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MORUYA/DEUA ESTUARINE PROCESSES STUDY

November 2003

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EXECUTIVE SUMMARY

This study has been undertaken in order to determine the estuarine processes that directly influence the future management of the Moruya/Deua River Estuary.

The Estuary Management Policy of the NSW Government is set out in the draft Estuary Management Manual of October 1992. The policy outlines a structured process leading to the implementation of a balanced long term management plan for the sustainable use of each estuary and its catchment in which all values and uses have been considered. Accordingly, the Moruya/Deua Estuary Management Committee was set up by Council in April 1999 for the purpose of preparing a management plan for the estuary.

Subsequently, a Data Study (Young and Thoms, 2000)) was undertaken to reference all data held by Government Departments, Academic Institutions, the CSIRO and other research organisations. Issues were to be discussed and prioritised, data gaps identified and the scope of process studies identified.

The Moruya/Deua River (Figure 2) has a large catchment compared to many other NSW South Coast estuaries (about 1,500 km^2 - Warner 1981, Young and Thoms 2000). The catchment is 10% flat coastal plain, 30% undulating and hilly, and 60% rugged mountains (Young and Thoms, 2000). Rural lands exist around the estuary, along the river valley and in the north-east corner. The rural lands are basically used for grazing, beef, dairy cattle and sheep. Gold mining has taken place within the catchment.

Major issues related to the estuary identified by the Data Compilation Study were:

- Erosion of banks and vegetation along the river;
- Loss of natural vegetation filters/buffers;
- Increased sedimentation in the estuary;
- Loss of seagrass due to sedimentation;
- Impact of sediment load on oysters in the lower estuary;
- Water quality particularly nutrient levels and faecal contamination, and their effects on the ecology and amenity of the estuary;
- Potential for acid sulphate soil disturbance and acid drainage to the estuary;
- The effect of commercial fishing on fish stocks;
- Impacts of boating activity on the upper estuary and
- Sediment mobility, affecting navigation and access.

The issue of the impact of individual developments on water quality is covered under the New South Wales Government's Development Application Process and has been omitted from consideration in the Process Study.

The Estuarine Processes Study was undertaken to develop an understanding of:

- The catchment and estuarine processes behind the erosion, sedimentation and water quality problems identified in the data compilation study;
- Sediment characteristics, sediment dynamics and hydrodynamic processes in the estuary;
- Water quality characteristics of the estuary including mixing and flushing behaviour; and
- The scale and nature of bank erosion in the estuary, an assessment of the likely causes and appropriate remedial measures.

The Estuarine Processes Study has been undertaken to provide information leading to the next stage in the estuarine management process; the preparation of a management plan for the estuary.

Estuarine Hydrodynamics

A numerical computer model was developed which uses the shape of the estuary, freshwater inflow from the catchment and tidal heights to predict water movement in the estuary. Knowledge of the water movement can then be used to understand sediment and water quality patterns in the estuary.

Using information on sediment particle sizes present in the estuary, transported in from the ocean and carried into the head of the estuary from the catchment, the sediment module predicts the transport, scouring and deposition of sand and silt particles.

The water quality module uses information about chemical reactions to predict the dispersal and attenuation of pollutants. Also, the water quality model has the ability to make predictions about dispersal of biological agents such as bacteria and viruses.

The output of the model is demonstrated with a number of different scenarios for the movement of sediments and dispersal of pollutants in the report and accompanying CD. However, the real value of the model is that now it has been constructed it can be used to run different scenarios that managers may need information about.

The mouth of the estuary is permanently open, under most conditions there is a significant input of freshwater from the catchment and there are extensive reaches of the estuary exposed to wind. As a result of these features, the estuary is well mixed with a gradient of increasing salinity with distance from the mouth.

The review of existing hydrodynamics data and subsequent results from hydrodynamics modelling of the Moruya Estuary yielded the following observations on the hydrodynamics of the Moruya/Deua Estuary:

Major observations for non-flood conditions were:

- Tidal gradients are steep in the lowest kilometre of the river, generating high velocities there;
- Tidal gradients are mild elsewhere in the estuary;
- The tide has only a small asymmetry with the outflowing tide lasting about 20 minutes longer than the inflowing tide;
- The small tidal asymmetry means that the velocities on inflowing tides are comparable with those on the outflowing tide being about 7% greater. (Consequently, potential for sediment movement is similar for inflowing and outflowing tides as wave stirring contributes to the inflowing sediment load offsetting the effect of higher outflow velocities.);
- Tidal flow velocities were similar for drought and average conditions indicating tidal generated velocities are the dominant source for water movement in the estuary; and
- At two sites, the entrance and near Quarry Wharf the shape of the estuary significantly affects tidal flows.

Under non-flood flow conditions, maximum current velocities are achieved at the entrance and along the rock wall at Pilot Station Backwater. Scouring of large sediment particles can be expected in these locations. In the rest of the estuary threshold flow velocities for scour of sand (approximately 0.1 - 0.4 ms^{-1}) occur up to the Mogendoura Creek junction. These generalisations ignore localised variations hence minor scouring is possible on the ebb tide upstream of the Mogendoura Creek junction. The model reveals that even during non-flood conditions there is a high potential for sediment movement in the lower reaches of the estuary.

Major observations under flood conditions were:

- During floods, water levels are independent of the tide, except near the mouth for the once in one year flood;
- The maximum water level is predicted to rise steeply with distance from the ocean;
- Velocities under flood conditions greatly exceed the threshold for scour near the entrance on all floods and throughout the estuary on all floods greater than the once in one year flood; and
- Very high velocities also occur in most of the channel upstream of the hospital, particularly near the confluence with Mogendoura Creek, where there is a small section of the channel with extremely high current velocity.

Under flood conditions, the ebb velocities all along the estuary are increased significantly, particularly at the entrance. With distance upstream, the general trend is for decreasing ebb velocities. However, a local peak is observed on the model output point at approximately 11 km from the ocean, near the junction with Mogendoura Creek (Figure 7). Flow acceleration around these sites is due to constrictions in the channel; the smaller channel cross-section must accommodate the same volume of water passing through and hence leads to greater current velocities. For all flood conditions, current velocities are above the threshold for scouring and sediment transport all along the estuary.

From the study of hydrodynamics, areas of concern for consideration in the Water Quality and Sediment Transport Studies were identified.

Sedimentation

The catchment geology is dominated by Paleozoic sedimentary (e.g. sandstone) and metamorphic rocks but with significant areas of granitic rocks also present. The sandstone and granites are particularly significant because they weather to sand and produce sandy alluvium. Thus weathering of rocks in the Moruya/Deua catchment is capable of supplying considerable amounts of sand. O'Brien (2001) identified that a large proportion of the sediment in the estuary came from areas where alluvial gold mining had occurred in the past. This may be because;

- gold mining mobilised the sediments,;
- gold mining occurred where there were large deposits of sediment suitable for transport into the estuary; or
- A combination of the two.

Coastal sands are another major source of sediment. Under normal conditions, wave-stirred sediments are picked up by the incoming tide and carried into the estuary. They are then deposited inside the estuary. In the estuary there is less wave stirring than in the ocean so particles are less likely to become resuspended and carried out by the outgoing tide. Thus, for normal flow conditions, there is a gradual build up of coastal sand inside the estuary mouth. Sand (river and coastal) is exported from the estuary during floods when the outgoing current is much stronger than the incoming current.

Inspection of the estuary sediment revealed sediment is mostly derived from the catchment, with the sand in the lower 2 km being derived from the coastal sediments. There is considerable evidence that the Moruya Estuary has a large input to the local coastal sediment beds. Quantities of sediment input from bank erosion are insignificant in the total sediment budget.

It has been speculated rates of sedimentation have increased in the Moruya Estuary over the past 30 years (Pollock, 1999). There have been a number of changes in the catchment that singularly or in combination may have increased sedimentation in the estuary. These are:

- Long term weather patterns;
- Introduction of stock;
- Bushfires; and
- Human activities.

Because the sandbanks are frequently changing it is very difficult to determine if there has been an actual increase in sedimentation without undertaking a comprehensive survey. A review by AMOG of aerial photos, taken between 1940 and the present showed that in the main estuary there has been no obvious long-term growth of shoals. We found there were periods of gradual sediment accumulation as well as periods of rapid build up and rapid scouring of sandbanks. An exception to the general trend was the Pilot Station Backwater, which showed a constant sediment build up between 1940 and the present period.

The hydrodynamic model predicted significant scouring throughout the estuary under flood conditions. Sediment is carried down from the catchments with the flood and also picked up from the riverbed so that the water is carrying the maximum sediment load. As a consequence any areas where current velocities decrease sedimentation occurs and scouring occurs where current velocities increase. The shape of the estuary is such that there are a number of constrictions that form "jets" as floodwater passes them. Erosion is high in these areas and sediment is deposited before and after these "jets" (Figure 9).

Water Quality

Since 1991 the Eurobodalla Shire had measured a range of water quality indices at seven sites, five between the mouth and the town, one at Kiora Bridge and the other in the lower reaches of the Deua River before it discharges into the estuary. The Deua River site is above the estuary. Therefore, this site does not measure estuarine water quality but is valuable in providing information on the quality of water flowing into the estuary.

Major points from the water quality review are:

- Faecal Coliforms (FC) - FC levels are of concern in the lower estuary and indicate potential problems for people eating wild caught oysters and other seafoods;
- Phosphate Concentration - At all sites the ANZECC guideline for Aquatic Ecosystem Protection for phosphate concentration was exceeded indicating high nutrient loading to the estuary. This can potentially contribute to algal blooms in the future, although available nitrogen is the limiting factor;

- NOx Concentration – At all sites nitrate concentrations were within acceptable limits;
- Ammonia Concentration – Ammonia concentrations were consistently above the ANZECC (2000) trigger levels for ecosystem maintenance. Ammonia is another source of nitrogen for plants and does indicate a potential for algal blooms.
- Dissolved Oxygen (DO) - Median DO concentration values recorded at all sites was within all ANZECC guidelines;
- pH - All sites recorded pH values within the ANZECC guidelines; and
- Turbidity - In the lower estuary turbidity values exceeded ANZECC guidelines for aquatic ecosystem protection. Turbidity values in the upper estuary were within the guidelines.

Numerical modelling can be used to provide a large amount of information about pollution events in the estuary and four scenarios were used to demonstrate the model.

1. Pollutant inflow at the junction of Racecourse Creek and the Moruya River with a spring tide;
2. Pollutant inflow at the junction of Racecourse Creek and the Moruya River with a neap tide;
3. Pollutant spill in the vicinity of the Town Wharf with a mean tide; and
4. Pollutant spill in the vicinity of Kiora Bridge with a mean tide.

The output of these model runs demonstrated the problems with flushing in the upper estuary. Material entering into the upper estuarine reaches moved back and forth as a slug over several tidal cycles before any appreciable dilution occurred. During this time it was only downstream a little way by the fresh water input. On the other hand material released below the Princes Highway Bridge was rapidly dispersed and a large proportion discharged into the ocean within the first few tidal cycles.

Results from the hydrodynamics water quality model of the Moruya Estuary have shown that tidal exchange is important to estuarine water quality. Tidal exchange allows clean marine water to dilute pollutants within estuary water. The rate of pollutant dispersal within the water of the Moruya estuary was found to vary with distance from the sea. In the lower estuary, where tidal exchange was highest, more than 50% flushing of pollutant occurred within 30 hours of discharge. In the upper estuary pollutant flushing took longer than five days.

Bank Erosion

Bank erosion is considered by the community to be a major problem in need of management. Erosion is a natural process due to natural meandering of river, wave action and sometimes flood events. The Moruya Estuary is highly susceptible to erosion because in a large number of places the banks are composed of unconsolidated fine materials with sands and silts mixed in different proportions.

Our field investigations found that in the upper estuary undercutting of the bank was common but generally not severe. Undercutting of the bank is caused by the action of waves, with the sediment then being carried away by the currents. These waves can be generated by wind and boat wash. Bank undercutting occurred both at Yarragee and higher up the estuary, such as near Kiora Bridge where boating would be infrequent indicating that wind generated waves play an important part in bank erosion of the upper estuary.

Problems of trampling and overgrazing associated with both stock and wildlife were also contributing to the minor erosion problems in the upper estuary.

The Data Compilation Study identified concerns that catchment activities such as runoff from gravel roads, land clearing, mining, grazing, etc, were causing erosion in the estuary. Such activities would definitely cause erosion problems in the catchment. It is recognised that for estuaries where there is little natural sediment in the catchment increasing catchment erosion adds sediments to the stream loads. The added weight and mechanical impacts of this added sediment can result in increased erosion in the estuary during floods. Presumably such an effect is what the data compilation was referring to (assuming when talking about estuary erosion they did not mean catchment erosion). Because of high natural erosion in its catchment, the Deua River would naturally carry very high sediment loads. Consequently, it is extremely unlikely that increased erosion in the catchment due to human activities will have any appreciable impact on estuarine erosion rates. This theory was backed up during the geomorphological field survey, as no evidence was found that catchment activities were directly responsible for erosion in the Moruya Estuary.

Very slight erosion was observed around Malabar Lagoon caused by wind waves acting on a poorly vegetated shoreline.

Most of the banks in the lower estuary have had rock walls erected to protect them from erosion. These walls are basically dumped rocks and do not appear to be withstanding the loads due to currents, water level fluctuations and wave action.

Site inspections of the rock walls revealed:

- Slumping of rock walls due to loss of toe support;
- Erosion of banks above and behind rock walls; and
- Large voids in the walls, reducing their effectiveness and increasing their susceptibility to failure.

There is a need to undertake an engineering audit to determine where the walls need to be replaced or strengthened. Remedial measures such as repair or rebuilding of the walls, the provision of filter layers under the main rock armour, the raising of crest heights, and the termination of walls can then be designed, costed and planned.

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1 INTRODUCTION

The Moruya/Deua River is on the south coast of New South Wales, approximately 25 km south of Batemans Bay (Figure 1.1). The river is unusual in that it possesses two names. Over its estuary it is called the Moruya River, and upstream of the head of the estuary it is called the Deua River.

The river forms a simple estuarine system, which includes some small tributaries, with a single ocean entrance (DPWS, 2000). The entrance at Moruya Heads is permanently open with twin training walls.

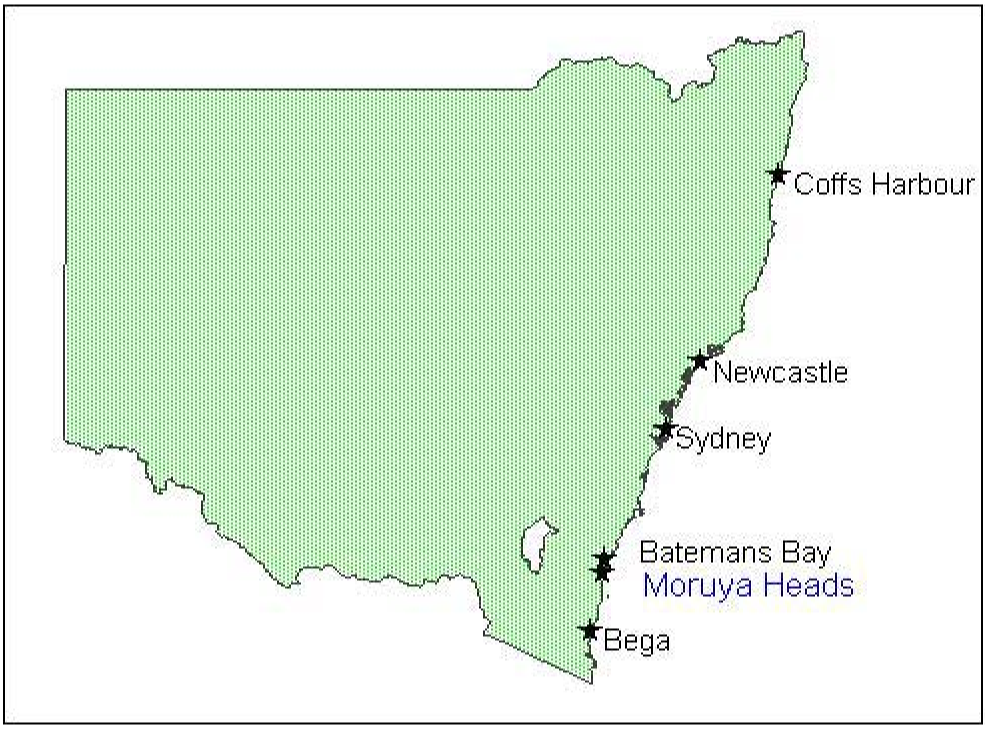

Figure 1.1: Location of the study area.

The estuary has been classified as a mature `barrier estuary' (Roy 1984) and has been largely in filled by fluvial sediments from the catchment. The estuary is tidal for approximately 19 km in length with an estuarine waterway area of 4.6 km2. The tidal river channel broadens down its length in response to increasing tidal influence and has a number of wetland areas located in tributary bays and creeks, the largest of which is Malabar Lagoon.

The catchment area is 1,550 km2 and extends approximately 50 km inland and 50 km south of the mouth (Figure 1.2). There are four major tributaries, Wamban Creek (74 km^2), Candoin Creek (19 km^2), Mogendoura Creek (42 km^2) and Malabar Creek (27 km^2) which with the river itself give five sources of freshwater input to the estuary. Ryans Creek, which is just downstream of the town, is not important for catchment area but is important in the estuary because it contains the Moruya sewage treatment plant and therefore has important management implications.

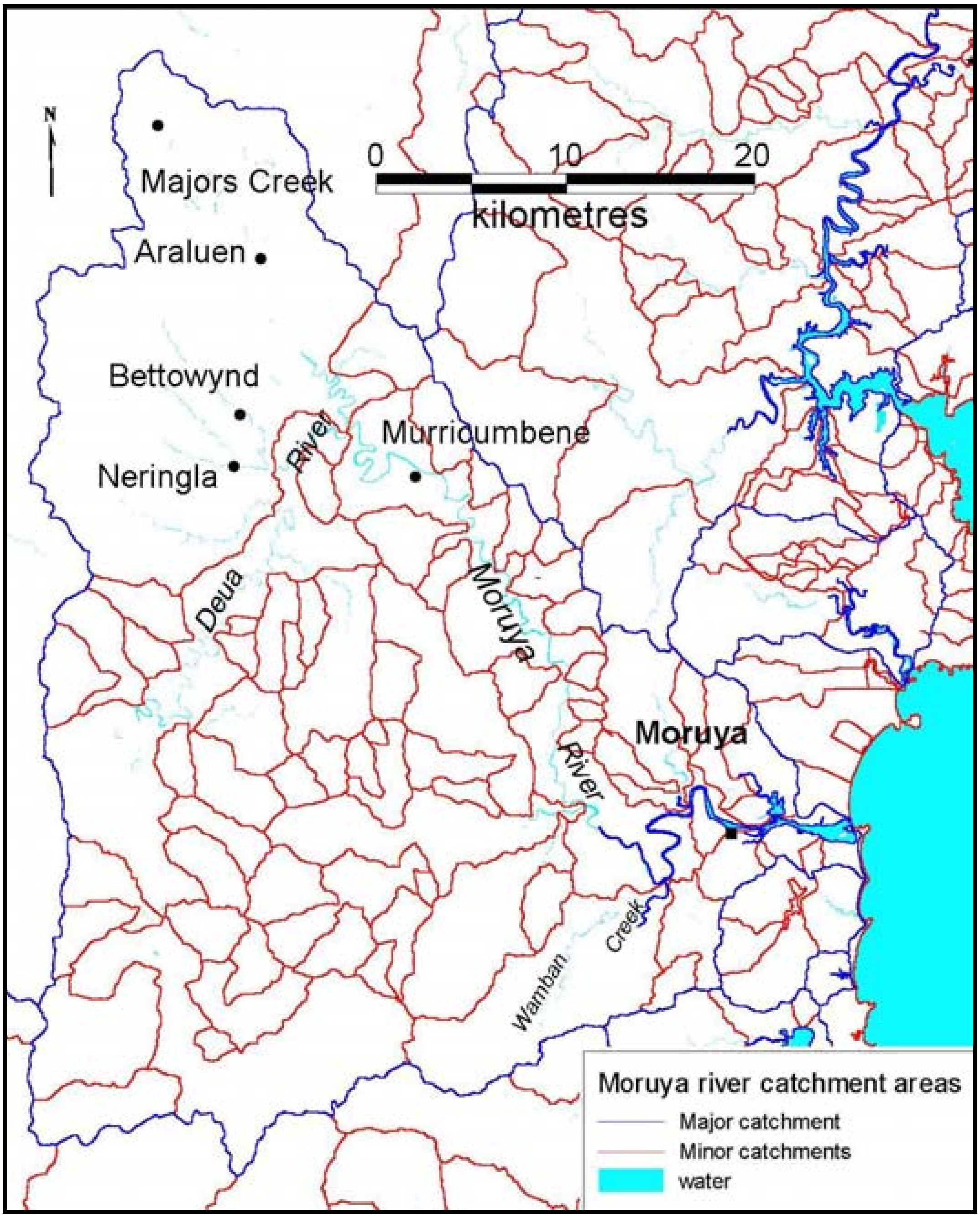

Figure 1.2: Moruya/Deua Estuary catchment.

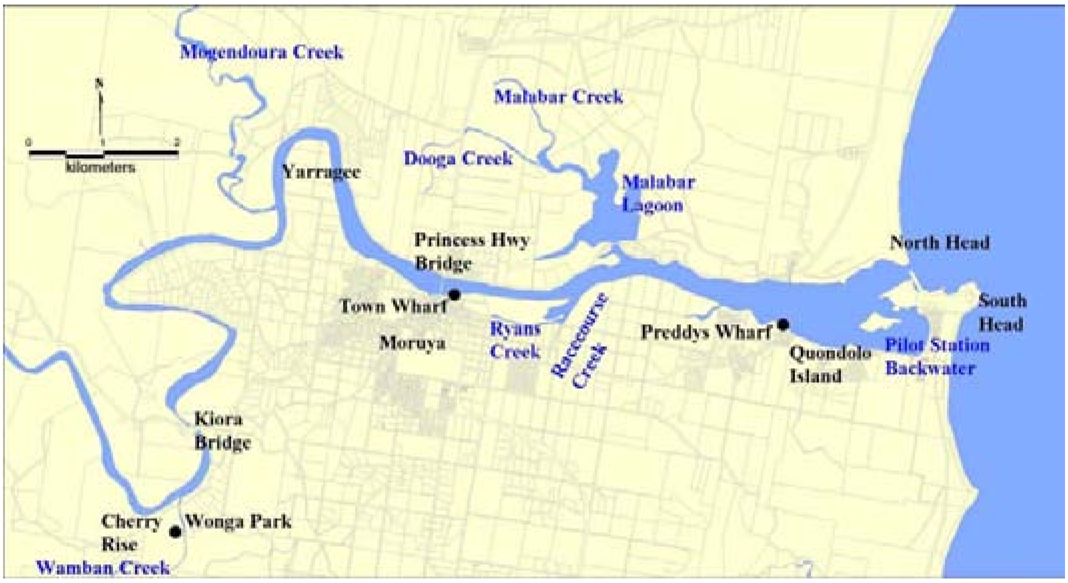

Figure 1.3: Moruya/Deua Estuary.

Figure 1.4: Moruya/Deua Estuary looking upstream from the mouth.

A training wall dominates the entrance and considerable segments of the estuary have been lined by rock protection in the past. An elevated sandy shoal, often exposed at low tide, occurs in the area immediately upstream of the Highway Bridge and for some distance above this there are sandbanks.

The Moruya/Deua River catchment is partly developed. A number of freshwater and estuarine SEPP 14 wetlands are associated with the estuary. Rocky reefs and sandy unvegetated habitats are the other dominant habitats recorded in the estuary.

The catchment is 10% flat coastal plain, 30% undulating and hilly, and 60% rugged mountain (Young and Thoms, 2000). Most of the catchment is forest with the only densely populated area being the town of Moruya on the Princes Highway. The land surrounding the estuary has been cleared and is used for dairy production.

A list of ecological, social and economic values of the Moruya River was identified in the Moruya River Estuary Data Compilation Study (Young and Thoms, 2000).

Ecological values were:

- Aquatic flora and fauna – diversity and abundance;
- Entrance permanently open;
- Sea grass beds;
- Wetlands - Malabar lagoon mangrove and salt marsh communities; and
- Water Quality.

Figure 1.5: River scenery is a recognised social value.

Social values were:

- Aboriginal and European Heritage;
- Multiple water based recreation activities – fishing, boating, surfing, canoeing;
- Access to riverbanks for picnics, fishing. - North Head Road;
- Quiet rural lifestyle; and
- Scenic value of river.

Economic values were:

- Access to inlet;
- Tourism;
- Fertile Floodplains;
- Sand Resource; and
- Oyster Industry.

Figure 1.6: Aquaculture is a recognised economic value.

The Data Compilation Study identified sedimentation of the river and sandbar formations, especially in the lower reaches, as a major concern. Sedimentation was perceived to be a result of the erosion factors within the catchment.

The following impacts and concerns of sediment were listed by the data compilation study:

- Upper estuary island formation diverting the river channels especially when she-oaks stabilise the islands causing permanent diversions;
- Decreased stability for boat navigation in some areas;
- Loss of sea grasses due to sedimentation within the river;
- Impact of sediment load on oyster leases on lower river stretches; and
- Origin of sediments which promote formation of sandbars at entrance of the river.

In 1998 the Moruya Estuary was re-classified by the National Land Water and Resources Audit from near pristine to modified. The new classification broadly indicates that the Estuary has problems due to a complexity of impacts from within the catchment, waterway and estuary. Remedial works and activities for recovery may range from minor to substantial. The change in classification was justified for the following reasons: rural and urban land use, tidal regime, training walls, and drainages and barrages on the floodplain. This reclassification probably reflects an increased knowledge of the estuary and its environment rather than a decline in the estuary and its surrounding environment.

1.1 STUDY AREA

The study area comprises the tidal waterway, foreshore and adjacent land of the Moruya/Deua River including the entrance and tributaries. Consideration is to be given to the wider catchment areas insofar as they affect the issues to be addressed such as urban, agricultural and forestry runoff which may be contributing to increased surface flows and input of sediment and nutrients.

1.2 STUDY OBJECTIVES

This Estuarine Processes Study has been undertaken in order to determine the processes which directly influence the future management of the estuary.

The Estuary Management Policy of the NSW Government is set out in the draft Estuary Management Manual of October 1992. The policy outlines a structured management process leading to the implementation of a balanced long term management plan for the ecologically sustainable use of each estuary and its catchment in which all values and uses have been considered. Accordingly, the Moruya/Deua River Estuary Management Committee was set up by Eurobodalla Shire Council in April 1999 for the purpose of preparing a management plan for the estuary.

Subsequently, a data compilation study was undertaken to reference all data held by Government Departments, Academic Institutions, the CSIRO and other research organisations. Issues were to be discussed and prioritised, data gaps identified and the scope of process studies identified.

Figure 1.7: Infrastructure damage caused by erosion.

Major issues identified by the Data Compilation Study were:

- Erosion of banks and vegetation along the river;
- Loss of natural vegetation filters/buffers;
- Increased sedimentation in the estuary;
- Loss of sea grass due to sedimentation;
- Impact of sediment load on oysters in the lower estuary;
- Water quality; in particular, nutrient levels and faecal contamination, and their effects on the ecology and amenity of the estuary;
- Potential for acid sulfate soil disturbance and acid drainage to the estuary;
- Effect of commercial fishing on fish stock;
- Impacts of boating activity on the upper estuary; and
- Sediment mobility, affecting navigation and access.

The Estuarine Processes Study was undertaken to develop an understanding of the various estuarine processes related to water circulation, pollutant fate and sediment dynamics and their interactions. These components of the Process Study will supply information on the water quality, erosion and sedimentation aspects of the estuary.

Figure 1.8: Loss of natural vegetation by erosion.

A separate Review and Process Study of the ecology of the sea grasses in the estuary has been the subject of another brief. An Honours Thesis from the University of Wollongong has been completed on the salt marsh vegetation communities in the estuary. Another Honours Thesis from the University of Canberra has addressed some of the sediment pattern and source aspects. These studies will be combined with this process study and considered in the preparation of a subsequent Management Study and Plan. This plan can then be soundly based and performance towards the agreed outcomes of the plan can be measured against current baseline conditions.

Figure 1.9: Re-vegetation has been undertaken in a limited number of areas.

This Process Study is to develop an understanding of water quality, erosion and sedimentation issues by providing information on:

- The catchment and estuarine processes behind the erosion, sedimentation and water quality problems identified;
- Sediment characteristics, sediment dynamics and hydrodynamics processes in the estuary;
- Water quality characteristics of the estuary including mixing and flushing behaviour; and
- The scale and nature of bank erosion in the estuary and an assessment of likely causes and appropriate remedial measures.

Figure 1.10: Eutrophication impacts are a major public concern.

1.3 ESTUARINE NUMERICAL MODELLING

Hydrodynamics, water quality and sediment transport modelling provides a cost-effective method for evaluating the response of an estuary to an event or condition of interest. For example, a sediment transport model could be used to assess the potential impact of a flood event on an estuarine structure and to evaluate a number of proposed management strategies to prevent bank erosion within an estuary.

The process of hydrodynamics, water quality and sediment transport modelling involves a number of stages as illustrated in the following flow chart (Figure 1.11).

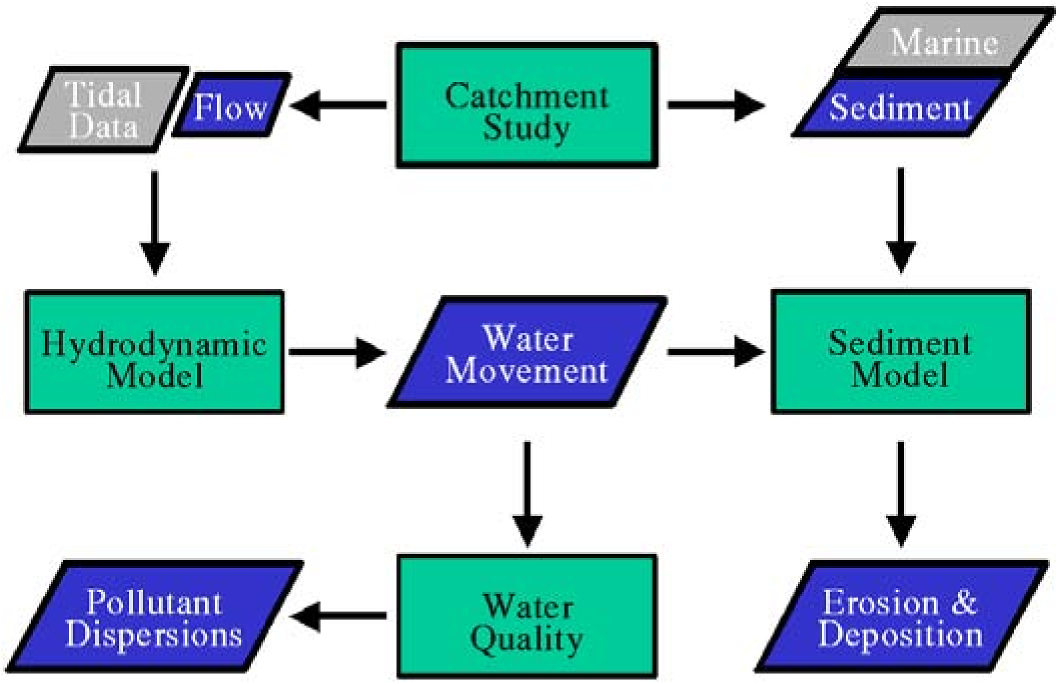

Figure 1.11: Hydrodynamics, water quality and sediment transport modelling process.

The development of a finite element mesh, or geometric representation, of a system is the first stage of a marine, estuarine or freshwater modelling program, and requires geographic information. A hydrodynamics model uses this information and river inflow and/or tidal information to calculate flow velocities and water surface elevations. These flow velocities can then be used to predict the dispersion of materials, including sediment, through the region of interest.

Knowledge of the nature of pollutant and sediment fluxes from the catchment to the estuary and their fate within the estuarine system are central to the development of effective management strategies for both present conditions and to evaluate future proposals for development in the catchment. The provision of effective management tools to assist evaluation of potentially different sedimentation, erosion and pollution effects under different catchment conditions was an objective of this study.

1.3.1 Numerical Modelling Suite

The RMA Modelling Suite, in conjunction with the pre- and post-processing software package, Surface Water Modelling System (SMS), has been employed for this study. The RMA Modelling Suite is a software package, consisting of a number of interlinked modules for the simulation of hydrodynamics, water quality and transport in aquatic environments, including bays, lakes, rivers and estuaries. The RMA Modelling Suite was originally developed by Norton, King and Orlob under contract to the US Army Corps of Engineers. The RMA-2 and RMA-11 modules of the RMA Modelling Suite have been employed for the hydrodynamics, water quality and sediment transport modelling for this study.

RMA-2 is a numerical model for hydrodynamics simulation. RMA-2 calculates water elevations and flow velocities resulting from river inflows and ocean tidal conditions across a defined study area. RMA-2 is also able to simulate the flooding and draining of areas, as may be caused by the action of tidal changes along coastal beaches and/or river banks.

RMA-11 is a model used to simulate pollutant and sediment movement. RMA-11 uses velocities and depths calculated by the RMA-2 module to calculate the transport of constituents from biotic, as well as sediment sources. The constituents which may be represented include temperature, BOD/DO (Biological Oxygen Demand/ Dissolved Oxygen), the nitrogen cycle, the Phosphorus cycle, algal growth and decay, cohesive and non-cohesive sediment, coliform load, salinity and any conservative or non-conservative arbitrary constituent.

SMS is a pre- and post-processing software package for surface water modelling, which is fully compatible with the RMA Modelling Suite. SMS was used to develop the mesh that was the geometric representation of the estuary. SMS also provides a number of tools for the visualisation of numerical results.

1.4 REPORT OUTLINE

This Estuarine Process Study has been divided into the following sections:

- Hydrodynamics Model;
- Sedimentation Process;
- Water Quality; and
- Bank Erosion and Mitigation.

Where appropriate, each section starts with a review of existing data and information, followed by a discussion of AMOG's field observations and modelling results.

2 ESTUARINE HYDRODYNAMICS

The behaviour and characteristics of estuaries are typically controlled by the mixing of river water and sea water through the continual motion generated by the rise and fall of the tide. Water movement determines the length of time water is resident in an estuary and how rapidly it moves from one location to another. These affect the dispersal of pollutants, and the erosion and deposition of sediment material in the river bed. Estuarine hydrodynamics behaviour therefore largely dictates the progression of important water quality, sedimentation and erosion processes.

This study constructed a numerical hydrodynamics model of the Moruya Estuary to gain a better understanding of the hydrodynamics of the estuary and hence the dispersal of pollutants and sediment deposition and erosion. Indicators such as flow velocities and water levels were the key outputs influencing the water quality and sediment transport studies discussed in Sections 3 and 4 of this report.

2.1 EXISTING DATA REVIEW

A tidal data collection was undertaken by Manly Hydraulics Laboratory (MHL) between 3 April and 10 May, 2000 to facilitate an understanding of the hydraulic processes operating in the estuary. Data collection sites for this study were established in order to monitor spatial and temporal variations in tidal flow patterns (MHL, 2000).

2.1.1 Tidal Characteristics

The tides along the southern New South Wales coast are dominated by the lunar semi-diurnal influence (M2 component of the tides), which has a period of 12 hours and 24 minutes. Thus, the tides oscillate between high and low levels at approximately every six hours. The hydrodynamics characteristics of the Moruya Estuary indicate that it acts like a typical river estuarine system, with maximum flow velocities occurring during the two hours following mid-tide and minimum flow velocities (slack water) usually recorded within one hour after high and low tide. Malabar Creek has different characteristics to the main estuary and behaves like a lagoon with a constricted entrance. Malabar Creek/Lagoon entrance has maximum flow velocities at the tidal peak and minimum flow velocities (slack water) 2-3 hours later (MHL, 2000).

The tidal limits of the Moruya Estuary and its tributaries are given by Manly Hydraulics Laboratory (MHL, 2000) as:

- For the Deua River, approximately 2 km upstream of Wamban Creek junction;
- For Malabar Creek, the downstream side of the Princes Highway Bridge;
- For Mogendoura Creek, the vicinity of Eastern Boundary Road;
- For Wamban Creek approximately 625 m upstream from the Deua River junction; and
- For Racecourse Creek, the downstream side of the South Head Road culvert.

2.1.2 Tidal Range

Tides are mainly controlled by the gravitational force of the sun and moon. Variations in the strength of these forces occur as the alignment of the earth, moon and sun changes. When in a row the gravitational forces are combined and tides are at maximum heights which are referred to as spring tides. When the sun and moon are farthest from alignment the combined gravitational forces of the sun and moon are minimal and minimum tide heights are experienced. These are known as neap tides. As well as the monthly changes with moon phase tide heights also vary throughout the year as the distances between the earth, the sun and moon change.

At spring tides there will be maximum exchange of estuarine and ocean water and tidal currents will be at their maximum velocities. During neap tides less water is moved about the estuary and tidal current velocities are at the minimum. Spring and neap tides will have different effects on sedimentation and erosion patterns and the patterns generated by pollution spills. The tidal heights recorded during the MHL study were 1.01 m for spring tide and 0.65 m for the neap tide.

The range in tidal heights (the height difference between high and low water) within the Moruya Estuary varies with distance from the ocean. From an examination of tidal planes data obtained from eight midstream data collection sites (Figure 2.1), a reduction in tidal range with increasing distance from the ocean (Figure 2.2) can be seen. The greatest reduction in tidal range occurs between the ocean and approximately 1 km upstream at Moruya Heads (Site 3). Further upstream of Moruya Heads, only slight variations in tidal range occur between measurement sites.

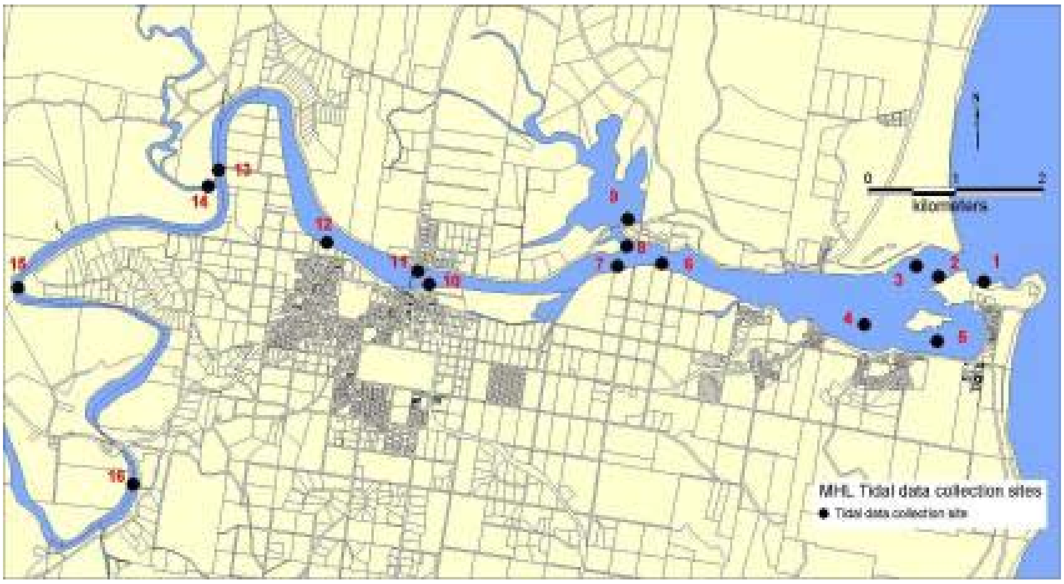

Figure 2.1: MHL tidal data collection sites (MHL, 2000).

The local high elevations 7.1 km from the ocean (Site 10) (Figure 2.2) are believed to be due to an error probably resulting from data loss that occurred from the 16 to 21 April 2000. The reductions in high water and mean water levels 14 km from the ocean (Site 16) are unexpected.

Tidal levels at all stations within the estuary showed a strong 14 day oscillation of height of about 0.16m. Mean water levels are raised during spring tides and lowered during neap tides. This large effect could have introduced some error into the determination of tidal planes.

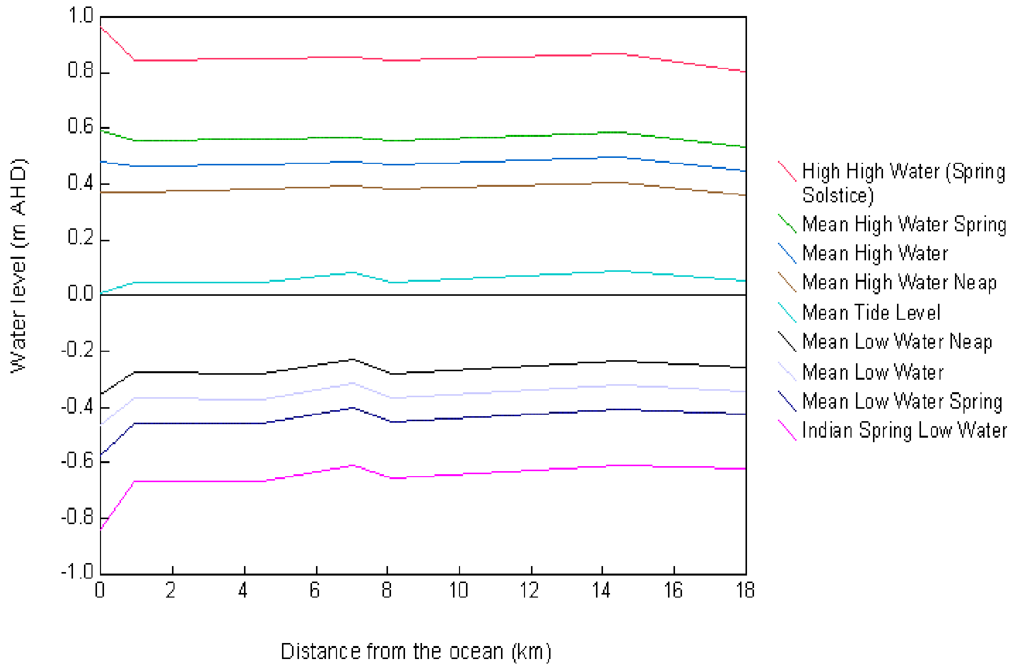

Figure 2.2: MHL observed tidal planes along the estuary (MHL, 2000).

This 14 day tidal height oscillation is caused by the lower flow resistance in deeper water. Consequently, on a spring flood tide less water is held back as it flows into and up the estuary than on a neap flood tide. Hence a greater proportion of the potential tidal water flows into the estuary on a spring tide than on a neap tide. The reverse occurs with ebb tides, trapping more water in the estuary and pumping up the spring water levels. The same mechanism leads to the differences in heights for the two daily tides being relatively large during neap tides.

2.1.3 Flow Velocities

Limited flow velocity data exists for the Moruya Estuary. MHL (2000) provides velocity readings during the course of a single ebb and flood tide on 5 April 2000, from six sites (Figure 2.1 Site Numbers 2, 4, 6, 7, 13 and 14). The tidal range on that day was 1.38m, about 12% greater than the mean spring tide range. The river flow on the preceding day was 1.46 m^3/s with negligible rainfall in the few days preceding the velocity measurements. The representative flow velocities are presented in Table 2.1.

Table 2.1 Maximum current velocities 5 April 2000 (from MHL, 2000)

	Flood		Ebb	
Site No	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)
2	0.95	0.7	>1.00	1.1
4	>1.00	0.8	-	-
6	0.35	1.9	0.45	2.2
7	0.15	1.0	0.25	0.8
13	0.35	1.2	0.45	0.8
14	0.15	1.3	0.15	1.4

The velocities are greatest at Site 2 and 4, close to the estuary mouth and very much less at the sites further upstream. The velocities for the ebb and flood tides were slightly different with the ebb velocity being greater.

2.2 CATCHMENT FLOWS

For most of the time, the estuary will be subject to base flows from the Deua River. Therefore low river flow patterns are important in investigating day-to-day events such as the dispersion of pollutants and the movement of sediment within the estuary.

Floods, although rare, are responsible for the movement of large amounts of sediment into the estuary, thus the potential for higher sediment erosion and deposition to occur. There are also much higher water velocities in the estuary during a flood event, allowing the water to pick up sediment from the bed of the river and carry it some distance before depositing it. Bank erosion due to hydraulic erosion by currents will also be maximised during flood events.

Stream flow characteristics of the Moruya Estuary were prepared, using the catchment inputs shown in Figure 2.3. The complete stream flow report is presented in Appendix A. Fresh water flows into the estuary via five major tributaries: Deua River, Malabar Creek, Mogendoura Creek, Wamban Creek and Candoin Creek (Figure 2.3). The various flow conditions were estimated for each of these tributaries. The catchment scenarios listed in Table 2.2 were used in the Process Study.

Table 2.2: Catchment input scenarios

Flow	Purpose
Dry weather flow (90% probability inflow)	Determinant of the importance of river inputs (by comparison of the dry weather and median flow analyses).
Median flow (50% probability inflow)	Input for water quality modeling
Once in 1 year flood	Input for sediment deposit and erosion modeling
Once in 5 year flood	Input for sediment deposit and erosion modeling
Once in 20 year flood	Input for sediment deposit and erosion modeling
Once in 50 year flood	Input for sediment deposit and erosion modeling

The dry weather inflow represents times when there is very little freshwater flowing from the rivers into the catchment. At these times, the longest residence times for pollutants can be expected to occur (i.e. pollutant spills will take the longest time to flush out). Thus, dry weather inflow conditions represent the worst case scenario for a pollution spill. For this study, dry weather refers to the 90% probability inflow condition.

The median flow condition is a flow such that half of the discharges will be higher and half lower than the value, as recorded over a period of several years. It is seen as the most common flow condition. It thus represents a typical case for a pollution event and the common current velocities for the movement of sediments within the estuary, and the formation of sand banks in the lower estuary.

Usually between any exceptionally large floods, there are many small floods and several intermediate sized floods. Different flood heights can be assigned a frequency at which they can be expected to occur.

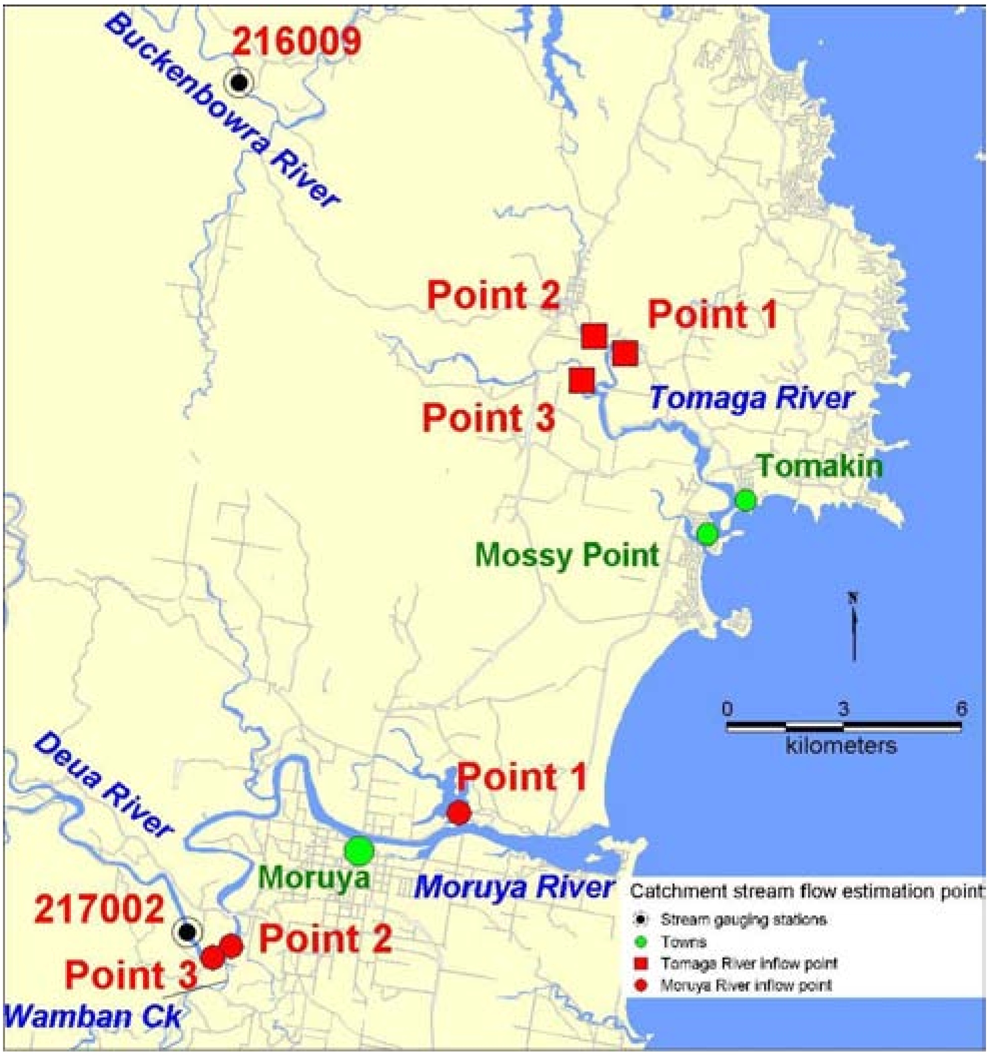

Figure 2.3: Locations used in calculating catchment inputs.

A "once in 1 year flood" is a flood event that would be expected to be equalled or exceeded on average once a year based on historical data. Similarly, a "once in 5 year flood" is a flood event that would be expected to be equalled or exceeded on average once every five years based on historical data. A "once in 20 year" and "once in 50 year" flood are similarly defined. For this Process Study, a range of flood events have been modelled to determine how different flood heights will reshape the estuary through erosion and deposition of sediment.

2.2.1 Catchment Rainfall

The Moruya Estuary has a high annual rainfall (860 mm), which is seasonal with the highest average monthly rainfall occurring in March and the lowest in August. There is one rainfall station within the Moruya catchment, located at Moruya Heads although other stations were operated in earlier years. There is variation in rainfall over the catchment due to the different elevations within the catchment and the mixture of coastal plain and mountain ridge landforms. The Northern Boundary has a high rainfall (> 889 mm) which decreases with distance further west so that the upper half of the Deua Valley receives less than 762 mm and increasing in the higher elevated south west corner of the catchment to 1016 mm (WCIC, 1970).

It is assumed that the general rainfall patterns are the same over all the catchment. This has been investigated by comparing annual rainfall at Moruya Heads on the coast with the inland station at Araluen. Figure 2.4 shows annual rainfall data at the two stations plotted sequentially; this agreement is striking. Figure 2.5 shows a linear regression between the two stations. The regression coefficient is 0.97 indicating only a 3% difference between the stations on average.

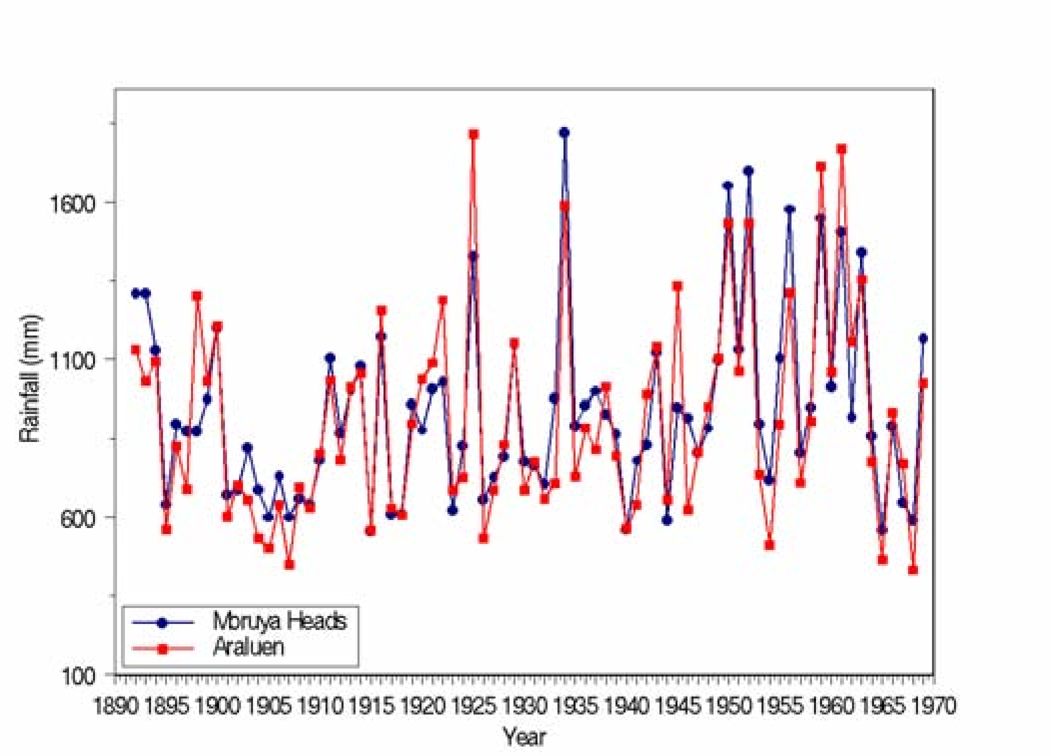

Figure 2.4: Annual rainfall for Araluen and Moruya Heads.

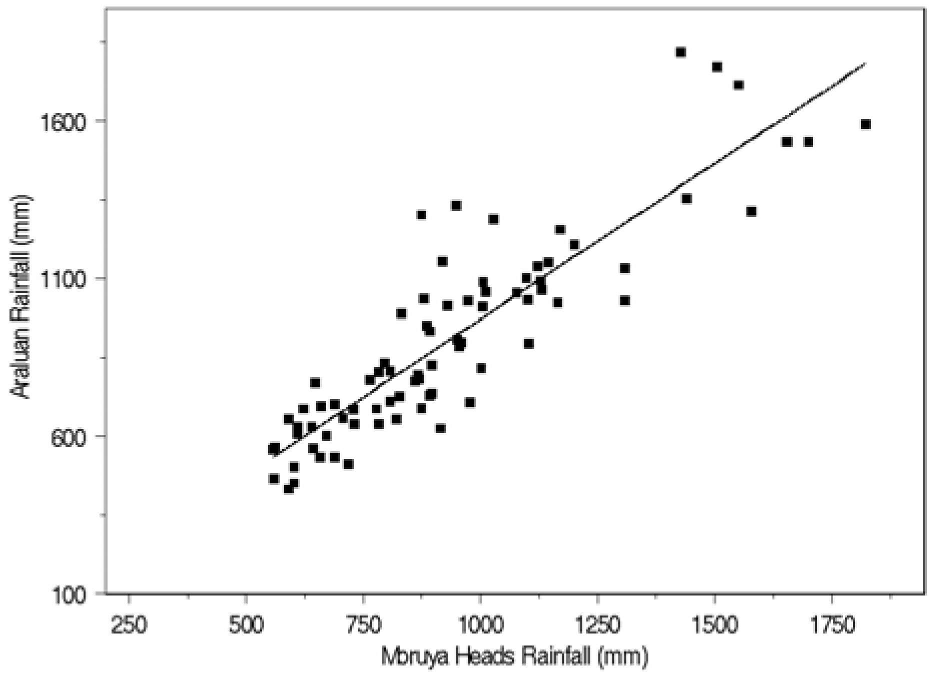

Figure 2.5: Correlation between annual rainfall for Araluen and Moruya Heads.

2.2.2 Dry Weather and Median Daily Flows

The stream flow characteristics for the Deua River were estimated using available stream flow data from gauge No. 217002 located in the river upstream of the junction of Wamban Creek (Figure 2.3).

The stream flow characteristics for the remaining tributaries were estimated based on data from an adjacent catchment. The catchment selected as most appropriate was the Buckenbowra River and flow data from Buckenbowra No. 3 (gauging station 216009) were used (Appendix A). The catchment area above Buckenbowra No. 3 gauging station is 168 km^2. Based on the comparative catchment areas for each of the tributaries, the dry weather and median daily flows were calculated using linear correction factors (Appendix A), and are presented in Table 2.3.

Table 2.3: Catchment inflows, estimated for a year.

Catchment	Catchment Area (km^2)	Flow (m^3/s)	
		Dry Weather	Median
Deua River	1200.00	0.278	1.811
Malabar Creek	27.18	0.007	0.030
Mogendoura Creek	41.83	0.011	0.046
Wamban Creek	73.55	0.019	0.082
Candoin Creek	18.68	0.005	0.021

Table 2.4: Seasonal catchment inflows (Summed for the three major tributaries).

Season	Flow (m^3/s)	
	Dry Weather	Median
Summer	0.193	1.737
Autumn	0.338	2.289
Winter	0.471	2.086
Spring	0.244	1.985

Dry weather flows were also obtained from the flow duration analysis undertaken on a seasonal basis. The mean daily flows were grouped according to the season (Table 2.4) and a flow duration analysis was then performed on daily flow data for each season. The seasons adopted by this study were summer (December-February), autumn (March-May), winter (June-August) and spring (September-November). This process provided estimates of median and dry weather flow in each season.

2.2.3 Flood Flows

The "once in 20 year" and "once in 50 year" flood flows for the Deua River were sourced from a detailed flood study undertaken by the DPWS (1992). Flows for the "once in 1 year" and "once in 5 years" floods were estimated based on this data, as well as a flood frequency analysis (DPWS, 1992).

The "Rational Method" as recommended for eastern New South Wales (Institution of Engineers, Australia, 1987) was used to determine the peak flood flows for the remaining estuary tributaries. The "Rational Method" is commonly used by engineers working on small catchments that do not have gauging data, and assumes that the frequency, or probability, of a runoff event (peak flow) is the same probability as the precipitation that caused it. That is, "five-year" rainfall intensity results in a "five-year" runoff event. Empirical results indicate that it gives reasonable results (Bloomsburg, *et. al.*, 1998). Rainfall intensity depends on the duration of a storm event in addition to its return period and spatial extent. Thus there are different magnitudes of the 5 year rainfall which has duration of 10 minutes and that which has duration of 1 hour, 24 hours etc. Experiments have shown that the duration which produces the greatest flood event is closely related to the area of the watershed. This information along with models of expected runoff events were used to estimate the magnitude of flood events. Parameters used for the estimation are given in Appendix A.

The flood flow estimates for the entire Moruya Catchment are given in Table 2.5.

Table 2.5: Peak flood flows (summed for the three major catchments)

Probability	Peak flow (m^3/s)
Once in 1 year flood	590
Once in 5 year flood	1650
Once in 20 year flood	3960
Once in 50 year flood	4940

2.3 HYDRODYNAMICS MODELLING

The hydrodynamics processes that shape the environment of the Moruya Estuary have been analysed using numerical modelling techniques. The RMA-2 module of the RMA modelling suite has been employed for this purpose.

Numerical hydrodynamics modelling requires the construction of a finite element mesh, or geographical representation, of the study area. The hydrodynamics model uses this mesh, along with river inflow and tidal information, to calculate flow velocities and water surface elevations throughout the region of interest.

2.3.1 Moruya Estuary Finite Element Mesh

For the purposes of this study, two representations of the Moruya Estuary were developed using the software package, SMS. These two finite element meshes are described as follows:

Large / Full Model:

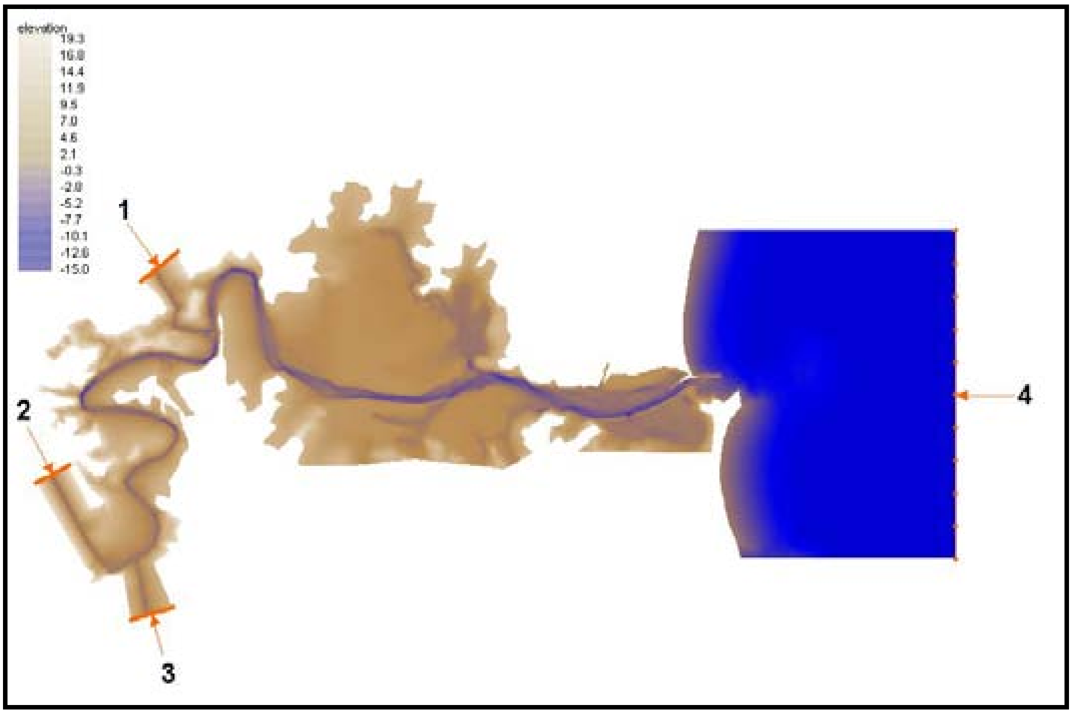

Figure 2.6: Moruya Estuary full finite element model.
Flow boundaries 1) model inflow from Mogendoura Creek through the run-up distance, 2) model inflow from the Deua River through the run-up distance, 3) combined model inflow from Wamban and Candoin Creeks from the run-up distance, 4) model inflow from the ocean.

This mesh (Figure 2.6) comprises the estuary waterways, adjacent land and ocean coastline, from around Cherry Rise and Wonga Park through to an extended ocean boundary. Previous flood surveys of Eurobodalla Shire around the Moruya River suggest that the floodplains can extend up to 17 metres above the Australian Height Datum around the end of the Deua River, up to around 7 metres above AHD in the plains of Mullenderee and up to around 3 metres close to the river mouth (Moruya Heads). The current model extends to the 20 metre elevation from around Cherry Rise/Wonga Park up to Yarragee, to 10 metre elevation from Yarragee to Moruya Heads and 3 metre elevation at the river mouth. The Full Model also contains artificial regions called run-up distances at Mogendoura Creek, the Deua and a region used to combine the flow from Wamban and Candoin Creeks. These run-up regions are not true geometric representations of the area but are used solely to allow the flow-fields to fully develop before entering the model main channel. This mesh generated 21990 nodes at each of which the flow calculations were computed at each time step, and was used primarily in the hydrodynamics modelling of flood events in the Moruya Estuary. This Full Model uses an averaged frictional behaviour along the main channel.

Small / Reduced Model:

This mesh (Figure 2.7) primarily comprises the estuary waterways and ocean coastline. From the mouth of the estuary to around Ryans Creek, adjacent land is also included to a maximum of approximately 3 metres in elevation. From Ryans Creek to Moruya Hospital the adjacent land includes overbank areas to a maximum elevation of 1 metre, and upstream of the Hospital, overbank areas included are close to the zero contours. In an analogous manner to the Full Model, run-up regions are also attached at Mogendoura Creek, the Deua River and combined Wamban and Candoin area. This mesh generated 9620 nodes at each of which the flow calculations were computed at each time step, and was used primarily in the hydrodynamics modelling of non-flood conditions. This Reduced Model possesses greater detail in terms of the frictional behaviour of the main channel, which is described by three frictional regions. This is in recognition of the fact that non-flood flow conditions will be more sensitive in their hydrodynamics behaviour to the frictional properties of the channel.

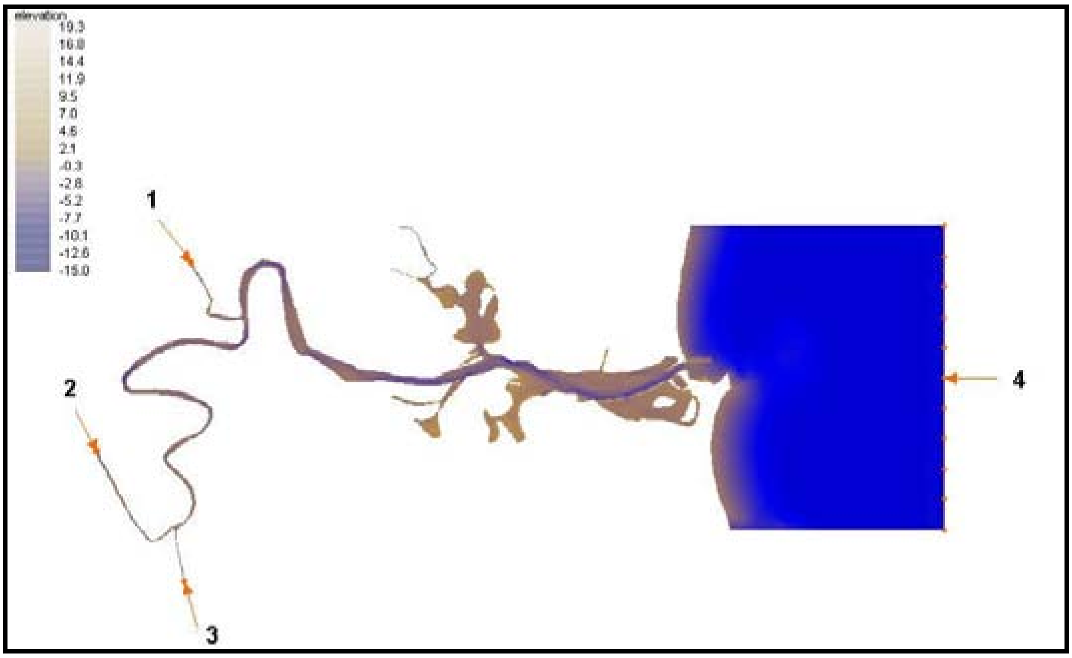

Figure 2.7: Moruya Estuary reduced finite element mesh model.
Flow boundaries 1) model inflow from Mogendoura Creek, 2) model inflow from the Deua River, 3) combined model inflow from Wamban and Candoin Creeks, 4) model inflow from the ocean.

The bathymetry of both Moruya Estuary meshes in the main channel was based on hydrographic survey data collected by DLWC in April 2000, as provided by the Eurobodalla Shire Council (ESC). In the Full Model, much of the overbank topography was based and interpolated from the 10 and 20 metre contours and from topographical observations made by AMOG staff.

A finite element mesh requires boundary lines along which flow conditions, such as tidal elevations and river inflow, can be defined. Four such lines have been defined for both Moruya Estuary meshes; one for each of the Deua River and Mogendoura Creek, one for Wamban Creek located downstream of the junction of Candoin Creek (which combines the catchment flow from both Wamban and Candoin Creeks) and the ocean boundary (Figure 2.6).

2.3.2 Hydrodynamics Calibration

Once constructed, a hydrodynamics model must be calibrated before predictive analyses can be undertaken. The calibration of a model involves the operation of the model with an assumed set of modelling parameters, which is adjusted until the model reproduces the events of field data.

Ideally, field data used to validate the tidal behaviour of the model would have consistent conditions and reflect minimal effects from anomalous events such as rain or flood. Hence, data corresponding to a period of minimum to no rainfall was sought. A comprehensive calibration would also ideally include data for the lower, middle and upper estuary. The hydrodynamics models were calibrated using field data for water surface elevation recorded for the period of 8 to 12 February 2000 at both the Moruya Hospital and Princes Highway Bridge tidal gauge sites.

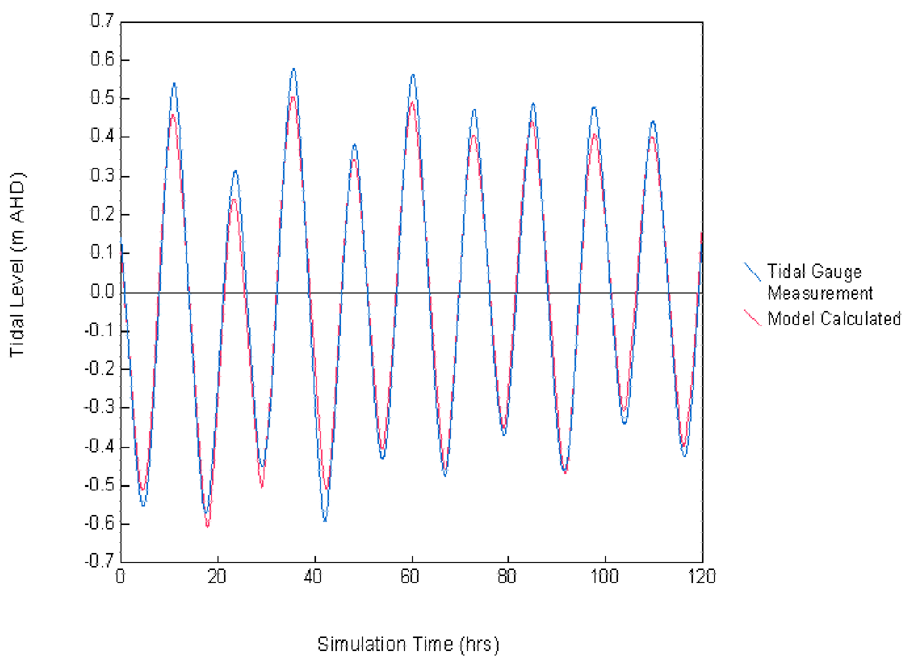

Figure 2.8: Moruya Hospital Tidal Gauge full model calibration results.

Tidal elevations recorded at Jervis Bay (HMAS Creswell) during this period were used to drive both models at the downstream ocean boundary. Rainfall recordings from Moruya Heads indicate that no rain fell during the calibration period and therefore, the calculated dry weather (90% probability) inflow conditions were applied at the estuarine boundary inlets.

The water surface elevations calculated using RMA-2 are compared to data collected by the tidal gauges in Figures 2.8 and 2.9 for the Full Model and in Figures 2.10 and 2.11 for the Reduced Model. The hydrodynamics response at the calibration locations for both models indicate extremely good predictions of the tidal phase, and very good predictions of both high water and low water tidal heights, with the few small discrepancies likely due to changes in atmospheric conditions during the calibration period. The calibration results are reflective of the model accuracy in the regions of calibration. In the absence of lower and upper estuary temporal data, the hydrodynamics behaviour of the models in these regions could not be calibrated.

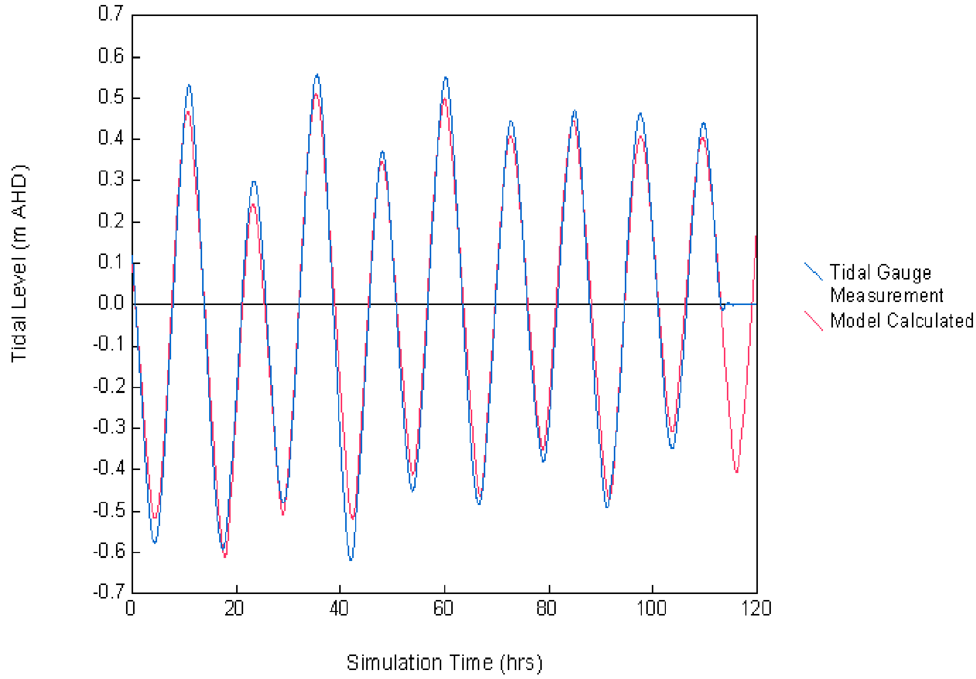

Figure 2.9: Full model calibration results for Princes Highway Tidal Gauge.

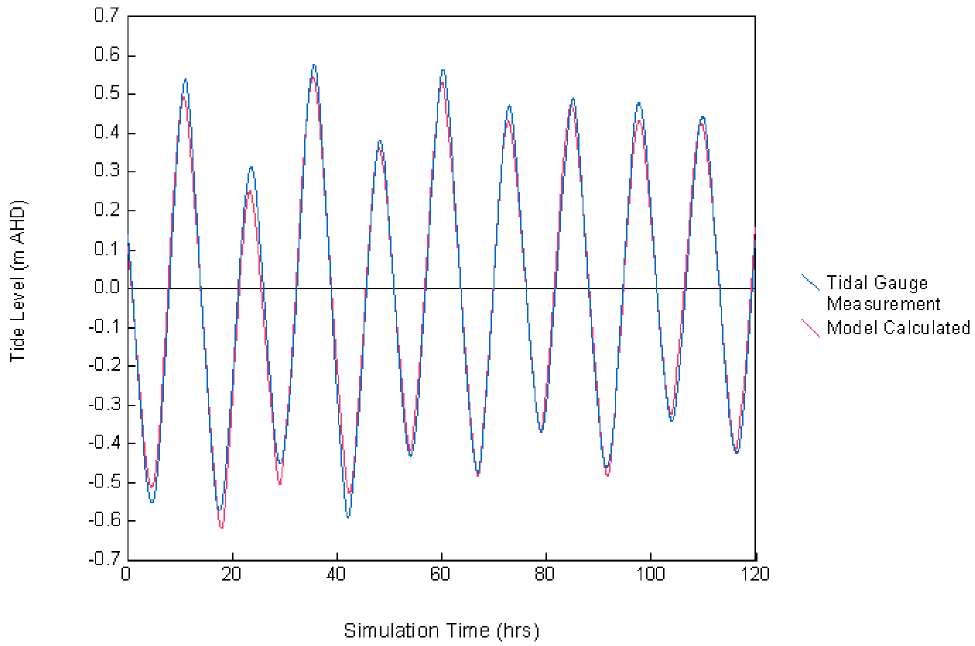

Figure 2.10: Moruya Hospital Tidal Gauge reduced model calibration results.

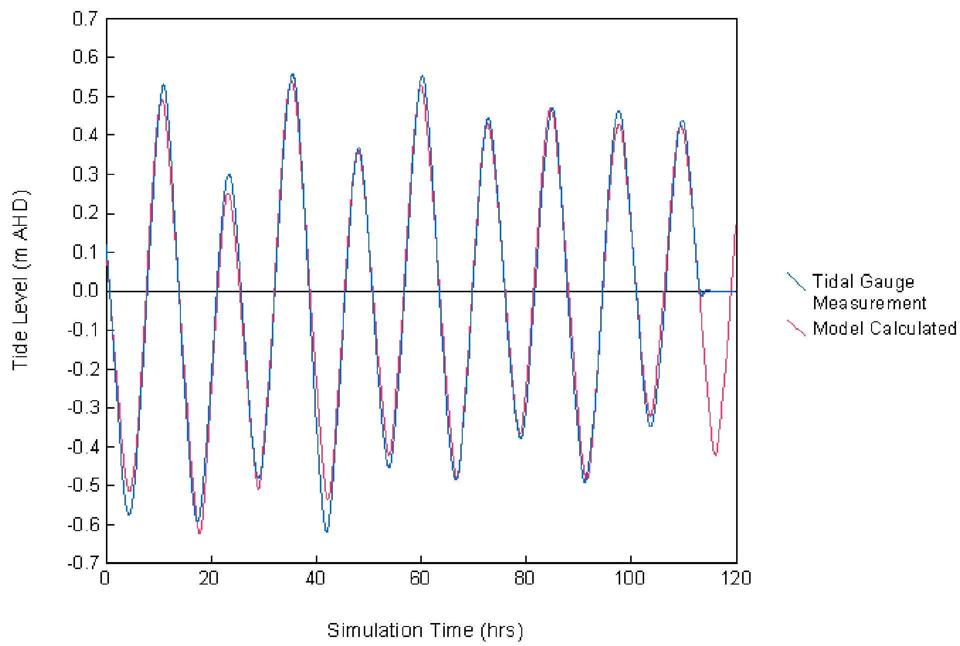

Figure 2.11: Princes Highway Tidal Gauge reduced model calibration results.

Meaningful velocity comparisons could not be made between the snapshots covering part of the cross section and the model results. For this reason they have not been prepared.

The velocity data in MHL (2000) was used to confirm that depth variations followed accepted hydraulic laws, diminishing from the surface to the bed, and without significant direction change from surface to bed. These principles are embodied in the depth-integrated hydrodynamics model RMA-2.

2.3.3 Hydrodynamics Analysis

Hydrodynamics predictive analysis has been undertaken for a range of river inflow and tidal conditions, covering the common conditions likely to arise in the estuary. Four non-flood and five flood conditions have been modelled.

Non-Flood Conditions on the Reduced Model

- Dry weather (90% probability) inflow conditions with mean tide;
- Median inflow conditions with neap tide;
- Median inflow conditions with mean tide; and
- Median inflow conditions with spring tide.

Flood Conditions on the Full Model

- Once in 1 year flood conditions with mean tide;
- Once in 5 year flood conditions with mean tide;
- Once in 20 year flood conditions with mean tide;
- Once in 20 year flood conditions with spring tide; and
- Once in 50 year flood conditions with mean tide.

Two separate data sources were found describing the tidal cycles present offshore of the Moruya Estuary:

- Tidal data for Jervis Bay, recorded during the period of June 2001 to June 2002 at HMAS Creswell; and
- Tidal data for the Moruya Estuary collected during the period of April 2000 to May 2000 by Manly Hydraulics Laboratory (MHL) for the New South Wales Department of Public Works and Services (DPWS).

The representative mean, neap and spring tides calculated from tidal harmonic constituents measured at HMAS Creswell are given in Figure 2.12, and representative tides calculated from the mean ocean side water levels and tidal ranges as measured by MHL are given in Figure 2.13. Discrepancies exist in both the tidal range and mean tidal level between the two sets. For the purpose of comparison with the MHL measured tidal planes of Figure 2.2, the Reduced Model was driven with both the Jervis Bay tides and the MHL tides. It is considered however that the Jervis Bay derived tidal data set provides a more representative picture of the ocean side tidal cycle as, due to the longer sampling period, it will be less sensitive to anomalous hydrological events. Hence, full hydrodynamics runs used in later sections (Sediment Transport and Water Quality Modelling) use the Jervis Bay derived tides to run both the Full and Reduced Models.

The mean tide has been selected to represent the average tidal conditions as discussed previously in Section 2.1.2. From previous discussions it can be anticipated that current velocities due to tidal forces will be at their highest for spring tides and lowest for neap tides.

Each hydrodynamics flow condition has been simulated for approximately 5 days.

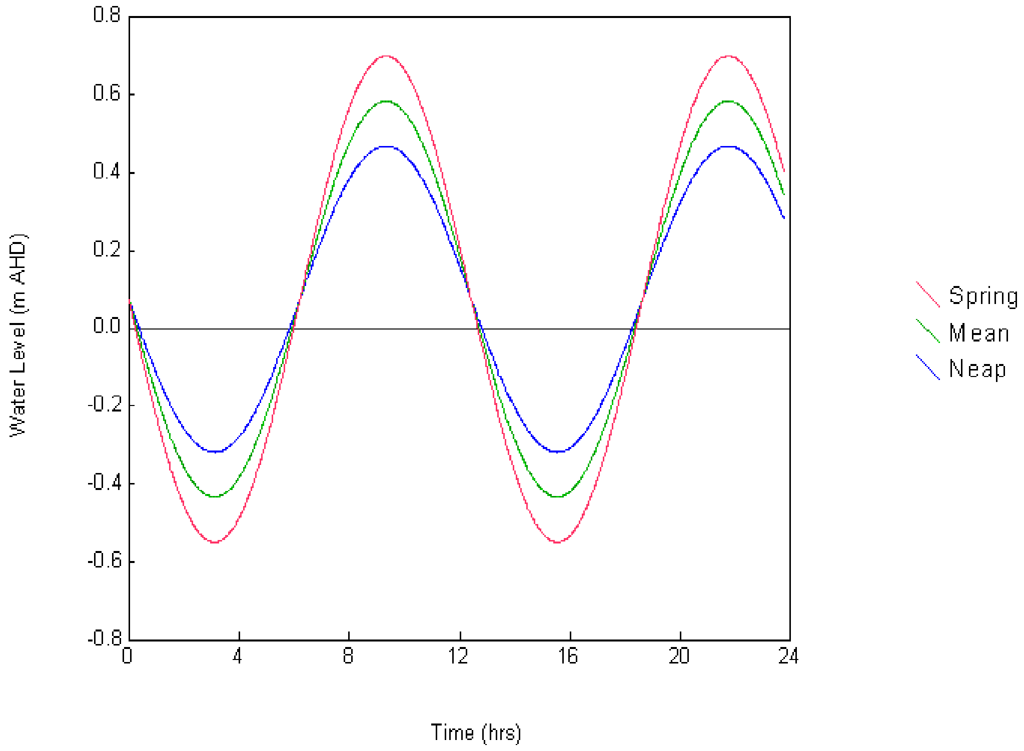

Figure 2.12: Derived Jervis Bay tidal elevations.

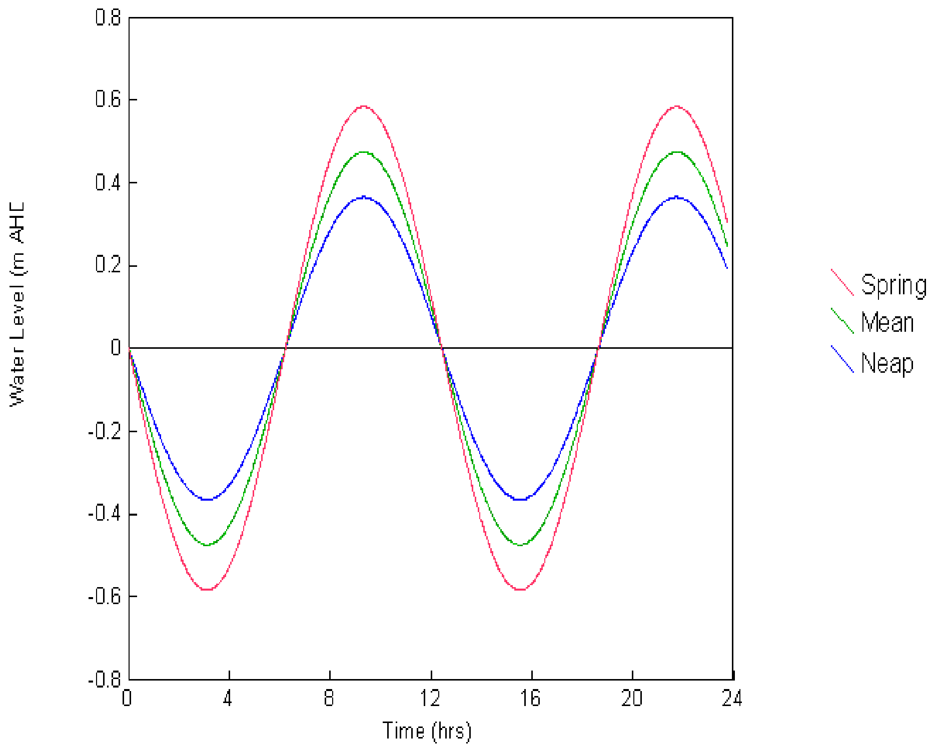

Figure 2.13: MHL data derived tidal elevations.

2.3.4 Non-Flood Condition Results

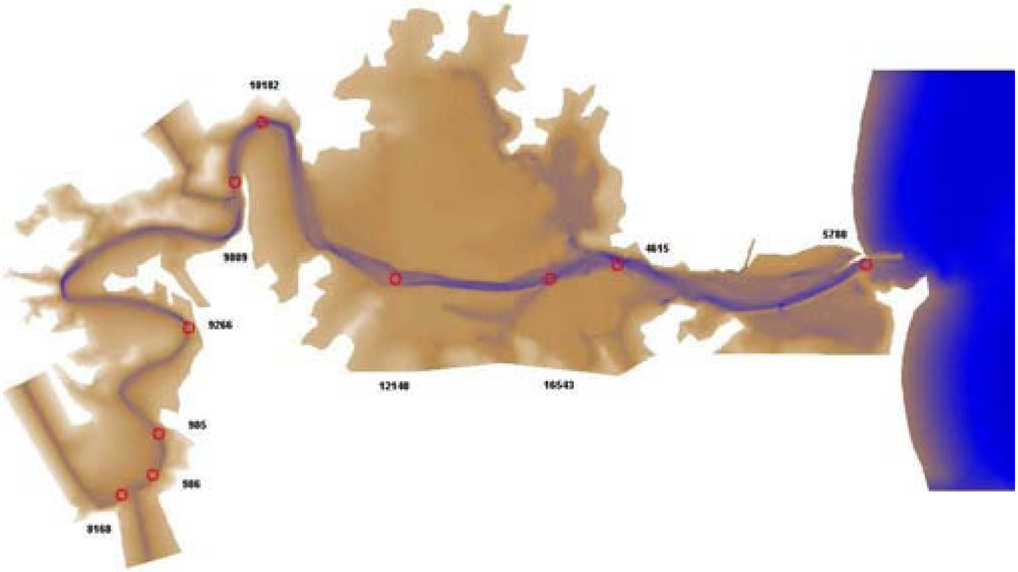

Figure 2.14: Model hydrodynamics data output points for the Full Model.

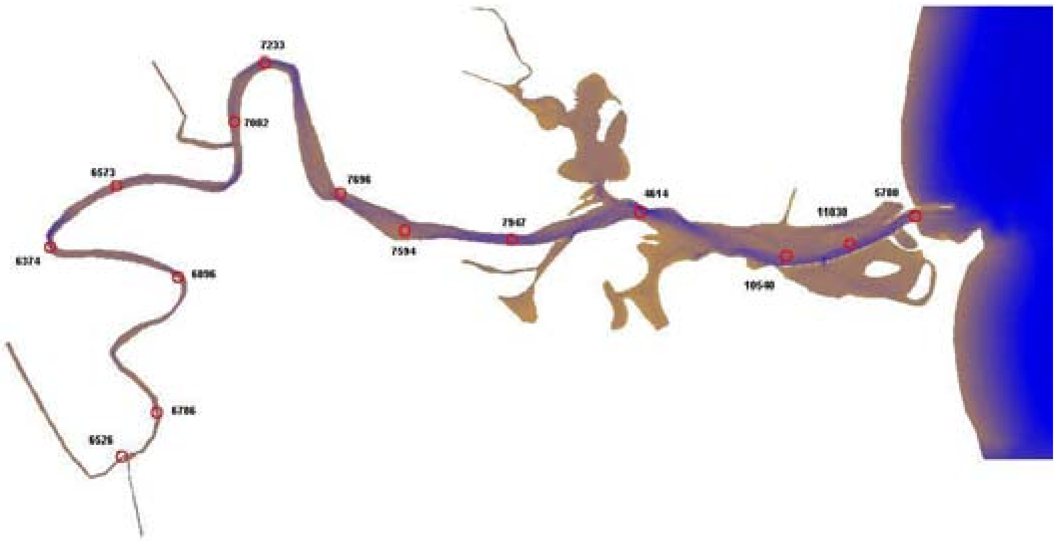

Figure 2.15: Model hydrodynamics output points for the Reduced Model.

Figures 2.14 and 2.15 indicates the data output points used in the general analysis of the models' hydrodynamics response, with non-flood flow conditions analysed using the Reduced Model and flood flow conditions analysed using the Full Model.

Flow velocities for the mean tide with median inflow and mean tide with 90% probability inflows are virtually the same for the estuary: i.e. for the same location under the two freshwater flow conditions, the degree of flushing in the area will be largely the same. Under normal conditions, the freshwater input from the major tributaries therefore has negligible impact on depth average flow velocities or water levels. This indicates that tidal generated velocities are the dominant source for water movement in the estuary.

In an estuary, tidal currents are influenced by the tidal heights, which decrease with increasing distance upstream and the water depth (Figures 2.2, 2.18 and 2.19). AMOG's model shows that in non-flood times, tidal currents are significantly attenuated at the entrance and between the mouth breakwater and Quarry Wharf (approximately 1 and 4 kms along the estuary), with flow velocities dropping from about 1.2 to 0.2 m s^{-1}. Flow velocities are an important factor in shaping the estuary. They influence the quantity and size of the sediment that the water can move. Therefore differences in current velocity for the flood and ebb tides will influence sand bank positions within the estuary. Figures 2.16 and 2.17 give the variation in current velocities for the estuary using the spring tide.

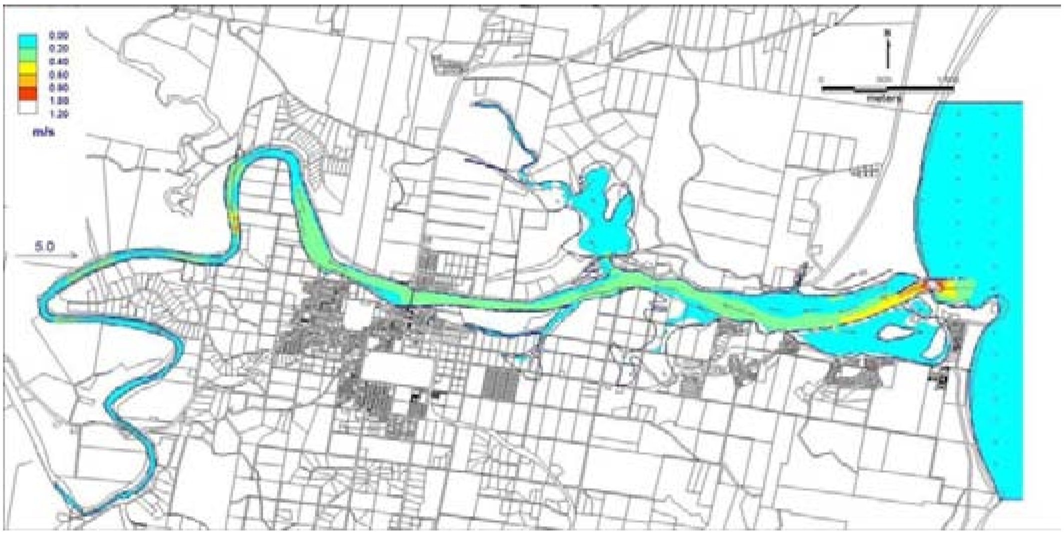

Figure 2.16: Maximum velocities, incoming spring tide with median inflow. (Units m/s).

Incoming and outgoing tidal flow velocity maxima are almost equal near the entrance, but further upstream the ebb velocities are generally greater than the incoming tide (Figures 2.17 and 2.18). The Reduced Model reveals that under non-flood flow conditions, threshold current velocities required for scouring and sediment transport (approximately 0.1 - 0.4 ms^{-1}, as discussed further in Sections 3 and 5) are achieved at the entrance (Figure 2.17 and 2.18) and along the rock wall sheltering the oyster leases in Pilots Station Backwater. In the rest of the estuary there are threshold flow velocities for scour up to the Mogendoura Creek junction. These are areas of least stagnation and it is expected that both sediment transport and pollutant dispersal will be at their highest in these reaches. This generalisation ignores localised variations hence localised minor scouring is possible on the ebb tide upstream of the Mogendoura Creek junction.

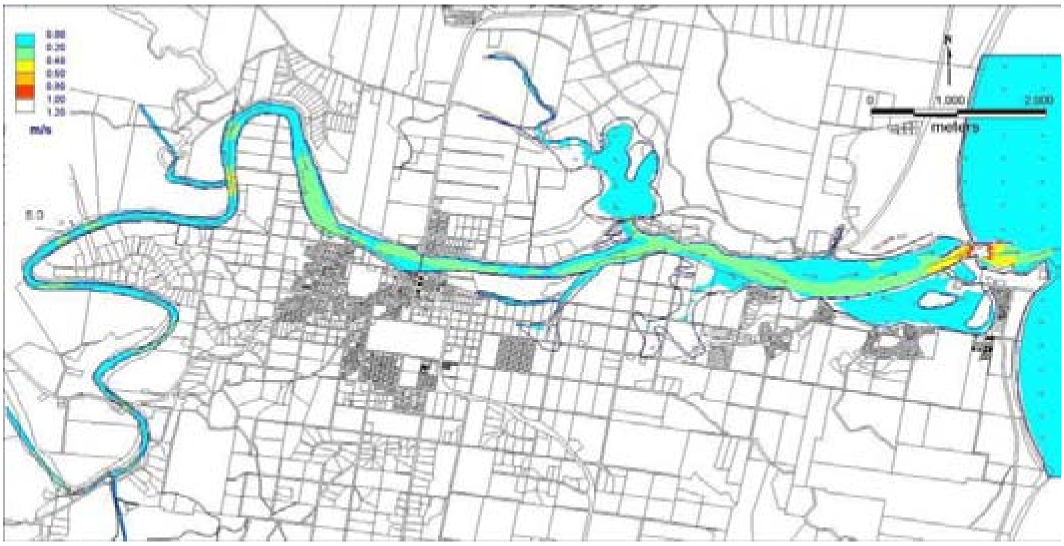

Figure 2.17: Maximum velocities, ebb spring tides with median inflow
(Units m/s).

The shape of the velocity-time curves (Figure 2.19) is such that velocities near the maxima occur for longer times in the upper estuary than in the lower estuary. However, as the flow velocities are larger in the lower estuary, there is greater potential for sand transport in this area under non-flood conditions.

The Reduced Model shows that the mean water level varies with distance from the ocean, and that this effect is greater for the spring tides than the neap tides. Although the latter effect is not shown in Figure 2.18, it is evident in the MHL data, as discussed in Section 2.1.2 of this report. The difference at 14 km from the ocean corresponds to a 14 day oscillation of 0.06 m range. This is consistent with the MHL observations.

The tidal ranges all reduce with the distance from the ocean, with the greatest reduction being over the first kilometre. This pattern and the magnitude of the reduction for the Reduced Model and MHL field data are in good agreement.

In the upper reaches of estuaries, the tidal heights may increase due to the reflection of the tidal wave from the edge of the estuary. Tidal reflection occurs because tidal waves can be reflected from the estuary's banks; these reflections are added to the main wave (constructive interference). Thus, if the estuary is the correct shape for constructive interference to occur, tidal heights can be greatly magnified with increasing distance from the mouth.

Field observations (MHL, 2000) indicate noticeable attenuation of the tidal height from approximately 14kms along the estuary (northwest of Yarragee Road) until at least Kiora Bridge (approximately 18kms along the estuary). The Reduced Model tidal planes, (Figure 2.18), do not show this trend. The field data indicate that any wave reflection occurring is too small to make a significant impact on the tidal height. The tidal reflection is minimised due to the shape and depth of the upper estuary and most likely due to the meandering of the main channel causing local high velocities (as previously highlighted) that dampen any tendency for tidal reflection. In the Reduced Model, the absence of this trend could be a result of using limited bathymetric data in the area, hence for the same tidal volume the tidal heights may be overestimated if the model channel is too constricted and vice versa. As previously discussed, however, since there is a disparity between HMAS Creswell/Jervis Bay derived tides and MHL derived tides, direct comparison between model and field results cannot be readily made here. This is expanded in Section 2.4 of this report.

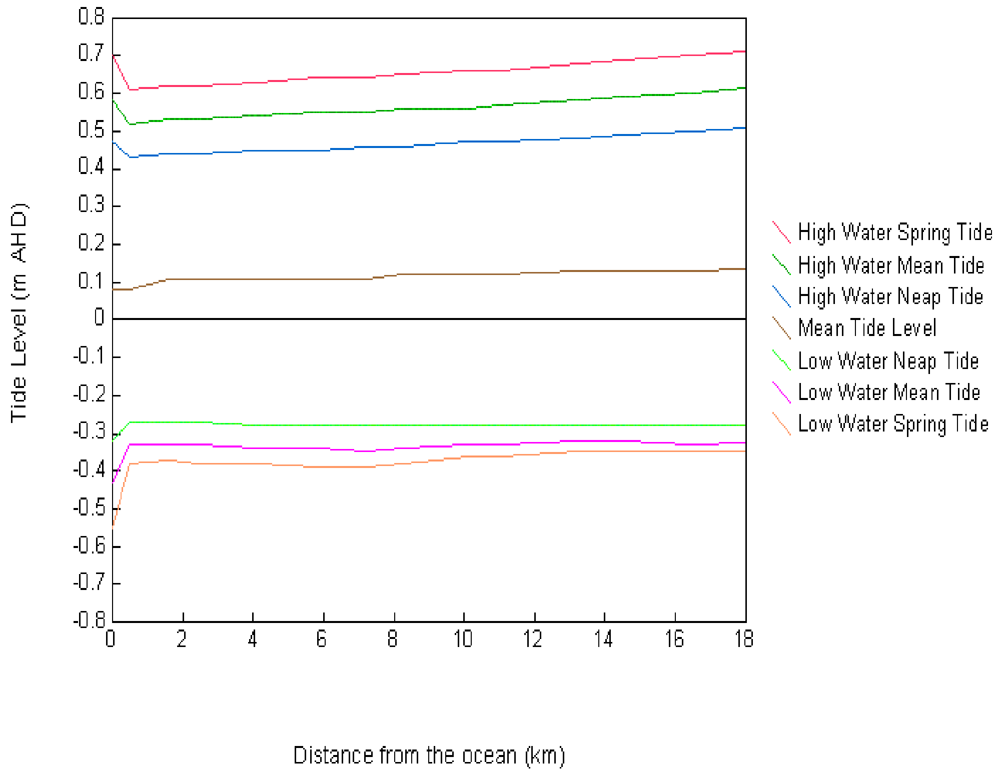

Figure 2.18: Reduced Model predicted tidal levels for Jervis Bay tides with median inflow.

The Reduced Model reveals that, within the estuary, the tidal cycle is slightly distorted along the estuary (Figure 2.19), with the duration of the ebb and incoming tides remaining reasonably constant. Lengthening or shortening of the ebb or incoming tide duration is normally due to the fact that the tidal inflow and tide height are not in phase - slack water follows high tide at all points up to the tidal limit. As a consequence, the incoming tide moves through deeper water and progresses faster than the falling tide. The incoming tide therefore has a shorter duration than the outgoing tide. This difference is small (less than ½ hour) due to the relatively deep channel of the Moruya Estuary and relatively small off-channel storages of tidal water. The maximum flood tide velocity is about 7% larger than the maximum ebb tide velocity.

While the tidal range decreases with distance along the Moruya Estuary from the ocean, this is not reflected in the altered duration of the incoming and outgoing tides.

Figure 2.19 is typical of the model output in that locality and does show the tidal distortion as discussed in the text.

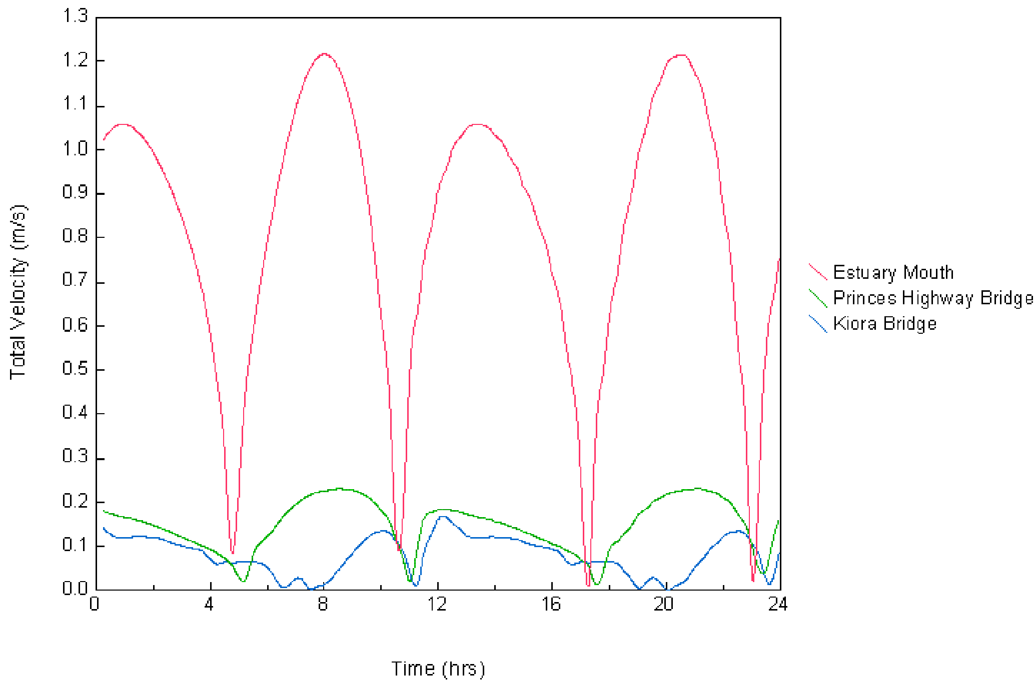

Figure 2.19: Reduced model predicted tidal velocities for Jervis Bay tides.

2.3.5 Flood Condition Results

Analysis of flood conditions in AMOG's model has been to investigate sediment transport and scouring of the river bed, not to predict flood levels. The model has not had detailed elevations entered for the flood plain. Heights in this area have been extrapolated from the 0 and 10 m contour lines on the maps provided by council, with some intermediate contour lines drawn by eye during AMOG's site visit. Also AMOG's model has not taken into account the effect of vegetation, particularly trees etc on water movement, which will increase flood levels. For these reasons AMOG's model should not be used for estimating flood levels and in this report we have not presented detailed data on the water levels.

Maximum current velocities for the 4 flood cases modelled are given in Appendix D. From these outputs the summary data plotted in Figure 2.20 and 2.21 have been obtained.

Figure 2.20 shows the maximum water levels predicted by AMOG's model as a function of distance from the ocean. For the flood inflows, the model results showed that river input determines the water level and depth, with the exception of the 1 year flood, where there were tidal influences on the maximum water surface elevation at the mouth of the estuary. Upstream of the entrance, the model shows that the maximum flood levels are appreciably higher, as illustrated by Figure 2.20. The Moruya Estuary topography is such that steeper banks exist in the upper estuary with smaller cross-sections hence the surface water elevation needs to be higher for the same volume of floodwater passing through.

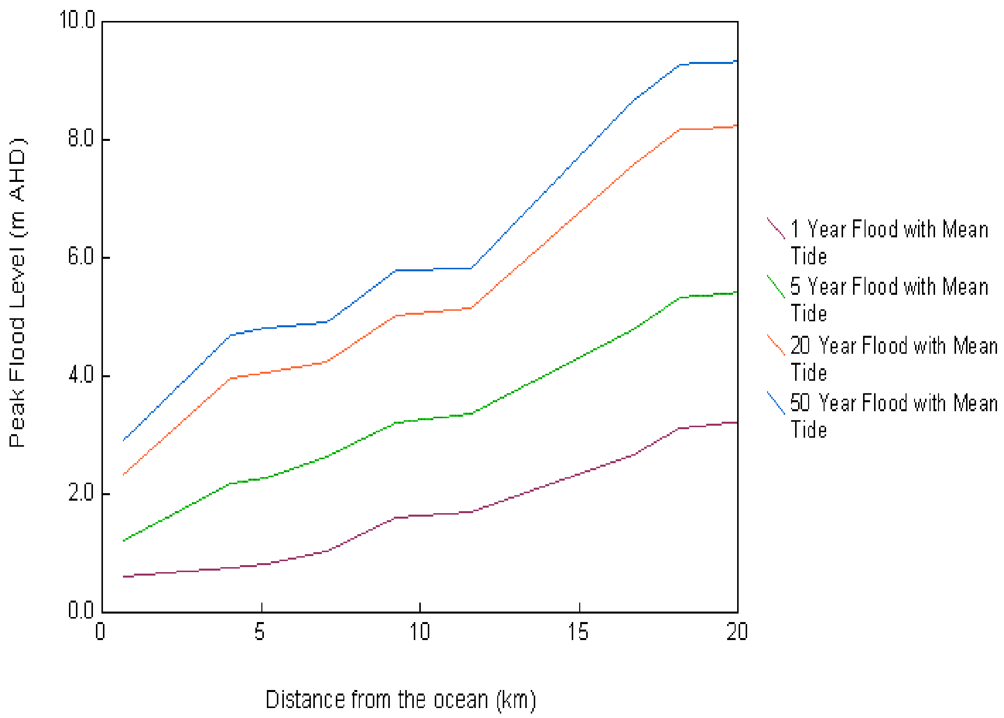

Figure 2.20: Full Model predicted peak flood levels.

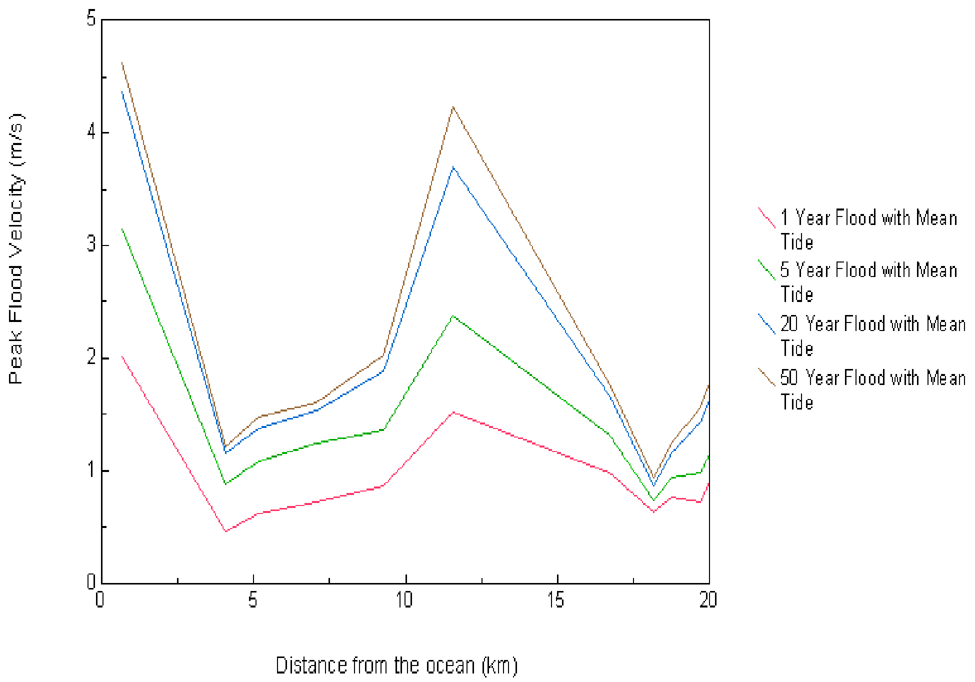

Figure 2.21: Model predicted peak flood velocity along the estuary.

Figure 2.21 shows the peak velocities for the 4 flood cases as a function of the distance from the ocean.

Under flood conditions, the ebb velocities all along the estuary are increased significantly, particularly at the entrance. With distance upstream, the general trend is for decreasing ebb velocities. However, a local peak is observed on the model output point at approximately 11 km from the ocean, near the junction with Mogendoura Creek. Flow acceleration around these sites is due to constrictions in the channel; the smaller channel cross-section must accommodate the same volume of water passing through and hence leads to greater current velocities. All along the estuary, rapid scouring will be experienced for all flood conditions. This is further quantified in Section 3 of this report.

Although flow velocities achieved all along the estuary for all flood scenarios greatly exceed the velocity at which scouring will occur, the extent to which this does occur will be highly dynamic as the estuary experiences rapid change in shape and depth. The entrance reach is comparatively short and may be expected to scour appreciably on the rising flood tide. As the entrance section scours, the resistance to flow decreases so that the upstream water surface slope will increase, upstream cross-sectional areas will decrease and current speeds will increase. This will lead to a zone of very rapid scouring extending upstream of Moruya Heads. The maximum flood levels will thus be significantly reduced and the duration of flooding above any given level will also be reduced. Thus the model results provide a conservative estimate of flood levels and velocities.

2.3.6 Results Compared to MHL Observations

The model outputs have been compared with the MHL measurements. These measurements show a sequence of spring-neap cycles which was made during a period of low river flow. Thus the comparison is restricted to the non-flood cases.

The model has been shown to reproduce the sequence of tides from spring to neap as recorded by MHL, with high accuracy (Figures 2.2 and 2.47). In this direct validation the actual ocean tide levels as measured by MHL were used as boundary conditions on the model.

The model has reproduced the main features of the non-flood tidal planes as recorded by MHL, and has shown the observed 14 day tidal variation. The MHL data are based on 37 days of recording and used the Jervis Bay gauge as a reference for the ocean tidal level. During the period when MHL tidal observations were conducted, ocean tides recorded at Jervis Bay were atypical. As well as the regular near six hour tides and the fortnightly changing pattern from spring to neap tides there was another strong 14 day tidal oscillation recorded at Jervis Bay with a height of 0.0751 m. A 14 day tidal oscillation of this magnitude was not seen on a 2 year record of Jervis Bay tides and is considered to be quite unusual.

This tidal oscillation occurring at the time of MHL's data observations resulted in a lower mean water level during neap tides and a raised mean water level during spring tides. The 14 day ocean tidal oscillation could be expected to cause atypical tides in the Moruya Estuary during the MHL observation period.

A 14 day tidal observation is frequently generated within estuaries by the different resistance to flow experienced by the flood and ebb tides. This oscillation in estuaries is often referred to as "spring tide pumping". The MHL data show that the 14 day tidal observation was larger in the estuary than the ocean. It is believed that the increased size of the 14 day tidal oscillation in the estuary observed by MHL was due to the natural spring tide pumping.

The ocean tidal ranges adopted by MHL on the basis of these data differ from those based on analysis of one year of record at Jervis Bay, which is the data we have used in this process study. Consequently, AMOG's data is not directly comparable to the MHL data. To enable comparison, the Reduced Model was run with the MHL ocean tidal ranges, as previously described, given in Table 2.6, together with the MHL mean tidal elevation at the ocean. The Reduced Model and MHL tidal ranges are compared in Figure 2.22.

Table 2.6: Ocean tidal ranges from MHL

Tide	Range m
Spring	1.168
Mean	0.949
Neap	0.731

Comparison of the mean water levels for each tidal condition would be valuable, but the MHL report presents only the global mean over the whole measuring period, and with the strong 14 day oscillation present a direct comparison is not warranted. The tidal planes predicted by the Reduced Model using the MHL tide cycles are given in Figure 2.22 for information, and those for Jervis Bay tide produced tidal planes have previously been given in Figure 2.18. From these predicted means it can be inferred that a 14 day tidal oscillation would be generated wholly within the estuary, even without the abnormal ocean 14 day tidal oscillation. The amplitude of this predicted 14 day oscillation in the estuary is 0.075 m which is in fair agreement with the additional spring tide pumping seen in the MHL data.

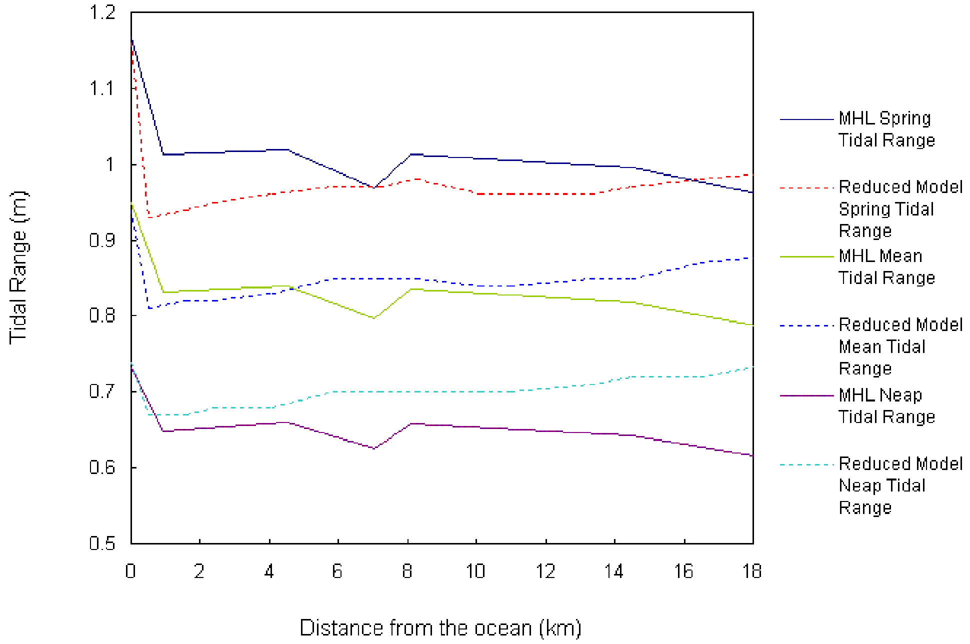

Figure 2.22: Comparison of measured (MHL) and Reduced Model tidal ranges with MHL tide driven simulation.

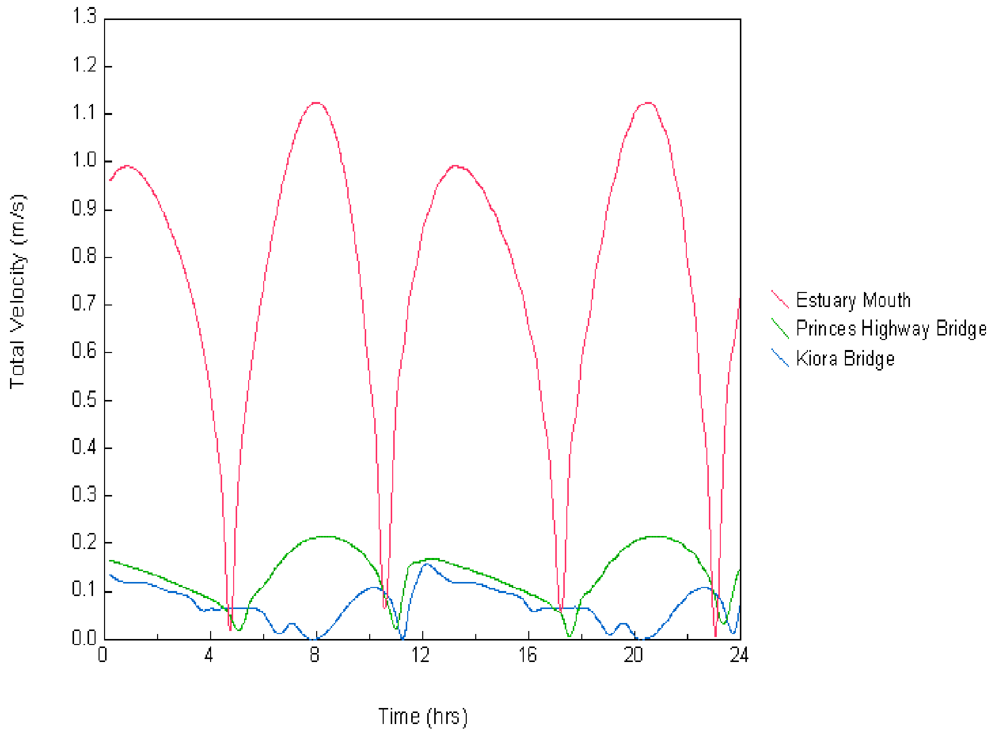

Figure 2.23: Reduced Model predicted tidal levels for median inflow along the estuary, MHL tide driven simulation.

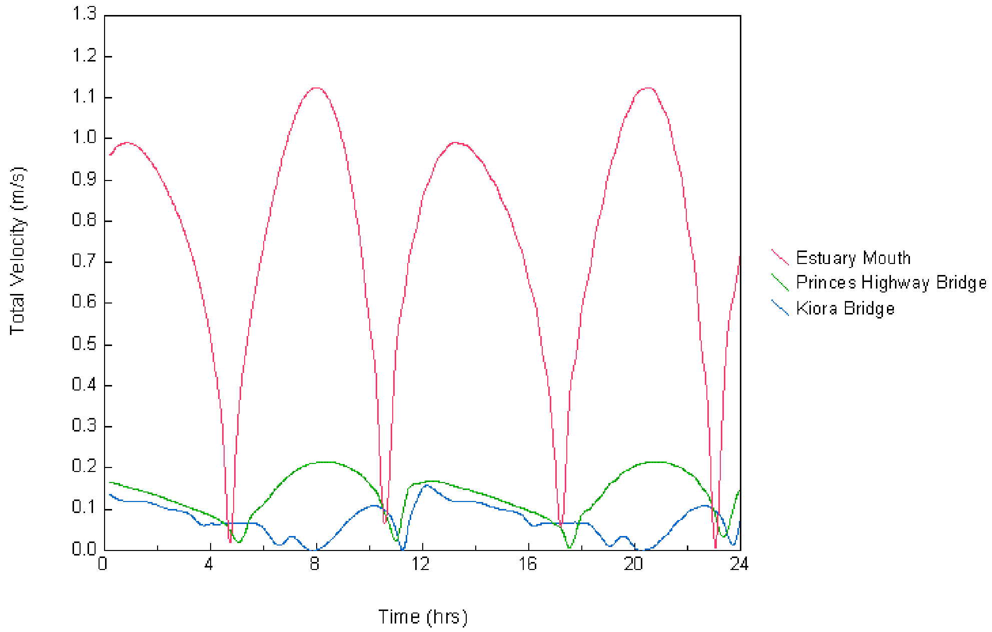

Figure 2.24: Reduced Model predicted tidal velocities in the lower, mid and upper estuary, MHL tide driven simulation.

2.4 CONCLUSIONS

The review of existing hydrodynamics data and subsequent results from hydrodynamics modelling of the Moruya Estuary yielded the following observations:

2.4.1 NON-FLOOD CONDITIONS

- Tidal gradients are steep in the lowest kilometre of the river, generating high velocities there.
- Tidal gradients are mild elsewhere in the estuary.
- The tide has only a small asymmetry with the ebb tide lasting about 20 minutes longer than the flood tide.
- The small tidal asymmetry means that the velocities on flood are comparable with those on the ebb being about 7% greater.

2.4.2 FLOOD CONDITIONS

- Water levels are independent of the tide, except near the mouth for the once in one year flood.
- The maximum water level is predicted to rise steeply with distance from the ocean.
- Velocities under flood conditions greatly exceed the threshold for scour near the entrance on all floods and throughout the estuary on all floods greater than the once in one year flood.
- Very high velocities also occur in most of the channel upstream of the hospital, particularly near the confluence with Mogendoura Creek, where there is a small section of the channel with extremely high current velocity.

- Scouring velocities predicted by the model would result in increased channel cross sections, delaying the rise of the water levels and reducing peak water levels and velocities. Hence the model results provide a conservative prediction of water levels and velocities.

Consequently, areas of concern for consideration in the Water Quality and Sediment Transport Studies have been identified. With respect to sediment transport, particular attention is needed at the mouth and river bends. Conversely, areas where pollutants are likely to experience the least dispersal will tend to occur in the upper estuary past the Mogendoura Creek junction, where current velocities are the lowest. These are explored further in Sections 3 and 4 of this report.

3 ESTUARINE SEDIMENT TRANSPORT

3.1 FORM AND EVOLUTION OF THE ESTUARY

The Moruya River estuary is a typical southern New South Wales major river estuary. The evolution of these estuarine inlets was proposed by Bird (1967) and refined by Roy (1984). It is considered that they have developed through the following sequence:

- The river and stream courses became deeply incised during prehistoric phases of lower sea level;
- The rise to the present sea level submerged the lower sections of these incised river valleys, forming estuarine inlets;
- Coastal process produced barrier systems, consisting of beaches, dunes and sand spits at mouths of the inlets;
- The area behind the coastal barrier has been in-filled by the deposition of sediment derived from the upstream catchment; and
- Major rivers now discharge fluvial sand into the sea during floods.

3.2 SEDIMENT SOURCES

The Moruya River has a large catchment compared to many other NSW South Coast estuaries (about 1,500 km^2 - Warner 1981, Young and Thoms 2000). The Catchment is 10% flat coastal plain, 30% undulating and hilly, and 60% rugged mountain (Young and Thoms, 2000). Rural lands exist around the estuary, along the river valley and in the north-east corner. The rural lands are basically used for grazing, beef, dairy cattle and sheep. Gold mining has taken place within the catchment.

The catchment geology is dominated by Paleozoic sedimentary (e.g. sandstone) and metamorphic rocks but with significant areas of granitic rocks also present. The sandstones and granites are particularly significant because they weather to sand and produce sandy alluvium. Sand is also produced as a result of the weathering of sandstone (O'Brien 2001). Thus weathering of rocks in the Moruya/Deua catchment is capable of supplying considerable amounts of sand.

Figure 3.1: Sandbanks near the mouth are formed from coastal sediments.

The estuary mouth is in a state of dynamic equilibrium with coastal sands being moved in during normal flow and coastal and river sand being exported during floods. Under normal conditions, wave-stirred sediments are picked up by the incoming tide and carried into the estuary. They are then deposited just inside the mouth of the estuary where the channel becomes deeper and wider and current speeds slow down. The slower currents are insufficient to keep the sand particles in suspension. In the estuary there is less wave stirring than in the ocean so particles are less likely to become resuspended and carried out by the outgoing tide. Thus, for normal flow conditions, there is a gradual build up of coastal sand inside the estuary mouth. Sand (river and coastal) is exported from the estuary during floods when the outgoing current is much stronger than the incoming current.

Rates of sediment moving from the ocean into the estuary are dependent on hydraulic factors, which influence the difference between sediment transport rates on the flood and ebb tides. For the Moruya there was a natural tendency for the river mouth to be impeded by the build-up of bars at the entrance, which were periodically opened and enlarged by floods (DPW 1978). Training walls were constructed in the mid nineteenth century to keep the entrance permanently open (DPW 1978) and the entrance was dredged from the late 1880s to the 1950s to maintain navigability of the river to the town wharf (Young and Thoms 2000). These modifications altered the regime of tidal processes within the estuary. The permanent entrance may allow coastal sediments to be carried further up the estuary than would have naturally been the case.

Sediment deposited in the estuary particularly near the mouth where there is high tidal energy and greater wave action are reworked and sorted into deposits (banks or strata) of sediment grains about the same size. Thus sandbanks of sediment with different characteristics build up in different locations.

Longshore transport of sediment (i.e. the movement of sand along the coast) occurs due to the arrival of waves with a direction of propagation at an acute angle to the shore. The forward momentum of the waves is converted into a current flowing parallel to the shore between the front of wave breaking and the shore. This longshore current transports sand which has been suspended by the wave action. In Southern New South Wales sand tends to move south down the beach. Hence, many estuaries such as the Tomaga and Moruya have rocky outcrops located on their southern bank. The rocky outcrops stop the southward movement of the river mouths. The training walls at the mouth of the Moruya Estuary prevent the sand moving down Bengello Beach from entering the estuary and reduce the inflow from the longshore drift. Therefore, coastal sand imports will not be as high as those before the walls were constructed.

Onshore-offshore transport is driven by wave stirring of sediment on the sea bed and then transport by the currents generated by the wave motion. A moderate to severe storm near the coast will generate steep waves which will erode the beach and transport sand offshore into deeper water. A more distant storm with very high winds will generate a range of waves. At the coast, the longer waves will drive sediment transport, moving sand from the offshore bar onto the beach and the vicinity of the estuary mouth. Thus onshore-offshore transport does not provide new sediment to the system but takes it from, and returns it to the beach and sub-sea bars. Although not important in supplying new sediment to the system, onshore-offshore transport is very important for beach stability and sediment build-up and removal in the mouth of the estuary.

3.2.1 Fluvial Sediments

The evolutionary model of estuary development given in section 3.1 implies that the sediments in the lower estuary associated with the coastal barrier system would be coastal or marine in origin, while the sediments in the estuary further upstream would be predominantly fluvial.

The main source of terrestrial sediment entering the estuary is from the Deua River, with much smaller inputs from Wamban Creek and Mogendoura Creek. Malabar Creek is another tributary of the estuary but because of its small catchment, which is mainly forest, it has an insignificant input of sediment to the estuary. Burra Creek is a major tributary of the Deua River flowing into the river about 12 km above the estuary and is responsible for a significant proportion of the sediment in the estuary (O'Brien, 2001).

Within the upper reaches of the estuary the stream bed is dominated by cobble stones in the shallow regions and gravel in the deeper sections. The banks are either natural rocks or unconsolidated river sand. In the mid and most of the lower reaches fluvial sands are dominant in the tidal river channels. Shells found in sands more than 2 km from the mouth had fragments which are distinctly larger and less abraded than those of the marine sand shell particles. It is believed that these shells originated in the estuary and are not an indication of marine input to the sediments in these regions.

O'Brien (2001) examined major element geochemistry, which indicated that most of the sediment in the estuary is of fluvial origin. Mineral particle magnetics analysis showed that fluvial sediments derived from the middle reaches of the Deua River and the lower parts of Araluen Creek are likely to be the major contributors of sand to the Moruya River estuary. Scott Nichol's PhD thesis (cited in O'Brien 2001) also argues that the Moruya River estuary is dominated by sediment sourced from the catchment. Nichol's thesis was not available for review at the time of preparation of this report.

Figure 3.2: Lower reaches of the river have large sand deposits.

Figure 3.3: Extensive banks of river sand exist in the mid-reaches of the estuary.

The Deua Valley is of variable width, some parts being narrow and gorge-like and others being broader and containing minor floodplains and alluvial terraces. Studies elsewhere have shown that such variations in valley morphology and topography are associated with variations in sediment transport, the narrow reaches having higher transport efficiencies than the wider floodplain reaches, which may be net sediment accumulation zones (e.g. Craigie et al. 2000). The large sand and gravel deposits just above the estuary would ensure that all flood waters entering the estuary would be transporting their maximum capacity of sediment.

Some understanding of the capacity of floods to move sediment into the estuary can be gained from a report by the Department of Public works (DPW, 1978). They noted that the low-level bridge at Kiora is often closed to traffic after floods due to sediment deposits over the road. After the 1945 flood, 12 feet (about 4 m) of sand needed to be removed to clear the road. They also drew attention to overbank deposition of sediments during floods (which may have been sourced from the upstream catchment or the estuarine channel). They noted that in the 1925 flood (record flood) many properties at Kiora and Yarragee were covered with sand 6-12 feet (2-4 m) deep as well as large amounts of timber.

The fine fluvial sediments are readily recognised under microscopic examination. They contain organic matter, clay, minerals and sand constituents (quartz, feldspars and rock fragments) derived from weathered rocks. Fine sediments are carried in suspension by floodwaters and deposit in tidal wetlands and on overbank floodplains.

3.2.2 Changes in Fluvial Sediment Supply

It has been postulated that rates of sedimentation have increased in the Moruya Estuary over the past 30 years (Pollock, 1999 cited in O'Brien, 2001). There have been a number of changes in the catchment that singularly or in combination may have increased sedimentation in the estuary. These factors are:

- Long term weather patterns;
- Introduction of stock;
- Bushfires; and
- Human activities

Because the sandbanks are frequently changing it is very difficult to determine if there has been an actual increase in sedimentation without undertaking a comprehensive survey. A review by AMOG of aerial photos, taken between 1940 and the present showed that in the main estuary there has been no obvious long-term growth of shoals. We found there were periods of gradual sediment accumulation and periods of rapid build up and scour of sandbanks. An exception to the general trend was the Pilot Station Backwater, which showed a constant sediment build up between 1940 and the present period.

Long Term Weather Patterns

Since the mid 1940's there has been a major shift in flood patterns. Between 1850 and 1940 seven floods greater than 4 m were recorded at the Princes Highway Bridge. Since 1940 no floods greater than 4 m have been recorded (Table 3.1). However there have been more frequent smaller floods. Both these extreme floods and the more frequent minor floods scourer the estuarine channels. The extreme floods are a more important source of sediment to the lower fluvial system and are responsible for building up the flood plain by deposition of sands and silts once the river has broken its banks.

Apparently contradicting this, Warner (1981) drew attention to the role of natural climatic variability in relation to the stability of the Moruya/Deua River system and rates of catchment sediment supply. He distinguished between flood-dominated regimes characterised by above average stream flows and flooding and high degrees of channel instability versus drought-dominated regimes characterised by smaller flows and more stable channel conditions. Warner identified the period 1900 to 1949 as a drought-dominated regimes and the period 1949 to 1981 as a flood-dominated regimes. This contradiction is confirmed by the Moruya River Flood History (DPW, 1978), as shown in Table 3.1. The same picture is provided by the annual rainfall date (Figure 3.4). A more accurate split would be 1949-1978 flood-dominated regimes, 1979-1990 drought-dominated regimes, 1990 -1995 flood-dominated regimes and 1995 to 2003 drought-dominated regimes.

Changes noted by Warner in the Deua Valley (upstream of the Wamban gauging station) in the recent flood-dominated regimes include channel widening, destabilisation of formerly stable alluvial benches and reductions in channel depths associated with the infill of pools resulting from increased quantities of sediment being in transit. This sediment has been moved downstream, some remaining in the estuary and some lost to sea.

During the recent drought-dominated regime Warner noted an increase in sedimentation. This was because there was an increase in sand deposition and retention within the estuary due to there being no major floods to scour the channels.

Table 3.1: Levels of Significant Floods at Princess Highway Bridge From DPW 1978.

Year	Month	Metres above AHD
1852	June/July	3.70
1857	March	3.60
1860	February	4.30
1860	July	2.70
1863	February	3.00
1864	April	2.65
1864	June	2.80
1867	March	4.20
1870	April	5.20
1871	May	3.00
1873	February	3.00
1879	September	3.25
1890	March	3.35
1891	June	3.50
1893	March	2.80
1895	January	2.80
1897	February	2.80
1898	February	5.20
1900	May	3.40
1914	March	4.60
1916	October	3.25
1922	July	2.70
1925	May	5.60
1934	January	4.40
1934	February	3.80
1944	May	3.00
1945	April	3.70
1949	May	2.65
1952	June	2.57
1953	May	3.25
1955	May	2.95
1959	October	2.80
1961	November	3.65
1963	April	2.65
1974	August	3.65
1975	March	3.70
1976	October	3.40
1978	March	3.40

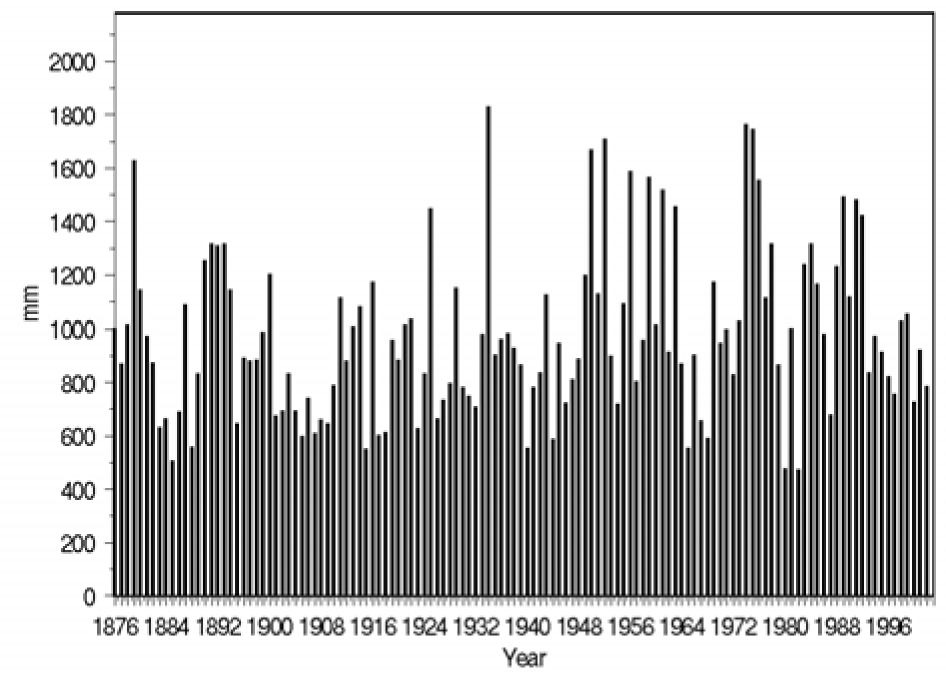

Figure 3.4: Moruya Heads annual rainfall 1876 to 2002.

Introduction of Stock

Many rivers in south-eastern Australia have "sand slugs" (i.e. a large sand band or series of sandbanks) which are gradually moving down the river beds. In many cases these sand slugs are approaching the estuary. It is thought that these sand slugs developed as a result of a period of high erosion following stock introduction. Such a sand slug may now be moving into the Moruya Estuary. However, this is unlikely as compared to other Australian estuaries, only a small proportion of the Moruya/Deua catchment has been used for grazing.

Bushfires

A relatively high frequency of bushfires in the Moruya River catchment was recorded over the period 1938-73 (Clarke and Pressey 1981). Vegetation damage caused by these bushfires may have exposed the soils to higher erosion rates and these may now be contributing to increased sediment availability in the estuary.

Human Activities

Human activities in the Moruya River catchment, including forestry, agriculture, gold mining, urbanisation, etc., are all factors which are known to have led to increased sand input to the estuary. Other human activities with potential implications for sediment supply include river management works and sand/gravel extraction. Of these activities gold mining may have contributed to the sediment supply while land clearing for roads and agriculture has resulted in more rapid runoff and probably a small increase in sediment supply. It is probable that gold mining provided a major input of

sediment to the river system and ultimately to the estuary. This is borne out by the identification of the dominant modern source of sediments being the lower Araluen Creek and some middle reaches of the Deua River (Phillips, 2001). These locations are the places that were most extensively dredged for gold. Phillips quotes sources estimating that 12 million cubic metres of soil was dredged in the Araluen area. In addition hydraulic sluicing was widely practiced.

3.2.3 Coastal Sediments

Coastal sediments are composed of well sorted quartz grains and small shell fragments, showing evidence of appreciable wave abrasion. Shell fragments are present in all of the coastal and marine sediments. These fragments are derived from the breakdown of shells from within the estuary and the near shore waters.

Outside the estuary mouth, the sediment is derived from reworking of older marine sands, fluvial inputs, erosion of headlands and transport into the region. There is visual evidence of erosion of the headlands and rocky outcrops around the Moruya Estuary.

Fluvial sediments that have recently been deposited in the coastal zone are easily recognised. They are rich in feldspar, charcoal wood particles and quartz and do not possess shell fragments. In the marine environment, weathering and abrasion by wave action will virtually eliminate the softer materials such as feldspars within a few years. Silts and organic material will be further reduced in size and lost to the sea as suspended particles. The harder quartz will be reduced in size, and the grains will become more rounded (without sharp edges), more spherical in shape and no longer distinguishable from beach sand.

The beach sediments at the mouth of the Moruya Estuary are characteristic of a high proportion of river sands. This indicates that the fluvial supply from the Moruya Estuary and its tributaries does not have time for its characteristics to be modified into coastal sediments between flood events. Hence it is reasonable to suggest that fluvial material is a major source of new sediments to Bengello Beach.

Our field observations found that coastal material was only found in the lowest reaches of the estuary. This agrees with O'Brien (2001), who carried out studies of sediment character (including grain size, roundness, and sediment composition) and showed that sediments in the lower 2 km of the estuary were characteristic of marine sediments. O'Brien found that sediments in other parts of the estuary were characteristic of fluvial sediments.

In particular, the lower estuary has finer sand, higher proportions of rounded and well rounded grains and higher shell content than the sections of the estuary further upstream.

In summary, the coastal sediments are a mixture of marine and river derived sands and there is a large supply of coastal sand from along Bengello Beach, but supply of this into the estuary is restricted by the northern training wall.

3.3 SEDIMENT BUDGET

The estuary sediment budget is concerned with the sources of sediment, its transport into the estuary, its transport through the estuary, its temporary storage and its loss through long-term deposition (new land formation) or to sea. It is important to have an understanding of sediment transport through the estuary to understand the impact of different flow conditions and different hydraulic conditions on the sediment budget.

The sources and distribution of sediment in the estuary are temporally as well as spatially variable. For example, immediately after large floods, when fluvial sediment is delivered to the coast, fluvial sediment would dominate the entire estuary, but under low flow conditions, tidal processes would bring coastal sediment upstream, leading to greater dominance of coastal sediments in the lower estuary after a prolonged period of low flow conditions.

From an examination of the estuary bed sediments it is possible to deduce a considerable amount about the sediment transport mechanisms operating in the estuary. Important features to observe are the distance upstream that marine sediments can be found and whether the bed sediments are being derived from bank erosion, material transport down the river or material imported from the ocean.

Knowledge about the sediment transport mechanisms is an important input to estuary management. If the bed sediments are made up of the same material as the banks this indicates that material eroding from the banks remains at the base and inhibits further erosion. The alternative is that the bank material slumps into the estuary and is carried away. This would result in a situation where erosion processes will start again and eventually another bank slump will occur. In this situation, the management strategy needs to ensure that erosion processes are not accelerated by human activities.

The main sediment types within the Moruya Estuary are: fluvial (ie. derived from stream action) sands and silts, fluvial gravels, fluvial cobbles, coastal marine sands, and sands and silts derived from bank erosion of the estuary.

In floods, clay, very fine sand and organic material move from the catchment into the estuary suspended in the water. This suspended material is loosely described as silt. Larger sand and gravel particles will move downstream bouncing and rolling along the bed or being intermittently suspended in the water.

In major flows, most of the silt is lost to the estuarine system through carriage out to sea. However, some silt is deposited within wetlands and on banks where the floodwaters move more slowly. The Moruya Estuary does not have well developed natural levees, but does have extensive flood plains which have been in filled with silts and sands from major flooding events.

In minor floods the silt will be carried into the estuary, where with increasing salinity, clay minerals that have been carried in suspension come together to form silt sized particles that settle out of the water. This is only expected to be significant for minor floods.

In poorly mixed deeper estuaries a flow of dense sea water may develop in the deeper waters flowing upstream to be diluted and mixed with outgoing brackish water. This provides a mechanism for return of sediment during and following floods and for the transport of sediment up the estuary. Because the Moruya estuary is usually well mixed such transport of sediment is expected to be minor and transient following a flood.

3.4 SEDIMENT TRANSPORT MODELLING

An assessment of the rates of accumulation of river and coastal sediment, as well as the erosion and deposition of sediment within the estuary has been undertaken using the RMA-11 module of the RMA modelling suite. RMA-11 uses the water surface elevation and flow velocities calculated during the hydrodynamics modelling to determine transport of sediment within the estuary.

3.4.1 Calibration

No data was available for the calibration of the sediment transport model, instead, sensibility checks were performed on the sedimentation / erosion patterns based on field observations by AMOG staff.

The hydrodynamics results for non-flood conditions show a recirculation of ocean currents behind the mouth breakwater. As a result, marine sediment could be cycled in and out of the estuary. As the model ocean captures this cycling within its geometry, it has been assumed that there is no net loss of sediment from the modelling domain at the ocean boundary, where current velocities are at all times small.

3.4.2 Sediment Transport Analysis

The sediment characteristics for input to the model have been estimated through field inspections, and are detailed in Table 3.2:

Table 3.2: Model Sediment Characteristics

Parameter	Value
Minimum grain diameter	0.003 mm
Maximum grain diameter	1.5 mm
35^{th} percentile grain diameter	0.15 mm
50^{th} percentile grain diameter	0.20 mm
90^{th} percentile grain diameter	0.50 mm
Specific gravity of sediment	2.65
Grain shape factor	0.7

Sediment transport has been assessed for a range of flow conditions, as follows:

- Median inflow conditions with mean tide;
- Once in 1 year flood conditions with mean tide;
- Once in 5 year flood conditions with mean tide;
- Once in 20 year flood conditions with mean tide; and
- Once in 50 year flood conditions with mean tide.

As discussed previously in Section 2.3.1, the Reduced Model is utilised in the simulation of non-flood sediment transport and the Full Model is utilised for flood sediment transport. The transport of sediments throughout the study area has been traced for a period of approximately 2.5 days for each flow condition.

There are a number of formulations available within RMA-11 including the more recent Van Rijn method, which calculates the bed load and the suspended load. However the Ackers-White method for sediment transport has been employed for this study. All the sand transport methods implemented within RMA-11 are simplifications of the empirical methods and thus the results obtained from the sand transport models should be considered to be indicative only.

The main assumption in this study has been that the sediment is assumed to be non-cohesive. In the analysis of the model results, it is important to note that the following limitations apply:

- One way coupling between the hydrodynamics flow and the sediment transport algorithms. Once the deposition and scouring occurs and the bed geometry changes the flow field was not recalculated or updated during the course of the simulation. This is particularly crucial for the Moruya given the severe bed changes that can be experienced during flood events;

- The erosion characteristics of cohesive sediments are not fully understood. Direct quantitative relationships between the physico-chemical properties and the erosion rate have not been fully established. The results presented in the next sections are for non-cohesive transport only; and
- Availability of insufficient site specific data requiring use of averaged properties and neglect of inhomogenity of the river bed.

In a flood event, it is expected that sediment would be carried from the catchment and a significant input of fluvial sediment will be supplied into the estuary. The sediment inflows at the three river tributaries resulting from the flood events have been calculated from the water inflow estimates using the Einstein-Brown bed load formulae. This formulation assumes that the flow is carrying its maximum load of sediment. However, due to the very large sediment loads calculated, the sediment input during the flood events were taken to be 25% of the maximum for the following reasons:

- In the upper estuary, sediment diameters were observed to be larger on average than the average over the estuary. Velocities necessary to transport these sediments would be much higher, hence the calculated maximum load is an overestimation;
- Sensitivity tests of the model showed that use of 100% of maximum sediment loads leads to rapid deposition in the upper estuary, which is unrealistic.
- The model assumes that the main channel is primarily composed of sand. Thus, the channel is never starved of sediment. In the upper estuary there are regions that do not act as sediment sources and thus the maximum load is not necessarily achieved in these areas.

Table 3.3 gives the fluvial sediment loadings used for flood sediment transport.

Table 3.3: Fluvial Sediment Loadings for Flood Sediment Transport (mg/L)

Flood	Deua River	Mogendoura Creek	Wamban / Candoin
Concentrations Mg/L			
1 Year Flood	387	0.34	0.14
5 Year Flood	796	1.54	0.2
20 Year Flood	3280	2.30	0.04
50 Year Flood	5450	4.2	0.03
Volumes m^3 (bulk density = $2000kg/m^3$			
1 Year Flood	3.6×10^3	0.3	0.3
5 Year Flood	20.7×10^3	3.6	1.0
20 Year Flood	226×10^3	9.0	0.3
50 Year Flood	497×10^3	20.9	0.4

3.4.3 Non-Flood Condition Results

The results provided in the following sections are indicative of cumulative bed change in the region after 2.5 days of tidal action for non-flood flows

In non-flood conditions the model reveals that in the lower estuary there is generally a tendency for sediment to settle, with isolated patches where erosion is occurring. This is expected because under normal conditions the estuary should be in a state of dynamic equilibrium. It would be expected that following an event that has reshaped the estuary erosion would occur in the prone areas until depths had increased to the point where current velocities had slowed down so that erosion no longer occurred. Sediment may have built up in some areas so that with decreased depth, current velocities had increased to the point where sediment was no longer being deposited, but more likely sedimentation would be limited because there is little erosion thus little suspended material to settle out of the water. With the change in current velocities caused by the spring - neap tidal cycles there will be a constant shifting of this equilibrium so that some sediment movement will always be occurring. This is the pattern being picked up in the non-flood condition sediment transport model. The erosion patches pictured in Figure 3.5 would probably have different locations if a new bathymetry survey was undertaken.

An exception to the pattern of only minor changes in bed levels associated with the non-flood sediment transport is at the mouth between the training walls. Here there is a patch with high erosion and nearby areas with moderate sedimentation (Figure 3.5). This is an area where, in reality, erosion and deposition patches would be continually migrating because with the changes in depth the current velocities would also be changing. This is a situation for which the RMA 11 sediment transport model is poorly suited. Under these situations the model overestimates scouring and deposition. Despite this shortcoming, the model results do show the influence of the training walls in focusing the currents to keep the mouth area free of sediment.

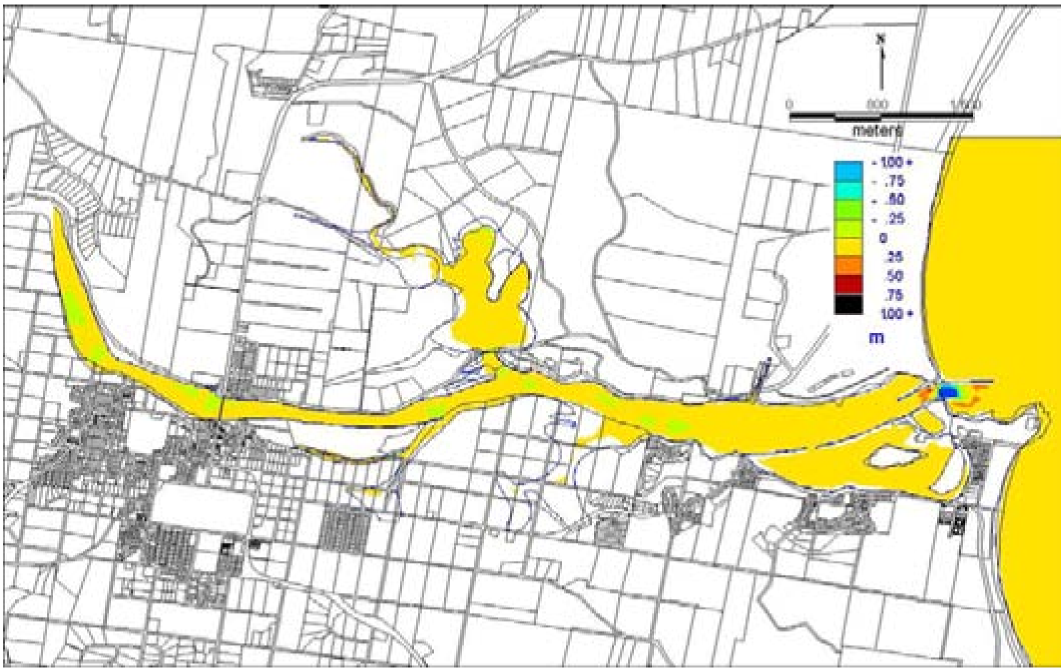

Figure 3.5: Bed change in the lower estuary for median inflow with mean tide action. Bed depth changes recorded at 25 cm intervals. (Note dark blue represents erosion of more than 1 metre.)

3.4.4 Flood Condition Results

The results provided in this section are indicative of cumulative bed change in the region after of 2.5 days of tidal action and the complete passing of the flood events.

As expected, significant scouring is experienced throughout the estuary under flood conditions. Sediment is carried down from the catchments with the flood and also picked up from the river bed so that the water is carrying the maximum sediment load. As a consequence any areas where current velocities decrease experience sedimentation. At the mouth, where the current velocities are the highest due to the narrowing of the river there are high erosion rates while just outside of the mouth where the water spreads out and current velocities decrease, deposition is enhanced. With increasing flood heights, the sedimentation area on the ocean side is extended due to higher current velocities needing greater deceleration distances. A net transport of fluvial sediment into the ocean is therefore experienced for all the floods.

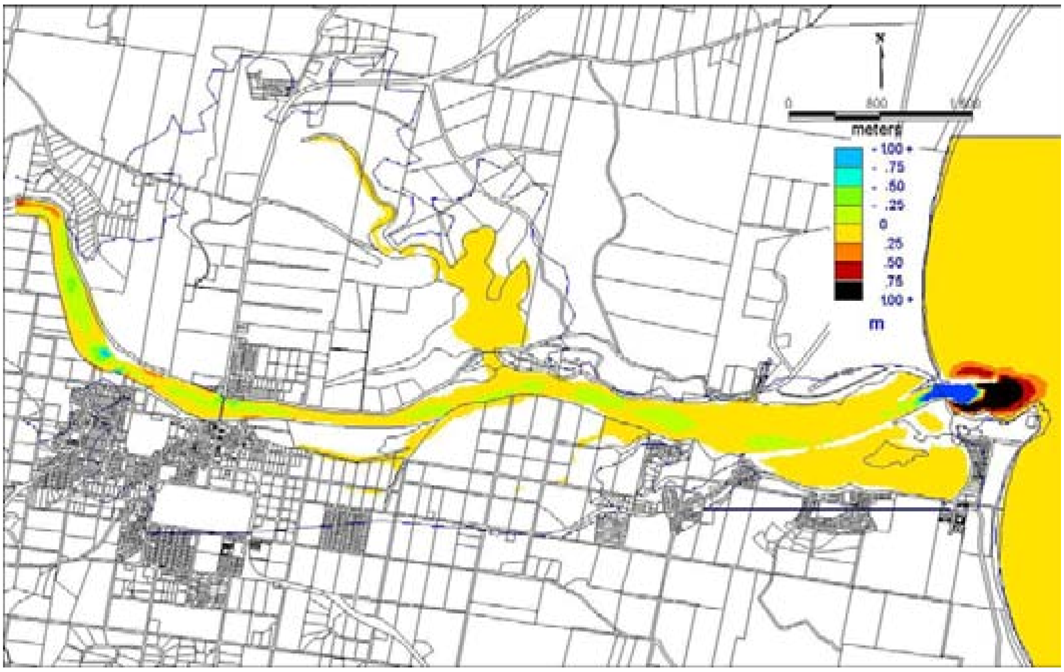

Figure 3.6: Bed change in the lower estuary for 1 Year Flood with mean tide action. (Note black represents deposits greater than 1 metre high, dark blue erosion of more than 1 metre.)

For the once in one year flood (Figure 3.6) most deposition occurs just outside the estuary mouth with minor sediment deposition in the estuary outside the channel area. In the estuary along the channel there is minor scouring, while the greatest scouring is predicted to occur at the mouth between the training walls.

There are three small areas in the estuary where AMOG's model predicts a once in one year magnitude flood will produce high scouring. One of these is along the bank just upstream from the hospital, an area where the site inspection highlighted the danger of bank erosion outflanking the existing rock wall bank protection. The other two areas are at the northern edge of the channel just upstream from the hospital and off the boat shed, on the north side of the estuary downstream of the bridge (Figure 3.6). At both of these locations sandbanks were present at the time the hydrographical survey was undertaken, and it is the scouring of these sand banks that is being recorded.

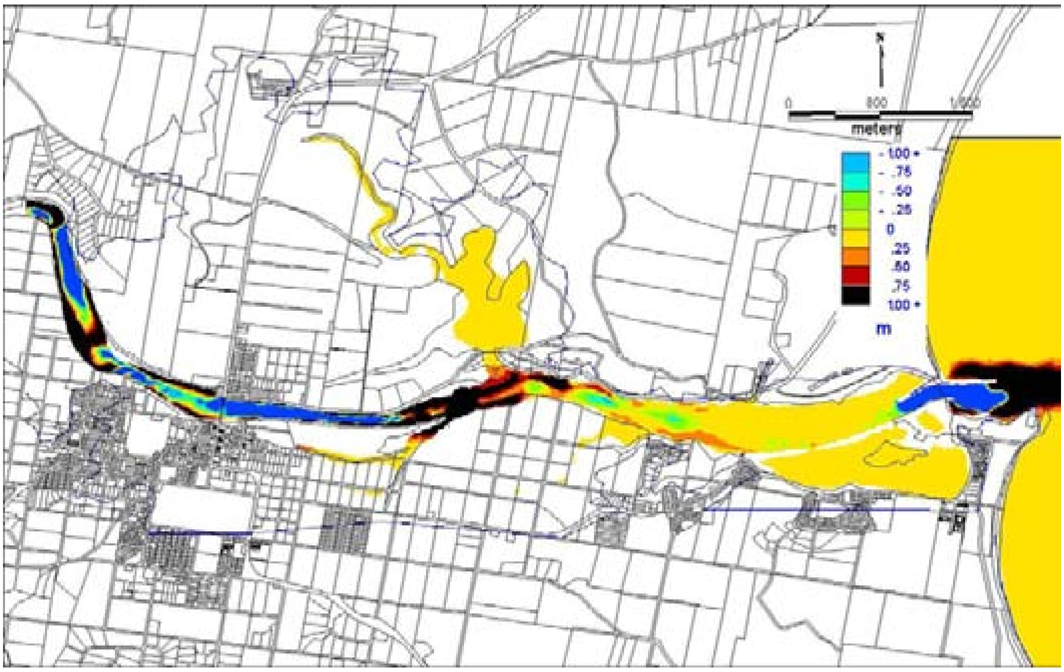

Figure 3.7: Bed change in the lower estuary for 5 Year Flood with mean tide action. (Note black represents deposits greater than 1 metre high, dark blue erosion of more than 1 metre.)

Sediment transport predictions for the once in 5 year magnitude flood are presented in Figure 3.7. This reveals that upstream of Malabar Lagoon there are alternating areas of high erosion and deposit.

Below Malabar Lagoon, at Quarry Wharf there is a natural constriction in the channel. This constriction has a major impact on water flow down the river with water backing up behind it and spreading out over the flood plains. After having passed through this constriction the water spreads out and current velocities decrease so that the high rates of erosion and deposition above the construction do not occur between Quarry Wharf and the river mouth. Generally in this area there is minor deposition with some scouring occurring along the south bank around The Anchorage and Preddys Wharf.

Where the river is again constricted by the training walls at the mouth, high rates of erosion are predicted and as the water fans out after exiting the mouth high rates of deposition are predicted in the ocean outside the river.

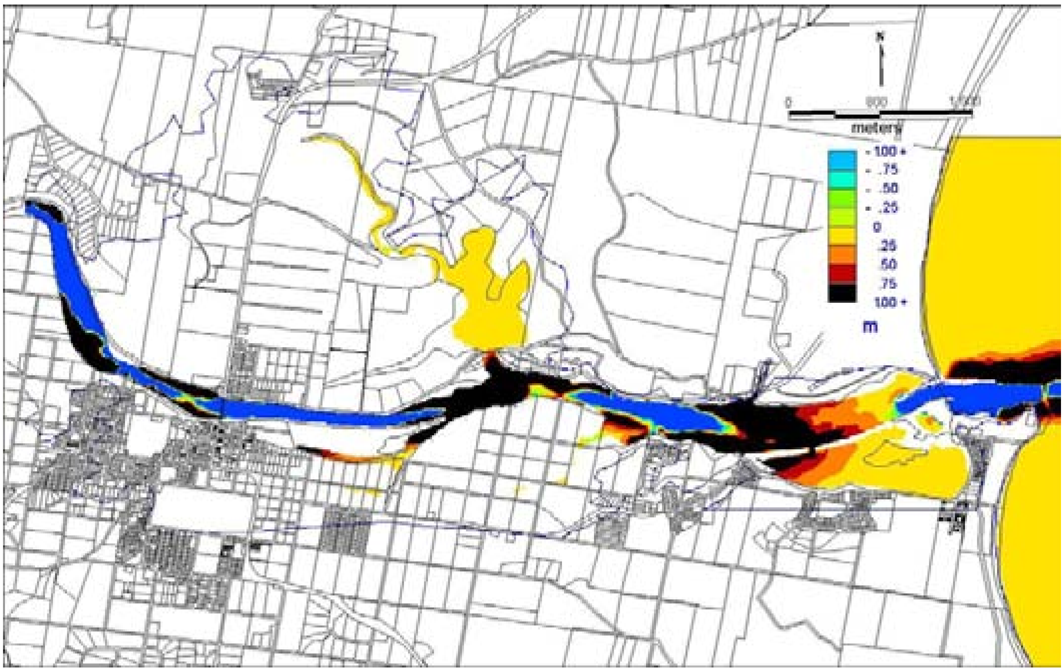

Figure 3.8: Bed change in the lower estuary for 20 Year Flood with mean tide action. (Note black represents deposits greater than 1 metre high, dark blue erosion of more than 1 metre.)

Sediment transport predictions for the once in 20 year magnitude flood are presented in Figure 3.8. Predictions for upstream of Malabar Lagoon are that there will be high levels of stream bed scouring with isolated patches of high sediment deposition associated with bends in the river. This deposition is not located on the inside of the bends where it would be predicted, but on the outside of the bends. This anomaly is explained when the current velocities and the over bank flow patterns are examined (Appendix D Figure D.7). These locations are in areas where current velocities are decelerating and thus sediment settles out.

In the one in 20 year flood the water passing through the natural constriction at Quarry Wharf is forming a jet so that downstream of the constriction there is an area of high erosion extending down to about Preddy's Wharf. Below this area there are bands of decreasing sediment rates. These extend both along the river bed and are also predicted to occur in Pilots Station Backwater.

The training walls at the mouth form another jet of water with high erosion between the walls and high rates of deposition in the ocean just outside the estuary.

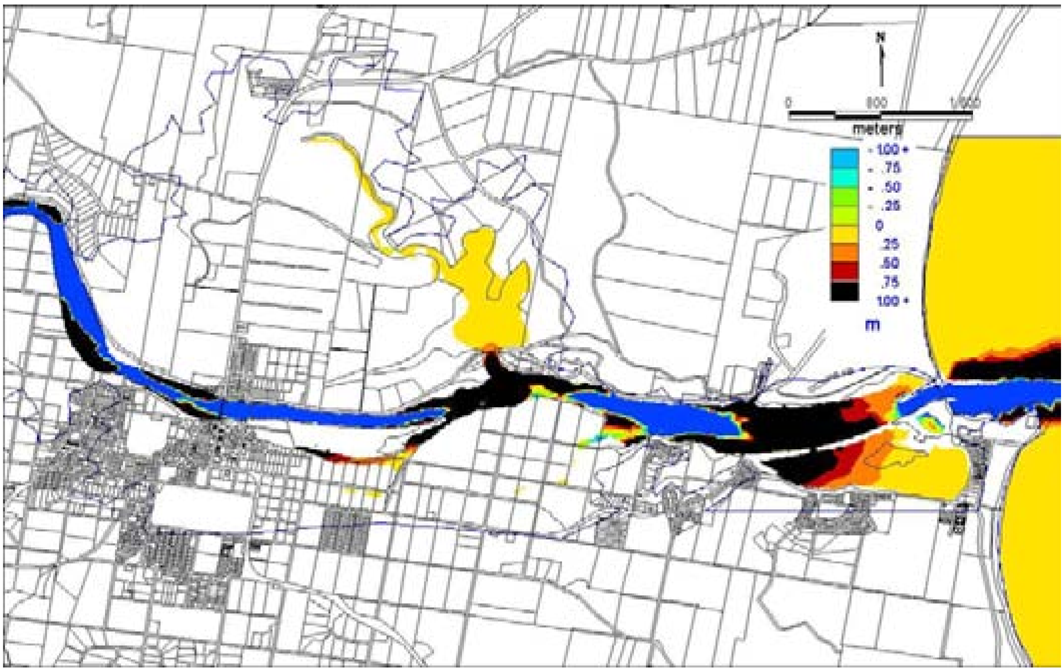

Figure 3.9: Bed change in the lower estuary for 50 Year Flood
with mean tide action. (Note black represents deposits greater than 1 metre
high, dark blue erosion of more than 1 metre.)

Sediment transport predictions for the once in 50 year magnitude flood are presented in Figure 3.9. Predictions are very similar to those for the once in 20 year flood except that greater sediment deposition is predicted for the area between Quarry Wharf and the mouth of the estuary.

Predictions for the upper estuary were similar for all flood conditions so only the 5 year flood results are presented here (Figure 3.10). There are sections of erosion associated with increasing current velocities at bends, which are normally also associated with constrictions in the river width. Between these bends there are areas of high deposition associated with the reduced current velocities found in these areas.

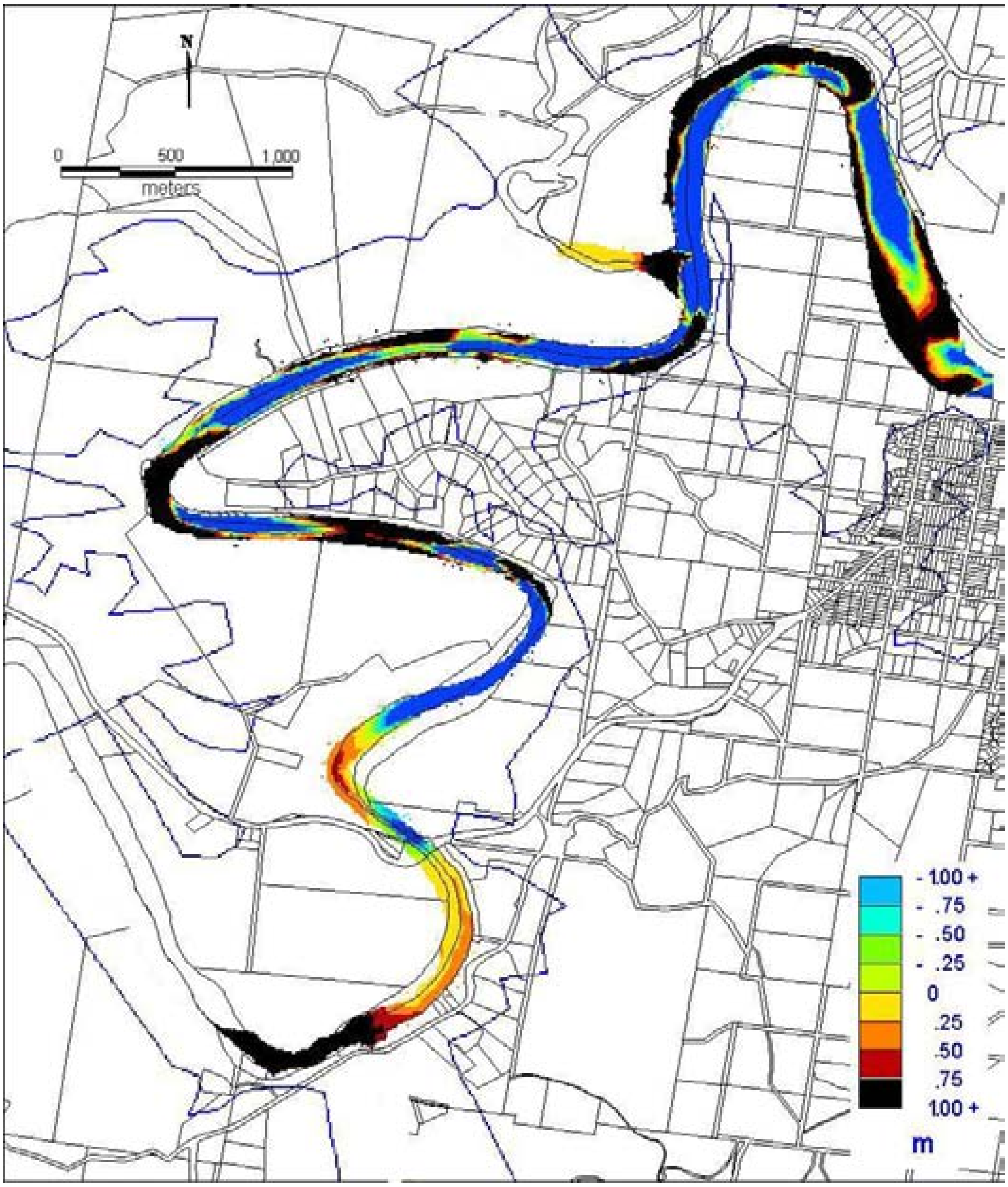

Figure 3.10: Bed change in the upper & mid-estuary for 5 Year Flood with mean tide action. (Note black represents deposits greater than 1 metre high, dark blue erosion of more than 1 metre.)

3.5 OVERVIEW

Sediment in the Moruya Estuary is mostly derived from the catchment, with a small proportion of the sand in the lower 2 km being derived from the coastal sediments. There is considerable evidence that the Moruya Estuary has a large input to the local coastal sediment beds. We found no evidence of sediment in the estuary originating from erosion of the estuary banks and quantities locally lost by erosion are insignificant in the total sediment budget. However, the eroding Moruya Estuary banks are mostly formed from deposits of catchment sediments and thus would be indistinguishable from the fluvial sediments.

4 ESTUARINE WATER QUALITY

"Water quality" is a measure of suitability of a body of water for particular use. The water's suitability is determined by what the intended use is and factors such as appearance, smell and the concentrations of pollutants (SPCC, 1990).

An estuary's water quality depends on the amounts of material that are being put into the estuary water, if they are concentrated in one location or dispersed throughout the estuary, and the speed at which they are removed from the estuary.

Materials find their way into the estuary's water from:

- Catchment input with stream flow;
- Coastal inputs with the tide;
- Runoff from rainfall;
- Storm water drains;
- Exchange with the atmospheric; and
- Decomposition of material in the sediments.

Materials are removed from the estuary by:

- Flushing out to sea;
- Bonding to sediment particles;
- Loss to the atmosphere; and
- Chemical reactions.

The mixing and flushing depend on the volumes of fresh water input and water moved by the tides and wind action. For many south eastern Australian estuaries where there is usually very little freshwater inflow from the catchment for mixing, the flushing of material from the estuary is driven by the to-and-fro movement of the tides. The action of the tide is dependent on the velocity of the tidal currents and the distance travelled in the to and fro movement between high and low tides. Both of these are highest at the mouth of the estuary and lowest at the head of the estuary. Therefore, generally mixing and exchange of water is highest at the mouth and poorest at the head of the estuary.

In this section we summarise existing water quality data and examine how this varies spatially across the estuary. We then use the model to show the behaviour of different "spills" in the estuary and how this impacts water quality in the different reaches.

4.1 INFORMATION BASIS

Water quality data has been collected by both the Eurobodalla Shire Council (ESC) and MHL. ESC has collected data since 1991. MHL did a short-term data collection between 21 April 1999 and 17 June 1999. The ESC data was made available in electronic form and MHL data was presented as hard copy. Both the ESC and DPWS data are reviewed in this report. The data set collected by ESC was the most comprehensive. Records exist from ten sites and these extend over a 10 year period commencing in 1991. The water quality data at sites M01, M02, MO3, MO4, MO5, MO6 and M010 were analysed. The location of these sites is shown in Figure 4.1.

Water quality parameters analysed include:

- Faecal coliforms;
- Nitrate;
- Ammonia;
- Orthophosphate;
- PH, biological oxygen demand (BOD);
- Temperature;
- Salinity;
- Electrical conductivity and
- Turbidity.

Samples were collected at regular intervals with high replication of most parameters. Note that not all parameters were recorded at each site.

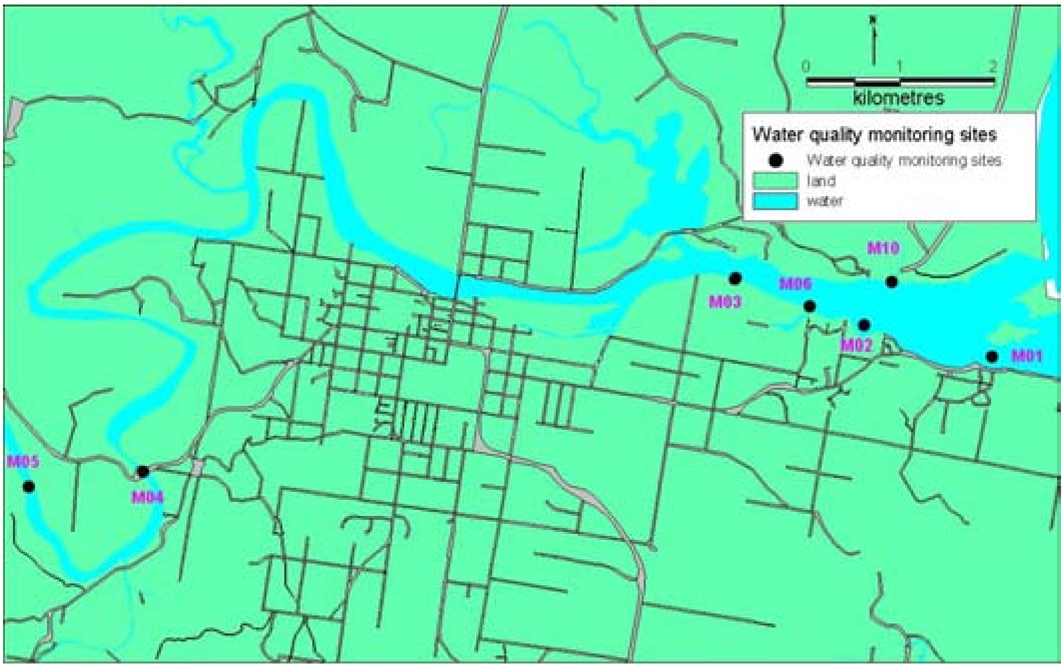

Figure 4.1: ESC water quality monitoring sites.

4.2 WATER QUALITY GUIDELINES

Water quality data from the Moruya Estuary have been assessed against values set down in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000). These guidelines are given in Table 4.1.

For the purposes of this study it is considered appropriate to use the general aquaculture lower Electrical Conductivity (EC) limit of 3000 mg/L (4.5 mS/cm). No upper EC value is recommended, given that it is unlikely that hyper saline conditions would occur (due to high regional rainfall, combined with a functional river mouth), exception Malabar Lagoon where the large surface area, shallow depths and artificially constructed inlet prevent efficient flushing.

Table 4.1: ANZECC (2000) estuarine water quality trigger values
Trigger values are not intended to be used as acceptable levels but to draw attention to possible problems. The values for aquaculture are not related to human health problems through eating products, which is the aquatic foods value, but to indicate where growth of the animals may be impacted.

Water Quality Indicator	Aquatic Foods	Aquaculture Species	Recreation and Contact	Aquatic Ecosystem Protection	Drinking Water
Faecal coliforms (Count)	14[1], 43[1]	-	150[2], 600[2]	-	0[3]
Nitrate (mg/L)	-	100.00	10.00	-	-
Nitrite (mg/L)	-	0.10	1.00	-	-
Ammonia (mg/L)	-	-	0.01	0.015	-
Total nitrogen (mg/L)	-	1.00	-	0.300	-
Phosphate (mg/L)	-	0.05	-	0.005	-
Total phosphorus (mg/L)	-	-	-	0.030	-
Dissolved oxygen (mg/L)	-	>5	>6.5	80 - 110 % Saturated	>6.5
Electrical conductivity (mS/cm)	-	4.5 - 52.5[4]	-	-	<1.5
pH	-	6.0 - 9.0	6.0 - 9.0	7.0 - 8.5	6.5 - 8.5
Turbidity (NTU)	-	-	-	0.5 - 10	Site specific

[1] In waters used for shell fishing, faecal coliforms concentrations should not exceed a median value of 14 MPN/100ml, with no more than 10% of samples exceeding 43 MPN/100ml

[2] Median faecal coliform concentrations over a five month swimming period (sampled at least monthly) should not exceed 150 faecal coliform organisms/100ml, with 4 out of 5 (80%) samples not containing more than 600 faecal coliform organisms/100ml.

[3] Raw waters requiring low-level treatment should have <10 faecal coliforms/100ml.

[4] ANZECC guidelines for the protection of aquaculture species in brackish water are intended as a guide only and are in the range 3000 - 35000 mg/L Salinity (4.5 - 52.5 mS/cm, assuming 1000mg/L = 1.5mS/cm). Salinity guidelines have also been recommended for various marine species, with good growth conditions for Sydney rock oysters found in the range 20000 - 40000 mg/L (30 - 60 mS/cm).

4.3 WATER QUALITY CONCERNS

Water quality of the estuary has an impact on;

- The aquatic food supply quality;
- Recreational users; and
- Environmental health of the estuary.

These factors have been discussed in the following sections.

4.3.1 Aquatic Food Supply Quality

The Moruya Estuary is used as both a commercial and recreational fishery. Commercial activities include oyster farming and crab trapping. Recreational uses include angling, crab and oyster collecting (Young and Thom, 2000). Oyster leases are all in the lower estuary, mostly in the bund around Quandolo Island near monitoring sites MO1 and MO2 (Figure 4.2). Recreational harvesting occurs over a much wider area.

A review of water quality compared to ANZECC guidelines for Aquatic foods will indicate whether the Moruya Estuary has water quality issues relating to the human consumption of aquatic foods.

The ANZECC trigger levels for aquaculture species is not related to health issues with eating the food produced in this water but to the well being of the animals being cultured. Although there is no aquaculture of finfish in the Moruya Estuary trigger levels set for the protection of aquaculture species are relevant. This is because some of the species the guidelines are set for are present within the Moruya Estuary as wild stocks (e.g. mullet, bream). These fish are important for the recreational and commercial fishing industry. Consequently their well being should be of importance to the management of the estuary.

Data on nutrient load and faecal contamination are available for the Moruya Estuary. These data were analysed to determine the current condition of the river and how these affect shell fish production.

4.3.2 Recreational Users

The Moruya Estuary is an important recreational destination for tourists and local residents and is used for fishing, swimming, boating and nature based activities. ANZECC guidelines have been established to protect recreational water quality and aesthetic values of waterways. These are based on the frequency of contact:

- Primary (e.g. swimming);
- Secondary (e.g. boating); and
- No contact (e.g. visual amenity).

It is important to determine whether the water quality of the Moruya Estuary is within the guideline levels for recreational use. Faecal coliforms are of concern due to activities such as swimming in which there is a high probability of water being swallowed. It is worth noting that the faecal coliform threshold is based on a median and an 80% exceedance (4 out of 5 samples).

4.3.3 Environmental Health

The Moruya Estuary supports a diverse range of activities with lifestyle, commercial and recreational benefits and it is ultimately the health of the ecosystem that ensures the continuing viability of these pursuits.

ANZECC have established trigger values (concentrations) for key water quality parameters, below which there is a low risk of adverse biological effects occurring. These are intended to be used in conjunction with professional management to provide an initial assessment of the water body. Results from water quality monitoring may trigger two responses;

- A test value below the trigger value may imply a continuation of monitoring to maintain the low risk status of a water body; and
- A high value may indicate the need for remedial action, or further site specific investigation.

4.3.4 Quality of Drinking Water

There are no present or future plans to take town water supplies from within the estuary. The water quality at monitoring site M05, which is a current town water supply intake is just upstream of the estuarine part of the river. Hence the standards for drinking water do not need to be applied in the Moruya River Estuary.

The M05 has been included in the set of estuarine monitoring sites because it provides a good indication of the quality of water flowing into the estuary.

4.4 WATER QUALITY DATA REVIEW

The interpretation of the ESC dataset has considered the following:

- For the purpose of this analysis all values below the detection limit have been converted to zeros. Nonsensical values (where the values exceeded possible values or were considered to be extremely improbable) were excluded.
- Caution should be applied to the findings of variables that are known to change diurnally (through the day) such as pH, temperature and dissolved oxygen. Owing to the different water chemistry of fresh and marine water, most variables will show some change with the tidal cycle. Thus the values supplied by ESC should be viewed as being representative of water quality specific to that location, time and tide.
- Caution should be applied to the findings of parameters that are known to vary spatially (e.g. electrical conductivity).
- The analysis of faecal coliforms from environmental sources can be tested using both the Most Probable Number (MPN) method and the Colony Forming Unit (CFU) method. Both methods provide for comparable results. Thus faecal coliform concentrations from the Moruya Estuary measured in CFU, have been assessed against ANZECC guidelines expressed as MPN.

The following water quality indicators were investigated for seven monitoring sites: M01, M02, M03, M04, M05, M06 and M10:

- Faecal coliforms;
- Nutrients;
- Electrical Conductivity;
- Dissolved oxygen;
- pH; and
- Turbidity.

It is assumed that as there are no significant sources of thermal inputs to the Moruya Estuary, temperature is not an indicator of water quality implications. Therefore it has been excluded from analysis. Remaining indicators are discussed in the sections that follow.

4.4.1 Box and Whisker Plots

Existing data has been presented as box and whisker plots separated for the different sites. Box and Whisker plots allow you to quickly compare data. The plot (Figure 4.2) consists of a box with extensions from the top and bottom. Inside the box there is a line and for some plots asterisks exist above or below the extension lines.

The line in the box gives the median value, where half of the readings are above and half are below. If the data is normally distributed this will be in the centre of the box and will be equal to the average value. In some cases where there are a lot of readings with similar values the median bar may fall on one of the limits of the box and not be visible. The upper and lower limits of the box are the 25 percentile and the 75 percentile. These are the values where a quarter of the readings are less than or greater than, so that 50% of the values fall in the box. The extended bars represent the range where 95% of the values could be expected to fall. The asterisks show data points which fall outside this range where 95% of readings could be expected. These may be statistical outliers or represent incorrect readings.

The value of the Box and Whisker plots is that the data does not have to be normally distributed to compare readings, as is the case if statistical comparisons are made. One of the signs that the data is not normally distributed is the box or lower whisker sitting on zero. This may occur where many readings, more than 25% in the case of the box sitting on zero, have been assigned the value of 0.00 because readings were below the limits of detection.

4.4.2 Faecal Coliforms

Faecal coliforms are bacteria that inhabit the intestines of mammals and are present in faecal matter. They occur in a range of animals including humans, cows, sheep and kangaroos. Therefore, the presence of faecal coliforms is not necessarily an indication of human sewage contamination. Methods to determine the source of faecal coliforms (ie. human, stock or wildlife) are available but are not normally used and have not been used here.

Faecal coliforms are used as an indicator of the degree of faecal contamination of water. Although faecal coliforms are themselves not necessarily a great danger to health they are an indirect measure of the possible presence of water borne human pathogens, such as Hepatitis A virus (NSW Government, 1992). Human pathogens can endanger people in direct contact with the water (e.g. swimmers) or those eating contaminated filter-feeders (e.g. oysters), which concentrate bacteria and viruses (NSW Government, 1992).

Sources of faecal coliforms include wastewater, overland or storm water flow (transport mechanism for faecal matter), wildlife, pet faeces washing into drains and uncontrolled stock access to water. As can be seen many of the sources are a result of faecal material washing into the estuary. Consequently readings are usually higher after rainfall.

The spatial variation in faecal coliform counts at the seven sites is shown in Figure 4.2. Analysis of Figure 4.2 shows that Site MO4 had the highest total faecal coliform counts. The faecal coliform counts at all monitored sites are generally within the ANZECC (2000) guidelines for recreational sites.

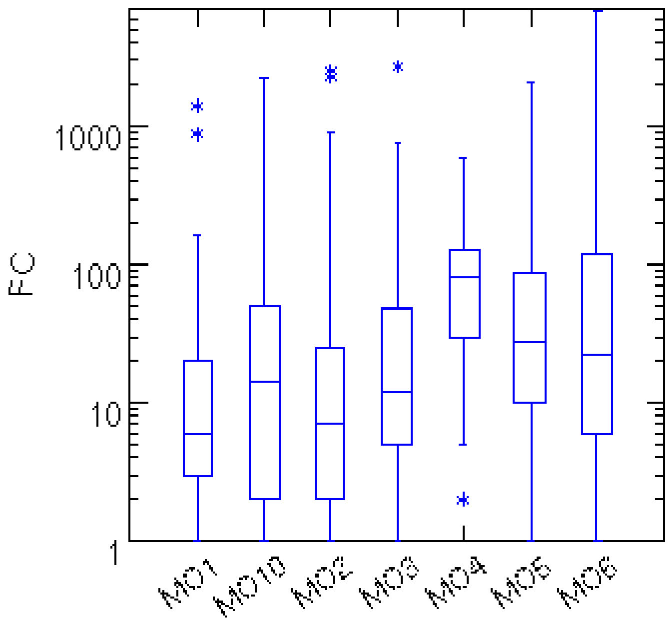

Figure 4.2: Spatial variation in faecal coliform counts
(Shown as FC) expressed as CFU/100ml

The occurrence of high faecal coliform counts at M04 (Kiora Bridge) is indicative of faecal contamination at this site. Water at this site comes from the Deua River and Wamban Creek. The lower level of faecal coliform at M05 on the Deua River upstream of the Wamban Creek confluence suggests that Wamban Creek or local input is an important source of faecal pollutants in the upper estuary. This is most likely due to animal wastes washing in from farms or even high concentrations of wildlife in the catchment. Reduced tidal exchange, low freshwater inflows and low current velocities in the upper estuary limits flushing and dilution so that there may be a prolonged presence of pollutants in this part of the estuary.

At Sites M01 and M02, which are close to the oyster farms, the FC counts exceed the ANZECC guidelines for Aquatic Foods. FC counts at site M06, which is upstream of site M01 and M02 are also high as at this point the tertiary effluent from the sewage plant is discharging into Ryans Creek.

There are a number of processes in place to ensure that people eating commercially produced oysters are not at risk of disease.

- Water quality is monitored at the lease sites and only sites deemed to be safe by the NSW Shellfish Quality Assurance Program can be used for growing of oysters.
- Only oysters grown in a location classified as having “clean water” can be sold directly for human consumption.

If a location does not have “clean water” the oysters are transferred to a site with “clean water” for a period of “self cleansing” or to a land based operation for depauperation. Depauperation is a process where, before being they are marketed, the oysters are kept in clean water to purge their gastrointestinal contents.

Due to the NSW Shellfish Quality Assurance Program the human health issues of water quality in regards to commercial oyster production are not an issue for the estuary management committee. However, there are potential problems for people consuming wild harvested oysters that need to be investigated.

4.4.3 Nutrients

Nitrogen and phosphorus are important nutrients for plant growth in aquatic ecosystems (ANZECC, 2000). The most direct impact of high nutrient input is that the breakdown of ammonia to nitrite and nitrate depletes dissolved oxygen levels, which can stress many animals. There are many complex indirect effects through the enhanced growth of plants usually algae. Increased plant growth can have several impacts on the environment:

- Toxic blue-green algae may grow, impacting on the recreational use of the water way;
- Algae can impact on oyster growth and sales values;
- Increased algae growth may reduce the light availability reducing the depths at which sea grass can grow. This will reduce the habitat available for the invertebrates and fish that are associated with sea grasses;
- Excessive growth of filamentous algae reduces current velocities producing stagnant water; and
- Algal mats can wash up on the foreshore causing unpleasant odours and an unsightly mess.

Plants and algae utilise nitrogen and phosphorus in a fixed ratio (Redfield ratio), such that if either nutrient exists at a low level it may limit the uptake of the other. In the estuarine environment phosphate is normally in excess so that nitrogen inputs limit plant growth and are the most problematic. However, in considering the likelihood of excessive plant and algal growth, nitrogen and phosphorus cannot be viewed in isolation.

Nitrogen exists in inorganic forms including nitrate, nitrite (nitrate/nitrite, collectively referred to as $NO_{x)}$ and ammonia and organic forms such as urea (from the breakdown of proteins). Of the biologically available forms of nitrogen, nitrate is the most common and ammonia the most readily useable by plants (ANZECC, 2000). Total nitrogen is the measure of both biologically available and unavailable forms.

Phosphorus exists in biologically available dissolved forms and in biologically unavailable forms bound to clay particles. Total phosphorus is a measure of both of these forms.

Sources for nutrient input include:

- Sewage treatment plant inputs;
- Runoff from agriculture, pasture and grazing lands;
- Urban runoff;
- Overflows from storm and sewer drains;
- Septic leachate and runoff from failed septic systems;
- Runoff from abandoned mines;
- Logging;
- Atmospheric deposition over the water;
- Runoff from development sites; and
- Leachate from waste disposal sites.

To some extent all of these possible sources apply to the Moruya Estuary. However the greatest potential source for nutrient input has to be the sewage treatment plant on Ryans Creek. However, nutrient levels at the ESC monitoring site M05 in the river above the estuary indicate that high nutrient input occurs with the river input. Most of these nutrients probably come from grazing lands in the catchment and the fruit growing area in the Deua River valley.

Nitrate Concentration

The spatial variation in nitrate concentration at the seven monitoring sites is presented in Figure 4.3.

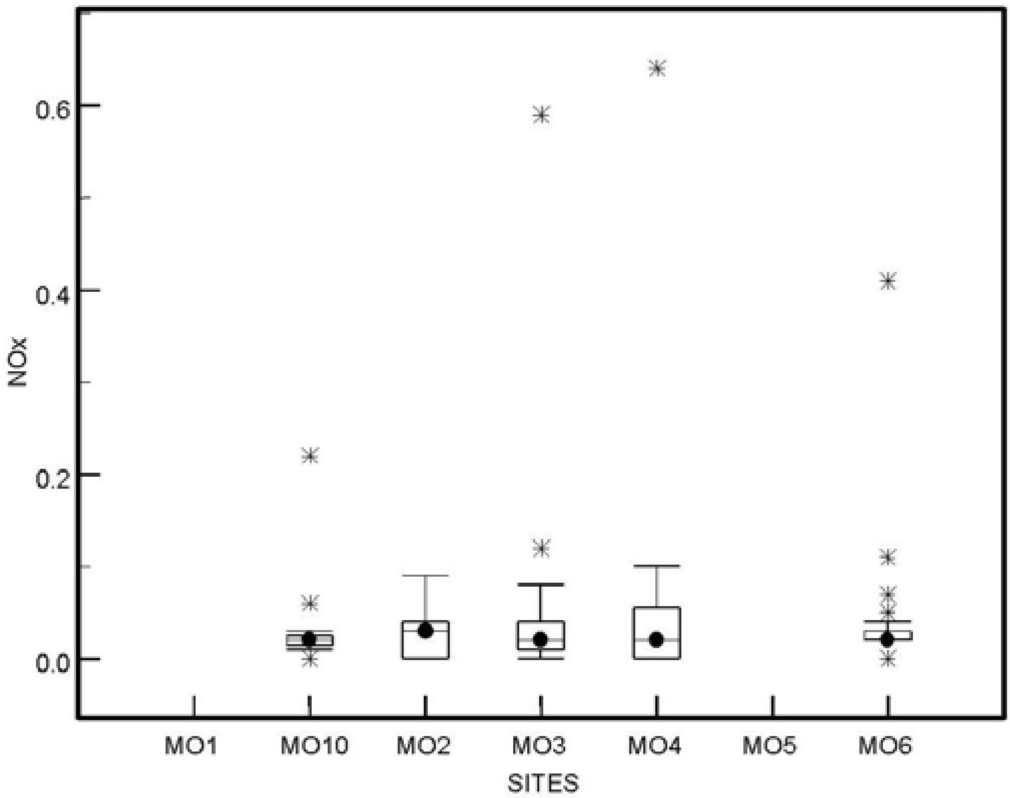

Figure 4.3: Spatial variation in nitrate concentrations
expressed in mg/L

The NOx concentrations at all the sites are below the ANZECC 2000 guideline trigger levels for contact recreation and aquaculture. At most of the site there are occasional readings (i.e. outliers) that have exceed the trigger level value of 0.15 mg/L recommended for maintenance of environmental quality.

Ammonia Concentration

The spatial variation in ammonia concentration at the seven monitoring sites is displayed in Figure 4.4.

The analysis of Figure 4.4 has found:

- Median Ammonia concentrations were highest at Site M10 (Malabar Lagoon) (0.05 mg/L).

- At site MO6 (Ryans Creek) the upper wiser was the highest for all sites monitored indicating that high values were more frequently encountered at this site then elsewhere.
- Ammonia concentrations at the five monitored sites frequently exceeded the ANZECC 2000 guideline trigger values for recreational contact (0.01 mg/L) and maintenance of environmental health (0.015 mg/L).
- Ammonia concentrations were lowest at Site M04 (Kiora Bridge). However even here only 5 of the 12 readings were less than 0.01 mg/L.

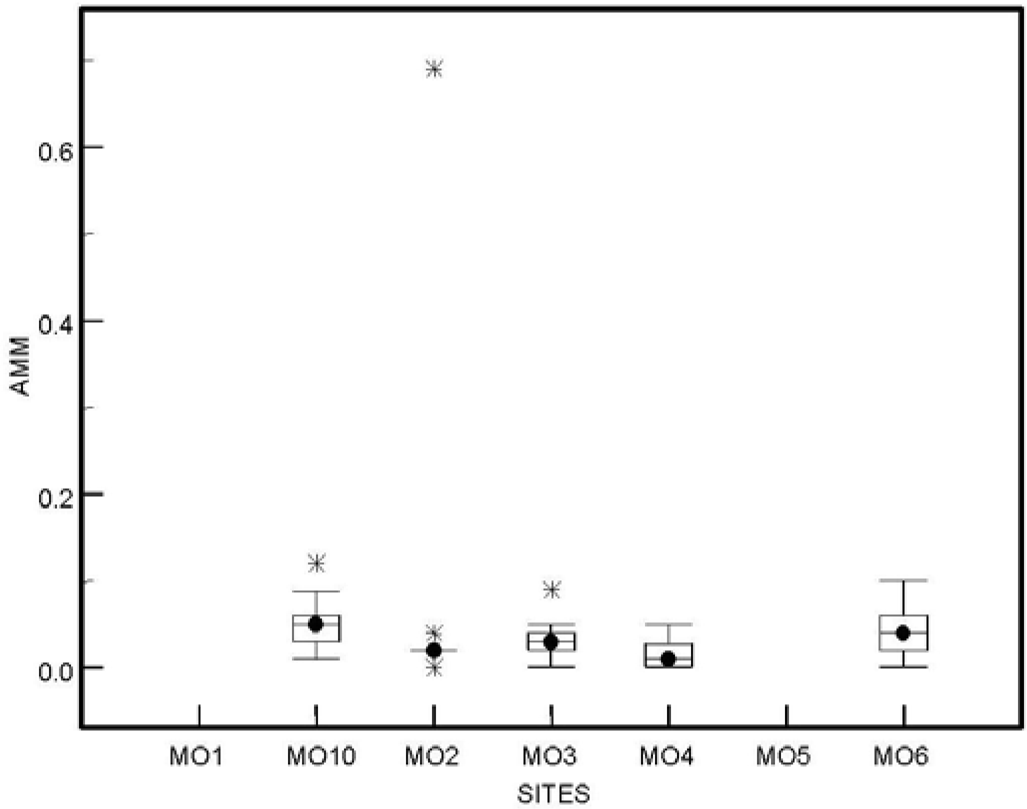

Figure 4.4: Spatial variation in ammonia concentration
(Expressed in mg/L.)

High ammonia concentration was found at nearly all the sites monitored. In reviewing the original data it was found that much had been collected using inappropriate methods so that elevated nutrient readings were given. This faulty data is believed to have been identified and removed from the data set. In view of these problems and the consistent exceedence of ANZECC trigger levels a more detailed analysis of ammonia concentrations in the Moruya Estuary should be considered.

Phosphate Concentrations

Phosphate concentrations for the seven monitoring sites are plotted in Figure 4.5.

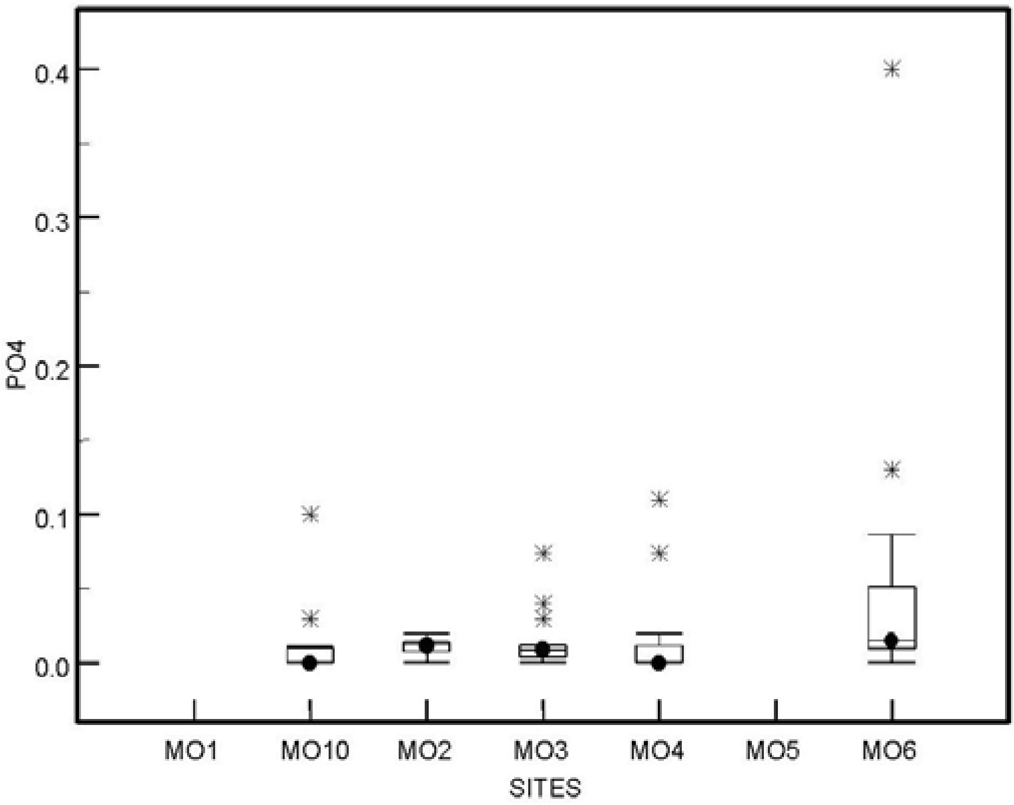

Figure 4.5: Spatial variation in phosphate concentration expressed in mg/L.

Observations from Figure 4.5 are:

- Phosphate concentrations were lowest at Site MO10 (Malabar Lagoon) and MO4 (Kiora Bridge) (median 0.00) indicating in more than half the cases levels concentrations were below detection levels;
- Phosphate concentrations were highest at M06 (Ryans Creek) suggesting that it may be associated with sewage inputs;
- At site MO6 (Ryans Creek) 25% of readings exceeded the ANZECC trigger levels for aquaculture species (0.05 mg/L) at other sites only outliers were above this concentration; and
- Exceedence of the trigger levels for ecosystem protection (0.005 mg/L) was high at all sites, 40%, 20%, 70%, 25% and 85% for sites MO10, MO2, MO3 MO4 and MO6 respectively.

4.4.4 Electrical Conductivity

Electrical conductivity is a measure of the total concentration of inorganic ions (salts) present within water and ranges from <1.0 mS/cm in freshwater to >50-60 mS/cm in sea water.

Knowledge of electrical conductivity allows estuarine managers to gain an understanding of prevailing physical, biological and chemical processes.

- Physical processes: Knowledge of salinity levels provides for an appreciation of the relative contribution of fresh and marine waters within an estuary. The distribution of the salt and fresh water gives an indication of the degree of estuarine mixing and dominant flushing mechanisms.

- Biological processes: Salinity can influence the distribution of aquatic organisms. Species that are suited to a wide range of salinity levels are ideally suited to estuary conditions. Species unable to cope with such changes are excluded.
- Chemical processes: Changing concentrations in salt can alter the chemical environment. The most obvious reaction is the precipitation of fine silt particles which are carried down the stream suspended in water. In salt water this material comes together to form larger particles which are too big to remain suspended and the material settles out.

Electrical Conductivity measurements at the seven monitoring sites are summarised in Figure 4.6.

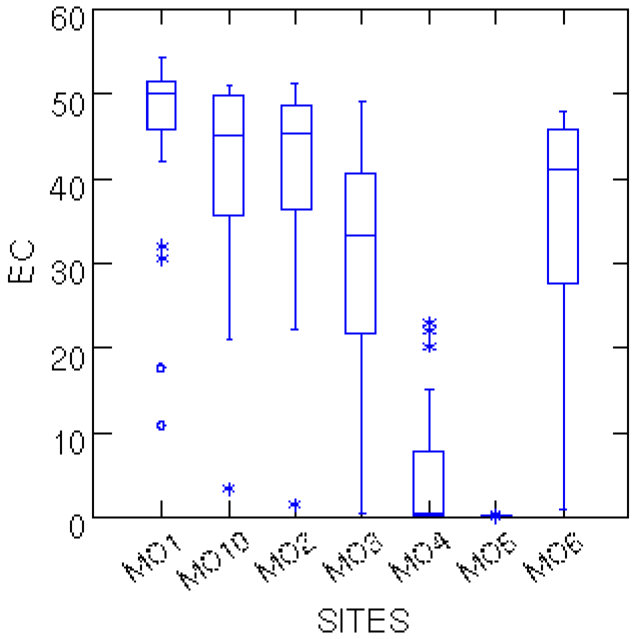

Figure 4.6: Spatial variation in electrical conductivity.
Expressed in mS/cm.

The following observations can be made from Figure 4.6:

- Electrical conductivity values decreased with distance from the sea. Site M04 and M05 recorded lowest Electrical Conductivity; and
- Variability in Electrical Conductivity was not uniform between each of the sites.

Electrical conductivity values show that M01, M02, M03, M06 and M010 are strongly influenced by marine water and M04 is strongly influenced by freshwater while site M05 is on the freshwater Deua River. Outliers of both high and low electrical conductivity values suggest that all sites experience occasions when either freshwater or marine water dominates. Freshwater at each of the sites is consistent with flood events, where a pulse of freshwater drives marine water from the estuary.

4.4.5 Dissolved Oxygen

The dissolved oxygen concentration is a measure of the balance between oxygen consuming processes (respiration) and oxygen releasing processes (photosynthesis and atmosphere - water oxygen transfer) (ANZECC, 2000). Dissolved oxygen concentrations are indicative of the degree of disturbance to these natural processes and define the living conditions for aerobic (oxygen requiring) organisms (ANZECC, 2000).

Dissolved oxygen (DO) is sensitive to temperature, salinity, biological and chemical activity and transfer rate with the atmosphere. Exchange with the atmosphere is the main source of dissolved oxygen and this can be increased through increased water surface turbulence, for example from breaking waves.

Low dissolved oxygen values are detrimental to oxygen requiring species (e.g. fish, crustaceans) and can lead to an increase in the toxicity of pollutants. Decomposing organic matter (sewage, rotting vegetation) is often responsible for reductions in dissolved oxygen. Typically, the DO concentration in fresh water is about 8 mg/l.

The spatial variation in dissolved oxygen concentrations at the seven monitoring sites is given in Figure 4.7.

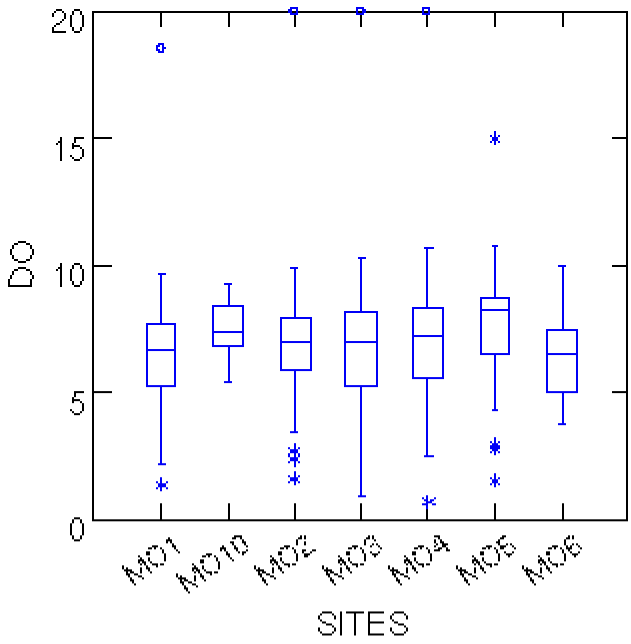

Figure 4.7: Spatial variation in dissolved oxygen concentrations. (Shown as DO) expressed in mg/L.

DO concentration at all sites were quite similar with similar median values. Low DO concentration occasionally recorded at Site MO1 and MO2 are possibly due to high BOD in this area due to the presence of Oyster farms. Minimum dissolved oxygen values at each of the sites show that on occasions anoxic conditions exist. This is indicative of the presence of pollutants with a high BOD. Generally the Dissolved Oxygen concentrations are well within all the ANZECC guidelines indicating good water quality in the estuary.

4.4.6 pH

pH is a measure of the acidity or alkalinity of water and has a scale from 0 (extremely acidic) to 14 (extremely alkaline), with 7 being neutral. pH is an important variable to measure for the following reasons:

- Low pH can have an adverse effect on fish and aquatic organisms;
- Changes in pH, particularly low pH can increase the toxicity of several pollutants (such as ammonia, cyanide, arsenic, aluminium); and
- Changes in pH alter the dominant chemical process occurring in the estuary.

The pH range of most natural freshwater is 6.5 - 8.0 and marine water is 8.0 - 8.2. The carbonate-bicarbonate buffering system is responsible for controlling the pH of most waters and this is particularly strong in marine waters. It should be noted that some naturally acidic waters, heavy with tannin from leaf litter, have a pH in the range 5.0 - 6.0. The final pH is determined by the concentrations of both acidic and alkaline substances dissolved within the water (ANZECC, 2000).

The spatial variation of pH at all sites is given in Figure 4.8.

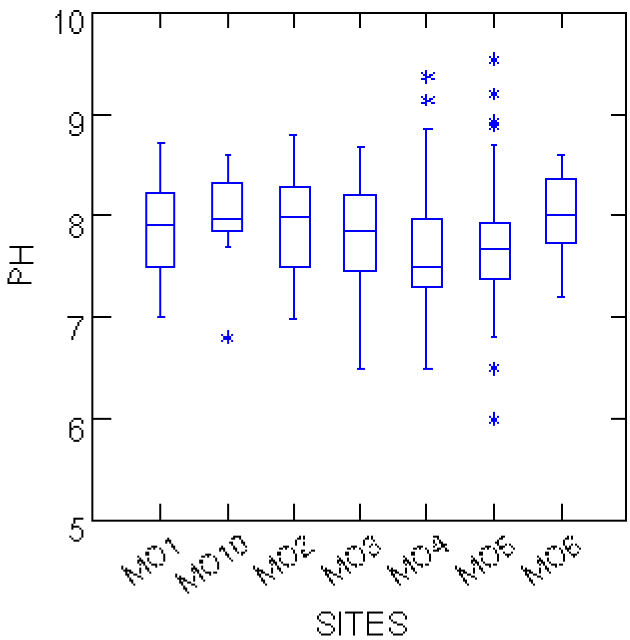

Figure 4.8: Spatial variation in pH.

Figure 4.8 shows that Sites M04 and MO5 occasionally recorded very high pH values. Site MO5 also recorded low pH values. The pH at M01, MO2, MO3, MO6 and MO10 is typical of marine water input. At all sites maximum values were in the typical range of marine water indicating limited freshwater input at times. These conditions would be expected during droughts. Minimum values were acidic at times only at sites MO3, MO4 and MO5 indicating the absence then of marine water, perhaps resultant of a freshwater pulse as found during flood conditions. The pH values at all sites were well within the ANZECC guideline values.

4.4.7 Turbidity

Turbidity refers to the ability of water to transmit light. Increased turbidity is caused by the presence of suspended particulate and colloidal matter such as clay, silt, phytoplankton, detritus and occasionally by a soluble dye such as tannin. Turbidity can be measured by the optical backscatter method using Nephelometric Turbidity Units (NTU).

Increased turbidity can reduce the amount of light that can pass through water and change an ecosystem significantly (ANZECC, 2000). Negative effects include shading of plants and algae and impairment of fish gills. Increased turbidity can be caused by algae, sediment inflow (e.g. land run off, bank erosion) and bed disturbance (e.g. tidal currents, dredging, livestock trampling). The turbidity measurements at the seven sites are presented in Figure 4.9.

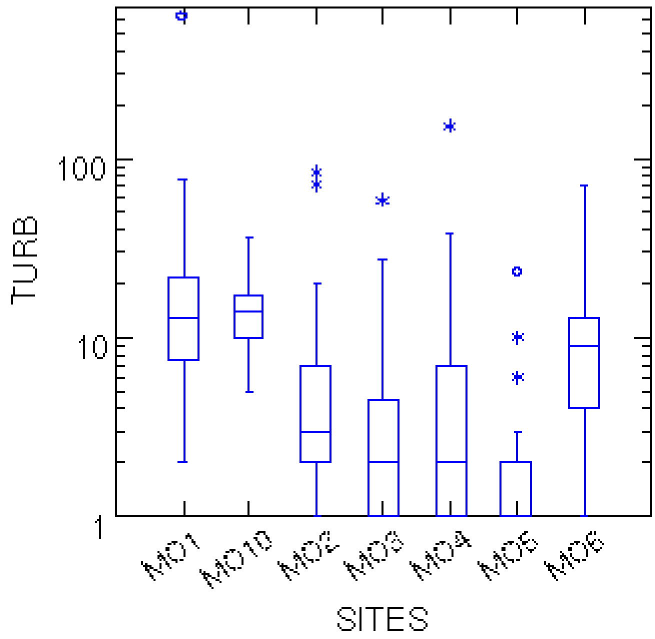

Figure 4.9: Variation in turbidity.
expressed in NTU

The median turbidity recorded at Site MO1 and MO10 is slightly over 10 NTU and it exceeds the ANZECC Aquatic Ecosystem Protection guidelines for turbidity. The higher turbidity in this area may be due to either the higher current velocities in this region or a high concentration of colloidal material in the sea water, or a combination of the two. Turbidity values further upstream are much lower and within the ANZECC guidelines for Aquatic Ecosystem Protection.

4.5 SITE OBSERVATIONS

The site visit did not record any indications of poor water quality. Much of the estuary is fenced so that stock was separated from the estuary by a buffer zone though in a few areas stock did have access to the estuary and were wading in the water.

The Moruya Sewage Treatment Plant has been releasing tertiary treated effluent into Ryans creek since 1973 at am average rate of 0.8 ml/day (Young and Thoms, 2000). Tertiary treated sewage, while avoiding many of the water quality problems caused by primary and secondary treated sewage, has a high concentration of nutrients. To some extent this has been reduced by developing an effluent reuse program. A low strength effluent has been used to irrigate the Moruya Golf Course for the last ten years.

The use of the treated effluent has lead to questions of water quality effects after rainfall events that would provide the opportunity for nutrients to leach out of the golf course and into the waterways. Although some movement of nutrients would be expected with rainfall it is improbable that large amounts of nutrients would accumulate in the soils of the golf course. The nutrients are being watered onto the course with the intention to encourage grass growth. Consequently many of the nutrients would be used by the grass during its growth. These will then become bound to the grass so that even if they did get carried into the estuary their release would be gradual similar to the natural release of leaves and other detritus carried into the estuary during rainfall. Much of this material would be broken down by bacteria and enter the food web without becoming devolved in the water.

4.6 WATER QUALITY MODELLING

The reduced model was used to calculate the water surface elevations and flow velocities to predict the dispersion of material throughout the study area during the water quality modelling. Dispersal and fate of pollutants have been calculated using the RMA-11 module of the RMA modelling suite.

Water quality modelling has considered the concentrations and distributions of the following constituents:

- Organic Nitrogen;
- Nitrite;
- Nitrate;
- Ammonia;
- Organic Phosphorus;
- Phosphate;
- Coliform; and
- An arbitrary conservative pollutant (Dye).

Table 4.2: Biochemical rate coefficients used for water quality modelling

Nitrogen				
Rate constant for the hydrolysis of organic nitrogen to ammonia	β_3	*1/day*	0.04	[1]
Organic nitrogen settling rate	σ_4	*m/day*	0.1	[1]
Rate of oxygen uptake per unit of ammonia oxidation	α_5	*mg-O/mgN*	3.43	[1]
Rate constant for the biological oxidation of ammonia to nitrite	β_1	*1/day*	1	[1]
Benthos source rate for ammonia	σ_3	*mg/m2 /day*	0.23	[1]
Rate of oxygen uptake per unit of nitrite oxidation	α_6	*Mg-O/mgN*	1.14	[1]
Rate constant for the biological oxidation of nitrite to nitrate	β_2	1/day	1.05	[2, Default value]
First order nitrification inhibition coefficient	K_{NITR}	L/mg	2	[2]
Phosphorus				
Rate Constant for the decay of organic phosphorus to dissolved phosphorus	β_4	1/day	0.3	[1]
Organic Phosphorus settling rate	σ_5	m/day	0.1	[1]
Benthos source rate for dissolved	σ_2	mg/m2/day	0.03	[1]

Table 4.2: Biochemical rate coefficients used for water quality modelling

phosphorus				
Phosphate decay rate	β_5	1/day	0.05	[2, Mean Value]
Coliform				
Coliform settling rate	K_{c3}	m/day	2	
90% decay time for darkness		Hr	96	
Coliform light coefficient	L_c	hr/	3.3	[2, Default value]
Light extinction coefficient	λ	1/m	0.3	
Arbitrary Conservative Pollutant				
Arbitrary conservative pollutant settling rate	σ_6	m/day	0.0	
Benthos source rate for arbitrary conservative pollutant	σ_7	mg/m2/day	0.0	
Rate constant for the growth of arbitrary conservative pollutant	K_6	1/day	0.0	

References
1) AMOG Consulting 1999
2) Brown & Barnwell 1987

4.6.1 Calibration

Calibration of the water quality model requires detailed field data, which can be compared to RMA-11 model results to adjust the rates of conversion, uptake and settling of model constituents. As detailed calibration data was not available, biochemical rate coefficients from previous estuarine studies and empirical formulae have been input to the model. These values are detailed in Table 4.3. The water quality model has been constructed in such a way that the modelling parameters can be easily modified should detailed monitoring data become available at a later date.

4.6.2 Water Quality Spill Scenarios

The water quality simulations were initialised with zero baseline pollutant concentrations. In reality, the estuary will have pollutant present at equilibrium concentrations. By having a zero baseline, the fate of pollutants from the modelled scenario only can be isolated and tracked.

Due to the fact that the estuary geometry is not homogeneous, its flushing behaviour is also inhomogeneous and a single flushing time cannot describe the whole estuary. Thus, spill scenarios in particular areas of concern have been chosen to track the flushing behaviour from these regions.

The water quality concentration distributions were assessed for median inflows for four spill scenarios along the estuary:

- Pollutant inflow at the mouth of Racecourse Creek, occurring during the Spring ebb high tide;
- Pollutant spill at the mouth of Racecourse Creek, occurring during the Neap ebb high tide;
- Pollutant spill at the Moruya Town Wharf, occurring during the Mean ebb high tide; and
- Pollutant spill at Kiora Bridge, occurring during the Mean ebb high tide.

For each of these scenarios, the pollutants were modelled as a constant inflow over a period of one hour. The pollutant inflow rates are given in Table 4.3. Aside from the conservative constituent, the relative mass flow rates reflect the typical composition of raw sewage. The pollutants were traced for a period of approximately four days following the end of the spill.

Table 4.3: Pollutant Inflow Rates

Pollutant	Inflow Rate
Organic Nitrogen	37.5 mg/s
Nitrite	0.0 mg/s
Nitrate	0.0 mg/s
Ammonia	62.5 mg/s
Organic Phosphorus	12.5 mg/s
Phosphate	12.5 mg/s
Faecal Coliform	25×10^6 MPN/10 s
Dye (conservative constituent)	1000 g/s

In the assessment of the water quality results, some of which are presented in the proceeding sections, the following limitations of the RMA-11 model and simplifications should be taken into consideration:

- Algal growth as a result of nutrient uptake is not simulated. The propagation of algae will not only remove nutrient from the estuary waterways but can have the potential to alter the flow fields (if significant growth is observed).
- Chemical equilibrium (with the exception of dissolved oxygen) is not factored into the RMA-11 equations, thus the effect of the spill on top of natural occurring nutrient concentrations is not taken into account.
- The fate of coliform is described simply and relies primarily on the amount of sunlight received by the organisms. Thus the potential for growth through nutrient uptake is not considered.
- Variations in meteorological conditions affect the degree of aeration and therefore the available oxygen for any oxidation reactions. It has been assumed for the purposes of this study that for the most part the Moruya is sufficiently aerated to effect these reactions such that anaerobic conditions are never achieved, and that the prevailing temperature is 20^oC throughout the simulations. Localised points of stagnation, in particular in the upper estuary, will obviously display higher model rates of nutrient reaction than what could be expected in reality.

4.6.3 Estuary Flushing Methodology

To assess the level of stagnation and potential retention of pollutants along the estuary, an indication of the degree of flushing is needed. The flushing time of an estuary can be defined as either:

- The time it takes for the entire volume of the water within the estuary to be replaced; or
- The time it takes for a given amount of material in the estuary to be taken out of the reaches of the estuary.

For the purpose of this study, the second definition is adopted. The time taken for the mass in the model estuary to reach 1/e which is approximately 37% of the original spill mass is adopted as the flushing time. This is obtained from the decay in total mass of an conservative constituent, i.e. dye, resulting from a spill, within the defined estuary reach. This decay curve is calculated from the concentrations predicted at points along the estuary and the average water volume associated with these regions. Figures 4.10 to 4.12 illustrate the distribution of output points for the four spill scenarios.

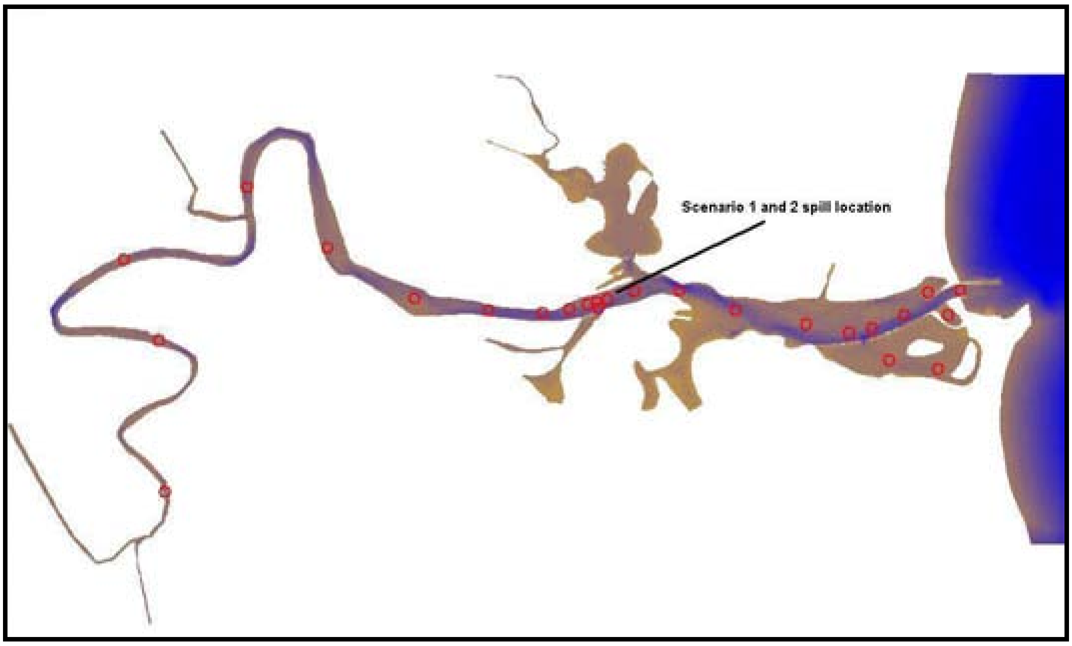

Figure 4.10: Spill scenario 1 and 2 location and water quality output nodes.

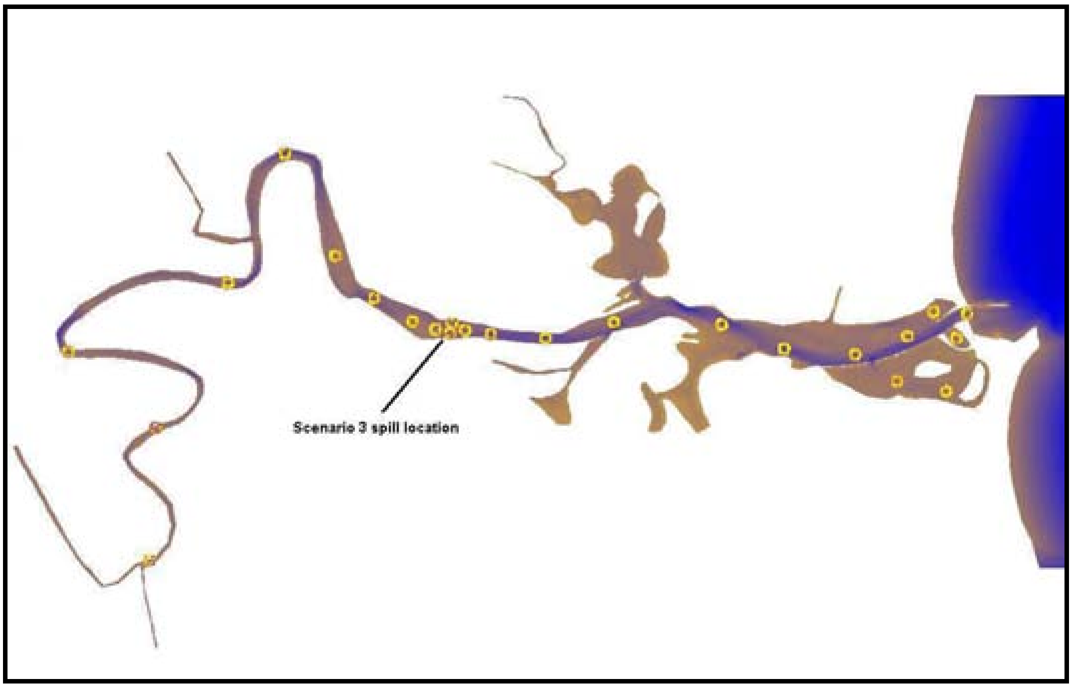

Figure 4.11: Spill scenario 3 location and water quality output nodes.

Figure 4.12: Spill scenario 4 location and water quality output nodes.

4.6.4 Results

To reduce the volume of material in this report only the fate of the dye is presented for all scenarios. The other constituents are presented on a CD as movie files from which snapshots can be obtained. These movies can be played on most computers containing Windows Media Player. The dye has been selected because this is a conservative pollutant that does not undergo any chemical transformations and loss to the environment. Therefore, its fate matches the dilution and movement of the "spill" allowing us to see where a spill will spread to and how long it will remain in the estuary at a reasonable concentration.

For this report the results have been presented as maps showing the dispersal and spread of the pollutant at different times. The times selected to display in the maps for spill concentrations are:

- 1 hour i.e. at the end of the spill;
- 6 hours i.e. half a tidal cycle from the release;
- 12 hours a full tidal cycle after the spill; and
- 3 days, several tidal cycles since the release.

In the special case of scenario 4, the dispersal of the dye at the end of the simulation is also presented.

4.6.4.1 Scenario 1: Racecourse Creek Junction, Spring Tide

The spring tide produces the highest current velocities and the largest volumetric flow rates in the estuary under non-flood conditions. As the dispersal of pollutant is dependent on the current velocities and the rate of flushing is dependent on the amount of water passing through the estuary, the Spring Tide will give the greatest dispersal and quickest flushing of the pollutant for non-flood conditions. This scenario is aimed at investigating the effect of a spill originating from Racecourse Creek and investigating its potential to reach the oyster growing leases at Pilots Station Backwater. The sewage works is in the vicinity of Ryans Creek a tributary of Racecourse Creek. Choosing the model spill to be at the mouth of the creek provides a worst case scenario that represents a real spill originating in Racecourse Creek which experiences very little dispersal during its travel towards the mouth. This is reasonable as the current velocity along Racecourse Creek is comparably smaller than that at the Moryua Estuary channel.

Figure 4.13 illustrates the fate of the conservative/arbitrary pollutant (dye) within the model estuary as a result of scenario 1. Figure 4.15 shows that within half a tidal cycle there is mass loss from the estuary and into the model ocean, such that the flushing graph is expected to provide a reasonable representation of mass loss after this time.

Interpolation from Figure 4.13 shows that approximately 37% of the initial maximum mass remains after a model simulation of 30 hours i.e. the flushing time for the initial spill mass to reach 1/e is 30 hours. Figure 4.13 shows that after 100 hours the model predicts that approximately 15% of the initial material spilled in the estuary will remain for Scenario 1.

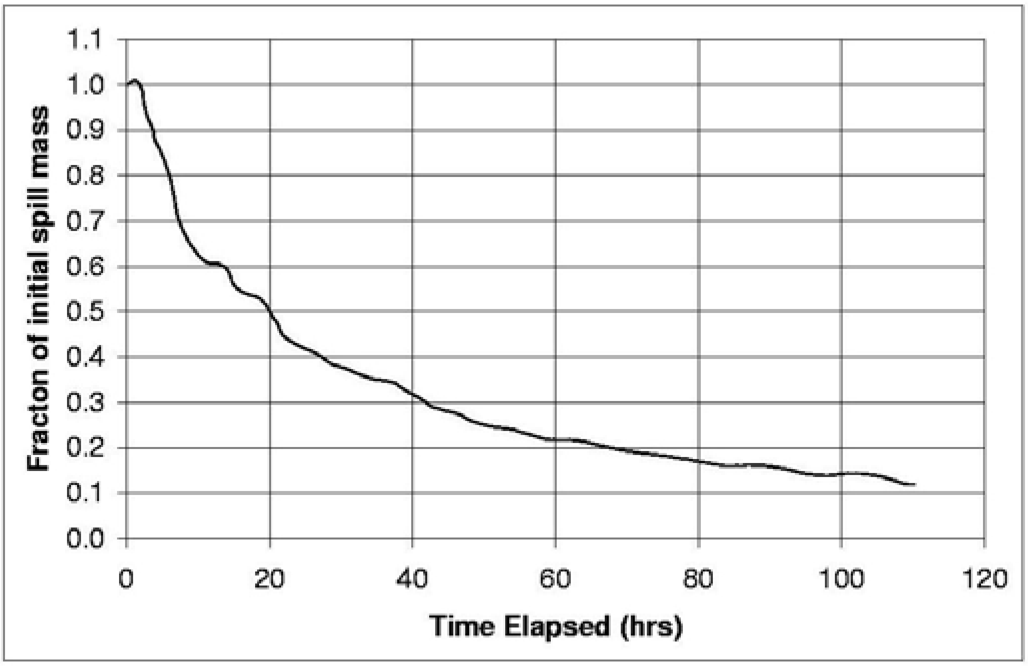

Figure 4.13: Dye Flushing from the Moruya Estuary, Scenario 1.

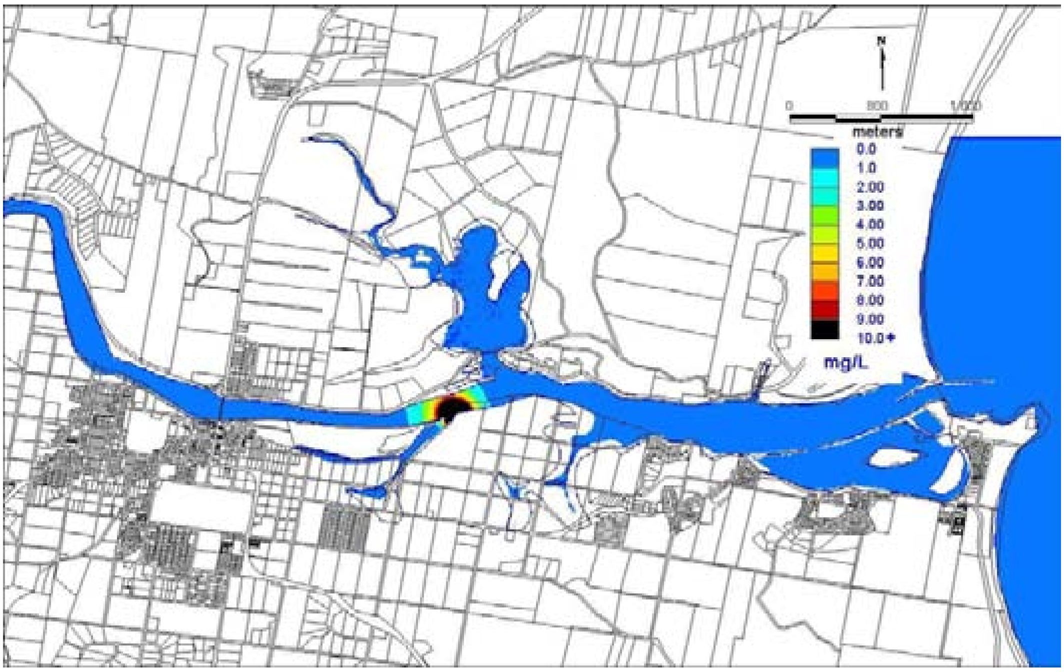

Figure 4.14: Dispersal of Dye after 1 hour, Scenario 1.

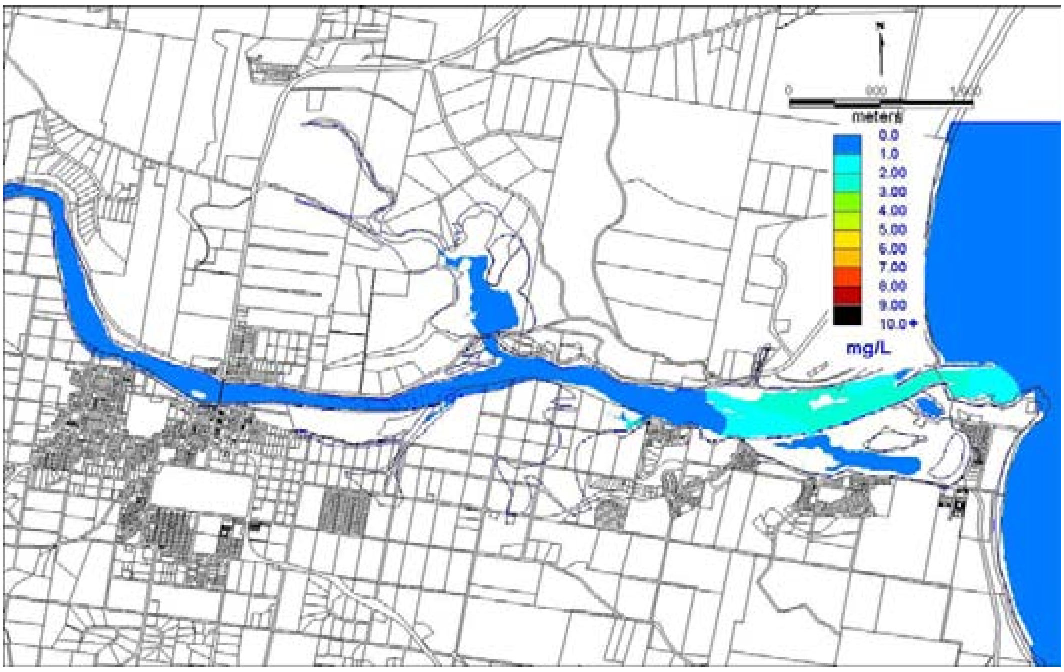

Figure 4.15: Dispersal of Dye after 6 hours, Scenario 1.

Scenario 1 was timed to occur at about high tide and it can be seen from Figure 4.12 that there has been no dispersal of the pollutant over the first hour as it has simply flowed out of Racecourse Creek and accumulated in high densities around the mouth.

The Scenario 1 spill was timed to occur at about high tide to allow the maximum travel downstream towards oyster leases in Pilot Station Backwater. It can be seen in Figure

4.15 that the model predicts that on the spring tide the slug of pollutant will be carried downstream and some of the pollutant carried out to sea with the outgoing tide. Water coming down the river has pushed the upper limit of the concentrated pollutant down to Preddys Wharf. Under these conditions the bulk of the pollutant would be in the estuary stream, just outside of Pilots Station Backwater indicating the oyster leases in the lower Moruya Estuary are vulnerable to spills from Racecourse Creek.

The following incoming tide pushes the pollutant back upstream so that after 12 hours the main concentration of the pollutant is concentrated around Racecourse Creek (Figure 4.16). Figure 4.16 also shows that the pollutant is moving into Malabar Lagoon and that there is concentration of the pollutant in the wetlands west of The Anchorage.

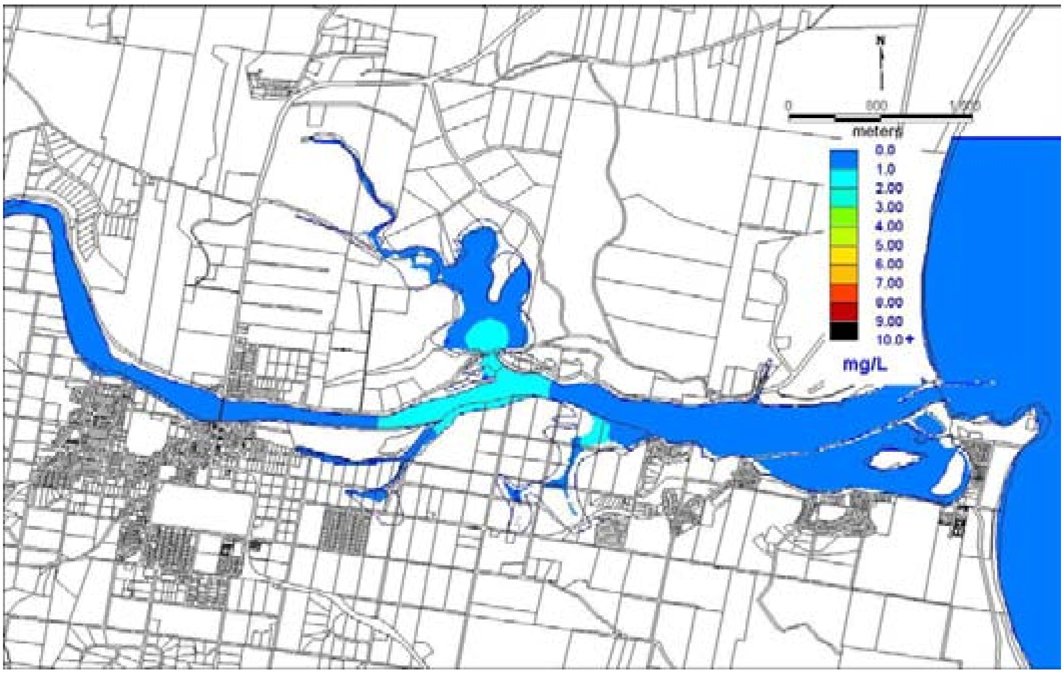

Figure 4.16: Dispersal of Dye after 12 hours, Scenario 1.

The model predicts that after 3 days only 20% of the original spill will remain in the estuary and this has been dispersed throughout the estuary so that concentrations were not enough to be visible on our map. Consequently the 3 day data map has not been presented.

4.6.4.2 Scenario 2: Racecourse Creek Junction, Neap Tide

The neap tide produces the lowest current velocities and lowest volumetric flow rates in the estuary under non-flood conditions. The neap tide will therefore give the lower dispersal rates and longer flushing times than the spring tide. Scenario 2 is aimed at investigating the effect of a spill originating from Racecourse Creek during a neap tide, so that this can be compared with the spring tide tested in Scenario 1.

Figure 4.17 illustrates the fate of the dye within the model estuary as a result of Scenario 2. Compared to Scenario 1, the initial rapid drop in mass is less severe for this scenario. This is because of a more even distribution of the pollutant over the nodes for which concentrations are being calculated. This is because there was a concentration of these nodes around the area where the spill occurred for the neap tide. The pollutants are predicted to move more slowly from this region.

Interpolation from Figure 4.17 shows that approximately 37% of the initial mass remains after a model simulation of 85 hours giving an estimated flushing time of close to three times that for the spring tide. Figure 4.17 shows that after 100 hours the model predicts approximately 30% of the initial material spilled in the estuary will remain for Scenario 2.

As with Scenario 1, there has been little spreading of the pollutant in the first hour. So that high concentrations are found in the estuary in the vicinity of the junction with Racecourse Creek (Figure 4.18).

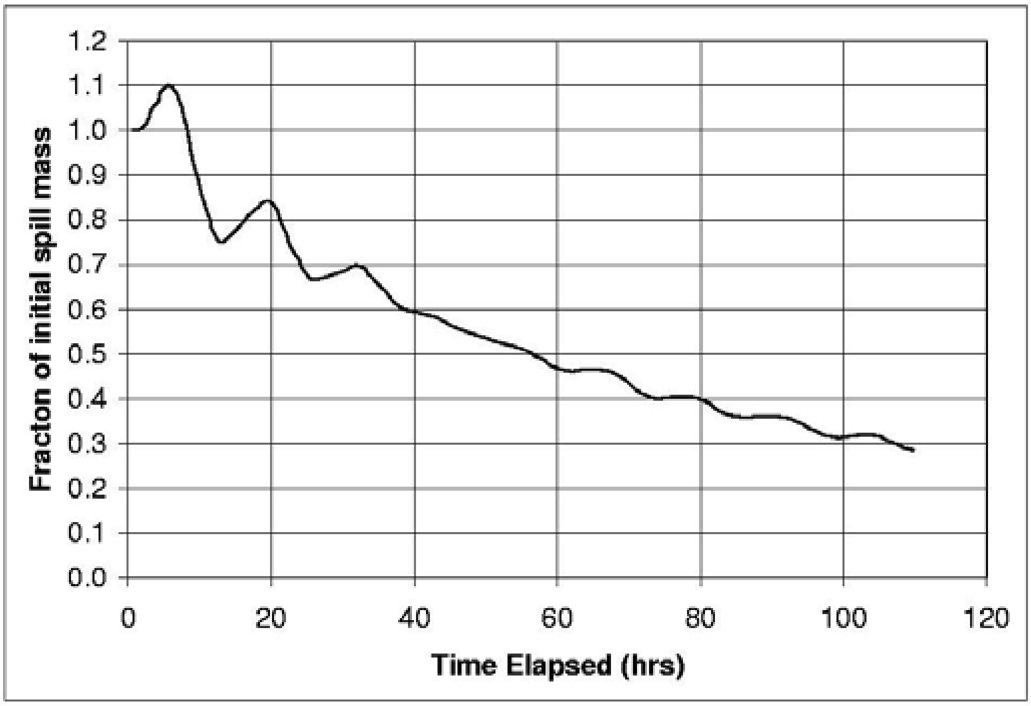

Figure 4.17: Dye Flushing from the Moruya Estuary, Scenario 2.

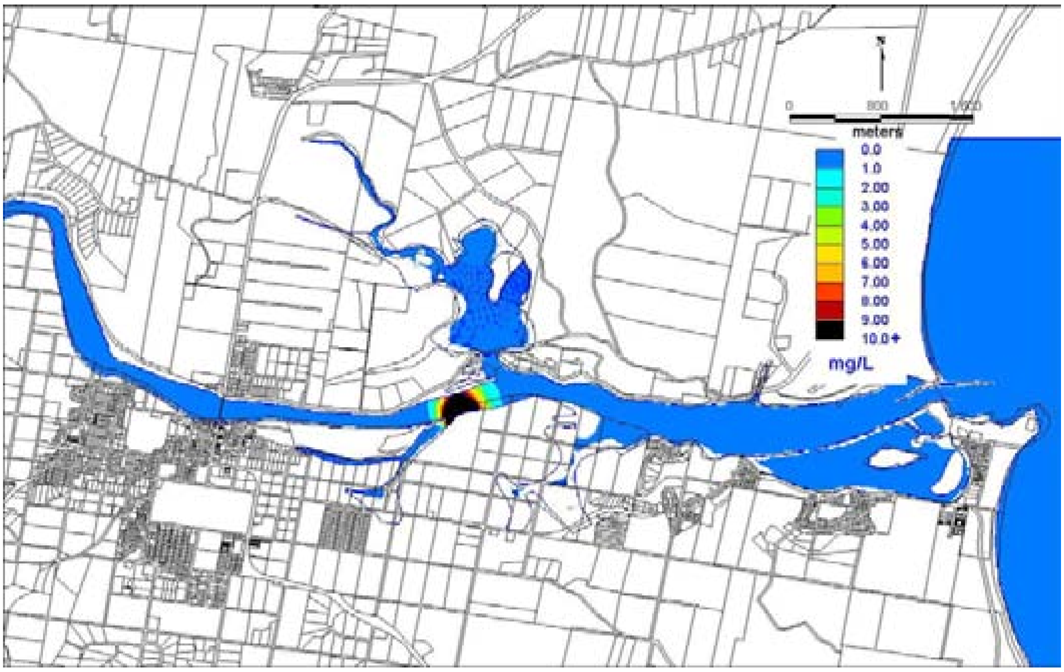

Figure 4.18: Dispersal of Dye after 1 hour, Scenario 2.

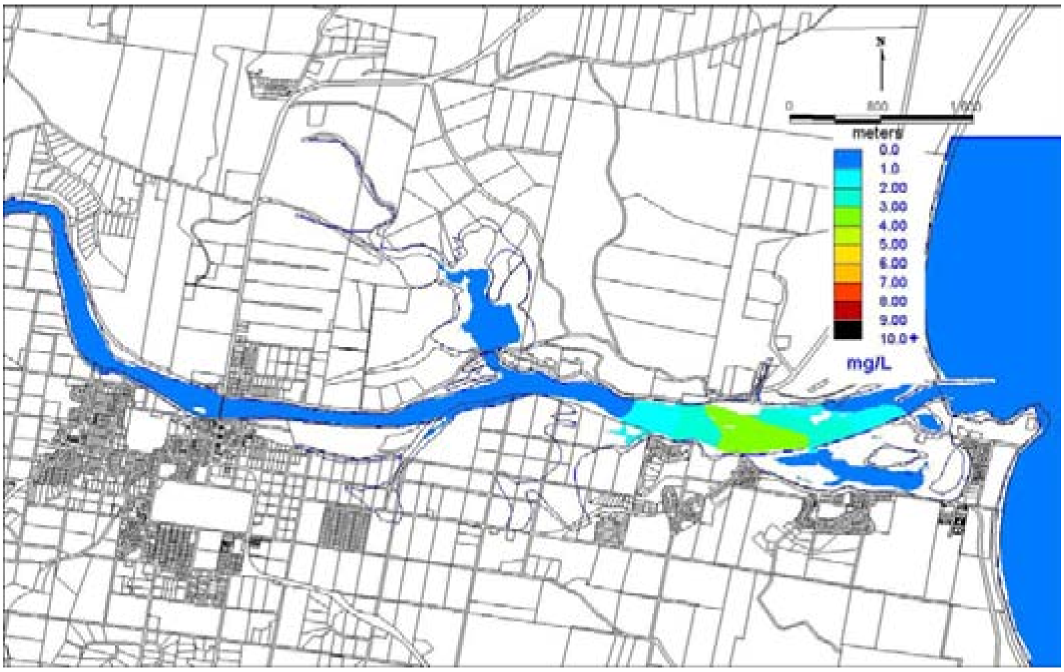

Figure 4.19: Dispersal of Dye after 6 hours, Scenario 2.

A major difference between Scenario 1 and Scenario 2 is the spread and dispersal of the dye within the first 6 hours (Figure 4.19). In Scenario 2, the pollutant is carried down stream so that the lower extent of the main concentration is just inside the training walls, so that on the first tide it is predicted that only minor amounts will be lost out to the ocean. Also the upper limit of the high concentration has not moved downstream as far as it did in Scenario 1. Another major difference between Scenarios 1 and 2 is the dilution of the pollutant. In Scenario 1 the highest concentrations after 6 hours were predicted to be between 1 and 2 mg/L. In Scenario 2 peak concentrations are predicted to be between 3 and 4 mg/L, which are predicted to be occurring around Preddys Wharf.

The model again shows that for a spill occurring at the sewage works in Ryans Creek during high tide there is the possibility for pollutants to be carried down to Pilots Station Backwater. The model also suggests that if such a spill was to occur during or near neap tides the consequences could be worse for the oyster leases as the pollutants are in much higher concentrations than if such a spill was to occur during spring tides.

Note that both cases tested looked at the worst possible scenario of the spill occurring at high tide. The possibilities of concentrated pollutants reaching Pilots Station Backwater would be less for spills at other times of the tide.

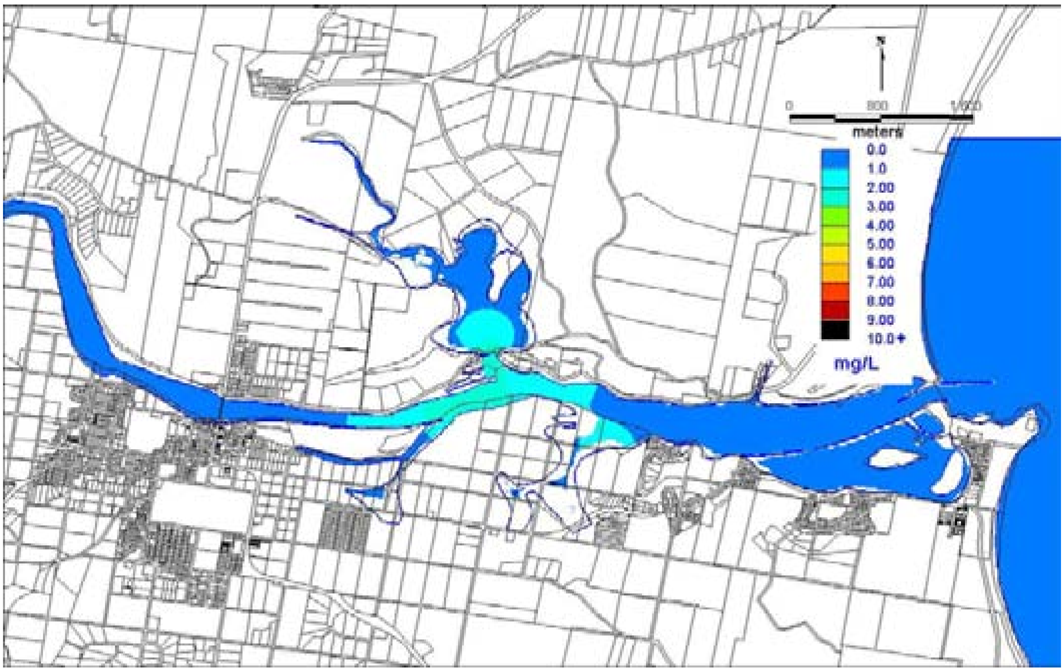

Figure 4.20: Dispersal of Dye after 12 hours, Scenario 2.

After 12 hours the spread of the pollutants for Scenario 2 is very similar to that for Scenario 1, with the pollutants having been carried back into the estuary and being concentrated in the vicinity of the junction with Racecourse Creek (Figure 4.20). The major difference is that concentrations for Scenario 2 remain higher than for Scenario 1.

The model predicts that after 3 days only 37% of the original spill will remain in the estuary and this has been dispersed throughout the estuary so that concentrations were not enough to be visible on our map. Consequently the 3 day data map has not been presented.

4.6.4.3 Scenario 3: Moruya Town Wharf, Mean Tide

The mean tide represents typical tidal conditions present in the estuary, inducing average current velocities and volumetric flow rates. This scenario represents a sewage discharge under average conditions in the vicinity of Moruya proper.

Figure 4.21 illustrates the fate of the dye within the model estuary as a result of the Scenario 3. The initial rapid drop is absent in this curve, as this scenario is performed in a region with deeper waters. An initial rapid dilution of the spill mass is therefore experienced, leading to a more homogenous mixing of the spill into the estuarine waters.

Extrapolating from Figure 4.21 the time for the pollutant to be dispersed so that only 37% of the initial mass remains in the estuary is approximately 125 hours. Figure 4.21 shows that after 100 hours the model predicts approximately 43% of the initial material spilled in the estuary will remain for Scenario 3.

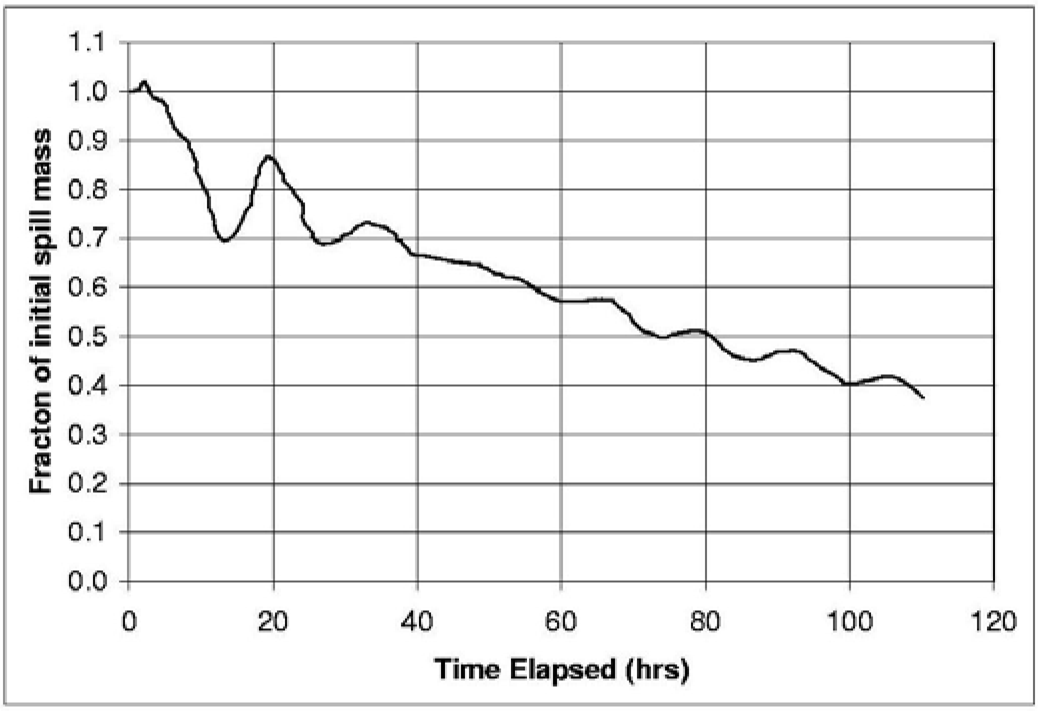

Figure 4.21: Dye Flushing from the Moruya Estuary, Scenario 3.

As Scenario 3 was timed to occur at high tide there was little dispersal of the spilled material in the first hour (Figure 4.22). After 6 hours the outgoing tide has carried the spill downstream so that the bulk of the spilled material is between the Anchorage and the junction of Racecourse Creek (Figure 4.23). Over the next 6 hours the incoming tide carries the spill back upstream so that the bulk of the material is in the estuary between Racecourse Creek and the hospital (Figure 4.24). Figure 4.24 also shows that major concentrations of the spill have been carried into Malabar Lagoon and up Racecourse Creek.

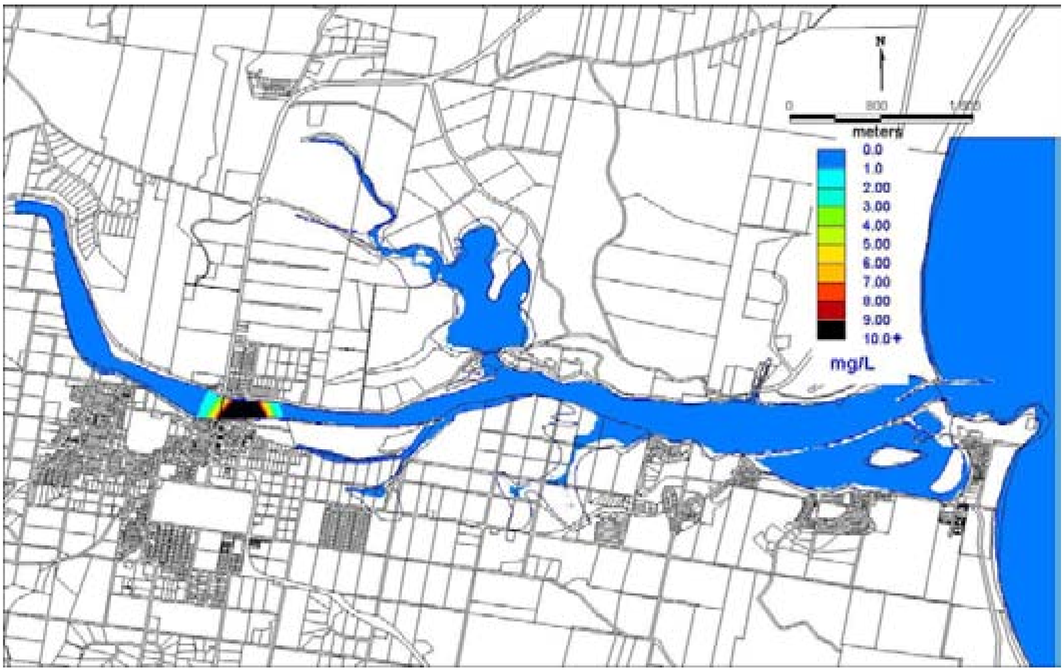

Figure 4.22: Dispersal of Dye after 1 hour, Scenario 3.

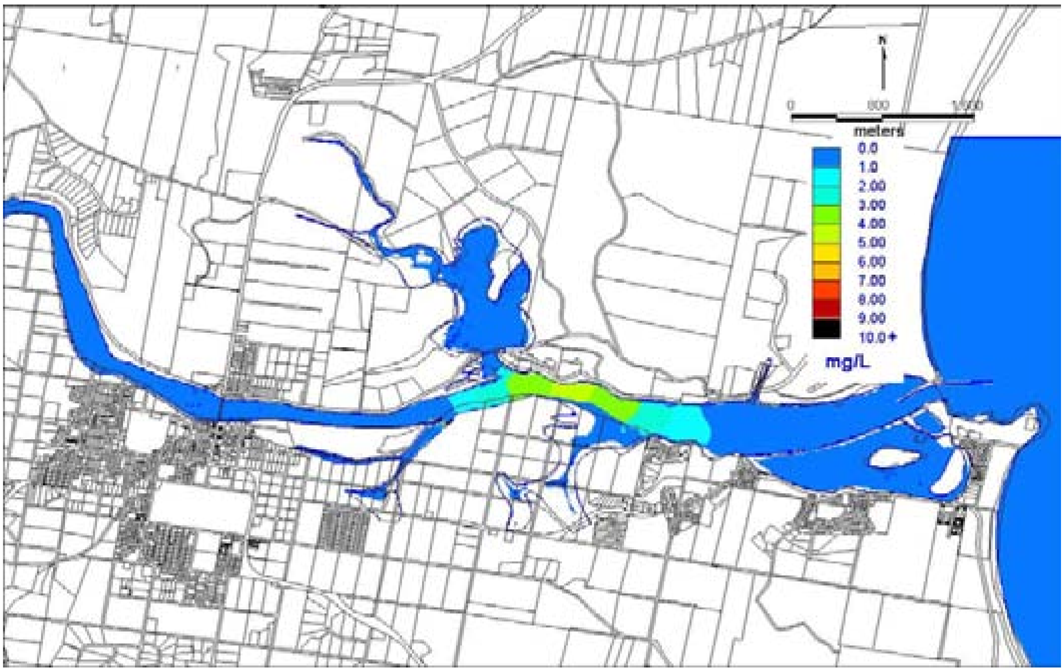

Figure 4.23: Dispersal of Dye after 6 hours, Scenario 3.

The model predicts that after 3 days approximately 50% of the original spill will remain in the estuary but this has been dispersed throughout the estuary so that concentrations were not enough to be visible on our map. Consequently the 3 day data map has not been presented.

4.6.4.4 Scenario 4: Kiora Bridge, Mean Tide

The results of the hydrodynamics modelling in the uppermost reaches of the estuary indicate that current velocities are generally low in that region. It was recognised earlier in Section 2.3 that this would therefore present a potential for pollutant stagnation. This scenario investigates the behaviour of a spill under mean tidal conditions in the upper reaches of the estuary, centred at Kiora Bridge.

Figure 4.24 illustrates the fate of the dye within the model estuary as a result of Scenario 4. There is an initial rapid drop in this curve, as the scenario is performed in a reach with shallow waters. Because no material is lost from the estuary over the 110 hours simulated in the model it is not possible to estimate a flushing time. Figure 4.24 shows that after 100 hours the model predicts all of the initial material spilled in the estuary will remain.

The dispersal maps show that over the first 12 hours the spill remains concentrated and in the vicinity of Kiora (Figures 4.25 to 4.27). Figure 4.28 reveals that after 3 days the model predicts the material will have been flushed downstream from the Kiora Bridge by about a kilometre by the freshwater inflow. After a simulation time of 4.5 days the bulk of the material is still upstream of Mogendoura Creek (Figure 4.8).

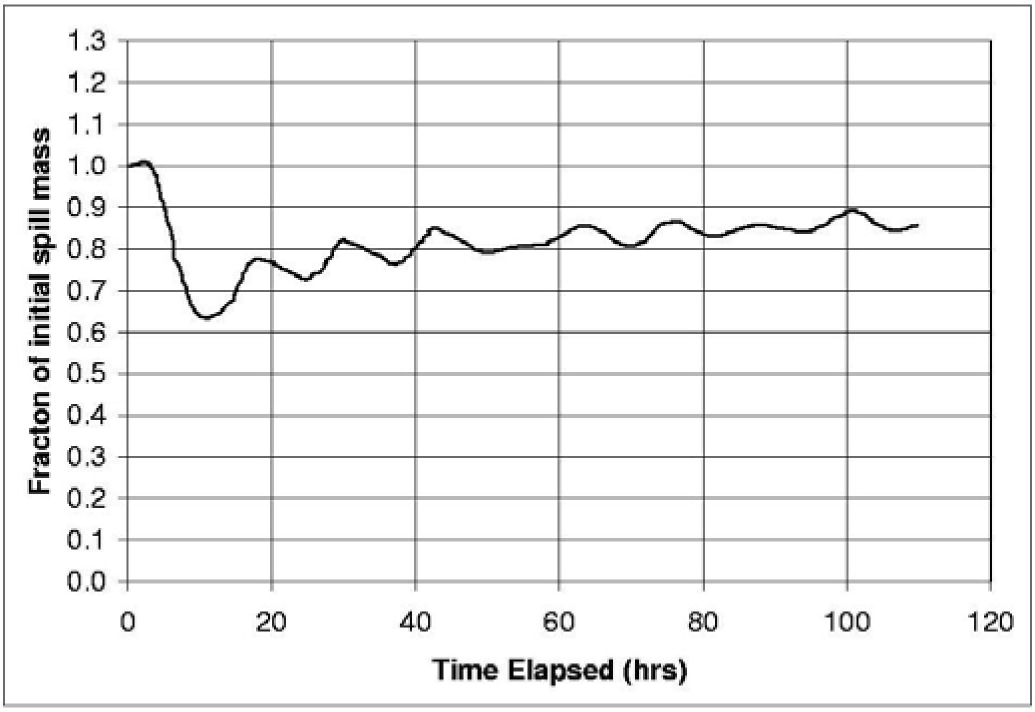

Figure 4.24: Dye Flushing from the Moruya Estuary, Scenario 4.

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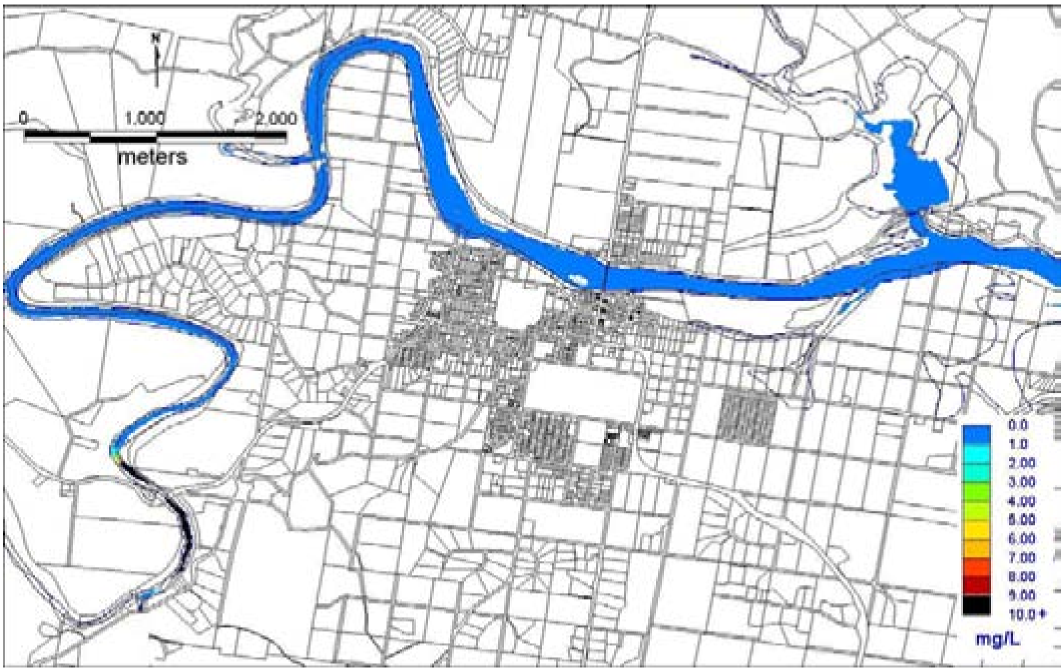

Figure 4.25: Dispersal of Dye after 1 hour, Scenario 4.

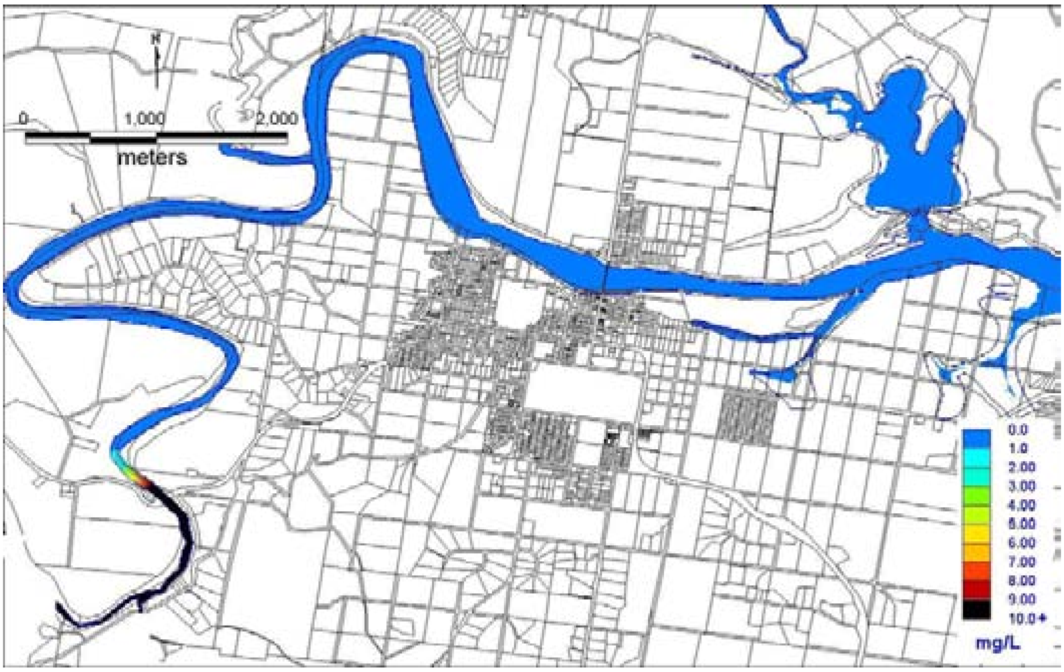

Figure 4.26: Dispersal of Dye after 6 hours, Scenario 4.

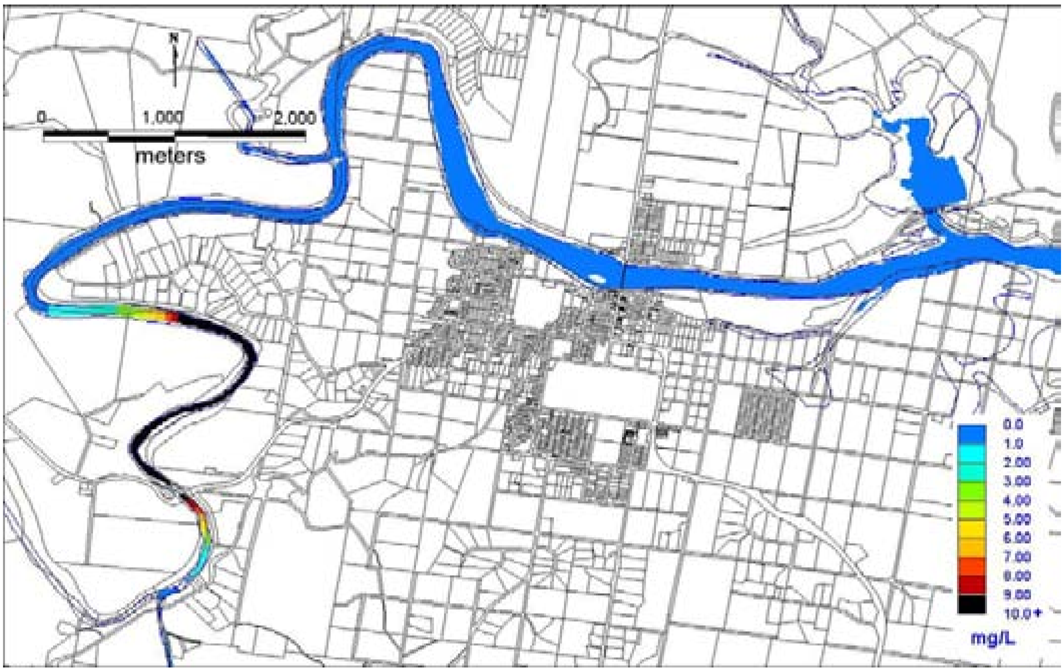

Figure 4.27: Dispersal of Dye after 12 hours, Scenario 4.

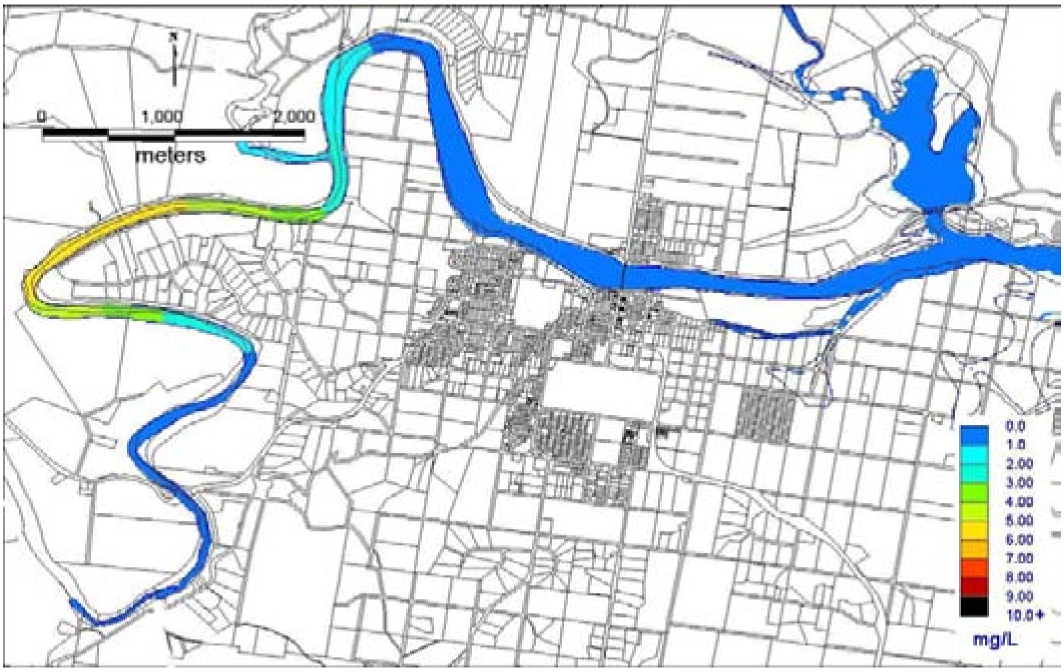

Figure 4.28: Dispersal of Dye after 3 days, Scenario 4.

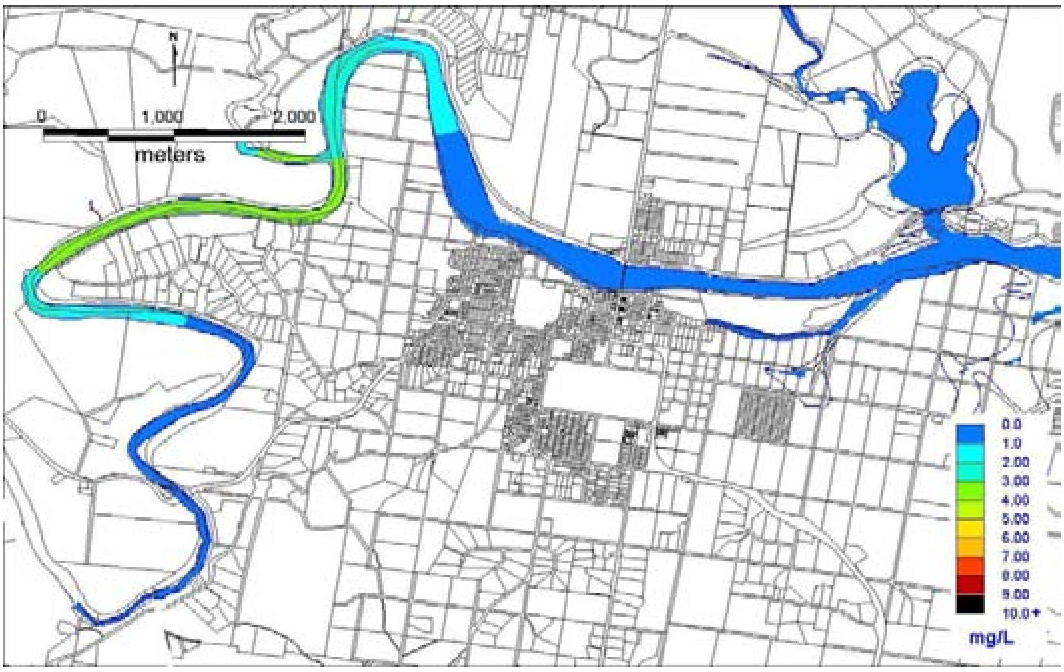

Figure 4.29: Dispersal of Dye at the end of the simulation, Scenario 4.

4.7 OVERVIEW

Water quality is a measure of the suitability of a body of water for particular uses. Water suitability is determined by the intended use and factors such as appearance, smell and the concentration of pollutants (SPCC, 1990).

Water quality data of the Moruya estuary have been compared to ANZECC water quality guidelines (2000) pertinent to uses including the protection of consumers of aquatic foods, recreational activities and the aquatic ecosystem health of the estuary. A review of the available water quality data shows that there are high concentrations of ammonia and phosphate. These are micronutrients required for the growth of plants. Consequently the data indicates that the Moruya Estuary has a potential for problems such as algae blooms caused by eutrophication (i.e. over fertilisation). The values obtained indicate that a more detailed investigation of these aspects of water quality is warranted.

Major points from the water quality review are:

- Faecal Coliforms (FC) - FC levels are of concern in the lower estuary and indicate potential problems for people eating wild caught oysters and other seafood;
- Phosphate Concentration - At all sites the ANZECC guideline for Aquatic Ecosystem Protection for phosphate concentration was exceeded indicating high nutrient loading to the estuary. This can potentially contribute to algal blooms in the future, although available nitrogen is the limiting factor;
- NOx Concentration – At all sites nitrate concentrations were within acceptable limits;
- Ammonia Concentration – Ammonia concentrations were consistently above the ANZECC (2000) trigger levels for ecosystem maintenance. Ammonia is

another source of nitrogen for plants and does indicate a potential for algal blooms.

- Dissolved Oxygen (DO) - Median DO concentration recorded at all sites was within all ANZECC guidelines;
- pH - All sites recorded pH values within the ANZECC guidelines; and
- Turbidity - In the lower estuary turbidity values exceeded ANZECC guidelines for aquatic ecosystem protection. Turbidity values in the upper estuary were within the guidelines.

Results from a hydrodynamics water quality model of the Moruya Estuary have shown that tidal exchange is important to estuarine water quality. Tidal exchange allows clean marine water to dilute pollutants within estuary water. The rate of pollutant dispersal within the water of the Moruya estuary was found to vary with distance from the sea. In the lower estuary, where tidal exchange was highest, more than 50% flushing of pollutant occurred within 30 hours of discharge. In the upper estuary pollutant flushing took longer than five days.

5 BANK EROSION

5.1 INTRODUCTION

The Data Compilation Study (Young and Thoms, 2000) reported that bank erosion is considered a major problem in need of management. It listed the following issues as possible factors causing erosion beyond the natural process:

- Increased sedimentation in the river channel (reduced channel cross sections and more material available for a sand blasting effect);
- Loss of natural vegetation filters/buffers;
- Poor tree retention along the banks; and
- Compromised foreshore usage.

Site inspection by the Geomorphologist, Dr Sandra Brizga and AMOG staff identified areas where:

- Animal and /or human traffic contributed to erosion;
- Banks of unconsolidated sediments are steep and slumping;
- Banks are slumping due to wave action;
- Rock walls have slumped due to loss of base support;
- Banks have eroded above and behind rock walls; and
- Large voids in the walls are reducing the effectiveness of the walls and increasing their susceptibility to failure.

Figure 5.1: Stability of rock-lined banks is a key issue in the lower estuary.

5.2 METHODOLOGY

A site inspection was undertaken by a Geomorphologist, Dr Sandra Brizga and her report is attached as an appendix. AMOG staff also made a site visit and their input has been added to Dr Brizga's work in this report.

The bank erosion component of the Process Study is based on the following investigations:

- Site inspections of the Moruya River estuary by boat and from land to provide a field assessment of the extent and type of bank erosion in the estuary;
- Analysis of recent and historical aerial photographs (the historical aerial photographs date from 1940 and are generally confined to the lower part of the estuary);
- Review of previous reports and information; and
- Assessment of the implications of the outputs of hydraulic modelling carried out by AMOG.

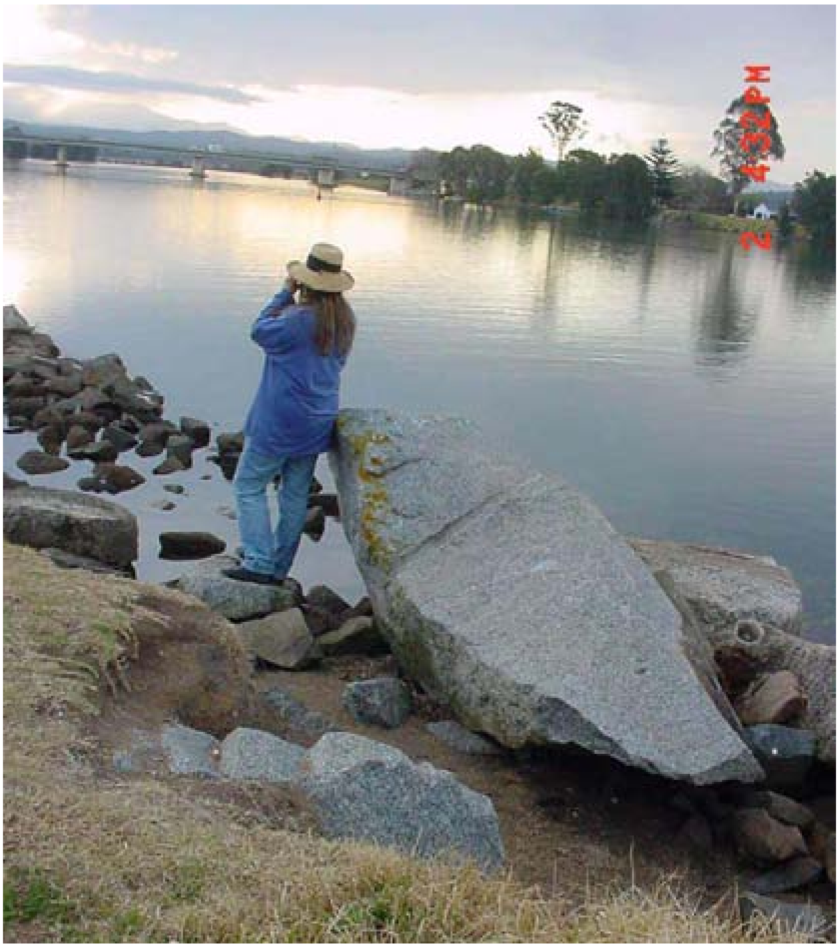

Figure 5.2: Bank scour due to large rocks.
Very large rocks do not necessarily provide effective bank protection. The large rock in the foreground of this photograph appears to have contributed to erosion by inducing scour behind it.

5.3 EROSION NATURE AND EXTENT

On the basis of the site inspection it was considered best to divide the estuary into three key areas for assessment of present erosion condition.

- Downstream of Princes Highway;
- Upstream of Princes Highway; and
- Malabar Lagoon.

These locations were each seen as having very different sets of erosion problems.

5.3.1 Downstream of Princes Highway

The banks of the Moruya River downstream of the Princes Highway have been extensively lined with rock riprap. Some of the rock walls along the river were constructed to facilitate navigation by coastal steamers, others for bank protection. Training walls for navigational purposes date back to the mid nineteenth century. The earliest known works were commenced in 1861 to provide a permanent channel at the river mouth (DPW 1978). More recently, the southern bank of the river opposite Malabar Creek confluence was rock lined to mitigate bank erosion as recommended by GHD (1981).

The stability of the rock-lined banks is a key issue in the Moruya River estuary downstream of the Princes Highway. Problems observed during the course of the site inspections include the collapse and slumping of sections of rock riprap due to loss of toe support, erosion of the banks above and behind the rock lining, and the existence of large voids in the rock matrix which reduce the effectiveness of the walls and increase susceptibility to failure. At the old Moruya Caravan Park, there are a number of substantial embayments behind the rock wall that may have been caused by instream flood and tidal scours or floodplain return flows. The collapse or slumping of rock walls causes rocks to fall into the river, posing a hazard to navigation.

Figure 5.3: Bank erosion behind the rock riprap.
Bank erosion behind the rock riprap lining was observed in a number of places.

Unlined banks occur in a few sections of the Moruya River estuary downstream of the Princes Highway:

- Banks formed of unconsolidated sediments at the downstream end of Racecourse Creek and on the inside of the bend opposite Garlandtown - these banks are affected by natural erosion processes that are likely to have been exacerbated in places by reductions in riparian vegetation and stock damage;
- Banks formed in bedrock, such as at the wharf near the Moruya Quarry - some bank erosion is evident in the sandy soils associated with granitic bedrock, but rates and extent of erosion are limited by the presence of hard bedrock; and
- The lagoon behind the training wall in the vicinity of Quandolo Island, where the natural river banks are separated from the main channel by a training wall which now effectively functions as the river bank under low and medium flow conditions- no erosion of the natural river banks was observed in the lagoon behind the training wall.

Comparison of a map made from 1999 aerial photographs with available historical aerial photographs does not show evidence of any major bank retreat due to erosion. However, it needs to be noted that the earliest photography made available to AMOG, from 1940, 1962, 1966 and 1971, covers only the lower 2 km of the river; the 1977 aerial photographs extend as far upstream as Racecourse Creek; and only the 1984 photographs cover the whole reach to the Princes Highway. Slow rates of bank retreat are also indicated by GHD (1981) who noted that bank erosion at Mynora Flats has occurred over a long period but the continued presence of car bodies in one area indicated that not much change had occurred in recent years. All the aerial photographs show extensive shoaling in the river channel, and changes in the position of sand shoals are apparent from comparisons of photographs for different dates. The most significant change apparent from the comparisons of aerial photographs is a build up of sediment in the Pilots Station Backwater since 1940. This coincides with the development of a barrier across the seaward end of the lagoon, extending from the pre-existing barrier to the breakwater.

Figure 5.4: Rock riprap lining only at high tide.
The vertical extent of the rock riprap lining in some areas is limited to the area around and just above high tide level.

5.3.2 Upstream of Princes Highway

Rock lining of the river banks upstream of the Princes Highway is limited to the area adjacent to, and immediately upstream of, Moruya. Like the rock lining in the lower estuary, there are problems with the stability and effectiveness of sections of rock lining in this reach.

Bank erosion in the unlined areas is widespread, particularly where the banks consist of unconsolidated alluvial sediments. Erosion occurs on both sides of the river, not just the outer banks of bends, although it should be more severe on outer banks where current velocities are higher. Bank slumps, collapse and tree falls apparently related to undercutting at high tide level were observed, and notching at high tide level was evident in some places.

A large proportion of the upper estuary banks are of unconsolidated silty sands that have been deposited during major floods. Such sediments are very susceptible to damage from trampling by animals or humans.

In the upper estuary localised damage to banks resulting from uncontrolled stock access was evident. In areas where stock had been excluded by fencing, damage was still evident. This may have been caused by the periodic stock access to these areas or due to wildlife. Some trampling damage was seen to be associated with wombat burrows.

5.3.3 Malabar Lagoon

Localised bank erosion was observed along the shoreline of Malabar Lagoon, adjacent to the western end of the road crossing. Local advice indicates that the area affected by erosion is reclaimed land and the erosion is occurring in the fill rather than natural bank materials. Minor erosion was also observed on the western shore of the lagoon within 800m of the road causeway, on cleared and heavily grazed land. No reports of erosion in Malabar Lagoon were found in the literature. Clarke and Pressey (1981) reported that anecdotal evidence from local residents indicated significant sedimentation of Malabar Creek and Malabar Lagoon took place in the period 1950-1980 (Clarke and Pressey 1981), which they attributed to receipt of sediment from erodible agricultural land.

Figure 5.5: Vertical banks subject to bank erosion at the rear of the motel.

Vertical banks subject to erosion occur upslope of the rock riprap in some areas, such as at the rear of the hotel upstream of the Princes Highway. Also note the close proximity of the development to the river banks.

5.4 CONTRIBUTORY FACTORS

5.4.1 Tidal Processes and Wave Action

Much of the bank erosion in the estuary was observed to be associated with water levels within the tidal range. This type of erosion is recognised by the existence of undercutting of the bank at high tide level and then a slumping or collapse of the overhanging bank (with or without trees).

The processes that contribute to this type of erosion include boat and wind generated wave action and frequent wetting and drying of the banks by tidal inundation.

5.4.2 Meander Process

In any meandering river channel, flow velocities are unevenly distributed across the river cross-section so that higher velocities at outer banks of bends lead to higher rates of erosion in these areas. The Moruya Estuary should not be an exception to this general rule, although the results of hydrodynamics modelling for the once in one and once in 20 year floods do not show large differences in velocities between inside and outside bank locations at bends. This agrees with the field observations that bank erosion was occurring on both the inside and outside of bends.

Figure 5.6: Natural bank erosion near The Anchorage.

5.4.3 Floods

The reports on flooding of the Moruya River reviewed for this study do not make any special mention of bank damage associated with floods. However, this could be a reflection of these reports focusing on over bank issues such as flooding depth and sedimentation problems, rather than an implicit statement on the lack of erosion associated with floods. Floods can cause bank erosion in a number of ways:

- Saturation of the upper bank areas resulting in slumps when water levels recede;
- By removing sediment from the toe of the banks;
- Causing undercutting; and
- Direct attrition of the banks by flowing water and flood debris.

Hydrodynamics modelling shows that for the once in one year flood, velocities are typically in the order of 0.5 to 1.5 m/s, while in the once in 20 year flood, they are typically in the order of 0.5 to 2.5 m/s. These velocities are in the range capable of removing the sandy bed material in the bank toe areas, and of eroding soils and unconsolidated sediments exposed in the banks. Consequently, natural erosion would occur even during the relatively small floods expected to occur each year.

5.4.4 Bank Composition

Three main types of bank materials occur naturally in the estuary:

- Quaternary alluvium - associated with erodible banks in unconsolidated sediments. Deposits were observed to be sandy and no cohesive, with little structural strength, vulnerable to slumping and erosion. These sediments are common in the upper estuary and are prone to damage by animal trampling. Below Moruya where the banks are of alluvium these are mostly protected by rock walls. However, as previously discussed, problems were observed with the stability of these walls;
- Paleozoic granite - associated with sandy soils and rock outcrops - the sandy soils are erodible but the outcrops limit the extent of erosion; and
- Paleozoic sedimentary rock - associated with relatively stable banks compared to the Quaternary alluvium and Paleozoic granite.

Figure 5.7: Bank erosion due to stock damage.
Animal damage, either stock or wildlife, is a contributory factor in bank erosion in some places particularly where the banks are of unconsolidated sediments.

Figure 5.8: Burrowing animal damage of eroding bank.
Burrowing animals take advantage of the eroded banks and may make minor local contributions to bank erosion processes.

The river banks are steep and high in some places, particularly upstream of Moruya. This is likely to be a contributory factor to erosion, with the erosion process being part of a natural adjustment to a more stable bank slope.

5.4.5 Riparian Zone Management

Riparian vegetation can play an important role in maintaining bank stability as a result of the binding of bank materials by roots, coverage of bare surfaces, and increased hydraulic roughness leading to reduced current velocities in the near-bank zone.

Riparian vegetation loss has occurred on some sections of bank in the Moruya River estuary, and is likely to be contributing to bank erosion processes in these areas. However, bank erosion was also evident at sites where the banks were fully vegetated, where collapse or slumping of the banks had led to down slope displacement of riparian vegetation or tree falls into the water.

5.4.6 Powerboats

Powerboats can contribute to bank erosion as a result of increased wave action caused by their wake. Young and Thoms (2000) noted concerns about powerboat wakes being a contributing factor in the bank erosion in the Yarragee reach of the estuary, which is used for water skiing.

Our observations found extensive undercutting of the bank caused by waves in this reach of the estuary and in other reaches further up the estuary such as near Kiora Bridge where, presumably, boats rarely travel. This shows that the banks are very susceptible to wave action and that even the natural wind generated waves produce undercutting.

Waves generated by boats would add to the impact of wind generated waves but we could not estimate to what extent.

Figure 5.9: Fallen trees associated with bank slumping.
A significant number of tree falls associated with bank slumping or collapse were observed in the Moruya River Estuary upstream of the Princes Highway Bridge.

5.4.7 Sea Level Change

Sea levels along the South Coast of NSW are thought to have been stable for the past 6500 years (O'Brien 2001). If sea levels rise in the future, this will shift the zone affected by tidal wetting and wave action up-bank, which in turn may lead to an increase in bank erosion, at least during the adjustment phase. This is indicated by experience in the upper section of the Mary River estuary, Queensland, where the raising of high tide levels as a result of tidal amplification in response to the installation tidal barrage exacerbated bank erosion (Cameron McNamara 1984).

Figure 5.10: Natural granite outcrops.
Natural granite outcrops limit the extent of bank retreat, although the sandy soils above them are vulnerable to erosion if they are exposed in the river banks.

Figure 5.11: Eroding bank upstream of the Princes Highway Bridge with no remnant indigenous riparian vegetation. Factors contributing to erosion at this site include natural meander processes (see sediment transport results for the 1 year flood), and wetting and wave action under low flow conditions. The erosion has possibly been exacerbated by boat wash.

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5.5 BANK STABILISATION AND REMEDIATION

Lower Estuary

The lower estuary is mostly protected by rock riprap so that there are no major bank erosion problems. These walls are failing in many places because of poor insight into the causes of erosion during the design and construction phases.

The forces that act on a sloping rock wall are:

A. External load due to waves and currents;
B. Interaction of external load and the inside of the structure leading to loss of soil from behind the rocks;
C. Load from the landward side due to high ground-water potential in the soil mass; and
D. Load from the sloping soil on the landward side.

The external Force A requires large heavy stones whereas Force B requires the structure to be sand tight or use of a filter material. If the protection is impermeable, then Force C becomes a threat and leads to failure. Forces C and D are large where the bank is high or steep. Thus the design needs to address all the contradicting factors.

Failure mechanisms that have been observed in the Moruya Estuary are:

- Toe erosion - Underestimated or neglected toe protection of rock revetments, leading to movements such as toppling forwards and to subsidence of the lowest stones, thereby destabilising the whole wall;
- Over topping - Rock protection does not extend high enough and floods or extreme tides wash over causing erosion of the bank and possibly removing rocks from the top of the wall; and
- Improper rock size and gradation. Rock of a mean size too small to withstand the hydraulic forces (A above) will be eroded as will rock with a grading which includes very fine sizes, while a grading with too high a content of very coarse rock will contain large voids permitting leaching of the bank soil.

The riprap walls should be inspected regularly to check they are meeting the intended purpose and to modify the design, if necessary.

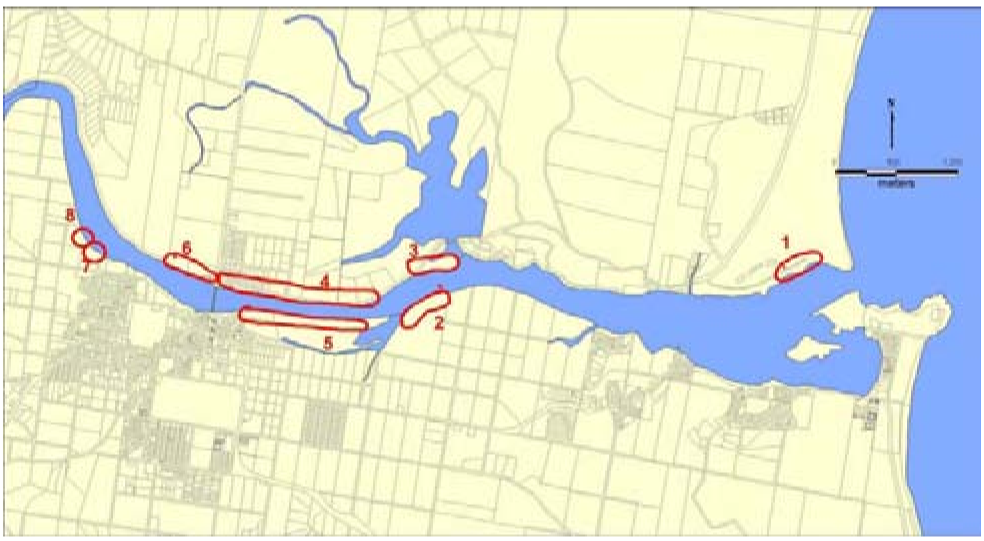

Figure 5.12: Areas with different problems in the rock riprap walls identified.

Table 5.1 Erosion problems identified in the lower estuary Locations of areas are shown in Figure 5.12	
AREA	PROBLEMS
1	Walls are only in high tide area with no protection from undercutting Erosion behind the wall Bank slumping Large interstitial spaces Rock migration into channel
2	Unprotected bank erosion
3	Unprotected bank erosion
4	Large interstitial spaces Toe support failure Wall instability Rock migration into channel
5	Erosion behind the wall
6	Erosion behind the wall Large rocks with interstitial spaces
7	Wall unstable
8	Unprotected bank eroding Danger of outflanking rock wall

The problems with the existing wall structures are both widespread and diverse in nature. As a first step towards the development of a remediation plan for the lower estuary, an engineering audit of the rock lining and the development of a detailed remedial strategy to address problems is required. The specifications for such an audit are provided in Appendix C.

The estimated cost for undertaking this work would depend on the size of the sections on which inspections were based. It is suggested that 100 m sections be used. This should require 3 to 5 days field work and 2 weeks to compile the data and report. The cost for getting this work undertaken should be approximately $25,000.

There are shorter lengths of bank which are not protected by rock. Options that are feasible for protection of these banks in the lower estuary are:

- Planting of vegetation along the stream edge;
- Reduction of trampling by people and stock;
- Reduction of bank height by sloping upper part;
- Provision of full height rock revetment;
- Provision of part-height rock protection; and
- Provision of shingle beach to protect the toe.

The costs for the construction of new rock revetment wall for areas not at present covered or replacing the existing walls (excluding cost for removal of existing walls) are approximately $1,000 per metre as per Table 5.2. These estimates are based on a required wall height of 3 m. In many places repairs to the existing walls would be possible and the costs of undertaking these would depend on the findings from the audit.

Table 5.2: Estimated per meter costs of building rock revetment wall
This cost is based on a wall height of about 3 m with 1.5 m of the wall extending below the water surface.

Description	Rate	Quantity	Cost ($)
Construction			
-Bank Face Preparation (cut and fill by machine)	$4.35/m^3$	30 m^3	130.50
- Geotextile Supply	$3.35/m^2$	12 m^2	40.20
- Geotextile Placement (Labour cost)	$2.00/m^2$	12 m^2	24.00
- Filter Layer (machine filled)	$26.70/m^3$	2 m^3	53.40
- Primary Rock Armour (machine dump)	$43.00/m^3$	9 m^3	387.00
- Primary Armour (hand placing)	$25.00/m^2$	12 m^2	300.00
Site Restoration			
- Sorting and removal of unsuitable material and carting 10 km	$34/m^3$	0.5 m^3	17.00
		Total	952.10
		Total Cost with 15% contingency	142.80
		Estimated costs (after rounding)	$1,000.00

5.5.1 Upper Estuary

Unconsolidated silt sands form the banks of much of the upper estuary and hence the banks are highly susceptible to erosion. The area would have moderate natural erosion, though clearing, introduction of stock and boating would have accelerated this. The land being eroded is mostly used for grazing and thus only low cost stabilisation projects are justified. This is further compounded because high current velocities during floods will carry away any protection structures. Consequently, a detailed evaluation needs to be undertaken on the risks and benefits before any work is undertaken.

The main erosion mechanism operating in the upper estuary during non-flood periods is scouring of the bank toe, followed by slumping then removal of the slumped material. This is a continually occurring cycle and erosion control methods need to break or at least slow down the cycle in those few localities where it is causing concern. Scouring of the bank toe is speeded up by wave action; either wind or boat generated and slumping is accelerated by trampling either from stock or wildlife.

Under flood conditions there may be toe erosion, general erosion of the bank, and the formation of scour channels at points where the flow breaks out of the channel onto the flood plain.

5.5.1.1 Bank Toe Protection

Options that are feasible for protection of the bank toe in the upper estuary are:

- Planting of vegetation along the stream edge;
- Protection with logs;
- Rock protection placed along the toe; and
- Provision of shingle beach at toe.

Vegetation along the river edge reduces current speeds, absorbs wave energy and binds the soil. Vegetation is the only one of the protection methods considered which can provide some protection during floods. Potential for using vegetation is limited because it can only be used in areas where there is a gradual slope to the bank, which is usually not an area of high erosion. Environmental conditions will also limit the plants that could be used. No natural reed or sedge beds were observed in the upper reaches of the Moruya, so presumably there are times when salinity is too high for such plants. The only choice would therefore be mangroves and these would probably need to be re-established after every major flood.

The toe can be protected from erosion by anchoring logs or brush against the stream bank, a process known as brushing. Logs provide the greatest protection, but require more work than the use of brush. They are difficult to handle and unless well keyed into the stream bed are susceptible to undercutting. By using volunteer labour such as a land care group, and sourcing low grade timber logs, costs could be expected to be about $6,000 for a 100 m section and extensive repair would be required following a flood. Use of brush instead of logs, particularly if collected by volunteers locally could greatly reduce these costs and is probably the most viable option for bank protection in the upper Moruya Estuary.

A ridge of stone can be placed along the toe of an eroding bank to remove the attack point from the toe. This method is seen as one of the most reliable and economical methods for protection of sand bed channels (Rutherfurd *et. al,* 2000). Costs are highly dependent on the amount of rocks required which can vary between 1,500 and 6,000 kg/m.

A softer solution to toe stabilisation, but applicable only where the river bed forms a beach with a very mild slope in front of the bank, is to armour the beach with shingle. A thin covering of shingle of 25-40mm will provide protection against the wind waves, will reform after minor disturbance, and provides a pleasant natural surface to walk on. Cost would be lower than for other options, but like them it would require replacement after a flood.

5.5.1.2 Bank Slumping

Remediation methods to slow down or prevent bank slumping need to address the low cohesion of the soil and reduce damage by trampling from stock and wildlife. Options that are feasible for reduction of slumping of the bank in the upper estuary are:

- Planting of vegetation along the stream edge;
- Reduction of trampling by stock and native animals; and
- Reduction of bank height.

Vegetation suitably selected and placed can be used to reduce the rate of erosion where the stream bed is not migrating. Shrubs and ground cover can be used to protect the bank face and tree roots can help to bind the soil and increase cohesion. Tree roots would probably only give a small increase to the cohesion of the sandy soils along the banks of the upper estuary.

To be of value, the riparian zone needs to be at least 5 m wide when the trees are fully established (Abernethy & Rutherfurd, 1999). Therefore, in areas where erosion is occurring the zone needs to be wider so as to allow the trees to establish while erosion is occurring. As noted in AMOG's field observations there are areas with natural riparian vegetation that are suffering from bank erosion. Revegetation can only be expected to slow and not prevent the erosion process.

Trampling by stock and wildlife also needs to be controlled to reduce erosion rates. In the upper estuary, where fences have been erected to prevent stock damage to the banks, wombats seem to have flourished. By reducing vegetation while feeding and damaging the soil by trampling, wombats are creating similar problems to stock. In addition wombat burrows weaken the bank and on collapsing can form channels that focus water flow and enhance erosion.

High banks are more prone to slumping. The effective height may be reduced by slanting the upper part of the bank (above highest tide level) down at about 30° and vegetating the sloping bank.

5.5.2 Malabar Lagoon

Like the upper estuary the land being eroded at Malabar Lagoon is being used for grazing and therefore only low cost methods of bank stabilisation and remediation are justified. Because of the low bank height, slumping is not an issue here so toe protection would be all that is required.

The two issues of concern are stock damage which could be prevented by fencing and undercutting by wave action. Wave action could be prevented by placing logs or a ridge of stone in front of the bank.

5.6 OVERVIEW

Bank erosion is considered by the community to be a major problem in need of management. Erosion is a natural process due to natural meandering of river, wave action and sometimes due to flood events. The Moruya Estuary is highly susceptible to erosion because in a large number of places the banks are composed of unconsolidated fine materials with sands and silts mixed in different proportions.

Our field investigations found that in the upper estuary undercutting of the bank was common but generally not severe. Undercutting of the bank is caused by the action of waves. These waves can be generated by wind and boat wash. Bank undercutting occurred both at Yarragee and higher up the estuary, such as near Kiora Bridge where boating would be infrequent indicating that wind generated waves play an important part in bank erosion of the upper estuary.

Problems of trampling and overgrazing associated with both stock and wildlife were also contributing to erosion problems in the upper estuary.

The Data Compilation Study identified concerns that catchment activities such as runoff from gravel roads, land clearing, mining, grazing, etc, were causing erosion in the estuary. Increased erosion due to such activities is usually associated with estuaries where there is very little natural sediment load. No evidence was found that such activities in the catchment were directly responsible for erosion in the Moruya Estuary but they do have the potential to increase the sediment load of the stream. Natural sediment loads for the major rivers in southern New South Wales are probably extremely high, e.g. the Towamba which has virtually no development in its catchment. Consequently it is very difficult to establish the impact of the above activities on sediment loads in the Moruya Estuary.

The potential for increased sediment load from human activities in the catchment is discussed in Section 3. Sediment loads being fed into the estuary since European settlement were probably near maximum. Consequently, there has probably been little increase in these loads since settlement, thus it is unlikely that these factors operating in the catchment are impacting on erosion. This is supported by the fact that the geomorphological study by Dr Sandra Brizga found no evidence to support catchment activities outside the estuary were having a significant impact on bank erosion in the Moruya Estuary.

Very slight erosion was observed around Malabar Lagoon probably because there is a net sediment input from eroding agricultural lands leading to sediment input to the Malabar Lagoon catchment during floods.

Most of the banks in the lower estuary have had rock walls erected to protect them from erosion. These walls are basically dumped rocks and do not appear to be withstanding the loads due to currents, water level fluctuations and waves action.

Site inspections of the rock walls revealed:

- Slumping of rock walls due to loss of toe support;
- Erosion of banks above and behind rock walls; and
- Large voids in the walls, reducing their effectiveness and increasing their susceptibility to failure.

There is a need to undertake an engineering audit to determine where the walls need to be replaced and strengthened.

6 CONCLUSIONS

This Process Study was undertaken to:

- Assess the dynamics of estuarine circulation;
- Establish the type, source, pattern and rate of sedimentation;
- Assess water quality and relate this to water movement; and
- Determine the scale and nature of bank erosion and make an assessment of likely causes and appropriate remedial measures.

6.1 ESTUARINE HYDRODYNAMICS

A hydrodynamics model of the Moruya Estuary was constructed and calibrated and several scenarios run. This model is now available for managers to run in testing other scenarios.

The model was found to give an excellent representation of the river system for neap tides and a good representation for spring tides.

Current velocity output from the hydrodynamics model revealed areas where attention to water quality and erosion are required in the subsequent analysis.

6.2 SEDIMENTATION

The Deua River was identified as the major source of sediment input to the estuary. Sediment stores in the lower sections of the river were found to be such that for any flood event the maximum amounts of sediment that could be carried by the currents would be fed into the estuary.

Coastal sediments carried in through the mouth were recognised as being a major contributor to sedimentation in the lower 2 km of the estuary.

It has been postulated that rates of sedimentation have increased in the Moruya Estuary over the past 30 years (Pollock, 1999 cited in O'Brien, 2001). Factors that may have contributed to increased sedimentation are increased bush fires, long term changes in weather patterns, increased urbanisation, clearing, livestock, mining, etc. However, from aerial photos taken over the past 60 years it was apparent that over this period, the Moruya estuary has always had extensive sandbanks and that these were constantly moving.

6.3 WATER QUALITY

Water quality in the estuary is generally good and within ANZECC guidelines for recreation and contact.

Phosphate concentrations at all sites exceeded the ANZECC guideline for Aquatic Ecosystem Protection. Phosphate could potentially contribute to algal blooms in the future. The management study should investigate ways to reduce phosphate inputs or at least ensure that they do not increase.

Sites in the lower estuary near the oyster leases had faecal coliform counts that exceeded the ANZECC guidelines for Aquatic Foods.

Close to the mouth of the estuary the turbidity values exceed ANZECC Aquatic Ecosystem Protection guidelines but turbidity values in the upper estuary are within the guidelines. This may be due to natural mixing in the faster flowing waters, or due to anthropogenic changes such as eutrophication and sewage discharge.

6.4 BANK EROSION

Downstream of the Princes Highway, stability of the rock-lined banks is a major issue. Problems observed during the course of the site inspections include the collapse and slumping of sections of rock riprap due to loss of toe support, erosion of the banks above and behind the rock lining, and the existence of large voids in the rock matrix which reduce the effectiveness of the rock lining and increase its susceptibility to failure. As well as damage to the banks, rocks falling in and moving into the channel are a potential boating hazard.

It was beyond the scope of this study to determine which areas are in need of major repairs and to prioritise the order that these be undertaken in. It is recommended that a comprehensive engineering audit of the rock walls in the lower estuary be undertaken.

Upstream of Princes Highway, a large proportion of the banks are of unconsolidated silty sands that have been deposited during major floods. Such sediments are very susceptible to damage from trampling and undercutting. In the upper estuary localised damage to banks resulting from uncontrolled stock access was evident. In areas where stock had been excluded by fencing damage was still evident. This may have been caused by the periodic stock access to these areas or due to wildlife. Occasionally, trampling damage was seen to be associated with wombat burrows. Erosion problems caused directly by human activities (trampling and car access) were limited to the popular "picnic area" at the end of Yarragee Road.

In the upper and mid-estuary undercutting of the banks was widespread. It occurred in areas where boating was likely and other areas where there was probably a low level of boating (e.g. near the Kiora Bridge). Such erosion is caused by frequent wetting of the banks (tidal action) and waves. Both wind and boat generated waves would be responsible for the undercutting. Undercutting was not only found to be occurring in areas where the riparian vegetation had been removed, but also in areas where there were well established forests. This suggests that bank stabilisation could not be achieved by a revegetation process alone.

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