas and increases the percentage in deeper areas.
W2.3 Entrance Dynamics

W2.3.1 Entrance Opening

Entrance opening is initiated when water levels inside the lagoon reach or exceed the beach berm height and outflow begins. Initiation is usually as a result of artificially lowering the berm by mechanical means to below lagoon level. At Wamberal Lagoon artificial opening accounts for 77% of all openings (Reference 1). Natural openings also occur as a result of freshwater inflows which raise the lagoon water level to above berm height.

During the course of this study an opening of the entrance to Wamberal Lagoon was observed in some detail on 13 September, 1993 (Appendix C). Water levels in the lagoon and at the ocean, the width and depth of the entrance channel, and the velocity of the outflow were measured or estimated. This data was then used to verify the RUBICON model set up for the lagoon (Appendix D).

Analysis of Wamberal Lagoon data and comparison with data from Dee Why and Narrabeen Lagoons was also undertaken as part of the Gosford Coastal Lagoons Flood Studies (Reference 11). This analysis identified 3 flow stages during the entrance opening process (Appendix C):

- initiation channel stage,
- weir/hydraulic jump stage,
- river flow stage.

The initiation channel stage lasts up to approximately 2 hours after the start of the opening. Major factors which affect the speed at which the channel develops include:

- initial channel cross-section,
- gradients along the channel,
- length of the channel,
- grain size of the berm sand.
Channel initiation can be accelerated by mechanically excavating a channel and depositing the material away from the channel.

When the breakout channel reaches about 5m in width and flow velocities exceed 2m/s, the weir/hydraulic jump stage commences. This stage lasts for approximately 2-3 hours until the steps or weirs are destroyed and a more regular channel is formed. During this stage the width increases rapidly to around 50m and the bed scours to a level around zero AHD. A depositional lobe forms in the surf zone with a level somewhat above zero AHD.

During the river flow stage the weir constructions are absent and a steadier flow regime is established. The flow becomes sub-critical and the rate of channel development substantially slows and eventually stops. The duration of this stage depends upon the volume of water in the lagoon and the volume of water entering the lagoon from the catchment. If catchment runoff is low the water is released within a few hours and the lagoon becomes tidal and the entrance starts to infill. However, during major catchment runoff events the channel continues to develop and to move the depositional lobe further into the surf zone.

W2.3.2 Artificial Entrance Opening

In the early 1970's Council began mechanically opening Wamberal Lagoon to control peak water levels and reduce flooding in surrounding residential areas. In 1989 Council adopted a formalised policy on lagoon opening in response to a recognised "duty of care" for flooding and the need to define limits for new residential developments. The policy adopted was for an estimated 1% flood plus a freeboard of 0.5m. The adopted opening level was 2.4m AHD for an assessed flood level of 3.1m AHD and a minimum floor level of 3.6m AHD.
Because much of the Wamberal Lagoon foreshore is Nature Reserve controlled by National Parks and Wildlife Services (NP&WS), special conditions apply to the opening procedures. Salient features of Council opening policy for the Lagoon are:

- The entrance berm is mechanically opened once the lagoon water level reaches 2.4m AHD. There is a mark on a pole in the reserve adjacent to Remembrance Drive, Wamberal (see Figure W2) which is used to initiate the lagoon opening process.
- Local residents and Council officers monitor the lagoon water level and report to Council’s overseers who are familiar with opening requirements.
- Unlike Terrigal Lagoon the beach berm is not maintained at a reduced level, and so is generally around 3.0 to 3.5m AHD.
- When a potential flooding problem is identified, NP&WS are notified and appropriate measures undertaken to identify and protect the ecology of the Nature Reserve.
- Following agreement with NP&WS or in an emergency situation, a bulldozer or backhoe is hired by Council. It takes approximately 3 hours for machinery to be in place.
- Excavation is undertaken from the ocean to the lagoon. The size of the channel varies depending on the conditions, type of machinery, height and width of the berm, etc.
- Final breakthrough into the lagoon is manually timed to coincide with the falling tide in an attempt to maximise the hydraulic gradient (water slope) between the lagoon and the ocean and so to maximise the size of the entrance which develops.

Comparison of the results of artificial and natural breakout from data contained in the "Lagoon Book" (Reference 1) show that in the last 20 years there have been 9 natural openings for a period of 6.6 days and 24 artificial openings for a period of 6.5 days. The essential similarity between the two periods reflects the fact that artificial opening occurs at a level similar to natural opening. It is probably also related to the fact that the
lagoon surface area (and volume) is comparatively large in relation to the catchment area (9%). This would tend to make breakout events relatively insensitive to single catchment runoff events.

W2.3.3 Entrance Size

The critical period for determining the size of the lagoon entrance is from initial berm breakout through to the next high tide. During this period there is rapid drawdown of the lagoon until the ocean tide level is reached and outflows cease. The volume of sand scoured from the entrance during this rapid drawdown period determines the size of the entrance.

The main factors affecting the volume of entrance scour are the level of water in the lagoon prior to opening, runoff from the catchment during opening, and the state of the tide and the level of the low tide. The volume of sand in the berm and the location of the cut also affect the entrance size.

The level of water in the lagoon prior to and during the initial first tide period is related to the berm level/or the opening (cut) level, and the inflow of water from the catchment. From data contained in the "Lagoon Book" (Reference 1) the average lagoon opening water level since 1971 has been 2.4m AHD (which reflects Council's policy of opening the entrance when levels reach the 2.4m AHD mark).

Numerical modelling of the entrance breakout was undertaken for a range of initial water levels and flood flows to determine the impact on entrance size. Table W9 sets out the results of this investigation. The results show that increasing the level of breakout or the volume of catchment runoff substantially increases the volume of entrance scour. (Note however, the recurrence interval for these events would also be far greater.)
TABLE W9

Entrance Dimensions following Breakout
Wamberal Lagoon

<table>
<thead>
<tr>
<th>Event</th>
<th>Berm Level (m AHD)</th>
<th>Flood ARI</th>
<th>Width (m)</th>
<th>Invert (m AHD)</th>
<th>Entrance Scour (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.4</td>
<td>none</td>
<td>50</td>
<td>+0.2</td>
<td>6 000</td>
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<tr>
<td></td>
<td>1.8</td>
<td>none</td>
<td>40</td>
<td>+0.4</td>
<td>3 500</td>
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<tr>
<td></td>
<td>3.6</td>
<td>none</td>
<td>70</td>
<td>-0.3</td>
<td>14 000</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>10%</td>
<td>65</td>
<td>-0.2</td>
<td>12 000</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>1%</td>
<td>65</td>
<td>-0.2</td>
<td>13 000</td>
</tr>
</tbody>
</table>

The above analysis was undertaken assuming breakout commenced with the falling tide, and that the tide would have a "normal" range of 1m about zero AHD. Sensitivity runs showed that by varying the start time to maximise and minimise the outflow gradient (the difference between the lagoon level and the ocean level) it is possible to approximately double the entrance scour volume (see Appendix C).

Positioning the channel such that the berm width (cross-sectional area along the channel) is minimised would increase the channel size and decrease the time for development. Such action would not only increase the gradient of the channel and hence the scour volume, but would also directly reduce the volume of sand to be scoured to achieve the same channel cross-section.

W2.3.4 Entrance Closure

Infilling of the entrance commences immediately the lagoon becomes tidal and ocean inflows occur. Under tidal conditions the channel rapidly fills to above zero AHD in the vicinity of the beach berm in response to the changed flow conditions and the high sediment movement rates in the beach littoral zone.
Entrance closure occurs when the beach berm builds to above ocean tide level. During the lagoon opening process sand is eroded from the berm and deposited in the inshore (surf) zone of Wamberal Beach. Beach processes (waves, littoral zone and aeolian sand movement) then move sand from the beach into the entrance channel. The extent of this movement prior to closure is largely determined by the tidal lunar phase.

Beach sediments infeed into the entrance channel because of shallow water tidal effects which make the inflowing (flood) tide shorter and hence faster than the outgoing (ebb) tide. The movement of sediments into the entrance prior to closure is associated with spring tide conditions. There is no evidence that these sediments move beyond the entrance channel into the lagoon.

During neap tide conditions (or low diurnal tide peaks) tidal flows become so small that sediment movement into the entrance ceases and wave action builds the beach berm to above tide level. Under these conditions most of the entrance channel remains in the flood scoured condition, although some channel infilling continues as a result of wave washover and wind transport.

W2.3.5 Opening Longevity

The main factors affecting the longevity of the entrance in an open condition are the:
- initial size of the entrance channel after the lagoon has opened,
- phase of the tide (neap or spring) following the opening,
- degree of catchment runoff during and following opening,
- wave climate and littoral zone sand transport at the entrance following opening,
- aeolian sand transport into the entrance following opening.

Factors affecting the initial size of the entrance channel have been reviewed in the previous sections. Opening the entrance during or approaching a neap tide period effectively retards tidal flushing of the lagoon and so encourages the re-formation of a beach berm across the entrance. Assuming limited catchment runoff and given adequate
littoral zone sediment movement the berm will quickly build to above tide level. Conversely, opening the entrance during or approaching a spring tide increases tidal flows into and out of the lagoon and so prolongs the likely period the channel will remain open. A high level of catchment runoff prolongs the period the channel remains open by maintaining a channel through the berm.

Aeolian and littoral zone sand transport at the entrance are highly dependent on the conditions prevailing at the time. Wamberal Beach faces south-east at the entrance, so winds contributing to aeolian infilling of the entrance would need to be from the south-west or the north-east quadrants. Bureau of Meteorology data for Nora Head Lighthouse show that winds from these directions represent a major proportion of winds and a substantial proportion of strong winds. It is therefore likely that aeolian transport contributes significantly both to the entrance closure mechanism but more particularly the berm building and channel infilling process after closure.

The development of a beach berm across the entrance due to littoral zone sand transport is the dominant mechanism by which the entrance is closed. The major variable factor affecting this process is the wave climate. Wamberal Beach at the lagoon entrance is fully exposed to waves from the dominant south-east direction. Littoral zone sand transport is therefore high. Previous Coastal Engineering Advice prepared by PW in 1985 (Reference 5) predicted up to 250m$^3$/m (run of beach) erosion during an extreme event. This quantity is equivalent to the volume of sand contained in the entrance berm and therefore represents the magnitude of littoral zone transport possible. There are no available estimates of gross sand transport under normal wave climate conditions, but given the degree of exposure at the entrance the magnitude of sand transport in the littoral zone would be very high compared to the channel volume.
### W2.3.6 Effects of Artificial Openings

Mechanical opening of Wamberal Lagoon entrance at 2.4m AHD decreases the maximum height at which the lagoon opens and hence decreases the maximum possible flood level. However, because the berm level only builds to a maximum of around 3.0m to 3.5m AHD, the average lagoon breakout would be somewhat less than 3.0m AHD even without mechanical opening. The difference between average breakout levels with or without the present entrance opening policy is therefore likely to be less than 0.5m and probably closer to zero. The difference between entrance size, number of openings per year, length of time the entrance remains open, etc., is therefore not likely to have a major impact on the estuarine processes given the high degree of natural variability from average conditions.
W3. WATER AND SEDIMENT QUALITY

W3.1 General

Water quality of a coastal lagoon needs to be considered in two ways - the water chemistry and the physical properties of the water body. Physical water quality generally relates to coastal lagoon processes - entrance opening, shoaling, influence of rainfall and seasons. Physical water quality is deduced by measurement of the physical properties of the water body - salinity, temperature, depth, dissolved oxygen, pH and turbidity. These physical properties may also be affected by developments (e.g., constriction to flow via bridges) or by changes in the water chemistry arising from human activity. Water chemistry is concerned with the substances carried within the water such as stormwater pollutants - faecal matter, heavy metals, biocides and fertilisers plus plant nutrients (phosphorus and nitrogen) which are generally increased by development of natural systems.

Sediment quality may be considered in the same way as the water quality with some additions/modifications. Sediment quality studies generally include analysis of the character of the sediments (mineralisation, organic matter, etc.) plus chemical analysis (heavy metals, hydrocarbons, biocides, etc.).

W3.2 Water and Sediment Data Review

There have been a number of water quality and sediment studies undertaken in Wamberal Lagoon and its catchment:

- PA Management Consultants (1975 - Reference 7),
- Eardley and Nash (1986 - References 17 and 18),
- Cheng (1992 - Reference 20),
- Gosford City Council (1993 - Reference 21),
- Marine Pollution Research Pty Ltd (this study),
- Laxton and Duell (1994 - Reference 22),
- Laxton and Duell (unpublished data - Reference 23).
Appendix E includes a review of these studies and collates and compares all the above data. The following sections summarise the results of this analysis.

W3.3 Runoff and Lagoon Water Quality Parameters

W3.3.1 Runoff Water Quality

Several of the cited water quality studies considered runoff water quality. Eardley and Nash collected water samples from up to 15 drainage points around the catchment (though not all at once and some sampled only once). Laxton and Duell sampled two main drainage lines monthly from September 1993 and are continuing sampling until August 1994. The data sets are generally comparable with respect to rainfall but sampled slightly different seasonal periods (Spring for Eardley/Nash and summer for Laxton).

Based on a comparison of the two data sets (see Appendix E) the following findings may be made:

- Water Temperature followed seasonal and diurnal changes. Mean temperature over the summer 1993/94 sampling period was 18°C.
- Conductivity/Salinity data were only available for the Laxton study. Results were generally higher than fresh water values. Laxton suggests that this may have been due to the very low freshwater flows combined with saltwater spray carried into the drains by wind.
- Acidity (pH) values were slightly lower in the Eardley/Nash study when compared with the Laxton/Duell study. This difference was probably due to seasonal differences. Mean pH values for the 1993/94 summer period were 7.55 for the northern drain and 7.95 for the southern drain. These values meet ANZECC (1992 - Reference 24) guideline value.
- Dissolved Oxygen data were only available for the Laxton study. Values were very variable with southern and northern drainage means of 6.2 and 8.7mg/L.
(62% and 92% saturation) respectively, meeting ANZECC guideline values for support of aquatic life.

- Ammonia concentrations were quite variable for the Eardley Nash study with concentrations ranging from 22 to > 240μg/L. The Laxton/Duell results were less variable with means of 80 and 90μg/L. Critical ammonia toxicity values are dependant on pH and temperature. Based on the range of pH and Temperature values reported by Laxton and Duell (Reference 22) the critical ammonia toxicity values over the summer 1993/94 period were 93 to 220μg/L. Thus mean runoff ammonia values were below the guideline values.

- Total Nitrogen (TN) concentrations in spring 1986 were very variable and ranged from 50 to > 2000μg/L. Mean TN over summer 1993/94 were 1200 and 2150μg/L for the north and south drains respectively. These concentrations are above the ANZECC guideline of 500μg/L for freshwaters.

- Total Phosphorus (TP) concentrations in spring 1986 were very variable and ranged from 10 to 160μg/L. Mean TP over summer 1993/94 were 93 and 173 μg/L for the north and south drains respectively. These concentrations are above the SPCC/ANZECC guideline of 50μg/L for freshwaters.

- Water clarity was measured in various ways over the two studies. The only comparable results are those expressed in FTU (Eardley/Nash) and NTU (Laxton/Duell) which are approximately equal. In Spring 1986 turbidity ranged from 2 to 24 FTU. Over the summer period 1993/94 turbidity ranged from 9 to 27 NTU.

- Chlorophyll-a concentrations were measured in runoff waters over summer 1993/94. Concentrations were quite low with mean values of 1.27 and 0.98μg/L, below the ANZECC guideline value of 2.0μg/L for oligotrophic (pristine) waters.

- Faecal coliform bacteria concentrations were measured in runoff waters over summer 1993/94. Concentrations were quite variable ranging from 62 to 1500 organisms per 100mL. Median values for each drain were 265 and 250 organisms per 100mL, well below the ANZECC guideline value of 1000 organisms per 100mL for secondary contact waters.
It is concluded from these results that present dry weather runoff water quality is adequate in most respects with the exception of nutrient concentrations which are very high with respect to Nitrogen and moderately high with respect to Phosphorus. Where comparisons were able to be made it would appear that runoff water quality has not varied considerably between 1986 and 1993.

W3.3.2 Lagoon Water Quality

All the cited water quality studies considered lagoon water quality. The original 1974 P A Management Consultants water quality data are not available and this limits the usefulness of comparisons with later data sets. Also, the data sets were not always comparable with respect to rainfall and season. However based on a comparison of the above data sets (see Appendix E) the following findings may be made:

- Water Temperature followed both seasonal and diurnal changes. Temperature ranged from 9 to 29.5°C (the low reading reported from lagoon bottom waters in the 1974/75 study and the high reading from the present Laxton study - shallow waters, February 1994).
- Salinity responded to rainfall, evaporation and lagoon opening status. Salinity varied from 1.5% (1974 bottom waters) to 44% (total water column, March 1991).
- Mean lagoon pH values varied from 7.2 to 8.5 (both in 1986). These values met ANZECC (Reference 24) guidelines.
- Dissolved Oxygen data were variable with mean oxygen concentrations ranging from 5 to 10.6mg/L (range 4.5 to 11.5mg/L). Two diurnal studies were undertaken and both showed negligible oxygen depletion at night. The Eardley study was conducted in October 1986 and the Laxton study in February 1994. As both studies were conducted in shallow water, bottom water deoxygenation would not have been expected to occur except under extreme conditions. Dissolved oxygen values in terms of percent saturation ranged from 21 to 164%.
The mean dissolved oxygen values met ANZECC guideline values for support of aquatic life even though individual values did not.

- Ammonia concentrations were quite variable for the Eardley Nash study with concentrations ranging from 15 to > 240μg/L. The Cheng results (1991 dry weather) were less variable (3 to 27μg/L). Ammonia concentrations over summer 1993/94 (Laxton/Duell) ranged from 33 to 167μg/L. Critical ammonia toxicity values are dependant on pH and temperature. Based on the range of pH and temperature values reported by Laxton and Duell the critical ammonia toxicity value over the summer 1993/94 period was 660μg/L. Thus mean lagoon ammonia values were below the guideline values.

- Total Nitrogen (TN) measurements were reported by Cheng and Laxton/Duell. TN concentrations in 1991 ranged from 26 to 161μg/L. TN over summer 1993/94 ranged from 112 to 1754μg/L. Mean site concentrations were similar (around 750μg/L). These mean concentrations are above the ANZECC guideline of 10 to 100μg/L and above the SPCC recommendation for maintenance of aquatic ecosystems - level 2 protection - 500μg/L (Reference 25).

- Total Phosphorus (TP) concentrations in 1991 were very variable and ranged from 13 to 95μg/L. TP over summer 1993/94 ranged from 13 to 217μg/L. Mean surface water concentrations were similar (around 76μg/L). Mean bottom water concentrations were about 58μg/L. These mean concentrations are above the ANZECC guideline of 5 - 15μg/L and above the SPCC recommendation for maintenance of aquatic ecosystems - level 2 protection - 50μg/L.

- Suspended solids (TSS) data are available for the 1986, 1991 and 1993/94 studies. In 1986 TSS varied from 10.3 to 76mg/L. Under drought and mildly wet conditions (1991) lagoon suspended solids concentrations ranged from 18 to 157mg/L (station means from 28 to 96mg/L). Over summer 1993/94, with low water levels and light run-off TSS ranged from 1.3 to 16.3mg/L. SPCC recommend a maximum TSS concentration of 25mg/L for freshwater systems and 5mg/L for marine dominated systems. The 1986 and 1991 data did not meet either guideline value (either as individual readings or as daily means whilst the
1993/94 data were well within the guidelines. Laxton and Duell also measured the volatile component of the TSS (VSS). Values ranged from 0.9 to 2.4mg/L and accounted for up to half the TSS.

- Turbidity (NTU/FTU) was measured in 1986, 1991 and 1993/94. In Spring 1986 turbidity ranged from 3 to 10 FTU. During 1991 turbidity ranged from 4 to 32.5 NTU and over the summer period 1993/94 turbidity ranged from 1 to 21 NTU.

- Secchi depths were reported from 1991 and 1993/93. Secchi depths ranged from 0.35 m to 1.25 m in 1991. In 1993/94 both MPR and Laxton/Duell reported that Secchi depths were always greater than bottom depth (as water depths were so low).

- Chlorophyll-a concentrations were reported from July 1986, 1991 and summer 1993/94. Concentrations in July 1986 ranged from 2 to 12µg/L, from 0.4 to 2µg/L in 1991 and from 0.5 to 12µg/L in 1993/94. These values were below or close to the ANZECC guideline range of 1 to 10µg/L for estuarine waters.

- Faecal coliform bacteria concentrations were measured by Gosford City Council in lagoon waters over the swimming seasons from January 1990 to March 1993 (Reference 21) and by Laxton/Duell in lagoon waters over summer 1993/94. Faecal coliform bacteria concentrations for the extended Council data set ranged from 0 to > 2500 with a median value of 40 organisms per 100mL. Of the 71 samples only 5 had 600 or more organisms per 100mL. Over summer 93/94 bacterial concentrations were low, ranging from 0 to 150 organisms per 100mL. Median values for each site were 0.5, 3 and 25 organisms per 100mL, well below the ANZECC guideline value of 150 organisms per 100mL for primary contact waters.

- The concentrations of the following heavy metals in the water column were measured twice, in March and April 1974:
PA Management Consultants concluded that the concentrations were well within guidelines but did not specify which guidelines they used. The concentrations would not be considered within the current ANZECC guidelines and did not meet all the NSW Clean Waters Act limits which were current at the time.

W3.3.3 Lagoon Water Quality Conclusions

From the above presentation of lagoon water quality over time it is clear that there are profound variations in a number of water quality parameters which may be correlated with seasonal, diurnal and physical features of intermittent lagoons.

Temperature and salinity can show wide, and especially in the case of salinity, fast fluctuations. Temperature fluctuations are generally seasonally based but may be exacerbated by the shallowness and turbidity of the lagoon, especially in summer. Under these conditions temperature may reach very high values during the day. Salinity fluctuates in response to freshwater runoff, entrance opening and evaporation. Again, owing to the shallow nature of the lagoon the fluctuations may be extreme, from freshwater to hypersaline, in a relatively short time.

Little water column stratification has been reported from the total study data base and consequently bottom water dissolved oxygen concentrations have been reported to be good. Whilst it may be concluded that this could hold for much of the time in such a shallow lagoon, the data base does not actually provide data on summer/high water level diurnal dissolved oxygen fluctuations. The Laxton/Duell diurnal study in February 1994
was the only study with an adequate continuous record (over three days) but it was hampered by very shallow conditions in the Lagoon.

Nutrient concentrations were generally higher than ANZECC guideline values but not excessively so. The data are insufficient at this time to make proper conclusions regarding seasonal and rainfall-linked variations in lagoon nutrient status. The best nutrient data base available thus far is the Laxton/Duell study (still under way), and it must be remembered that the reported results are for a summer period following a short breakout and closure with little subsequent rain.

For the lagoon conditions studied, Chlorophyll-a concentrations were generally low indicating that even though there were adequate nutrients to sustain abundant algae populations the blooms were kept in check. This may have been due to the conditions under which the various studies were undertaken, either over winter months, during a period of hypersalinity or under shallow water/turbulent conditions when turbidity was high inhibiting algal growth. None of the studies sufficiently incorporated a "mature" stage of the lagoon, i.e. high water levels, lower turbidity plus adequate sunlight/day length to sustain both algae and benthic plant life (as existed just prior to the start of this study in September 1993).

The indication from the Laxton/Duell water quality study is that the lagoon may now be entering such a phase. The continuing monthly water quality monitoring data will indicate whether this is so.
W3.4 Sediment Quality

There have been several studies of sediment quality:

- PA Management Pty Ltd (Reference 7) reported on sediment heavy metal and phosphate concentrations for sediments collected in March 1974.
- Eardley and Nash (Reference 17) reported on sediment total phosphorus concentrations (from September 1986).
- Cheng (Reference 20) reported on sediment heavy metal, total phosphorus, total nitrogen and total hydrocarbon content (from March 1991).
- Laxton and Duell (Reference 22) reported on TP and TN from sediments collected in March 1994.

Full results are shown in Appendix 5 and Mean Nutrient and Heavy Metal Concentration results are summarised below:

**TABLE W10**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Study Year</th>
<th>US EPA Region V Guidelines</th>
<th>Environment Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>74</td>
<td>86</td>
<td>91</td>
</tr>
<tr>
<td>TP</td>
<td>119</td>
<td>162</td>
<td>94</td>
</tr>
<tr>
<td>TN</td>
<td></td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>Lead</td>
<td>21</td>
<td></td>
<td>&lt;30</td>
</tr>
<tr>
<td>Copper</td>
<td>15.5</td>
<td></td>
<td>7.9</td>
</tr>
<tr>
<td>Arsenic</td>
<td>7.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>18.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>28.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>&lt;3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL HC’s</td>
<td></td>
<td></td>
<td>&lt;1000</td>
</tr>
</tbody>
</table>
There are no published Australian sediment quality criteria. The US EPA have published ranges of sediment nutrient and heavy metal concentrations. Total phosphorus concentrations less than 420mg/kg may be considered non polluted, 420 to 650mg/Kg could be considered lightly contaminated and concentrations > 650mg/kg could be considered as contaminated. The guideline limits for total nitrogen are given as 1000 and 2000mg/Kg respectively. However, it is cautioned that these concentrations should not be applied rigidly, as sediment nutrient concentrations can (and do) vary widely throughout natural sediments.

Mean Total Phosphorus concentrations varied from 25 to 162mg/Kg, well within the recommended guideline value of 420mg/Kg. Mean Total Nitrogen varied from 130 to 809mg/Kg, within the US EPA guideline value of 1000mg/Kg.

The heavy metal and hydrocarbon concentrations measured in 1974 and in 1991 were all below the recommended US EPA guideline values for contaminants in sediments. Arsenic concentrations in 1974 were higher than the recommendation. However arsenic concentrations in sediments are known to be naturally high along the NSW coast with background concentrations ranging from 1 to 180mg/kg. Environment Canada criteria (Reference 29) allow up to 40mg/kg. The measured levels in Wamberal Lagoon could therefore be judged safe.

A comparison of copper concentrations from the five sites common to the 1974 and 1991 studies reveals that all 1991 concentrations were less than the 1974 values. A similar comparison of lead concentrations was not so straightforward. In 1974 all concentrations were reported as below detection limit (of 30mg/Kg). Three of the 1991 results were greater than 30mg/Kg.
W3.5 Water Balance and Exchange

An estimate of average annual water inputs and outputs for the lagoon was made in Section W2.1. The results of this analysis are as shown in Table W5.

The tidal prism for the lagoon varies considerably, but was estimated to be 60ML for "typical" entrance conditions and average tidal conditions (Section W2.1). The lagoon volume when tidal is approximately 200ML. Therefore, the volume of an average tidal cycle is approximately 30% of the lagoon volume.

Assuming 50% mixing of tidal waters there would be an almost complete exchange of water during an average 6.5 day opening period. Therefore it is reasonable to assume that there is a comprehensive exchange of lagoon water 2.8 times per year on average. However, the "Lagoon Book" (Reference 1) shows that over the last 20 years there has been one 20 month period from June 1979 to March 1981 during which the lagoon entrance was not opened, as well as one 11 month period and three 8 month periods.

Analysis of rainfall over those periods shows that these periods were dry and hence catchment runoff would have been limited. Tidal exchange and hence flushing of the lagoon is therefore very dependent on rainfall, and varies significantly from year to year.

W3.6 Nutrient Budget

Nutrient Budget Pollutant loads to the lagoon from the catchment have been estimated using the DUPLE model (Appendix B) and results are summarised in Section W3.6.1 below. These nutrient supply figures plus the information on mean water and sediment nutrient loads and the information on lagoon hydraulics have been combined to construct a nutrient budget for Wamberal Lagoon. This budget is summarised in W3.6.2.
W3.6.1 Runoff Water Quality

Numerical modelling using the DUPLE model (Appendix B) was used to estimate pollutant loads from the catchment. Tentative runoff-pollutant load relationships similar to those used for the Botany Wetlands catchment (Reference 10) were adopted as follows:

- Suspended Solids - load (kg/km²) = 200 * Runoff
- Total Phosphorous - load (kg/km²) = 0.39 * Runoff⁰.⁸
- Total Nitrogen - load (kg/km²) = 3.0 * Runoff⁰.⁸⁴

An estimate of pollution loads for urban development levels half the existing levels and twice the existing levels was also made. The results of this analysis is given in Table W11.

TABLE W11

<table>
<thead>
<tr>
<th>Impervious Development</th>
<th>Suspended Solids (tonnes/annum)</th>
<th>Total Phosphorous (kg/annum)</th>
<th>Total Nitrogen (kg/annum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>120</td>
<td>150</td>
<td>1300</td>
</tr>
<tr>
<td>existing - 17%</td>
<td>320</td>
<td>440</td>
<td>3600</td>
</tr>
<tr>
<td>30%</td>
<td>550</td>
<td>680</td>
<td>5700</td>
</tr>
</tbody>
</table>

W3.6.2 Lagoon Nutrient Model

Nutrient budgets are an important management tool as they indicate the movement of nutrients to or from the sediments (and thus indicate the possibility of algae blooms). Further, when the runoff calculations incorporate measured concentrations on a sub-catchment basis, the information may be used to highlight "hot-spots". Pollution control measures can then be implemented on an optimal basis. The information may also be used to predict changes in relative sub-catchment pollutant contributions arising from implementation of pollution control measures or from proposed developments.
The water balance figures provided in Table W5 and the water quality results presented above have been used to calculate a preliminary nutrient budget (in terms of Total Phosphorus). The budget is shown in Table W12 below. Mean ocean water TP concentration of 32μg/L has been assumed and a mean lake concentration of 62μg/L has been adopted (see Appendix E).

**TABLE W12**

**Total Phosphorus Budget**

<table>
<thead>
<tr>
<th>Component</th>
<th>Input Volume (ML)</th>
<th>TP (kg)</th>
<th>Volume (ML)</th>
<th>Output TP (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>1400</td>
<td>44.8</td>
<td>1400</td>
<td>88.8</td>
</tr>
<tr>
<td>Flood Flow</td>
<td></td>
<td></td>
<td>150</td>
<td>9.3</td>
</tr>
<tr>
<td>Breakout Prism</td>
<td></td>
<td></td>
<td>2100</td>
<td>130.2</td>
</tr>
<tr>
<td>Precipitation</td>
<td>750</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runoff</td>
<td>2200</td>
<td>252</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Overtop</td>
<td>150</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation</td>
<td></td>
<td></td>
<td>800</td>
<td>0</td>
</tr>
<tr>
<td>Seepage</td>
<td></td>
<td></td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>4500</strong></td>
<td><strong>401.6</strong></td>
<td><strong>4500</strong></td>
<td><strong>227.3</strong></td>
</tr>
</tbody>
</table>

This preliminary budget indicates a net excess of phosphorus (i.e., the inflows - about 300kg per annum - are greater than the outflows - about 230kg per annum). Thus there is a net 70kg per annum excess Total Phosphorus available for aquatic plant life and for deposition into the lagoon sediments.

This budget is preliminary as it relies on the current drainage and lagoon water quality study data (to June 1994). The calculation of groundwater/surface flow inputs are based on calculated mean annual surface runoff figures from three sub-catchments (Appendix B)
and mean drainage Total Phosphorus concentrations from the Gosford Lagoon Water Quality Study (Appendix E).

Additional analysis should be undertaken to refine and extend the nutrient budget calculations after the Gosford Lagoon Water Quality Study has been completed. This refinement should include Total Nitrogen which is also likely to be a major part of the nutrient budget. Incorporation of the full Water Quality Study results would provide better delineation of individual sub-catchment contributions to total runoff, plus better estimates of coastal water contributions. Depending on the form of the final results of the Water Quality Study (i.e., the actual proportion of wet and dry weather results) it may be possible to construct a series of "dry" and "wet" year budgets.
W4. BIOLOGICAL AND ECOLOGICAL PROCESSES

W4.1 General

Lagoon hydrology, hydraulics and water quality interact directly with lagoon biology and ecological process within the lagoon waters and around the fringe of the lagoon. Thus, for example, aquatic plant and benthic (bottom living) animal life will be dependent on water depth and water characteristics. Different plants and animals will live and grow in freshwater, brackish and saline waters. Also, lagoon biology can affect the physical and chemical processes of the lagoon. Abundant aquatic plant life can enhance the oxygenation of lagoon waters but excessive algae in the water column may lead to self-shading of bottom plant life, death of benthic plants and subsequent de-oxygenation of bottom waters.

Catchment biology may also affect lagoon water quality. Thus for example, wooded catchments may contribute little sediment to the lagoon by virtue of low erosion potential but may contribute large amounts of organic matter via leaf litter.

This chapter provides an overview of the catchment and lagoon biology and discusses ecological processes. The information on lagoon ecology plus the information on physical lagoon processes and water quality dynamics discussed in the previous chapters were then used to develop an estuary processes model (Section W4.3).

W4.2 Flora

The flora of the Wamberal lagoon and catchment may be considered on the basis of its interaction with the lagoon waters. The catchment and terrestrial plant life around the lagoon contribute to lagoon function but lagoon waters do not directly affect these plant communities (other than possibly under flood conditions). The aquatic plant life within and fringing the lagoon is on the other hand intimately related to lagoon water quality and physical process.
W4.2.1 Coastal and Lagoon Terrestrial Fringing Vegetation

General catchment, lagoon terrestrial fringing and dune vegetation have been described in the PA consultants report, in the Gosford City Council Wamberal Lagoon Catchment Study (Reference 19), NPWS Wamberal Lagoon Nature Reserve Plan of Management (Reference 26), Wyrrabalong National Park Survey (Reference 27) and the Gosford City Council Wetland Management Study (Reference 28). These documents should be consulted for detailed plant lists (see also Appendix F). Figure W8 shows the main vegetation associations in the catchment and Figure W9 shows the distribution of the main submerged, fringing and swamp forest vegetation associations.

The Wamberal Lagoon Nature Reserve terrestrial vegetation includes littoral rainforest, coastal Banksia scrub, ti-tree (Melaleuca) woodland, swamp forest and heath. The Nature Reserve also includes sand dune vegetation on the dunes separating the lagoon from the sea. This vegetation is described as an excellent example of dunal succession. A number of interesting plant species (in terms of locality or rarity) have been reported from the Nature Reserve; two species of lilly pilly, one of which (Syzygium paniculatum) is endangered, a saltmarsh species (Wilsonia backhousei) which is at its known northern limit at Wamberal and a rare fern, Lindsaea dimorpha.

Forest associations dominate the natural vegetation of the remainder of the catchment. These range from open to almost cleared forest on the sandstone ridges and open forest to woodland on the lowlands with rainforest elements (see Reference 19 for detailed floral association and ecotone descriptions). Vegetation on the sandstone outcrops is dominated by Eucalyptus botryoides and Sydney apple Angophora costata. The Council's significant tree register lists Port Jackson figs (Ficus rubiginosa) from the Wamberal area.

Damp margins of the low-lying catchment creeks and drains are often fringed by Eucalyptus robusta (swamp mahogany) open forests. Between the swamp mahogany forest and the lagoon fringing (hydrosere) vegetation, swamp forest (dominated by swamp oak Casuarina glauca and broad-leafed paperbark Melaleuca quinquenervia)
generally occur. The swamp forest associations may also support a variety of reed and
ti-tree (*Leptospermum*) species. The margins of Forresters Creek and Forresters swamp
are mainly ti-tree scrub (*Leptospermum* *spp.* and *M. unguiculata*). Forresters Swamp
is dominated by sedges (*Baumea* *spp.* and *Lepidosperma* *spp*).

W4.2.2 Lagoon Submerged and Emergent Vegetation

Fringing and aquatic plant distributions have been described by several authors
(References 17, 18, 19, 20, 26, 27, 28 and 31). The emergent communities of
Wamberal Lagoon and the Nature reserve comprise continually wet reed beds (*Leptironia*
*sp.*, *Eleocharis* *sp.*) and partially dry reed beds (sea rush, *Juncus kraussii*, common reed
*Phragmites australis* and bulrush *Typha orientalis*). The lagoon margins are fringed by
reeds, sea rush and saltmarsh species. The lagoon waters support a variety of attached
and floating algae and two rooted submerged aquatic plant groups, *Ruppia* *sp.* and
seagrasses of the Zosteraeae.

The distribution and composition of the lagoon submerged, floating and emergent flora
is quite dynamic and varies with water level, turbidity and salinity:

- In 1984 and 1986 most of the lagoon surface supported *Ruppia spiralis* and a
  fringe of eel grass, *Zostera capricorni* occurred along the northern side of the
  entrance channel. Cover in 1984 was estimated as 24.5Ha, about 43% of total
  lagoon surface area.

- In 1986 several algae were also reported as dominant beds (*Enteromorpha*
  *intestinalis*, *Cladophora* *sp.*, *Ulva* *sp.*, *Chara* *sp.* and *Gracilaria* *sp.*). *Ruppia*
dominated Forresters Creek while *Enteromorpha* prevailed in the actual lagoon.
  *Chara* dominated in lagoon waters towards the entrance channel with *Zostera*
  confined to the entrance channel.

- In 1991 there was no *Ruppia* and very little to no macro-algae in March and
  July. There was a small fringe of *Zostera* near the entrance in March (and at
subsequent surveys) and small patches of *Ruppia* were observed in September. Cover was estimated as less than 1% (< 2Ha).

- In September 1993, following lagoon breakout, the lagoon was empty and the bottom was covered principally in *Ruppia, Enteromorpha, Chara* and numerous epiphytic and floating algae species. A *Zostera* fringe extended along the northern edge of the entrance channel. Cover was estimated as at least 40% of lagoon surface area. By October there was little algae and only a reduced *Zostera* fringe remaining. This situation did not change substantially until June 1994 when small patches of *Ruppia* and attached algae were observed in the lagoon. There were reports of algae scums in the intervening months.

It is concluded that the distribution of aquatic flora in Wamberal Lagoon is dynamic and linked to hydraulic, hydrological and seasonal factors. These links are discussed further in Section W4.3. Figure W9 shows the maximum submerged aquatic vegetation associations for Wamberal Lagoon. This association was only observed 1983 and was inferred for the distribution in August 1993 from the exposed distribution in September 1993. Cover may vary from 0 to about 50% of lagoon surface area.

The lagoon fringing and submerged vegetation is wholly contained in the Wamberal Lagoon Nature Reserve and portions of the vegetation are further protected as SEPP14 wetlands (Wetlands 907, 909; Reference 32).

**W4.3 Fauna**

The fauna of Wamberal lagoon may be sub-divided into three groups, the terrestrial animals of the catchment and fringing vegetation habitats, the water related birds (aquatic birds) and the fauna of the lagoon.
W4.3.1 Terrestrial Fauna

Terrestrial fauna of the Wamberal Lagoon catchment (mammals, birds, reptiles and amphibians) have been described generally in References 17, 18, 19, 26, 27 and 28. A combined terrestrial faunal list for animals from the Wamberal Nature Reserve and for Wyrrabalong National Park (immediately north of Wamberal Lagoon Nature Reserve) is shown in Appendix F. Of the listed animals eight species of reptiles, one frog and 7 mammal species have been reported from the Nature Reserve. One reptile, the diamond python (Python spilotes) is listed as Vulnerable on Schedule 12 of the NPW Act.

Thirty-two terrestrial birds and three raptors (birds of prey) have been recorded from the Nature Reserve by NPWS and by the Wamberal Conservation Society (in Reference 18). None of the terrestrial birds are on Schedule 12 but one raptor the Osprey (Pandion haliaetus) is listed as endangered. The current status of the osprey sighting in the area is unknown. The nearest recorded osprey nest for the area is from Eraring and this nest was inactive in the 1990 survey (Reference 33).

W4.3.2 Aquatic Birds

Appendix F contains a composite list of aquatic bird observations from the Gosford four lagoons. This list contains 34 aquatic birds. The Wamberal Conservation Society have recorded 30 aquatic bird species from the Wamberal Lagoon area including 8 wading birds, none of which are listed in Schedule 12. Whilst the lagoon is considered a minor site for wading birds (Reference 34) it is nevertheless important in a regional context by virtue of its proximity to priority 3 wader bird sites (sites with counts over the 1% level for at least one or 2 species - Tuggerah Lakes and Lake Macquarie). Its significance is increased by the fact that the wading bird habitats in Wamberal Lagoon are protected by Nature Reserve status whereas much of the habitat in the two Lakes has limited protection. In December 1993 eleven aquatic birds were observed on Wamberal Lagoon. Silver gulls were the most abundant (+ 200) with black swans the next abundant (69
birds). The swans were congregated in the upper - northern half - of the lagoon. Two waders were observed; masked plovers and bar-tailed godwits.

**W4.3.3 Lagoon Benthos**

There have been three studies of the benthic fauna of Wamberal Lagoon (References 7, 17 and 18). Two field benthic studies were also undertaken for this study by MPR. The first in October 1993 sampled the lagoon when empty (or at least very shallow) and the second (in November/December 1993) sampled the lagoon when it was only slightly deeper. The same sites as studied in 1974/75 were sampled but the methodology was different. In 1974 sediment samples were sieved through a 2mm sieve. Since that time benthic sampling has standardised on a 1mm sieve as this size retains a significantly greater proportion of the benthic fauna. (This was confirmed experimentally in the MPR 1993 study - see Appendix F for full results)

Full results of the two 1993 surveys are contained in Appendix F along with the summary results of the 1974/75 study. The following summarises the results for Wamberal Lagoon:

- Wamberal Lagoon supports a rich and varied benthic community. In October and December 1993 following lagoon closure in September the lagoon supported more than 37 species of benthos for a total of 2584 individuals counted from 40 samples. After making allowance for the use of a finer sieve in the 1993 study the fauna of the lagoon would appear to be similar to that described in 1974/75.

- Based on the 1974/75 benthic results it would appear that benthic faunal community structure collapses rapidly following lagoon opening and takes some time to recover. However, just how much the 74/75 results were skewed by the use of a 2mm sieve for sorting is unclear. In October 1993, 17 benthic taxa (and 140 individuals) were found one month after lagoon closure and 30 taxa (plus 2444 individuals) were found two months after closure, indicating a more rapid recovery. The rapid collapse of benthic community structure for larger
animals observed in 1974/75 may be due to a combination of death by exposure, rapid predation by aquatic birds which quickly converge on exposed shoals following lagoon opening and season. Predation could account for the predominance of polychaete worms in the October 1993 abundance and the predominance of molluscs, particularly bivalves, in the December sample as observations indicated rapid exposure of bivalve molluscs on the shoal surfaces after the lagoon emptied.

- The 1974/75 results indicate that there is a progression from predominantly marine/estuarine benthic species to a somewhat more brackish water fauna as the lagoon fills. The 1993 data support this conclusion.

W4.3.4 Fish and Mobile Invertebrates

The NSW Fisheries Department’s Fisheries Research Institute (FRI) undertook fish surveys of Wamberal Lagoon in June and August 1986, prior to the lagoon opening in late August of that year. Whilst results have not been published, portion of their fish list has been published (Reference 19). This list along with the results of a netting survey undertaken by MPR in October 1993 have been combined with information from a variety of sources to produce a combined fish list for the Gosford Lagoons (Appendix F).

FRI caught 20 fish species although only 17 were listed in Reference 19. FRI concluded that Wamberal Lagoon supported a relatively high diversity of fish fauna. The combined Gosford Lagoon fauna list in Appendix F shows only the 17 species for the 1986 Wamberal survey plus an additional 3 species from the 1974/75 and 1993 studies.

In 1986 yellowfin (silver) bream, sea mullet and sand whiting were abundant with juvenile sand mullet, flat-tailed mullet, river garfish and silver trevally also found. In 1993, 4 species were caught along with some small undetermined juveniles (12 fish). Three juvenile sea mullet and two silver biddies were caught along with an adult sand whiting.
Three mobile invertebrate species, the eastern king prawn, school prawn and mud crab are reported from the lagoons although not from Wamberal Lagoon.

W4.4 Wamberal Lagoon Estuarine Process Model

In this Section the linkages between physical processes, lagoon water quality and lagoon ecology are discussed in terms of a general estuarine process model developed for intermittent lagoons (Appendix F).

Wamberal Lagoon is an intermittently opening lagoon. The frequency and duration of opening is a function of catchment and lagoon size, rainfall and coastal hydraulics (see Chapter W2. above). The depth of water in the lagoons varies as a function of rainfall (filling), height of beach berm (level to which water can fill), evaporation and seepage rates. When the lagoon is open to the sea the water level will be a function of coastal tides and entrance dynamics.

The generalised estuarine process model for intermittent lagoon ecological process (Appendix F) has been applied to Wamberal Lagoon and Figure W10 shows the "most likely" evolutionary pathway for Wamberal lagoon. Note that some process/lagoon evolutionary stages are more likely to follow as a consequence of a preceding stage than others. This is shown by the use of solid lines for likely evolutionary paths, dashed lines for less likely evolutionary paths and dotted lines for the least likely paths.

The water quality and biological characteristics of the model as applied to Wamberal Lagoon may be summarised as follows:

- **Mature Lagoon** - closed, medium to high water level, generally brackish but may be more estuarine. Has a well established benthic flora and (depending on season) an established diverse phytoplankton and algae population. Waters are generally clear or at least less turbid than at other times. Benthos is well
established (diverse and abundant). Aquatic bird life which feeds on the benthic plants is generally abundant.

- **Breakout** - Generally occurs when lagoon mechanically opened (75% of time) or naturally opens (25% of time). Both occur at about 2.4m AHD.

- **Flushing Rate** is generally slow (i.e., the lagoon drains slowly and there is little tidal movement in and out of the lagoon. Nutrients in the sediments and plant material are generally retained in the lagoon basin. When flushing is fast (either via rapid runoff or tidal scouring) much of this nutrient load will be flushed to sea. Generally, under low flushing conditions, some of the plankton and loose algae and most of the rooted plants (seagrass) will be retained in the lagoon. Most of the aquatic plants and much of the benthos becomes exposed on sand bars and shoals. Fish and mobile invertebrates will generally "run" to sea. Wading and shallow fishing birds may become seasonally abundant and the aquatic birds which live off benthic plants (principally swans) may be forced off the lagoon.

- **Estuarine Lagoon** - Defined by the period when the lagoon is open to the sea and is influenced by tidal flushing. Wamberal generally stays open for a short time and there is little tidal movement (Section W3.2). Thus, Wamberal is rarely fully estuarine and then only for a short time. Fish and mobile invertebrates enter and leave the estuary with the tides. Wading and fishing birds may be seasonally abundant. Some benthic plant feeding birds may be found (if tidal exchange is sufficient to keep some or all of the benthic plants alive). Seasonally some of the shallow or exposed shoals and sand flats may "cook" and result in high benthos mortality, especially around the rim of the lagoon and on the northern mudflat.

- **Filling Rate** for Wamberal is generally slow (Section W3.2) and the newly closed off lagoon will generally evolve in one of two ways (depending on season and rainfall); direct evolution to the "mature" stage via a "transitional lagoon" stage or indirect evolution to the mature stage via a cycling between the "hypersaline" and "transitional" lagoon stages.
Transitional Lagoon stage for Wamberal occurs following closure. Water levels are generally low or raising slowly, salinity is variable and generally there is high turbidity (due to shallowness of the lagoon combined with rapid wind mixing of bottom sediments). A transitional lagoon supports little or no new plant life due to the extreme turbidity of the water column. Seasonally, the shallowness and turbidity of the lagoon may still leave the rim and mud flat benthos susceptible to over heating. There is generally salinity stratification.

Hypersaline Lagoon stage forms when Wamberal is closed off from the sea, there is little or no runoff water into the lagoon and evaporation of the lagoon waters leads to salinities in excess of sea water concentrations (i.e., above 36‰ but generally ≥ 40‰). Lagoon level is generally quite low and temperature/salinity stratification can occur for short periods at night, leading to temporary deoxygenation of bottom waters. Under hypersaline conditions most of the benthic and aquatic plants die and the benthic fauna will generally be depleted (if not killed outright).

It must be emphasised that there can be a gradation between some of the lagoon types, especially in the salinity regime of the mature stage which may vary somewhat without changing the basic physical/water quality nature of the stage but can have biological consequences (such as a shift from brackish to fresh water tolerant species). The season in which the process occurs, the timing of the processes and the time between stages are also important, both with respect to water quality and biological response. The response of biological attributes will be especially governed by season (temperature, day length etc.) and timing of the lagoon evolutionary process.

The proposed model appears to fit the existing physical and water quality data within the limits of the data analysis able to be undertaken on available data. Further development of the Estuarine Process Model to allow it to be used as a predictive model for lagoon management (and applied to Wamberal Lagoon and the other Gosford Lagoons) is hampered by lack of water quality and biological data for both the mature stage of the model and for the critical change-over period from Transitional to Mature Lagoon.
Based on a preliminary analysis of the latest Laxton/Duell data (March to June 1994), it would appear that the change-over from Transitional to Mature Lagoon is initiated by a combination of the breakdown of the salinity stratification, at least within the euphotic zone (defined as the depth to which 10% of available surface sunlight penetrates), and a reduction in turbidity (also partly a function of depth).
W5. CULTURAL ASPECTS

W5.1 General

This chapter forms a concluding chapter for the report and brings together the various study strands with respect to human uses of the lagoon. In this chapter the extent to which human activities including catchment development and usage of the lagoon have modified or disrupted the estuarine processes are outlined. The interaction of some of these activities are also highlighted. Specifically, conclusions are drawn regarding the impacts (both positive and negative) on:

Habitat values
- species diversity and abundance,
- fishery usage and productivity,

Lagoon Usage
- visual aesthetic qualities,
- recreational opportunities,
- suitability for tourist activities.

Pollution
- sedimentation rates,
- water quality.

5.2 Habitat Values

The main habitat areas of Wamberal Lagoon are the lagoon waters, bottom sediments fringing wetland and swamp forest vegetation habitats which support benthic fauna and flora, fish and aquatic birds, plus coastal terrestrial fauna. The fringing and wetland vegetation habitats of the catchment and lagoon have high habitat value on both a local and regional basis. Most of the immediate lagoon habitats are protected by Nature Reserve
feature of the mature lagoon stage for Wamberal Lagoon and there may be ecological as well as aesthetic consequences.

Excessive algae blanketing aquatic plants cuts down light to the aquatic plants leading to their death. Excessive plant life and excessive plant decay generally leads to high biological oxygen demands which may result in deoxygenation of lagoon and sediment interstitial waters (internal waters - between the grains) with consequential fish and benthos kills. Finally, under some seasonal circumstances, changes in water chemistry arising from excessive algae growth can lead to changes in algae community composition favouring toxic blue-green algae blooms.

It must be stressed that these latter conditions do not appear to apply to Wamberal Lagoon at this time and may not apply under the present hydraulic conditions and physical morphology of the lagoon. However, any management actions which may alter the present status quo without addressing the runoff inputs to the lagoon could lead to the conditions described.
compared with the lagoon full situation. However, lagoon opening occurs naturally and at a frequency and period not very dissimilar to Council's current entrance opening policy. The effect on visual aesthetics is therefore not substantial.

W5.4 Recreational Opportunities and Tourism

The majority of the Wamberal Lagoon foreshores is part of the Wamberal Lagoon Nature Reserve and as such recreational activities other than walking and sight-seeing are restricted. The lagoon does not have any specific tourist facilities other than its natural attributes.

In the foreshore park area along Remembrance Drive there are barbeques, picnic seating, playground equipment and car parking. Some wading and swimming is undertaken near the entrance particularly for younger children. Riding the standing waves which form during entrance breakout is popular with older children and there are reports that the entrance has been opened (illegally) for this purpose. Boating and sailboarding on the lagoon is limited and no facilities for launching are provided.

W5.5 Water and Sediment Pollution

Whilst this report has indicated that lagoon water and sediment pollution are generally not excessive, the major water and sediment pollution problem facing Wamberal Lagoon is the continuing moderate to high nutrient and sediment load introduced into the lagoon by development related and urban runoff. As described above, one of the main consequences of this continuing nutrient load is episodes of excessive aquatic plant biomass, particularly floating and attached algae.

While the levels of aquatic plant biomass are nowhere near the levels encountered in some adjacent estuaries (e.g., Tuggerah Lakes) the levels are still considered high. If runoff sediment and nutrient levels are left unchecked, nuisance algae may become a regular
The nature of Wamberal Lagoon is such that it retains much of the aquatic vegetation on the lagoon floor when opened to the sea (i.e., under low flush conditions - see above). During the estuarine phase much of this vegetation and some benthic fauna remains exposed, leading to rapid decay of the vegetation plus death and decay of the fauna. Whilst much of this material is valuable for the lagoon biological community food chain (e.g., for birds and crabs) the decay also leads to odour problems for adjacent home owners. This problem may be worse in the hot summer months. Part of the problem lies with the amount of plant biomass, particularly of nuisance algae, which may build up as a consequence of the nutrients introduced into the lagoon from the catchment over time and now stored in the lagoon sediments.

W5.3 Visual Aesthetics

Wamberal Lagoon is closed to tidal flows with an average water level around +1.5m to 2.5m AHD for over 90% of time. The appearance of the lagoon is therefore generally one of an open waterway area. Most of the foreshore is park or nature reserve. Council imposes conditions on building and construction works within these areas to limit negative impacts.

The wetland areas to the west and north of the lagoon are maintained in a natural condition, as is the coastal sand barrier to the east. Only the southern foreshore along Remembrance Drive is not in a natural condition, and this area is a well timbered, grassed park.

Because of the expanse of water and naturally timbered nature of the foreshore, the visual aesthetics of Wamberal Lagoon are very high, with little adverse cultural impact, when the lagoon entrance is closed.

When the lagoon is tidal, following entrance opening, there are large areas of exposed bed covered in (dying) algae and seagrass. The exposed bed is not visually attractive when
status and by total commercial fishing closures but this protection does not control other impacts on the lagoon such as catchment development, or artificial lagoon opening.

Catchment development contributes urban and road sediments and pollutants - mainly nutrients, trace hydrocarbons (oils and greases), trace heavy metals, faecal matter (human via sewage system overflows and from animals) plus gross pollutants such as litter, plant and grass clippings. To prevent these pollutants reaching the lagoon requires source control, catchment controls and outlet controls. Lagoon fringing wetland vegetation provides some passive outlet control by a final filtering process.

Wamberal Lagoon has high estuarine and coastal waters fish nursery value. This nursery value is enhanced by the total ban on commercial fishing within the lagoon waters. Angling is a minor recreational activity in Wamberal Lagoon and is undertaken on a casual basis from portions of the shore where lines may be cast into deeper waters (mainly around the entrance channel). Fishing from the remainder of the shoreline is restricted by fringing vegetation and soft muds. Boat fishing is restricted by lack of launching facilities and generally by lack of suitable depth.

Wamberal Lagoon has high aquatic bird habitat value under most lagoon water levels. When full and mature the lagoon supports extensive benthic aquatic plant life which is an important food item for swans and some ducks. The reed beds provide shelter and under suitable conditions, breeding habitat for a number of aquatic bird species. When the entrance is open the exposed lagoon shoals and bottoms plus the retained deeper pools provide valuable feeding and roosting habitat for fishing and wading aquatic birds. In summer months when many wading birds migrate to Australia the Wamberal lagoon estuary may supplement the feeding and roosting requirements of substantial wading bird populations from the larger adjacent wader bird habitats of Lakes Macquarie and Tuggerah and from Brisbane Waters.
FIGURE W1
CATCHMENT MAP
FIGURE W2
LAGOON MAP

NOTE CONTOURS BASED UPON INFORMATION FROM P.A. MANAGEMENT CONSULTANTS (REF. 7)
APPROX. DATUM A.H.D

SCALE

100 0 100 200 300 400m
continuing slow evaporation with minor rainfall
LAGOON LEVEL

Lagoons level < ocean but no inflow due to berm height

Increased evaporation

Rainfall

WATER LEVEL (mAHD)

January 94       February 94

LAGOON AND OCEAN LEVELS
JANUARY AND FEBRUARY 1994
FIGURE 6.3
LAGOON AND OCEAN LEVELS
MARCH AND APRIL 1994

WATER LEVEL (mAHD)

gradual rain

rainfall

March 94
April 94

Created 15/05/94 13:20
recent fluvial input mainly fine silt and clays

alluvial deposits

fluvial sediments

WAMBERAL LAGOON NATURE RESERVE

LEGEND

• 1975 Sample Site
• 1993 Sample Site
■ 1994 Sample Site

Beach and Nearshore Marine Sand
Reworked Marine Barrier Sand
Fluvial Sediments

SCALE

100 0 100 200 300 400m

FIGURE W4
SURFACE SEDIMENTS
DESCRIPTION  SAND (SP) - yellow brown medium grained sand

PRETREATMENT  WASH SIEVE

LOSS IN MASS ON PRETREATMENT  0.00%

SOIL PARTICLE DENSITY  2.67 t/m³ (assumed)

TEST METHOD  AS1289 C6 2 & C6.3-1977

LABORATORY  Sydney

REPORT No  50971-3

SIGNED  S M C Becket

GROUND TEST PTY LIMITED
A subsidiary of D J Douglas & Partners Pty Ltd
FIGURE W6
SOIL LANDSCAPES

LEGEND
RESIDUAL LANDSCAPES
Woodbury's Bridge (wo)
COLLUVIAL LANDSCAPES
Watagan (wn)
EROSIONAL LANDSCAPES
Enna (er)
ALLUVIAL SOIL LANDSCAPES
Wyong (wy)
AEOLIAN LANDSCAPES
Norah Head (nr)
Tuggerah (tq)
BEACH LANDSCAPES
Narrabeen (na)

SCALE
250 0 250 500 750 1000m
FIGURE W11
CATCHMENT DEVELOPMENT/ZONING

LEGEND

- Residential
- Open Space
- Scenic Protection
- National Parks

SOUTH PACIFIC OCEAN

SCALE

250 0 250 500 750 1000m