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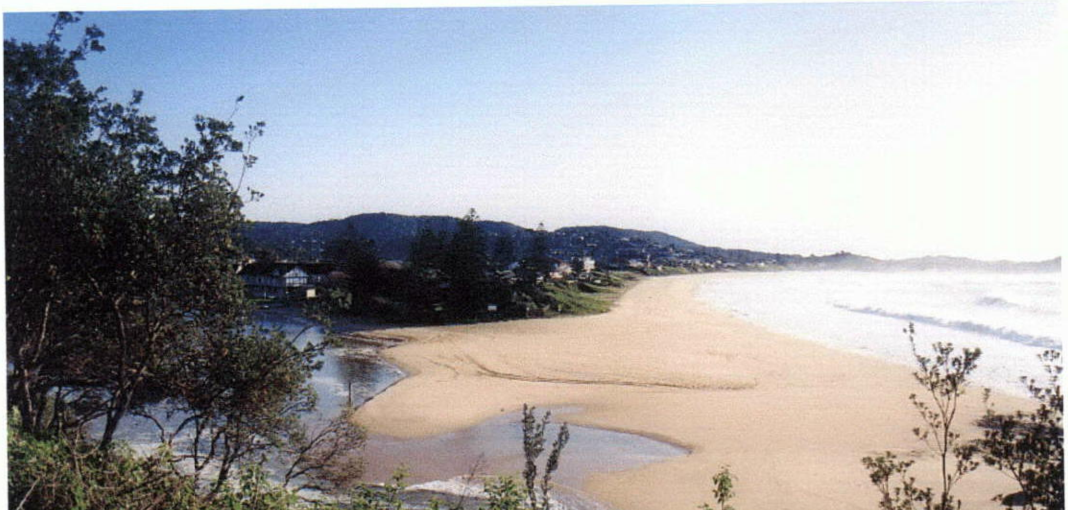
GOSFORD CITY COUNCIL

TERRIGAL LAGOON FLOODPLAIN MANAGEMENT STUDY



NOVEMBER 2001

WEBB, McKEOWN & ASSOCIATES PTY LTD

GOSFORD CITY COUNCIL

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Webb, McKeown & Associates Pty Ltd
Level 2, 160 Clarence Street, SYDNEY 2000
Telephone: (02) 9299 2855
Facsimile: (02) 9262 6208
92067:TerrigalFPMS.wpd

Prepared by: ____________

Verified by: ____________

FOREWORD

The State Government's Flood Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through the following four sequential stages:

1. Flood Study
   - determines the nature and extent of the flood problem.
2. Floodplain Management Study
   - evaluates management options for the floodplain in respect of both existing and proposed development.
3. Floodplain Management Plan
   - involves formal adoption by Council of a plan of management for the floodplain.
4. Implementation of the Plan
   - implementation of flood mitigation works and measures to protect existing development,
   - use of development controls and planning measures to ensure new development is compatible with the flood hazard,
   - amendments to relevant Local Environmental Plans to reflect Council's flood policy and development controls.

The Terrigal Lagoon Floodplain Management Study constitutes the second stage of the management process for Terrigal Lagoon and its catchment area. This study has been prepared for Gosford City Council by Webb, McKeown & Associates and provides the basis for the future management of flood liable lands adjacent to Terrigal Lagoon.

This study was largely undertaken in accordance with the NSW Government's 1986 Floodplain Development Manual. This manual was superseded by the Floodplain Management Manual which was introduced in January 2001 when this present report was nearing completion. The terminology and approach used in this report largely relate to the 1986 manual. In some places the updated terminology has been introduced, and carried through to the Plan.

SUMMARY

Terrigal Lagoon has a catchment area of approximately 9.5 square kilometres and lies wholly within the boundaries of Gosford City Council. The area of the lagoon is approximately 0.3 square kilometres. Flooding of roads and residential areas within the catchment has occurred on a number of occasions in the last 20 years.

In the Terrigal Lagoon Flood Study a WBNM hydrologic model and a RUBICON hydraulic model were established and used to determine the design flood levels in the lagoon and adjoining floodplain.

Gosford City Council sought to examine the range of floodplain management measures which could be employed, firstly to protect existing development as far as possible, and secondly to ensure that any new development would be flood compatible. In accordance with the 1986 Floodplain Development Manual, Council approached Public Works (now Department of Land and Water Conservation - DLWC) for assistance in the preparation of a Floodplain Management Study and Plan. Council established a Floodplain Management Committee, consisting of Councillors, Council Officers, Public Works, Department of Planning and community representatives to overview the study.

The design flood levels determined in the Flood Study have been used in this report to define the extent of the existing flood problem within each of the following floodplain management areas.

	Floodplain Management Areas
1.	The lagoon water body
2.	Bundara Avenue
3.	Northern End of Ocean View Drive Bridge
4.	Southern Shore of the Lagoon
5.	West Arm (west of the Willoughby Road Bridge)
6.	Farrand Crescent
7.	Ogilvie Street
8.	Golf Course
9.	Windsor Road
10.	Upstream of Willoughby Road causeway
11.	Upstream Catchments

The number of buildings inundated above floor level in different flood events is shown below for each floodplain management area.

Design Flood	Floodplain Management Areas - Buildings Inundated									Total	Tangible Flood Damages ($000's)
	2	3	4	5	6	7	8	9	10		
Extreme	114	26	15	2	19	3	4	23	4	210	4020
1% AEP	88	20	8	0	16	2	3	16	4	157	2801
2% AEP	86	17	6	0	15	2	3	12	3	144	2450
5% AEP	82	13	5	0	15	1	3	5	2	126	2030
10% AEP	71	9	4	0	15	1	2	3	2	107	1629
20% AEP	64	7	3	0	14	1	2	1	2	94	1345

Notes: Tangible damages do not include damages to public utilities (roads, reserves, etc.).
The average annual damages based on the above figures are $680 000.
Based upon existing design flood levels (1% AEP = 3.0 mAHD).
Excluding Area 11.

A review of the Flood Standard was undertaken as part of the study and the 1% AEP flood was considered to be an appropriate Flood Standard for the catchment.

Initially a descriptive assessment of the range of available floodplain management measures was undertaken. Subsequently these were further refined and a more detailed examination of several of the more prospective measures undertaken for each flood liable area. The measures were evaluated taking into account Rivercare guidelines and the principles of Ecologically Sustainable Development. The tabulation on the following pages shows the measures considered and their outcomes.

The majority of work undertaken for this study was completed in 1994. Damages and cost estimates have been updated to $1999.

Floodplain Management Measures - Terrigal Lagoon

MEASURE	PURPOSE	COMMENT
FLOOD MODIFICATION:		
DAMS/RETARDING BASINS/ON-SITE DETENTION (Section 4.2.1)	Reduce flooding downstream.	Not viable on economic and practical grounds.
RETARDING BASINS (Section 4.2.1)	Reduce flooding downstream.	Possible.
RIVER IMPROVEMENT WORKS (Section 4.2.2) • Dune maintenance • Desnagging • Dredging • Realignment • Reconstruction • Remove hydraulic restrictions	Increase hydraulic capacity of creek to reduce flooding.	• Lowering of entrance berm would provide a significant benefit. • Not applicable. • Nil benefit in the lagoon. • Environmental concerns. • Not applicable. • - high cost, - environmental impacts, - limited benefits.
FLOODWAYS (Section 4.2.3)	Provide a defined overbank area where a significant volume of water flows during floods.	Not applicable for lowering lagoon levels.
LEVEES (Section 4.2.4)	Prevent flooding of protected areas.	Relatively expensive and may introduce further problems. Several possible locations.
CATCHMENT TREATMENT (Section 4.2.5)	Reduce runoff from catchment.	Should be considered as a long term measure.
PROPERTY MODIFICATION:		
HOUSE RAISING (Section 4.3.1)	Prevent flooding of individual buildings.	Should be considered although most dwellings are only marginally affected.
PLANNING AND DEVELOPMENT CONTROLS (Section 4.3.2)	Reduce potential hazard and losses.	Should be considered. Existing development may inhibit rezoning.
VOLUNTARY PURCHASE (Section 4.3.3)	Purchase of flood liable properties in hazardous areas.	High cost and most dwellings are in low hazard areas.
RESPONSE MODIFICATION:		
FLOOD WARNING (Section 4.4.1)	Enables evacuation of people and property to reduce actual flood damages.	Probably insufficient time available.
INFORMATION/EDUCATION (Section 4.4.2)	Educate people to minimise flood damages and reduce the flood problem.	A cheap, effective method but requires continued effort.
FLOOD INSURANCE (Section 4.4.3)	Offset a random cost with a series of regular payments.	Not available at the present time.
FLOOD HAZARD AT ROAD CROSSINGS (Section 4.5)	Reduce the hazard at road crossings.	Within the residential areas there are no practical solutions. At Willoughby Road in the long term the crossing should be upgraded. In the short term improved information and public education are required.

Development Control Measures - Terrigal Lagoon

The following development control measures were examined.

STRATEGY	RESPONSE
Maintaining a minimum water level in the lagoon.	Rejected as not viable.
Dredging of the lagoon.	No justification for this measure to be undertaken.
Upstream catchment development.	Close monitoring of proposed developments and the use of measures to minimise increases in flow should be employed.
Filling on the perimeter of the lagoon.	Limited amount of filling (for building pads or on low lying land to 0.2 m above the let out level) to be permitted subject to strict guidelines.
Greenhouse Effect.	Effect to be monitored. Possibly introduce an additional "Greenhouse" freeboard of say 0.3 m.

Subject to the guidelines provided in this report, the above measures will not result in a major impact upon the flooding behaviour of the catchment. Consideration should be given to the possible economic, social and environmental costs.

TERRIGAL LAGOON
FLOODPLAIN MANAGEMENT STUDY

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1. INTRODUCTION

1.1 General

Terrigal Lagoon is a small coastal lagoon within the Gosford City area (Figure 1). The lagoon has a surface area of approximately 0.3 square kilometres discharging to the Pacific Ocean at Terrigal Beach. The total catchment area to the Pacific Ocean is approximately 9.5 square kilometres and thus the lagoon represents 3% of the total catchment area.

A number of properties surrounding the lagoon are very low lying, and flooding has caused damage and loss of property in the past. In an attempt to reduce the flood problems, Council mechanically opens the entrance when the lagoon water level approaches a critical point. The task of opening the lagoon entrance during floods can be both difficult and dangerous at times.

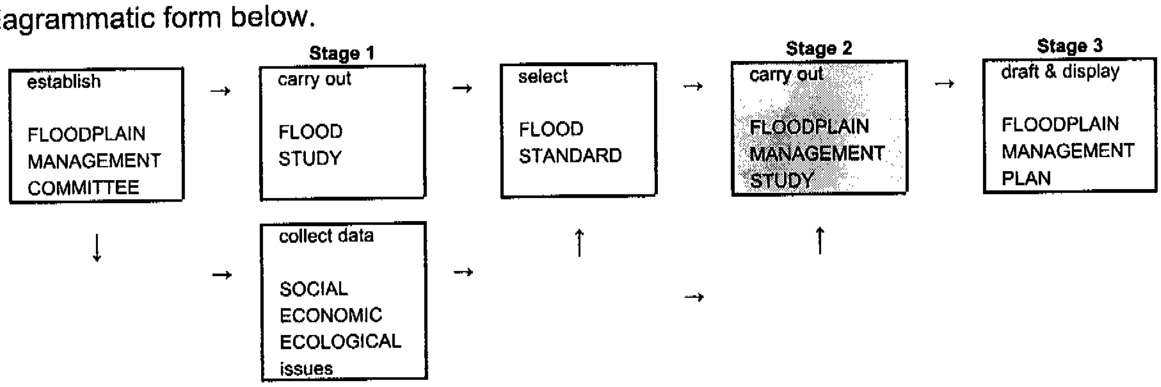
In the last 30 years the catchment has undergone significant changes, from a predominantly rural community, to a highly urbanised community impacts in parts. There has also been a significant increase in population and a heightened awareness of environmental issues. These changes have already affected the lagoon and there is the potential for further change. There is therefore a need to define the existing flood problem, develop appropriate strategies and carefully manage future development upon the floodplain.

A Flood Study (Reference 1) completed the first stage of the floodplain management process. This present report describes the preparation of a Floodplain Management Study, this being the second stage in the development of an overall Floodplain Management Plan for Terrigal Lagoon.

All levels in this Report are to Australian Height Datum (AHD). AHD is the common national plane approximating mean sea level.

1.2 Approach to the Study

Details of the floodplain management process are provided in the Foreword of this Report in diagrammatic form below.



The objective of this study was to determine suitable floodplain management strategies for the flood liable areas adjoining Terrigal Lagoon. These strategies needed to address all of the following factors:

- the existing flood problem,
- the control of lagoon water levels arising from catchment runoff and also inundation by ocean surge,
- the control of silt entering the lagoon, and removal of existing silt deposits,
- the effects of further urban development,
- the aesthetic, recreational and environmental condition of the lagoon and foreshore areas,
- any possible flood mitigation works,
- the control of pollutants entering the lagoon.

Future development options need to satisfy all of the above factors and meet the following criteria:

- flood risk to existing flood liable development shall not be greater than under existing catchment conditions,
- new development should not be liable to flooding in the designated flood,
- Rivercare guidelines,
- the principles of Ecologically Sustainable Development.

Meeting these criteria by means of compensatory works is acceptable provided that environmentally acceptable solutions are used.

The investigations documented in this report are intended to assist Gosford City Council in developing a Floodplain Management Plan for the study area. Council proposes to examine the extent of new development that is achievable whilst minimising the effects on existing development and ensuring the lagoon's long term environmental stability.

1.3 Floodplain Management Areas

For the purposes of this investigation the study area has been subdivided into the following Floodplain Management Areas. These are shown on Figure 2.

Floodplain Management Areas			
1.	The lagoon water body	6.	Farrand Crescent
2.	Bundara Avenue	7.	Ogilvie Street
3.	Northern End of Ocean View Drive Bridge	8.	Golf Course
4.	Southern Shore of the Lagoon	9.	Windsor Road
5.	West Arm (west of the Willoughby Road Bridge)	10.	Upstream of Willoughby Road causeway
		11.	Upstream Catchments

Note: Area 11 - Upstream Catchments - has not been examined in detail in the Study except for possible developments in Area 11 affecting other Areas (Section 6.3).

2. BACKGROUND

2.1 Catchment Description

2.1.1 General

A large part of the upper catchment is rural land which has been largely cleared of natural vegetation. It is mainly used for hobby farm activities. The lower slopes in the vicinity of the lagoon contain extensive urban development.

A golf course lies at the limit of the northern arm of the lagoon (Figure 2). It is dissected by a creek herein termed North Arm. Upstream of Willoughby Road the catchment rises sharply (with slopes up to 50%) into the hills and the creek splits into two branches. Willoughby Road is crossed by a two-cell culvert and a concrete causeway. This was constructed in 1978 together with a levee bank on the northern bank of the creek immediately downstream of the causeway (adjoining the rear of properties along Windsor Road). The northern branch of North Arm runs under The Entrance Road and then crosses Brush Road at the limit of the study area. The southern branch of the North Arm becomes an ill-defined watercourse upstream of Willoughby Road.

A large knoll of land rises from the centre of the catchment separating the two arms of the lagoon into a North and West Arm. The West Arm of the lagoon is bounded by Brunswick Road and Terrigal Drive. Upstream the land quickly rises reaching maximum slopes of 30%. The catchment south of Terrigal Drive is highly urbanised and contains the Terrigal central business district. Terrigal Lagoon is crossed by two bridges near the entrance - at Willoughby Road and at Ocean View Drive.

The urban area bounded by Lake View Drive, Lumeah Avenue and Ocean View Drive was filled from dredged material in the 1960's prior to the existing subdivisions. Other areas on the perimeter of the lagoon have also been filled from material dredged from the lagoon. A description of the present and past vegetation of the catchment is provided in several of the reports documented in Reference 2.

The lagoon is an important recreational amenity. At present two commercial tourist operators use the lagoon comprising boat hire near the entrance and sailboard hire near the Willoughby Road bridge. Swimming at the lagoon entrance is also a popular activity for younger children although the lagoon is considered a health hazard if the entrance has been closed for a long time.

2.1.2 Description

The average bed level of the lagoon varies from -0.5 mAHD to +0.5 mAHD although there are holes down to -3 mAHD or possibly deeper. The holes are a result of dredging activities in the last 20 years. A hydrosurvey of the lagoon was undertaken as part of the Flood Study (Reference 1). No other detailed survey of the lagoon has been undertaken. The outlet to the Pacific Ocean is normally blocked by a sand bar or beach berm. Thus the water level in the lagoon is not normally influenced by the tides.

There is no rigorous historical record of lagoon levels which means that an average lagoon level cannot be obtained. However from the information currently available it would appear that the normal level is approximately 1.0 mAHD. Variations in lagoon levels of over 1 m in a day are reasonably common due to the effects of either rainfall or opening of the entrance.

The lagoon area represents 3% of the total catchment area at normal water level. At 3.0 mAHD the lagoon area represents 10% of the total catchment area. 60 mm of runoff (rainfall minus losses such as infiltration, storage, evaporation) translates to approximately a 1 m rise in the lagoon level if the entrance remains closed.

Once the entrance is open the water level may fall by 1 m in 4 to 6 hours. It is only since July 1993 when an automatic gauge was installed that accurate measurements of the rate of rise and fall of the lagoon are available.

The lagoon is an attractive feature in the local area and a major drawcard for the tourist industry. Reduction in the aesthetic quality of the lagoon would have a significant impact upon the local community.

Interviews with local residents and previous reports have suggested that:

- the bed of the lagoon has been raised as a result of increased sedimentation following urbanisation/catchment development,
- the water quality of the lagoon has been reduced due to an increase in pollutants contained in the catchment runoff,
- in the 1940's there were holes 6 m to 10 m deep and there were abundant prawns during the season. Fishing boats used to tie up on the south side of the entrance (Reference 4).

No data could be obtained to independently verify the above suggestions.

In the early 1960's the lagoon was dredged east of the Willoughby Road bridge (Reference 4). The dredged material was used to reclaim the land on which the Presbyterian Church and the Farrand Crescent subdivision now stand. On the western bank of the lagoon the Ogilvie Street properties are on reclaimed land. These filling operations have reduced the lagoon surface area.

In 1965 Gosford Council undertook dredging near Ogilvie Street and in the Willoughby Road bridge area (Reference 4). The dredged material was used to establish Lions Park and Rotary Park. Subsequently in the late 1960's developers with dredges and drag lines worked off Lake View Drive and filled the triangular shaped residential area bounded by Lumeah Avenue, Ocean View Drive and Lake View Drive. The fill levels are to approximately 2 mAHD.

Seventy-six water depth measurements were taken in August 1984 (Reference 4) and the results showed that the average bed invert level was -0.1 mAHD with the greatest depth at -4 mAHD. These data are generally consistent with the recent survey data collected as part of the Flood Study.

Terrigal Lagoon was formed during the Holocene Epoch some 6000 years ago. During this period the dune system developed as part of a "coastal sand barrier" between the rocky headland of Terrigal Point and Broken Head. This barrier system enclosed two small waterways/estuaries creating both Terrigal and Wamberal Lagoons.

The bed sediments of the lagoon comprise silts/clayey sands in the upper reaches derived from erosion of the catchments. These have formed depositional delta formations on the lagoon bed. The remainder of the lagoon bed sediments are marine sands. Downstream of the Ocean View Drive bridge the surface sediments are beach or nearshore marine sands which have been moved into the estuary.

The salinity of the water in the lagoon is generally higher than fresh water and exhibits fast and large variations. There is little water column stratification and the nutrient concentrations are generally higher than the recommended guideline values. On average there is a comprehensive exchange of lagoon water approximately every 40 days. A more detailed description of water quality and environmental aspects of the lagoon is provided in Reference 3.

2.1.3 Land Use

The land use zonings within the study area are mainly:

- residential "A",
- open space - recreation (the golf course), and
- open space - environmental protection (lagoon and foreshores).

Other less significant zonings include Special Uses (schools, churches, fire brigade, etc.) and Scenic Protection - Small Rural Holdings (upstream of Willoughby Road). The zonings for the whole Terrigal Lagoon catchment are shown on Figure 3. The predominant zonings in each of the ten Floodplain Management Areas are given in Table 1.

Table 1: Predominant Land Use Zonings

Area	Predominant Zoning
1	6 (b) Open Space - Environmental Protection
2	2 (a) Residential "A"
3	2 (a) Residential "A"
4	2 (a) Residential "A" and 2 (b) Residential "B"
5	6 (b) Open Space - Environmental Protection
6	2 (a) Residential "A"
7	2 (a) Residential "A"
8	6 Open Space
9	2 (a) Residential "A"
10	7 (c) Scenic Protection - Small Rural Holdings

2.2 Study Limits

The hydrological investigations for this study considered the whole of the Terrigal Lagoon catchment. The extent of the hydraulic modelling, and the investigation of existing flooding problems, was limited to the study area nominated by Council, namely:

- southern limit - Terrigal Drive,
- western limit - Brush Road, Weemala Crescent and Brunswick Road,
- northern limit - Old Gosford Road.

2.3 Previous Studies

2.3.1 General

A number of previous investigations have been undertaken in the area. The more important of these are:

- Terrigal Lagoon Flood Study (Reference 1),
- Coastal Lagoons Data Inventory (Reference 2),
- Gosford Lagoons Estuary Processes Study (Reference 3),
- The Entrance Dynamics of Wamberal, Terrigal, Avoca and Cockrone Lagoons (Reference 5).

A Compendium of Data used in References 1 and 3 has been published as Reference 6.

2.3.2 Terrigal Lagoon Flood Study

All available rainfall, flood and survey data were collected and analysed as part of this study (Reference 1). The primary objectives of the Flood Study were to:

- determine the flood behaviour of Terrigal Lagoon and its tributaries under existing conditions,
- set up a numerical model of the catchment to determine flood flows, velocities and levels for design events,
- formulate the model such that the effects on flood behaviour of catchment development and flood mitigation options could be investigated.

A major component of the study was to establish and calibrate a computer-based entrance opening procedure. This procedure was tested on Terrigal and Wamberal Lagoons, and Avoca and Cockrone Lakes.

The Flood Study did not consider local flooding which may occur due to inadequate urban drainage provisions. Due to the paucity of the historical flood data, the accuracy of the design levels within Terrigal Lagoon is considered to be ±0.4 m. The analyses showed that the lagoon level is largely dependent upon the beach berm level.

2.3.3 Coastal Lagoons Data Inventory

This study (Reference 2) was completed in 1993 and provides an inventory of all the reports undertaken on the four coastal lagoons within Gosford City Council area. The most important reports as far as this study is concerned are:

- *Management Plan for Terrigal Lagoon (1984)* (Reference 4) which set out to analyse the existing situation for Terrigal Lagoon and its environs and to *recommend improvements in the operational, recreational and conservational aspects of the area.*

- *Terrigal Trunk Drainage Study, Management Study and Management Plan (1993)* (Reference 7) was an urban stormwater drainage study which encompassed the following three catchments:
  - Grasslands Avenue - 0.41 km^2,
  - Riviera Avenue - 0.64 km^2,
  - Terrigal Central Business District - 0.60 km^2.

- *Terrigal Valley Trunk Drainage Strategy (1991)* (Reference 8) was a study which encompassed the 2.3 square kilometre catchment which enters Terrigal Lagoon near the junction of Terrigal Drive and Brunswick Road. The study concluded that increased development would compound existing flood problems and proposed measures costing $3.1 million (1991 dollars).

- *Terrigal Lagoon Stormwater Drainage Study (1982)* (Reference 9) assessed the damage and flood problems affecting land in the following two catchments which drain into Terrigal Lagoon:
  - Terrigal Valley - 2.9 km^2,
  - Willoughby Road - 3.4 km^2.

2.3.4 The Gosford Lagoons Estuary Processes Study

Because of the development pressures and concerns regarding the capacity of the lagoons' physical, water quality and ecological systems to cope with the increased demand, this Estuary Processes Study (Reference 3) was commissioned by Gosford City Council under the NSW Government's Estuary Management Program. The study forms part of a detailed examination of the coastal zone, and a review of coastal zone management being undertaken by Council.

The main objectives of the Estuary Processes Study were to determine by means of measurement, analysis, interpretation and documentation a good understanding of:

- the various physical processes of importance to the estuaries,
- the various water quality parameters of importance to the estuaries,
- ecological and biological processes and characteristics that are essential to the productivity and self renewing capacity of the estuaries,
- the extent to which human activities have modified or disrupted the above,
- the interactions between the physical and biological processes, water quality, and human usages,
- any additional data or processes information necessary to aid the preparation of the subsequent stages of any Estuary Management Study and Plan.

2.3.5 The Entrance Dynamics of Wamberal, Terrigal, Avoca and Cockrone Lagoons

This study (Reference 5) was commissioned in conjunction with the Terrigal Lagoon Flood Study in order to:

- assist in the understanding of lagoon breakout processes,
- assess the likely magnitude of inundation from ocean waves penetrating into the lagoons.

2.4 The Ocean Entrance

2.4.1 General

Since the early 1970's Gosford City Council has adopted a policy of mechanically opening the entrance of Terrigal Lagoon. A policy statement regarding the opening of the coastal lagoons within the Gosford City area was prepared in 1984 and is summarised below:

- Council has a "duty of care" to prevent flooding of low-lying houses,
- there is pressure from tourist facility operators and local residents to leave the lagoon as full of water as possible,
- there is pressure from environmental groups to minimise the interference by Council in natural processes,
- the 1% AEP lagoon level (prior to the recent Flood Study) was estimated from historic information and set at 2.85 mAHD in 1984. No rigorous modelling of the hydrology or hydraulics of the lagoon was undertaken,
- a freeboard (or safety margin) of 0.5 m above the 1% AEP level is used to set the minimum floor level (MFL) (currently adopted = 3.4 mAHD). Prior to the late 1980's the freeboard was 0.3 m (MFL = 3.2 mAHD),
- ocean waves surging into the lagoon have occurred in the past and caused damage at the mouth,
- an entrance opening policy has been adopted taking account of all the above (refer Section 2.4.2).

2.4.2 Entrance Opening Policy

The salient features of Gosford City Council's entrance opening policy for Terrigal Lagoon are provided below:

- the entrance berm is to be mechanically opened once the water level reaches 1.2 mAHD. There is a mark on a power pole 10 m upstream of the Ocean View Drive bridge on the northern bank to indicate this level (level = 1.185 mAHD as surveyed by Council in September 1993). In 1968 a procedure was adopted for Council to open the lagoon at a level of approximately 1.35 mAHD (6.45 feet Gosford Datum). It is understood that the level was reduced to the current level following the January 1978 flood event,
- mechanical opening of the entrance is the responsibility of Council's overseers. These employees live in the vicinity of the catchment and are familiar with the entrance and the characteristics of the lagoon,
- the beach berm at the entrance is maintained at a low level to ensure that a channel can be mechanically cut if necessary or the lagoon can cut a channel itself. Generally the low point in the beach berm is maintained at approximately 1.8 mAHD (ranges from 1.2 mAHD to 2.0 mAHD). However this is at the discretion of the overseers and their decision is influenced by many factors including the weather forecast, the ocean

conditions, availability of machinery, etc. Two "line of sight" marks are used by the overseers to estimate the height of the beach berm and thus the need to lower the dune,

- the machinery (a bulldozer) is hired by Council and takes approximately 3 hours to place into position. However, if telephone lines are cut or roads flooded, and there is significant wave activity, it may take some time after this to open the entrance.

2.4.3 History of Entrance Conditions

Council has recorded (in its "Lagoon Book") conditions within the lagoon and at the entrance since 1970. Prior to 1977 only the occurrences of openings were recorded. Subsequently a more detailed record has been provided.

In general the entrance has been opened by Council to minimise possible flooding. Records also show that it has been opened for environmental considerations such as the construction of sewerage works or to "clean out" the lagoon.

The Lagoon Book is the only available record of entrance conditions apart from various photographs in reports held by Council or by local residents. The Council data are summarised in the Flood Study (Reference 1).

3. EXISTING FLOOD PROBLEM

3.1 General

3.1.1 Causes of Flooding

Flooding within the study area may occur as a result of the following factors:

- *elevated lagoon level due to intense rain over the catchment.* The lagoon level rises while the rate of inflow to the lagoon is greater than the outflow to the ocean. Generally the lagoon is not open to the ocean at the start of intense rain,
- *elevated water levels within a creek as a result of intense rain over the catchment.* The level in a creek may be affected by an elevated lagoon level or a constriction downstream,
- *local runoff over a small area accumulating in low spots (roads).* Generally this occurs in areas which are flat or have little crossfall. The problem may be compounded by inadequate local drainage and elevated lagoon levels at the downstream exit of the urban drainage (pipe, road drainage) system,
- *elevated ocean levels.* Generally elevated ocean levels occur in combination with increased wave activity,
- *ocean waves penetrating into the lagoon area,* and
- *local wind conditions generating waves within the lagoon.*

These factors may occur in isolation or in combination with each other. For example, the floods in February 1981 resulted from intense local rain in the absence of significant ocean activity and with only a slightly elevated lagoon level. In May 1974 the storm produced only minor rainfall but was a major ocean event causing significant coastal damage. In January 1978 the storm produced high rainfalls and significant ocean activity.

3.1.2 Flood Damages

The cost of flood damages and the extent of the disruption to the community depends upon many factors including:

- the magnitude of the flood,
- the depth and velocity of the floodwaters,
- the land usage and susceptibility to damage,
- the awareness of the community to flooding,
- the effective warning time,
- the availability of an evacuation plan or damage minimisation program,
- erosion of the river bank, flood borne debris, sedimentation.

Flood damages can be defined as being *tangible* or *intangible*. Tangible damages are those for which a monetary value can be assigned, in contrast to intangible damages, which cannot easily be attributed a monetary value. A summary of the types of damages with details of how the damages are calculated is provided in Appendix A.

In this study floor levels have been obtained from field survey. For many two-storey buildings it is unclear whether the ground floor is used for habitation or not and if it has been approved by Council. Council may have records of whether approval for ground floor habitation has been granted, but these have not been examined as part of this study.

The yard level has been taken as the general ground level near the building. On steeply sloping lots this level may not represent the lowest level in the lot.

3.2 Description of Floodplain Management Areas

The following sections describe each of the Floodplain Management Areas (Figure 2), including the issues which are relevant to the area and any flood problems which have been identified in the course of the study (questionnaire, Council records, field interviews).

3.2.1 The Lagoon Water Body (Area 1)

Description: This area (approximately 30ha) includes only the areal extent of the lagoon at normal water level (say 1.0 mAHD). As there are clearly no buildings within this area there are no flooding problems. Generally at this level there are few exposed mud flats and the majority of the area is therefore water. The two bridges which cross the lagoon are clear of the 1% flood level and have adequate waterway capacity. If a permanent open entrance was proposed, the Ocean View Drive bridge may become a restriction. The major issues in this area are water quality, sedimentation, visual quality, and the possible impacts of development, including dredging and recreational usage.

3.2.2 Bundara Avenue (Area 2)

Description: This area is bounded by Lake View Road, Ocean View Drive and Lumeah Avenue. The majority of this land was filled in the 1960's for residential development. North of Lumeah Avenue the land rises steeply and is not flood liable. There are approximately 180 lots containing a residential building within this area. The lowest floor level is at 1.8 mAHD. The majority of the buildings are less than 30 years old and comprise a mixture of brick and non-brick buildings. The residents generally enjoy a scenic outlook over the lagoon and have ready access to the lagoon and the ocean.

Flooding: There have been numerous reports (Council files, questionnaire, field interviews, photographs) of flooding in the vicinity of Bundara Avenue. Respondents to the questionnaire have indicated that at least 13 buildings in this area have had water above floor level during periods of prolonged rainfall. Properties in Renown Street, Arila Avenue, Lake View Road and Bundara Avenue have all been affected. At least 6 of these buildings are in Bundara Avenue, west of Lake View Road. No. 35 Bundara Avenue has reported up to 0.3 m depth of water in one room. As a result of frequent inundation, the owner raised the level of the floor following the February 1990 event. In the street outside the property, water has "ponded to the bumper bar level of the parked cars".

The residents indicated that the degree of inundation in the past was dependent on if, and when, the lagoon was opened to the ocean. The residents generally believe that once it is opened water levels drop rapidly. There was no firm agreement as to the flow direction during flood events. This is to be expected because of the relatively flat nature of the terrain. A suggestion made by some residents was that the construction of a sewage pumping station on the previously vacant block between Nos. 36 and 38 Bundara Avenue added to the problem by raising the level of an overland flow path to the lagoon. Many residents believe that ponding of water in the streets results from a combination of inadequate local drainage and high lagoon levels.

Access to high ground and risk to life is not a major problem in this area. The lagoon rises relatively slowly and it is unlikely that the residents would be unaware that it was rising and become trapped. Velocities would be minimal (say less than 0.5 m/s) and residents could generally wade or drive out. However any above floor inundation increases the risk of drowning (small children), accidents (tripping over submerged objects) and possible electrocution (using power tools or pumps). Residents should be able to raise goods above flood level, but damage to carpets, cars and non-raisable items (fridges) will still occur. Vehicles passing through the area causing "waves" could increase local flood levels.

3.2.3 Northern End of Ocean View Drive Bridge (Area 3)

Description: This area comprises the residential subdivision generally bounded by Terrigal Lagoon to the west and south, the Pacific Ocean to the east and to the intersection of Lake View Road and Ocean View Drive in the north. There are approximately 50 flood liable lots within this area. The majority are residential lots, but include the Clan Motor Lodge and a shop. The lowest floor level in this area is at 2.3 mAHD. This area differs from the Bundara Avenue area (Section 3.2.2) as:

- there have been few reported flood problems,
- ponding of local runoff does not appear to occur as there is a reasonable fall in ground level from the east (Pacific Street) to the lagoon,
- the southern part of this area (facing the lagoon) has been affected by waves running into the lagoon from the ocean. Wave inundation effects (Section 2.3.5) therefore need to be considered in setting floor levels.

The residents in this area have ready access to the beach and have scenic views across the lagoon, similar to the Bundara Avenue area.

Flooding: The Clan Motor Lodge experienced flooding over the verandah floor in either 1974 or 1978. This was caused by waves running into the lagoon, not elevated lagoon levels. Council has also indicated that above floor flooding has occurred in "one or two" residences in the past. The questionnaire did not reveal any further flood problems in this area. The risk to life and potential flood damages are similar to the Bundara Avenue area.

3.2.4 Southern Shore of the Lagoon (Area 4)

Description: This area comprises the southern shore of the lagoon from the Ocean View Drive bridge, along Terrigal Drive to Brunswick Road near the western extremity of the lagoon. There are approximately 50 flood liable lots. The majority of these are residential, but include two service stations, a Fire Station, a Scout Hall, Visitors Centre, the Terrigal Pacific Motel and the Terrigal Hotel Complex as well as a few vacant lots. The majority of the buildings have floor levels above 3.0 mAHD. The lowest residential floor level is 2.7 mAHD. The residents generally face north and enjoy a scenic vista across the lagoon.

Flooding: No flood problems have been reported within this area, although there are reported flood problems in the upper catchment which drains through this area to the lagoon. This catchment was investigated in Reference 7. The risk to life from flooding within this area is small although the issues described in the Bundara Avenue area may also apply here.

3.2.5 West Arm (west of the Willoughby Road Bridge) (Area 5)

Description: This area comprises the lagoon and floodplain west of the Willoughby Road bridge excluding the lots south of Terrigal Drive. The floor level of the lowest building on the north side of Terrigal Drive is 3.4 mAHD. The residents generally have a pleasant vista comprising lagoon, bush and ocean outlooks. A major part of this area is designated as SEPP14 Wetland No. 910.

Issues which relate to this area are similar to those for Areas 2, 3 and 4. An additional issue in this area is the potential for future development upon the floodplain such as is occurring at the corner of Terrigal Drive and Brunswick Road. The upstream catchment which enters at this point, has the potential for further development and was examined in Reference 8. The effect of any developments should be determined to ensure that they do not result in a reduction in the environmental quality of the area.

Flooding: There are no reported flood problems in this area and the buildings are all located on high ground (above 3.1 mAHD). The risk to life from flooding is very small.

3.2.6 Farrand Crescent (Area 6)

Description: Farrand Crescent is a small cul-de-sac situated on the western side at the intersection of the north and west arms of Terrigal Lagoon (Figure 2). Previous reports indicate that part of the land upon which Farrand Crescent is located has been filled. This area also includes four lots on Willoughby Road, situated between Farrand Crescent and the Willoughby Road bridge.

All of the 18 lots in Farrand Crescent are residential buildings with a mix of single/two storey and brick/non-brick construction. The number of two storey buildings which have approval for ground floor habitation has not been determined. The four lots in Willoughby Road include a sewage pumping station, a church and a hall. The majority of the buildings have floor levels below 3.0 mAHD and a number have floor levels less than 2.5 mAHD. The lowest floor level is 1.9 mAHD.

As with residents of the Bundara Avenue area, people in Farrand Crescent believe opening of the lagoon and the time this occurs is the crucial factor determining the extent of flooding. Also, many residents believe dredging of the lagoon will significantly improve the situation. These residents enjoy a pleasant vista over the lagoon towards the beach.

Flooding: Of the 18 lots in Farrand Crescent, at least three have experienced inundation above floor level. Responses from resident questionnaires indicate that flooding in the area has occurred several times in the last 20 years. Local drainage does not appear to be a problem as there is a reasonable fall in ground level from Willoughby Road to the lagoon.

3.2.7 Ogilvie Street (Area 7)

Description: The eastern side of Ogilvie Street comprises approximately 25 lots adjoining Terrigal Lagoon. The lots are all over 30 m in length (east-west) with the majority over 50 m. The land falls steeply from high ground (up to 10 mAHD) along Ogilvie Street towards the lagoon. All the buildings are located on the high western side of the lots close to Ogilvie Street. The majority of the buildings have floor levels above 4.5 mAHD and are not flood affected. There are 4 buildings with floor levels lower than 3.5 mAHD with the lowest being at 2.6 mAHD. These residents all enjoy panoramic lagoon and ocean views.

Flooding: There are no reports of flooding problems in this area. Local drainage appears not to be a problem due to the steep fall in the land from Ogilvie Street to the lagoon.

3.2.8 Golf Course (Area 8)

Description: The majority of the floodplain of the North Arm of the lagoon is the golf course. This is an excellent example of flood compatible land use. Potential flood liable lots within this area are the 9 residential lots and the Terrigal Memorial Country Club located on Dover Road west of Lumeah Avenue, 11 lots in and around Selma Close and 5 lots at the corner of Willoughby Road and Beaufort Road. This area also includes the lots on the western side of Plymouth Drive, although all these buildings are located on high ground. Lots on Windsor Road are discussed in Section 3.2.9 (Windsor Road area). Part of the golf course is designated as SEPP14 Wetland No. 908.

Flooding: There have been no reported flooding problems within this area, although flooding of the golf course has occurred on several occasions. The residential lots along Dover Road have floor levels above 3.4 mAHD. The Country Club has a cool room at 2.4 mAHD and a cellar at 2.8 mAHD. There are 2 buildings on Selma Close with floor levels lower than 3.0 mAHD and 5 below 3.5 mAHD. The lowest building floor level is 2.6 mAHD. The buildings at the corner of Willoughby Road/Beaufort Road have floor levels above 4.5 mAHD and are therefore not flood liable.

3.2.9 Windsor Road (Area 9)

Description: Windsor Road is situated on the northern bank of the North Arm of Terrigal Lagoon (see Figure 2). A number of houses on Windsor Road (southern side) which back onto the golf course have experienced flooding of their yards. The houses on the northern side of the road are on higher ground and have floor levels above 3.2 mAHD. Two concrete floodways take local runoff from Windsor Road, between the houses, and on to the golf course. The inverts of the floodways are at 2.0 mAHD and 2.2 mAHD (Figure 4). The houses on Windsor Road are all modern brick homes (generally single storey) and have pleasant vistas of the golf course. The flood gradient along the North Arm is influenced by the level in the lagoon. The lowest floor level is at 2.8 mAHD and there are approximately 20 buildings with floor levels below 3.5 mAHD.

Flooding: The resident of No. 28 Windsor Road indicated that water has entered the house on 2 to 3 occasions in the 10 years from 1984 to 1994. The floor level is at 2.9 mAHD which is just below the 1% AEP lagoon flood level of 3.0 mAHD. It is estimated that the depth was less than 0.02 m. The building is of brick and slab-on-ground construction. The resident noted that the flooding quickly receded and the problem has been greatly reduced since Council cleaned out the natural channel in the golf course. It is probable that flooding occurred as a result of local runoff and not from elevated lagoon levels. In recent years the highest lagoon level has been approximately 2.1 mAHD.

The residents in this area have generally indicated that the cause of flooding is from local runoff which concentrates at the two floodways, rather than from elevated lagoon levels.

Following the January 1978 flood Council constructed an earth levee within the golf course, near the intersection with Willoughby Road with the objective of protecting the Windsor Road properties. There have not been any records of flooding in the immediate area since the levee was built. The existence of an access track (Figure 4) upstream of Willoughby Road has the potential to cause problems in large events. Water from upstream of Willoughby Road which cannot pass through the culvert and causeway on Willoughby Road is likely to flow down the access track and into Windsor Road. The track is aligned such that water is directed behind the existing levee, possibly threatening the properties the levee was designed to protect.

Survey shows that the crest of Willoughby Road is at 4.9 mAHD and is therefore above 1% AEP design flood level (approx. 4.5 mAHD). The levee provides protection for only the first 9 houses downstream of Willoughby Road adjoining the Golf Course. Thereafter the levee ties into natural ground at approximately 2.5 mAHD.

3.2.10 Upstream of Willoughby Road Causeway (Area 10)

Description: Upstream of the causeway on Willoughby Road the North Arm divides into two branches. The northern branch heads north under The Entrance Road and thence westward to Brush Road. There it traverses a number of large rural-residential blocks with habitable floor levels above 6.0 mAHD.

The southern branch is ill-defined and passes through rural lots with a few recently constructed brick houses all of which have floor levels above 5.0 mAHD. The residents enjoy rural bush views and are surrounded by vegetation.

Flooding: There is only one report of a building being inundated above floor level, this being in January 1989 (22 Brush Road). Since the creek runs through all the lots, the residents will have experienced inundation of their land and consequent drainage problems associated with the saturated ground as there is no sub-surface drainage system. The resulting damage is likely to be only minor and the main concern is probably inconvenience. The risk to life is low as the floodwaters are generally shallow with velocities of around 1 m/s.

3.3 The Flood Problem - Design Floods

3.3.1 Properties Inundated

Design flood data at each cross-section were obtained from the Flood Study (Reference 1) and have been used to identify the number of properties and buildings inundated within the study area for each of the design events. The results are provided in Table 2 and Figure 8. The data were only for rainfall induced events and did not include ocean inundation. This approach was taken as ocean inundation data were not available for the full range of design events and a rigorous approach would require an envelope of data from the two inundation mechanisms.

Also, a much more complex procedure, which could not be justified, is required to assess the benefits of each flood mitigation measure (such as lowering the berm level). The approach used only assessed the benefits from a reduction in the rainfall induced inundation.

The design flood levels (rainfall induced) in the lagoon are:

Event (AEP)	mAHD
Extreme Flood	3.2
0.2%	3.2
0.5%	3.1
1%	3.0
2%	2.9
5%	2.8
10%	2.7
20%	2.6
50%	2.4

Table 2: Flood Problem: Design Floods - Rainfall Induced Inundation

Design Flood	Inundation	Floodplain Management Areas (refer to Legend)									Total
		2	3	4	5	6	7	8	9	10	
Extreme	Buildings	114	26	15	2	19	3	4	23	4	210
	Yards	137	26	20	6	20	5	6	34	16	270
0.2% AEP	Buildings	99	22	12	1	17	3	4	20	4	182
	Yards	127	26	18	4	20	4	6	28	15	248
0.5% AEP	Buildings	91	21	9	0	16	3	3	17	4	164
	Yards	118	26	18	3	20	4	5	26	15	235
1% AEP	Buildings	88	20	8	0	16	2	3	16	4	157
	Yards	116	26	18	3	20	3	4	24	15	229
2% AEP	Buildings	86	17	6	0	15	2	3	12	3	144
	Yards	111	26	14	1	20	3	4	21	14	214
5% AEP	Buildings	82	13	5	0	15	1	3	5	2	126
	Yards	100	22	9	1	17	3	3	18	13	186
10% AEP	Buildings	71	9	4	0	15	1	2	3	2	107
	Yards	91	21	8	0	16	3	3	17	13	172
20% AEP	Buildings	64	7	3	0	14	1	2	1	2	94
	Yards	87	17	6	0	15	2	3	13	13	156

LEGEND:

1. The lagoon water body
2. Bundara Avenue
3. Northern End of Ocean View Drive Bridge
4. Southern Shore of the Lagoon
5. West Arm (west of Willoughby Road Bridge)
6. Farrand Crescent
7. Ogilvie Street
8. Golf Course
9. Windsor Road
10. Upstream of Willoughby Road causeway

3.3.2 Estimation of Tangible Flood Damages

Tangible flood damages were calculated for the design floods based on a procedure described in Appendix A and the results are shown in Table 3. It should be emphasised that these figures include only tangible damages to buildings and residents resulting from rainfall induced inundation. The costs of intangible damages and damages to public utilities have been excluded from the estimates. Recent studies reveal that the damage to public utilities can vary significantly but may comprise 50% of the private tangible flood damages.

Table 3: Tangible Flood Damages ($000's) - Rainfall Induced Inundation

Design Flood	Floodplain Management Areas*									Total
	2	3	4	5	6	7	8	9	10	
Extreme	2310	460	220	10	420	50	80	360	110	4020
0.2% AEP	2080	380	150	6	390	40	70	240	80	3436
0.5% AEP	1920	330	120	1	370	30	60	170	60	3061
1% AEP	1790	280	100	1	360	30	60	130	50	2801
2% AEP	1640	220	70	0	330	20	50	80	40	2450
5% AEP	1400	150	50	0	300	10	40	40	40	2030
10% AEP	1160	90	30	0	270	9	20	20	30	1629
20% AEP	970	60	20	0	230	5	20	10	30	1345

NOTE: * Refer to legend of Table 2 for description of areas.

3.3.3 Annual Average Flood Damages

The average annual damages (AAD) for the study area resulting from rainfall induced flooding are $680 000, excluding intangible damages and damages to public utilities. The present worth of the change in flood damages resulting from a flood mitigation measure has been calculated using a 7% discount rate and a 25 year project life in this study. These figures are based on NSW State Treasury guidelines.

3.4 Classification of Flood Liable Land

3.4.1 Hydraulic Category

The 1986 Floodplain Development Manual (Reference 10) defines three hydraulic categories:

- Floodway,
- Flood Storage,
- Flood Fringe.

"*Floodways* are those areas where a significant volume of water flows during floods. They are often aligned with obvious naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, the areas with deeper flow or areas where the higher velocities occur.

Flood storage areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas will rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows, which may have the effect of altering the area otherwise defined as floodway. In general, all of these effects would be adverse, but in many cases they may not be significant.

Flood fringe is the remaining areas of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels." (Reference 10).

3.4.2 Flood Hazard Category

Flood hazard is a measure of the overall adverse effects of flooding. It incorporates the following factors:

- threat to life,
- danger and difficulty in evacuating people and property,
- the potential for damage, social disruption and loss of production.

Lands are classified in the 1986 Floodplain Development Manual as either *Low* or *High* hazard for a flood equivalent to the Flood Standard or Designated Flood (in this case the 1% AEP flood) based upon several factors including:

- flood awareness of the community,
- depth and velocity of floodwaters,
- effective evacuation time,
- evacuation difficulties including isolation of some areas as floodwaters rise, access problems, distance to high ground, number of people, availability of equipment,
- additional concerns such as bank erosion, damage due to flood borne debris,
- rate of rise of floodwaters,
- duration of flooding.

3.4.3 Classification

All areas excluding the lagoon water body (Area 1), the West Arm road bridge (Area 5), the Golf Course (Area 8) and upstream of Willoughby Road causeway (Area 10) are:

- on the perimeter of the floodplain,
- affected by shallow slowly rising floodwaters,
- located within relatively easy access to flood free ground.

The classification for Areas 2, 3, 4, 6, 7 and 9 is flood fringe and low hazard with the exception of the southern shore of Area 3 facing the lagoon, which is a high hazard area as it is affected by ocean inundation (breaking waves). The lagoon water body (Area 1) is a high hazard floodway on account of the depth (over 2 m). The West Arm (Area 5) is a low hazard flood storage area. The Golf Course (Area 8) is floodway within (say) 20 m of the creek with flood fringe on the perimeter. The hazard for Area 8 is low in the flood fringe and high in the floodway. Upstream of Willoughby Road (Area 10) the area is high hazard floodway within (say) 10 m of the creek and low hazard flood fringe thereafter. The flood classifications are shown on Figure 2.

3.5 Discussion of the Existing Flood Problem

The Terrigal Lagoon floodplain has a significant flood problem. This is mainly due to elevated lagoon levels rather than excessive flows in the creeks feeding the lagoon. Catchment runoff increases the lagoon water level (from a starting level of say 1.2 mAHD) until it ultimately overtops the entrance berm (assumed to be at 2.5 mAHD at the time of the flood) and an ocean entrance is progressively eroded through the entrance berm. The North and West Arms are the only parts of the study area which have flood levels above those of the lagoon.

The risk to life in the study area is generally small as the lagoon rises reasonably slowly compared to the rate of rise in the tributary creeks. Velocities are also very low. Evacuation and raising of goods above flood level can therefore be readily undertaken to reduce flood damages. The majority of residents have a moderate degree of flood awareness and are generally familiar with the lagoon opening procedure.

Local drainage is a major issue at Windsor Road (Area 9) and Bundara Avenue (Area 2). The damage resulting from local drainage problems is still minor compared to flooding from elevated lagoon levels. Nevertheless it happens more frequently causing inconvenience and disruption. Residents generally accept that major flooding will always occur, but that the local drainage problems should be reduced.

It is recommended therefore that local drainage studies be undertaken in these two areas. The situation should be carefully monitored when the next event occurs to provide information on where the restrictions are.

As the height of the beach berm is the key factor for determining design flood levels in the lagoon, consideration must be given to measures which would reduce this level.

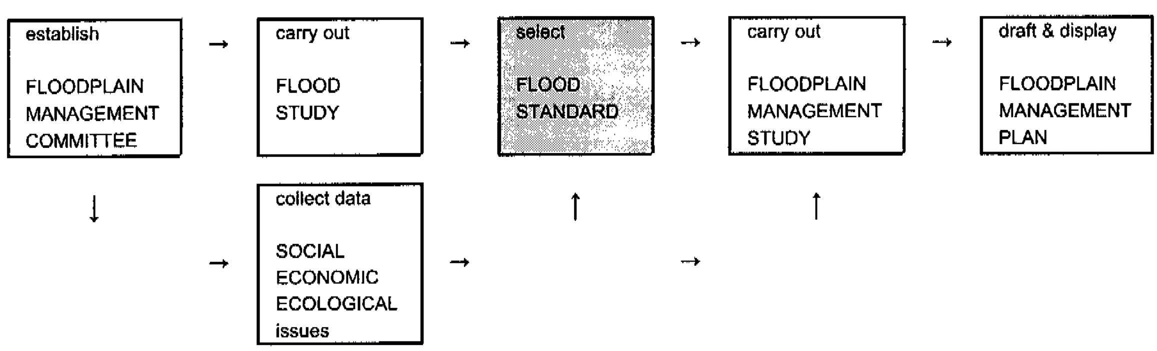
3.6 Review of the Flood Standard

3.6.1 General

The flood level used to determine the area of land that should be subjected to flood related building and development conditions is termed the *Flood Standard* or *Designated Flood.*

The *Flood Standard* and the *Level of Protection* are not necessarily the same level. The *Level of Protection* is the flood level above which the mitigation measure (typically a levee) is exceeded and flooding occurs. The *Level of Protection* is primarily based on the economics of the situation, the physical limitations of the site, and the height to which floods can rise relative to ground levels in the area.

Selection of the Flood Standard involves balancing *Social, Economic, Ecological* and *Flooding* considerations against the consequences of flooding with a view to reducing the potential for property damage and the risk to life and limb. The Flood Standard may vary from locality to locality, and the process of selecting the standard should be fully documented. Selection of the Flood Standard is one of the most critical decisions in the floodplain management process which is outlined below.



Since publication of the Floodplain Development Manual in December 1986 (Reference 10), Councils have almost universally adopted the 1% AEP flood as the Flood Standard, particularly for residential development. This is despite the fact that there are no apparent technical reasons for adopting the 1% AEP flood as the Flood Standard. The determination of the appropriate flood frequency should be based on an understanding of flood behaviour together with social, economic and ecological considerations. It also requires balancing of short term savings against long term costs.

3.6.2 Criteria for Selection

Considered and sensible selection of the Flood Standard involves weighing up the consequences of the following factors:

Size of Flood

The 1% AEP flood is not an immutable standard when deciding on the Flood Standard. It should be determined by the level of risk that best suits the area or community. In the Gulf of Mexico (USA) a 0.2% AEP flood has been adopted. In Canberra a 2% AEP flood was considered appropriate and a 5% AEP standard has been chosen for an industrial subdivision on the south coast of New South Wales.

Flood Behaviour

Flood behaviour across a range of levels (say 5% AEP to Extreme) and the likely flood damages, should be considered in evaluating the standard. For example, if the damages and hazard increased significantly in going from a 1% AEP Flood Standard to a 0.5% AEP Flood Standard, the latter may be more appropriate. On the other hand, if there are little additional damages then selection of the 1% AEP flood could be appropriate. The design flood levels for the lagoon (Section 3.3.1) indicate only a 0.5 m increase in level from the 10% AEP event to the Extreme Flood and a uniform increase in damages with depth.

Land Use

Once land has been developed, the options for future management are greatly reduced. This is primarily because of the size of the public and private investment in improvements to the land which cannot reasonably be ignored. On undeveloped land there is more flexibility in determining floodplain management options, and the cost implications of development controls are not imposed on any existing development. As a large part of the floodplain has already been developed with few remaining vacant lots in this catchment, changing the Flood Standard is unlikely to alter the amount of flood damages in the short term.

Consequences of Larger Floods

It should be recognised in setting a standard that larger floods than the proposed Flood Standard will occur in the future. With larger floods there may be increased damages and increased risk to life. Access to higher ground may also be cut by floodwaters. This factor should be properly recognised or else a false sense of security against flooding may be created for those residents situated above the Flood Standard. Surrounding the lagoon the Extreme Flood level is only 0.2 m above the 1% AEP rainfall induced level and in North Arm the difference is approximately 0.5 m. This means that the consequences of a flood larger than the 1% AEP event are not as severe as in many other catchments.

3.6.3 Recommended Flood Standard

Taking into consideration the above factors it is recommended that the 1% AEP flood should continue to be adopted as the Flood Standard for the study area. It is considered that this flood provides an acceptable level of risk for the community. Adopting a lower standard would cause an increase in flood damages. Raising the standard cannot be justified as the Extreme Flood is generally less than 0.5 m above the 1% AEP event and therefore within the proposed 0.5 m freeboard. Floor levels should be set at a minimum of 0.5 m above the 1% AEP Flood Standard. Council should also ensure that minimum floor levels (MFL) are set for all new buildings and not just for those lots which are below the Flood Standard. Larger floods than the 1% AEP will occur and if possible a higher floor level should be adopted by the residents.

4. PRELIMINARY ASSESSMENT OF GENERAL FLOODPLAIN MANAGEMENT MEASURES

4.1 Approaches to Floodplain Management

4.1.1 Alternative Measures

Measures which can be employed to mitigate flooding and reduce flood damages can be separated into three broad categories:

Flood modification measures modify the flood's physical behaviour (depth, velocity) and include flood mitigation dams, retarding basins, on-site detention, channel improvements, levees, floodways or catchment treatment.

Property modification measures modify land use and development controls. This is generally accomplished through such means as flood proofing (house raising or sealing entrances), planning and building regulations (zoning) or voluntary purchase.

Response modification measures modify the community's response to flood hazard by informing flood-affected property owners about the nature of flooding so that they can make informed decisions. Examples of such measures include provision of flood warning and emergency services, improved information, awareness and education of the community and provision of flood insurance.

4.1.2 Selection of Appropriate Measures

There are a number of methods available for determining which floodplain management measures or measures should be selected. Generally the benefit/cost (B/C) approach is adopted, as this quantifies the worth of each option on a relative basis, and enables ranking against similar projects in other areas. The benefit/cost ratio is the ratio of the net present worth of the reduction in flood damages (benefit) to the cost of the works. Generally the B/C ratio expresses only the reduction in tangible damages as it is difficult to accurately include intangible flood damages, such as anxiety, ill health and other social and environmental effects.

The potential environmental impact of any proposed flood mitigation works is becoming of increasing concern to society and this cannot be evaluated using the classical B/C approach. An alternative is to use a multi-objective framework which enables consideration of the non-quantifiable factors with the quantifiable impacts. Careful consideration of the appropriate weighting to award to each factor is required to prevent outcomes from being biassed. This latter approach was generally adopted in this study.

4.2 Flood Modification Measures

4.2.1 Dams

Flood storage dams, or dams which have significant flood storage capabilities such as Burrendong Dam near Wellington, New South Wales, can significantly reduce downstream flood levels. However, dams are extremely expensive and can generally only be justified for flood mitigation in economic terms if combined with a water supply or power generation dam. Construction of a large dam is also likely to have a significant environmental effect.

For this and other reasons a single large flood mitigation dam is not economically viable for this catchment. An alternative might be to construct several smaller dams or retarding basins which perform the same task. These have been employed successfully in many locations throughout the Sydney Region. Generally they are only viable if they can be incorporated as an integral part of a new subdivision. Preliminary investigation suggests that they are not practical in this instance for reducing the existing flood hazard. They constitute an acceptable procedure for any new upstream development in restricting the increase in peak flows caused by urbanisation or to act as water quality control structures.

On-site detention can be designed to provide the same function as a retarding basin, by distributing the storage over all the contributing lots. On-site detention has been adopted by many Councils as a means of permitting future catchment development without increasing the flood hazard downstream. It can be applied to any new development (residential, commercial or industrial) however it is more difficult to regulate and maintain for small developments.

Retarding basins would have only a minor impact upon the peak lagoon level as this is largely determined by the volume of runoff rather than the peak flow. Retarding basins would only be of value to the properties affected by upstream runoff, namely along Windsor Road and further upstream.

4.2.2 River Improvement Works

River improvement works and construction of flood channels have been used successfully on other rivers to reduce flood levels. The measures include dune maintenance, desnagging, dredging, realignment, and reconstruction of the channel proper to improve its hydraulic efficiency and waterway area.

- **Dune maintenance** to prevent the excessive build up of sand at the entrance is regularly undertaken by Council. This ensures that a man-made or natural opening can occur prior to inundation of building floors. There are some environmental impacts of this measure which need to be balanced against the consequences of high lagoon levels.

- **Desnagging** and vegetation clearing along the banks would have some benefit on the North Arm tributary. A likely disadvantage of these works is that it may lead to an increase in the likelihood of erosion (and siltation of the lagoon) and destabilisation of the banks, ultimately causing bank collapse. Upstream of Willoughby Road this measure could be employed to reduce flood levels, but as few buildings are affected it cannot be justified. Downstream of Willoughby Road the creek through the golf course is reasonably well maintained. An annual inspection will ensure that it does not deteriorate.

- **Dredging** can also be employed to increase the waterway capacity of a channel. If dredging is solely undertaken as a flood mitigation measure it is unlikely to be economical. However if the extracted material can be sold it may be possible to undertake the works at little cost or even a profit.

  Dredging of the lagoon has been mentioned in a number of previous reports, in the questionnaires undertaken as part of this study, and also during field interviews as a means of reducing flood levels.

  Whilst dredging may be of value for aesthetic, water quality or a number of other reasons it would have minimal benefit as a flood mitigation measure. This is because dredging can only be done below the normal lagoon water level of about 1.0 mAHD. The additional flood storage volume which is created would not be available for storing runoff unless the water level prior to the flood peak was below 1.0 mAHD. Generally this is not the case in the Gosford area as the flood producing storms are preceded by a day or two of light rain. These antecedent rains raise the lagoon water level to the opening level of 1.2 mAHD prior to the rains which produce the flood event.

- **Creek Realignment** can be beneficial if it is possible to replace a sinuous natural channel with a man-made hydraulically efficient and shorter channel. The only opportunity for creek realignment is along the North Arm. It is unlikely that there would be any significant benefit as the creek is already relatively efficient. A major drawback would be the likely visual and environmental impact of any realignment works. There would probably be opposition from the Golf Club as it will also require reconstruction of the golf course. The benefits are unlikely to outweigh the costs and probable environmental consequences.

- **Creek Reconstruction** of the main channel can also be employed to provide increased hydraulic efficiency. This measure is only practical on the North Arm and the mitigation benefits are again unlikely to outweigh the costs and likely environmental consequences.

- **Removal of Hydraulic Restrictions** is a further way of increasing hydraulic efficiency. For example, widening the restrictions at bridges will reduce flood levels upstream. Within the creeks in the study area there are no restrictions which can be removed which will provide a significant hydraulic benefit to affected properties. Both the Ocean View Drive and Willoughby Road bridges have adequate waterway capacity if the berm at the entrance is the restriction (i.e. at 2.5 mAHD). This is the assumed design flood condition.

Removal of the hydraulic restriction at the entrance (the sand berm) will have a significant impact upon lowering the lagoon flood levels and should be considered further.

4.2.3 Floodways

Artificial floodways are a further way to reduce flood levels by increasing the waterway capacity in the overbank areas. This is achieved either by lowering the overbank area, or by providing a depressed area across a peninsula. Generally this measure is employed on creeks which meander across a floodplain where more direct overland routes are available. Preliminary investigation has shown that there is no opportunity for creating a cost effective floodway which will provide a significant hydraulic benefit in this area.

4.2.4 Levees

Levees have been used in many towns in NSW to lessen flood damages. Preliminary investigations suggest that further levees or partial levees may be appropriate in this catchment. The following are some general comments regarding levees.

Levees require a large amount of good quality compacted fill and they therefore have to protect a considerable number of buildings to be cost-effective. They can introduce new problems with local drainage, and this issue requires examination in detail to ensure that flooding from local runoff inside the levee does not occur after construction. The internal drainage is of major concern in catchments with a short critical storm durations and relatively level ground within the leveed area. For these areas there is little opportunity to release the runoff from the leveed area prior to the peak outside and there is generally no place to store the runoff within the area. Recent studies at Erina have highlighted the importance of adequate internal drainage within leveed areas. Pumping water out is one alternative to ponding or pre-releasing the runoff, however this is expensive and pumps have been known to fail during previous floods in NSW.

A levee tends to increase flood levels upstream depending on the loss of storage and hydraulic restrictions it imposes. This is unlikely to be a significant factor for levees around Terrigal Lagoon. Levees may also detract from the visual amenity of an area, and this would appear to be a particular problem around the lagoon. The consequences of overtopping in a design event greater than the adopted Flood Standard should also be examined.

Additional concerns with levees are:

- road access,

- landtake required to build the levee,
- maintenance of a good quality grass cover on the embankment,
- possibility of failure during a flood.

The level of protection provided by a levee is usually determined on the basis of a benefit/cost analysis, taking into account social and environmental concerns. This study considered levees with crest levels ranging from the 20% AEP level to the Extreme level with and without freeboard.

4.2.5 Catchment Treatment

Catchment treatment is the process of modifying the upper catchment to reduce downstream flood peaks. In a rural catchment, afforestation or contour banking may be possible. For an urban catchment, implementation of such a strategy involves planning to maximise the amount of pervious area, maintaining natural channels where practical, and the use of on-site detention basins or retarding basins.

As a general concept, catchment treatment should be employed in the future development of the tributaries entering the lagoon. This may not have a measurable impact on flood levels within the study area, but the general philosophy should be encouraged.

4.3 Property Modification Measures

4.3.1 Flood Proofing of Buildings

Flood proofing is the practice of modifying buildings to minimise tangible flood damages. It should be noted that external damage, vehicular damage, and loss of time and inconvenience in after flood cleaning up will generally still occur. A reduction in intangible damages may also occur although this cannot be quantified. Various alternatives are summarised below:

FLOOD PROOFING MEASURES	
Contingent	**Permanent**
Removal of contents	Permanent closure of openings
Controlled flooding	Elevation of high value/high risk contents
Sealing of openings	House raising
Lifting of contents	Waterproof fittings and materials

- **Contingent Measures:** are dependent upon adequate flood warning and response to be effective. The actual/potential damages ratio (A/P) expresses the residual flood damages as a result of contingent measures. Studies in Australia have shown that the A/P ratio is generally a function of the warning time and the level of preparedness (awareness) of the community. For towns like Lismore, with over 10 hours warning time and a high level of flood preparedness, the A/P ratio approaches 0.5. Based on this information the likely A/P ratio for Terrigal Lagoon is approximately 0.8. Contingent measures can generally only affect the internal and yard damages but not structural or indirect damages.

The questionnaire and field interviews have shown that contingent measures in the catchment are currently employed during floods. There is therefore little additional improvement possible using these measures. Public education on an ongoing basis to reinforce the lessons learnt in previous floods in other areas may assist in reducing flood damages in future floods. The publication of the Flood Facts broadsheet by Council, which can be provided to the public with their rates notices, is encouraged.

- **Permanent Measures - House Raising:** can either be used in isolation or in conjunction with other options to form a total floodplain management package. House raising costs approximately $40 000 per house. House raising does not eliminate the potential risk to life, and tangible damages will still occur, although they may be significantly reduced. Generally, house raising is only viable for non-brick structures although some brick houses have been successfully raised. The cost may vary considerably from the above figure depending on individual circumstances. It is highly unlikely that raising all flood liable buildings in the study area would prove to be cost effective for Council. It is still a practice which Council should support.

House raising causes few environmental impacts. The most significant possible impact is the effect upon the streetscape of having some houses higher than others. The extent of the affectation largely depends upon the nature of the existing streetscape. House raising may also mean additional costs to the householder to re-align items which are not generally included in the package (e.g. pergolas).

A detailed survey of the number of buildings suitable for house raising has not been undertaken. Preliminary investigation indicates that the number may be small (say less than 25 with floor levels below the 1% AEP level) as a large number of buildings are brick (the majority in areas 6, 8, 9 and 10) or unsuitable (not on piers).

The B/C ratios for raising a residential building (assuming a cost of $40 000) are:

Possible Number of Houses *	Floor Level at	mAHD	Benefit/Cost Ratio
2	50% Flood Level	2.4	1.5
6	20% Flood Level	2.6	0.4
3	10% Flood Level	2.7	0.2
6	5% Flood Level	2.8	0.1
5	2% Flood Level	2.9	<0.05
3	1% Flood Level	3.0	<0.05

* The number of houses which become inundated at the given flood level.

Experience in other areas of New South Wales has indicated that house raising is becoming less viable as a floodplain management measure for the following reasons:

- generally the most suitable (and most frequently inundated houses) have already been raised. This is particularly the case at Terrigal Lagoon where a number have been raised in Area 2,
- the houses which can be raised are generally the older buildings in the area and many have reached the end of their economic life. Consequently it may be more economical to construct a new house at a higher level,
- many of these houses were built as holiday homes. With the development of the Gosford region they ae now sought after for redevelopment as permanent homes in a highly desirable location,
- a number of these homes are occupied by elderly residents (possibly in retirement) who have lived in the area for a number of years. These residents are generally reluctant to undergo the experience of house raising/ renovations and will not live in houses with steps from the yard to the living area.

In conclusion it is considered that a house raising program will not be financially or socially successful for the above reasons. However it should be pursued further for houses inundated in the 20% AEP and small events (say 8 houses). In the first instance this will require a visual inspection of the house to be followed up by an interview with the owner.

- **Permanent Measures - Permanent Closure of Openings:** waterproofing or closure of openings is generally only practical for commercial brick premises and is not practical for residential buildings. An indicative cost to flood proof a building is $20 000. This measure is probably not viable if the depth of inundation is greater than 1 m. Above this depth there is the likelihood that the building may collapse unless the fabric is double brick or stone. Tests in the USA have shown that brick veneer buildings suffer structural damage with more than 1 m of inundation. Water leakage may also occur as it is very difficult to seal every opening. This is particularly relevant on Terrigal Lagoon due to the relatively long period of inundation. There is also the risk of damage to the foundations as a result of uplift pressures. A public awareness campaign to advise residents to permanently relocate high value goods above the 1% AEP flood level may be viable, particularly for commercial properties.

Permanent closure causes no major environmental impacts. The only disadvantage of such measures are that owners may accidentally or intentionally remove the measures during future renovations. It is essential therefore that the measures which are employed are as permanent as possible. The questionnaire has shown that some permanent measures are currently employed in the catchment.

4.3.2 Planning and Development Controls

Planning regulations and controls can be used to limit development so that the nature of the development is compatible with the flood risk. The disadvantage of this practice is that the land may not be used to its full potential. As a consequence considerable local opposition can arise from existing residents and developers if they perceive that their land values have been reduced.

Approval of future development within the floodplain should be subject to strict development controls, particularly with regard to matters such as:

- establishment of a Flood Standard and the appropriate freeboard,
- proposed use of the subject land,
- structural integrity of buildings under the Flood Standard and Extreme Flood conditions,
- minimisation of possible flood damages,
- impact of buildings, additions, associated structures and fill on flood flows,
- approval for minor additions,
- flood proof material.

Care must be taken with zoning to ensure that any development or land use is compatible with the flood hazard. A major issue with zoning is the definition of the boundaries. Rather than adopting a given probability of occurrence (say 1% AEP), it may be more equitable to consider the type of flood hazard and proposed development, as well as potential flood damages. Zoning should be treated as a primary measure in order to minimise future flood damages while at the same time optimising the land use potential. Consideration must also be given to the public, social and environmental issues of such zoning.

4.3.3 Voluntary Purchase

Voluntary purchase of buildings in a flood liable area has been employed at many locations, including Lismore, Grafton, Maitland and on Erina Creek and Narara Creek at Gosford. Generally it is most suited to areas where there are older dwellings with a high flood hazard which are uneconomical to protect. It could be considered for some properties adjoining Terrigal Lagoon, however indications from the public interaction program suggest that it is unlikely that it would be accepted by the residents. Furthermore, it would be expensive and could only be undertaken over a period of many years.

There can be many social problems associated with voluntary purchase schemes such as:

- establishing a market value for the property which is acceptable to both parties,
- break up of the social fabric of the area,
- it may be difficult to provide alternative equivalent priced accommodation in the nearby area with an equivalent setting.

An indicative cost to purchase all the 157 buildings inundated above floor level in a 1% AEP flood is approximately $47 million (assuming an average of $300 000 per building). The high cost makes this option impractical. Because all the buildings experience similar depths of inundation and flood hazard, it is not possible to identify a few high hazard buildings which could be purchased as a high priority. Consideration should still be given to voluntary purchase for isolated buildings which cannot be protected by other options providing this is an integral part of the Floodplain Management Plan. This measure is considered further in Section 5.

4.4 Response Modification Measures

4.4.1 Flood Warning

Flood warning, and the implementation of evacuation procedures by the State Emergency Services, is widely used throughout NSW to reduce flood damages and protect lives. The Bureau of Meteorology is responsible for flood warnings on major river systems but not on smaller catchments such as Terrigal Lagoon.

The aim of a flood warning system is to enable residents to carry out contingent flood proofing measures. These include moving goods above the reach of floodwaters, building temporary sand bag walls across openings to prevent the ingress of water, and if necessary, evacuating the area. A flood warning system is usually based upon stations which automatically record rainfall or river levels at upstream locations and telemeter the information to a central location. The effectiveness of a flood warning scheme depends upon the following:

- the maximum potential warning time before the onset of flooding,
- the actual warning time provided before the onset of flooding,
- accuracy of the warning,

- flood awareness of the community responding to a warning,
- the reduction in flood damages that can be achieved by installing a flood warning system. Generally it can only reduce the internal and external damages but not the structural, indirect or intangible damages.

Studies have shown that flood warning systems generally have high B/C ratios, but only if sufficient warning time is provided. This is a function of the maximum warning time, the time and method of disseminating the warning, and the ability of the people to respond effectively. Even with an effective flood warning system some tangible and intangible flood damages will still occur.

Residents of Terrigal Lagoon are likely to have a maximum of 2 hours warning time from the onset of rain until the flood levels peak. Therefore a flood warning system based upon rain gauges or river recorders would not provide adequate warning. It may be a disadvantage as residents may live with a false sense of security.

Warning time can be improved if forward rainfall projections are used in preparing the flood warnings. This can be achieved through the use of satellite imagery and/or radar information together with interpretation of developing synoptic situations. Application of such sophisticated approaches for a flood warning system in the catchment is unlikely to be cost-effective if undertaken solely for Terrigal Lagoon. If it was implemented as part of a coastal flood warning system, it may be viable. Such a system, based on a procedure known as "Ready-Set-Go", has been proposed for the Sydney-Newcastle-Wollongong Region (Reference 12). It is understood that further studies are currently being undertaken on this procedure. An estimated capital cost of such a system is $16 million ($1994).

If it is assumed that a flood warning system will reduce flood damages by 10% for each design event, the net present worth of this reduction in flood damages is $0.8M. This equals approximately 5% of the estimated capital cost. Thus if the benefit from (say) 20 catchments were combined the system would have a B/C ratio of 1.0. Based on this limited information the system would appear to be viable.

4.4.2 Flood Awareness and Education

As previously stated (Section 4.4.1), the implementation of an effective flood warning scheme can lead to significant reductions in flood damages. A key element of any scheme is the flood awareness of the community. Flood awareness in a community will lead to, amongst other things, the minimisation of the lag time between flood warning and community action.

Analysis of responses to the resident questionnaire, and subsequent interviews, give the overall impression that the community within the Terrigal Lagoon catchment is only moderately flood aware. While most residents are aware of the impact which the lagoon entrance has on flood levels, very few have a contingency plan for their own property and belongings. Also, many residents do not seem to know the appropriate authorities to contact with respect to flooding. Efforts to increase flood awareness in the catchment are therefore likely to be highly beneficial.

Flood awareness campaigns in Australia and the USA have been shown to significantly reduce the potential flood damages. Such schemes are difficult to implement in an urban community with a reasonably rapid turnover of inhabitants, particularly with rented accommodation or caravan parks in the floodplain. The perceived value and lack of interest also tends to diminish with time since the last flood. It is a relatively cost-effective procedure, and the Flood Facts brochure issued by Gosford City Council with their rates notice is recommended. Examples of flood awareness and education methods are provided in Table 4.

Table 4: Flood Awareness and Education Methods

METHOD	COMMENT
Letter/Pamphlet from Council	These may be sent (annually, bi-annually) with the rate notice or separately. A Council database of flood liable properties/addresses makes this a relatively inexpensive and effective measure. The pamphlet can inform residents of subsidies, changes to flood levels or any other relevant information.
School Project or Local Historical Society	This provides an excellent means of informing the younger generation about creeks and flooding. It may involve talks from various authorities and can be combined with water quality, etc.
Annual Display at (say) Council Offices, Library, Schools, Local Fairs	This is an inexpensive way of informing the community and may also be combined with related displays.
Historical Flood Markers or Depth Indicators on Roads	Signs or marks can be prominently displayed in parks, on telegraph poles or such like to indicate the level reached in previous floods. Depth indicators on roads advise drivers of the hazard.
Articles in the Local Newspapers	Ongoing articles in the newspapers will ensure that the problem is not forgotten until the next flood occurs.
Collection of Data from Future Floods	Collection of data assists in reinforcing to the residents that Council is aware of their problem and ensures that the design flood levels are as accurate as possible.
Notification of 149 Certificate Details	All property owners should be notified if they are flood affected. Future owners are advised during the property searches at the time of purchase provided they obtain all parts of the Certificate.
Type of Information Available	A recurring problem is that new owners consider they were not adequately advised that their property was flood affected on the 149 Certificate during the purchase process. Council may wish to advise interested parties, when they inquire during the property purchase process, regarding flood information currently available, how it can be obtained and the cost.
Establishment of a Flood Affectation Database	A database would provide information on (say) which houses require evacuation, which roads will be affected (or damaged) and cannot be used for rescue vehicles, which public structures will be affected (e.g. levees overtopped, sewer pumps to be switched off, telephone or power cuts). This database should be reviewed after each flood event. It could be developed by various interested authorities (SES, Police, Council).
Flood Preparedness Program	Providing information to the community regarding flooding informs it of the problem. However, it does not necessarily adequately prepare people to react effectively to the problem. A Flood Preparedness Program would ensure that the community is adequately prepared. The SES would take a lead role in this.
Foster Community Ownership of the Problem	Flood damage in future events can be minimised if the community (residents, owners, Council and other public authorities) is aware of the problem and takes steps to find solutions. For example, Council should have a maintenance program to ensure that the openings of culverts, etc., are regularly maintained. Residents have a responsibility to advise Council if they see a maintenance problem such as broken flap gate or blocked drain. This approach can be linked to water quality, coastal, estuarine or other water related issues.

4.4.3 Flood Insurance

Flood insurance does not reduce flood damages, rather, it transforms the stochastic sequence of losses into a regular series of payments. At present flood insurance is not readily available for homes in Australia, although it is common for commercial and industrial properties. This option is currently being further examined by the NSW Government in light of the floods in North Wollongong in August 1998. Reference 11 provides a summary of the main issues regarding flood insurance.

4.5 Flood Hazard at Road Crossings

A number of roads are inundated even in small flood events. The majority are in the residential subdivisions within Areas 2, 3, 4, 6 and 9, and the hazard is generally low (shallow depth less than 0.5 m and practically nil velocity). The hazard rises as the depth increases (up to 1.0 m deep in a 1% AEP event). There are no practical solutions to this problem other than ensuring that the residents and the SES are adequately informed.

The only high hazard crossing is at Willoughby Road which becomes inundated in minor floods (<50% AEP events). Depth indicators are provided and local residents are likely to be aware of the hazard. The route is not required for evacuation or emergency use during a flood (other routes are available) but may be "attempted" by drivers. Vehicles could easily be swept off the road and into the golf course during even a minor event.

The cost of upgrading the crossing to (say) a 1% AEP standard is of the order of $200 000 and should be a long term objective. In the short term a review of the signs and highlighting the problem to the SES and in educational material should be undertaken.

4.6 Conclusions

A range of floodplain management measures has been canvassed for Terrigal Lagoon and assessments made of their viability. The information is summarised in the table shown in the Summary at the beginning of this report.

The following are some recommendations regarding suitable floodplain management measures on a catchment wide basis:

- the Flood Study has identified the lack of available flood data from within the catchment. It is recommended that more data (rainfall, flood height, flow, entrance opening) be collected and analysed. As a useful first step the four lagoon openings in June/July 1994 have been analysed and documented. Council's "Lagoon Book" should also be regularly and systematically updated. This will ensure that the nature of the flood problem is accurately determined and quantified on an event basis,
- installation of a water level rise alarm system for the lagoon or similar is recommended (based on the automatic water level recorder). An indicative cost of such a system is $5 000 with a maintenance cost of 5% per annum. The questionnaire and field interviews have identified that there is a delay from the time the lagoon reaches the opening level (1.2 mAHD) to the time of the mechanical opening of the lagoon. This delay may be 4 to 6 hours. Installation of an alarm system linked to Council's Erina

Depot, possibly including a pluviograph (which records the rate of rainfall) would ensure that Council becomes aware immediately when the level is reached. The system could be used (when coupled with a pluviograph) for forward projections of the likely rate of rise of the lagoon. It may also be used to provide a siren warning (or similar) to all residents once a critical level is reached and a further increase in level is likely. The critical level should be determined in consultation with the local residents, but would probably be greater than 2.0 mAHD,

- continuation of Council's development control policy regarding minimum floor levels and building controls will ensure that future development will not be at risk of flooding at the designated flood level. Flood compatible use of the floodplain (e.g. golf course) is to be encouraged,
- the use of catchment treatment to reduce increases in runoff is supported. Where applicable, on-site detention should be encouraged as well as re-afforestation and other measures which increase the amount of surface infiltration,
- local drainage studies at Bundara Avenue (Area 2) and Windsor Road (Area 9) are recommended,
- Council's present policy on providing information and education to residents regarding flooding is to be encouraged and would be expanded to include the methods listed in Table 4,
- further consideration of voluntary purchase and house raising is provided in Section 5.

5. DETAILED ASSESSMENT OF FLOODPLAIN MANAGEMENT MEASURES

5.1 General

Based upon a preliminary assessment of measures, it is apparent that many measures are not practical for the Terrigal Lagoon catchment. One measure which benefits the majority of the flood problem areas is improvement to the ocean entrance hydraulics to achieve lowering of the rainfall induced design lagoon levels. This is discussed in Section 5.2. The subsequent sections describe floodplain management measures for each of the previously identified Floodplain Management Areas.

5.2 Lowering of Design Lagoon Levels - Rainfall Induced

5.2.1 General

Design levels in the lagoon are influenced by a number of factors including:

- the volume of runoff,
- the peak runoff flow,
- initial or starting lagoon level for design flood analysis (and associated opening level),
- ocean levels,
- wave runup,
- entrance condition (either open or closed),
- dimensions of the berm at the entrance.

The two mechanisms which produce elevated lagoon levels are rainfall and ocean inundation. The design levels for these mechanisms are shown on Figure 5. Design lagoon levels from ocean inundation in the absence of significant rainfall were determined in Reference 5.

5.2.2 Ocean Inundation

Downstream of the Ocean View Bridge, ocean inundation produces higher levels than rainfall induced events. The effect of ocean inundation rapidly diminishes upstream of the Ocean View Drive bridge. A consequence of this is that there is no practical means of reducing design levels. The only possible method of reducing the ocean induced levels would be to increase the beach berm to prevent overtopping. However, this would have the effect of raising levels in rainfall induced events. Lowering the berm would generally permit more ocean penetration (increased frequency and magnitude). The exact extent has not been estimated and would depend upon the shape of the beach profile, the extent of erosion/accretion prior to the peak and many other factors. It is likely that the impact will change with different ocean conditions (prevailing wind, tide, etc.).

5.2.3 Rainfall Induced Events

Sensitivity analyses were undertaken in the Flood Study for the 1% AEP flood to examine the robustness of the assumptions adopted in the design flood analyses. The results are shown on Figure 6. The results from these analyses have been used to demonstrate the effects if it was decided to undertake works which would change the adopted design levels.

- **Altering the Lagoon Starting Level (for the design flood analysis) or Opening Level (currently 1.2 mAHD)**

  Lowering the lagoon starting level (to 0.7 mAHD) or raising the lagoon starting level (to 2.2 mAHD) was found to reduce the peak lagoon flood level by 0.05 m and 0.15 m, respectively for the adopted design flood scenario. Can a level lower than 1.2 mAHD reasonably be assumed as the lagoon starting level? It would only be possible if this level became the opening level for the lagoon. This could be achieved, but it is likely that there would be considerable opposition from local residents wishing to maintain a high water level in the lagoon for aesthetic and other reasons.

  Raising the lagoon starting level to 2.2 mAHD only produces a reduction in peak lagoon level for the adopted design case of a 9 hour duration storm. If the lagoon starting level was taken as 2.2 mAHD, 6 hours becomes the critical storm duration and produces a design level approximately 0.04 m higher than the existing flood level (9 hours duration). Thus there could be a disbenefit in raising the starting level.

  The starting water level in the lagoon assumed for the design flood analyses is the level at which Council opens the lagoon. If this level was to be changed, consideration should be given to the following:
  - for flooding purposes, having no water in the lagoon prior to the design storm would produce the lowest flood level,
  - both local residents and visitors regard the lagoon as having a high aesthetic value due to the appearance of the body of water. This is much reduced if a low water level results in exposed mud flats,
  - the recreational value of the lagoon is reduced if there is insufficient water,
  - residents have complained of obnoxious odours from exposed mud flats,
  - the salinity and water quality attributes of the lagoon are affected if there is insufficient water. This may affect the vegetation, as well as the aquatic and avifauna balance of the lagoon.

  Apart from flooding, the remaining points support a higher rather than a lower starting water level. It is concluded that lowering the starting water level would not be supported by the local residents.

- **Reducing the Peaks of the Inflow Volume**

Reducing the hydrograph peaks (by using retarding basins or on-site detention) and runoff volume (by increasing infiltration) will reduce the peak lagoon level. Two scenarios were simulated for the existing 1% AEP 9h storm:

- in the first case the hydrograph peaks were reduced but the runoff volume was maintained (retarding basin in the upper catchment near Willoughby Road could be used to produce such a result). The peak lagoon level was reduced by 0.05 m. One consideration which should be noted is that the peak lagoon level results from a 9 hour duration storm. Retarding basins are generally designed to reduce the peak of a short (say 1 to 2 hour) duration storm,
- in the second test, the continuing loss was increased from 2.5 mm/h to 5 mm/h, simulating the effect of increased infiltration. The peak lagoon level was reduced by 0.05 m.

It is clear that a small reduction in the peak lagoon level can be achieved by reducing the inflow peak or the total volume of runoff. The substantial costs which would be involved in providing such a benefit (e.g. constructing retarding basins) would make this option impractical. Such a measure could possibly be considered if combined with a water quality function.

- **Entrance Condition and Dimensions of the Berm**

Figures 6 and 7 show that changing the entrance condition has the largest impact upon the peak lagoon levels. A peak level of 2.2 mAHD (reduction of 0.8 mAHD) can be achieved if the entrance is assumed to be open at the start of the flood-producing rains.

The beach berm level adopted for all design events is 2.5 mAHD. This level was derived from a combination of natural factors (wave/wind activity) and lagoon management factors (ability of Council to open the entrance at a designated level) as part of the Flood Study (Reference 1). The level is higher than the general level at which Council maintains the berm to reflect the impact of natural factors during the design event (e.g. Council unable to clear the entrance). There is no way of changing the natural factors, but the management factors can be changed. (Council's existing opening policy is discussed in Section 2.4.2.) The lagoon management factors are discussed in detail below:

- **Maintenance of the Beach Berm Level Prior to a Flood**
  This is carried out by Council's overseers in order to minimise the build up of sand prior to a flood. Generally, the low point in the berm is maintained at approximately 1.8 mAHD (ranges from 1.2 mAHD to 2.0 mAHD). This level is at the discretion of the overseers, and their decision is influenced by many

factors, including the weather forecast, the ocean conditions and the availability of machinery. Since the present system was introduced in the mid 1970's, it has generally worked satisfactorily. A more formalised procedure could be implemented which would ensure that a level of (say) 1.7 mAHD was not exceeded. A 0.1 m reduction in the managed level (1.8 mAHD to 1.7 mAHD) should equate to a similar reduction in the beach berm level adopted for design (2.5 mAHD to 2.4 mAHD). The advantages of such a procedure over the present system could only be accurately determined from a long term field trial. This is not recommended at this time pending more rigorous collection of data so that the existing procedure can be monitored with greater accuracy.

At present, it is estimated that the annual maintenance cost of lowering the entrance is $12 000 (say $1 000 each for 10 openings and 2 lowerings). An indicative benefit/cost analysis was undertaken to assess the economic viability of Council maintaining the entrance at a lower level (1.7 mAHD). It was assumed that the design flood levels could be reduced by 0.1 m through the introduction of this measure (lowering the design berm level from 2.5 mAHD to 2.4 mAHD). Consequently the number of buildings inundated would be reduced (from rainfall induced inundation) as shown in Table 5. The number of additional openings or berm lowerings (cost - $1000 each) which are required to maintain the berm at 1.7 mAHD is unknown and a range of costs is shown on Table 6. It should be noted that this is not a rigorous analysis as it has not taken account of the possible change in damages resulting from ocean inundation (lowering the berm may cause more flooding by ocean inundation). This possible adverse impact is difficult to quantify. Whilst there is a direct correlation between the berm level and the peak rainfall induced flood level this is not the case with ocean inundation. During an ocean inundation event the beach berm is likely to be significantly altered by the effect of wave action and a 0.1 m reduction in the level is unlikely to result in a significant change to the peak level. Reference 5 suggests that lowering the berm may in fact reduce the level of inundation. Further research is required in this area.

Table 5: Effect of Council Maintaining the Entrance Berm at 1.7 mAHD rather than 1.8 mAHD and Consequent Reduction in the Design Berm Level from 2.5 mAHD to 2.4 mAHD

- Benefit/Cost Ratios

Additional Annual Cost to Council	Approximate Benefit/Cost Ratio
$2000	>50
$5000	28
$10000	14

- Reduction in Number of Buildings Inundated (Rainfall Induced Inundation)

Flood	Buildings Inundated assuming a 0.1 m Reduction in the Design Flood Level	Buildings Becoming Flood Free	
		Number	(%)
Extreme	183	27	13
0.2% AEP	165	17	9
0.5% AEP	152	12	7
1% AEP	140	17	11
2% AEP	129	15	10
5% AEP	108	18	14
10% AEP	91	16	15
20% AEP	76	18	19
50% AEP	47	9	16

The design flood scenario assumes that whilst Council maintains the berm level at 1.7 mAHD, during the storm, or in the preceding week, the berm may build up to a higher level. Interviews with local residents and Council officers suggest that this is a relatively common occurrence. The full benefit of implementing Council's maintenance program is therefore much reduced. It will take several years before the benefits of this program (to maintain the berm at 1.7 mAHD as opposed to 1.8 mAHD) can be accurately assessed.

It is recommended that the following data collection and analyses be undertaken:

- estimates of the width (perpendicular to flow direction), length (parallel to flow direction) and crest level of the berm to be obtained regularly (perhaps weekly). During periods of storm (ocean and rainfall) activity these parameters to be obtained on a daily (or even hourly) basis,
- more accurate records to be obtained for the cost and time required to lower the beach berm. This should include the periodic maintenance cost,
- each future opening to be monitored and data similar to the September 1993 opening at Wamberal Lagoon collected,
- all the above data are to be analysed after a period of perhaps two years, and the situation reviewed.

An indicative cost to undertake the above recommendations is $15 000.

- **Lowering the Beach Berm During or Immediately Prior to a Flood**

Whilst the berm crest may build up from the maintained level of 1.7 mAHD to (say) above 2 mAHD as a result of ocean activity before the flood peak, Council has a further opportunity of lowering the berm immediately prior or during the rainfall induced event. Should this procedure be successful the expected flooding of houses may not eventuate. If the berm is "open" prior to the peak the 1% AEP flood level would be reduced by 0.8 m (say 2.2 mAHD). This process is critical for determining the peak lagoon level. The most important factors are the :

- height of the beach berm prior to the flood-producing event. This is largely dependent upon the efficiency of the maintenance procedure (discussed above) and the effect of ocean activity,
- time of initiating the opening relative to the rainfall and flood peak,
- availability of staff and machinery (possibly at night or during the weekend),
- meteorological conditions which may limit the availability and/or effectiveness of the opening (wind or wave activity, flooded roads, staff or machinery occupied elsewhere, communication breakdowns, etc.),
- procedure adopted. This includes the location of the cut and whether the adjoining dune is lowered, the size of the initial cut, and the timing of the cut relative to the timing of the peak flow and the tide.

This measures has been used in the past by Council. It is recommended that all future openings of this type should be documented, and the information collected used to reassess the opening strategy.

5.3 Bundara Avenue (Area 2)

88 buildings are inundated in this area in a 1% AEP flood and 64 in a 20% AEP event. The following floodplain management measures have been considered in detail for this area:

- levees,
- house raising,
- investigation into the local drainage.

5.3.1 Levees

A levee around this area (to the AEP 1% flood level) would be approximately 1300 m long, 2 m high, and construction would cost in the order of $700 000. It would provide protection for the 88 buildings which are inundated above floor level in the 1% AEP flood.

There are a number of additional costs which have not been included above such as:

- roadworks,
- landtake costs and possible house purchase,
- re-location of services,
- resolution of internal damage.

An accurate assessment of the additional cost is not possible without detailed survey and assessment. An indicative cost is that it could be up to $800 000 which produces a total cost of approximately $1.5M. On this basis the levee has an indicative B/C ratio of approximately 3. The high B/C ratio is because the main contribution to the average annual damages is from the small more frequent floods (smaller than the 1% AEP). Eliminating these events significantly reduces the average annual damages as shown in Table 3.

The major disbenefits of such a levee are:

- it could be considered unacceptable for aesthetic reasons and it would disrupt residents' views of the lagoon,
- the structure may impede pedestrian and vehicular traffic (the levee may need to cross a number of roads),
- in an overtopping flood the damage may be increased (above the existing scenario) as infill development may have occurred,
- relatively high cost,
- the existing problem of poor local drainage will be exacerbated unless expensive pumps (or other such measures) are incorporated in the design,
- further reduction in the flood storage capacity of the lagoon will occur although this will not significantly affect flood levels outside the protected area,

- possible negative impact upon land values (aesthetically unattractive),
- a major public consultation process would be required to ensure acceptance of the scheme. The levee would be seen as a disbenefit (view across lagoon and construction/traffic disruption) to those people who are within the leveed area but will not receive any benefit (except yard damage) as they are not flood liable (house already raised).

In summary it is considered that a levee may be economically viable but is unlikely to be supported by all the local residents.

5.3.2 House Raising

House raising is one of the most effective means of preventing flood damages but it is only applicable for a limited number of buildings (non brick and pier construction). Preliminary investigation suggests that this area is likely to provide the most number of suitable houses for house raising (10 houses with floor levels below the 5% AEP level) out of all the floodplain management areas surrounding the lagoon.

However, it is only economically viable (B/C greater than 1) for buildings inundated in smaller that 20% events (refer Section 4.3.1). A detailed survey and interview with residents should be undertaken to determine which buildings are appropriate.

Voluntary purchase of the remaining buildings is not financially or socially viable. It is likely that a number of the older low lying buildings will be progressively redeveloped.

5.3.3 Local Drainage

It appears that flooding in this area is exacerbated by poor/inadequate local drainage. Respondents to the questionnaire believe that the ponding of water in streets is partly as a result of the inadequate drainage system. Detailed examination of urban drainage is beyond the scope of this report, but a more thorough investigation to highlight the problems and propose solutions is recommended for this area.

5.4 Northern End of Ocean View Drive Bridge (Area 3)

There are approximately 20 buildings inundated above floor level in a 1% AEP rainfall induced flood within this area. The floor levels are slightly higher than for Area 2, and only 7 buildings are inundated in a 20% AEP rainfall induced event. The 1% ocean induced level is 3.3 mAHD and would inundate 4 buildings, all of which would be inundated in the 1% AEP rainfall induced flood.
The following floodplain management measures were investigated:

- levees,

- house raising.

It is recommended that specific advice and information be provided to the property owners located on the northern shore of the lagoon adjacent to Ocean View Drive bridge regarding the effects of ocean inundation. This will ensure that the owners are fully informed of the risk to life and likely damage in a major ocean event. Council should satisfy themselves that there are adequate evacuation measures. Furthermore, design standards should be introduced to ensure that all new buildings (within 100 m of the northern shore) are constructed to withstand and dissipate forces from inundation by ocean waves and with floor levels 0.5 m (or greater) above the 1% ocean inundation level of 3.3 mAHD.

5.4.1 Levees

It would appear that this area is suited for a levee, as the affected buildings are clustered together within a relatively small area. The length of the levee would be approximately 500 m, at a height of 2 m. This would provide protection to approximately the 1% AEP level. The cost of constructing the levee would be approximately $400 000, without the additional costs for landtake and roadworks.

There are likely to be some major concerns regarding the alignment of a levee at this location. Firstly, one of the affected properties is the Clan Motor Lodge, which is situated on the edge of the lagoon. A 2 m high levee between the building and the water is likely to have a significant adverse visual impact upon the motel and restaurant. Another major issue is the crossing of Ocean View Drive. A levee would need to cross the road near the northern abutment of the Ocean View Drive bridge. Extensive roadworks, and possibly reconstruction of the bridge, would need to be undertaken as the crest of the levee would be up to 2 m above the existing road level. A third major issue is the fact that waves from ocean inundation may cause overtopping of a levee as they "run-up" the batter. Other issues related to levees, such as internal drainage and landtake, are also pertinent at this location.

It is considered that the major issues outlined above rule out the possibility of a levee at this location. In the future a levee could be reconsidered if the existing situation changes, for example if there is any major re-development in the area.

5.4.2 House Raising

The houses within this area are a mixture of more recent, two-storey brick construction and older, single-storey non-brick buildings. House raising may be viable for some buildings (6 houses with floor levels below the 5% AEP flood level). The exact number can only be determined following a detailed survey and interview with the residents. Considerable redevelopment has occurred in this area in the last 10 years and it is possible that some of the buildings may already have been removed. Voluntary purchase of the remaining buildings is not financially or socially viable.

5.5 Southern Shore of the Lagoon (Area 4)

There are 8 buildings inundated above floor level in a 1% AEP flood within this area. Only 3 buildings are inundated in a 20% AEP event. Six of these buildings are on Terrigal Drive near the intersection with Willoughby Road while the other two adjoin the caravan park at the corner of Brunswick Road and Terrigal Drive. Two of the buildings near Willoughby Road include the Scout Hall and the Fire Station. The floodplain management measures that have been considered are:

- levees,
- house raising,
- improvements to local drainage.

5.5.1 Levees

Two levees would be required to protect the affected buildings. At the Brunswick Road intersection, a levee could be located along the western bank of the tributary which crosses Terrigal Drive. To protect the two houses, the levee would need to cross Brunswick Road just before the intersection and run along the northern side of Terrigal Drive. The total length of the required levee is approximately 100 m at a height of 1 m. Such a levee would cost in the order of $100 000 not including roadworks at Brunswick Road. Also, part of the levee may need to be located in private property along Terrigal Drive adding further to the cost. The high cost and the likely adverse public reaction to a levee makes the house raising option more attractive.

A levee to protect the buildings near Willoughby Road would need to be located within the foreshore reserve at a height of between 1 m and 1.5 m above ground level. It would also have to cross Terrigal Avenue. The approximate cost is $250 000. The cost does not include roadworks on Terrigal Drive.

There is likely to be a significant visual impact from the levee as the view of the lagoon from Rotary Park and Terrigal Drive would be disrupted. A levee in this area appears to be impractical and alternative measures should be considered.

5.5.2 House Raising

Preliminary inspection has not indicated any residential buildings suitable for house raising. The lowest two buildings are used for non-residential purposes.

5.5.3 Local Drainage

Flooding problems have been reported within the catchment which drains through this area to the lagoon. Reference 7 investigated this catchment, together with two adjoining catchments, and proposed a number of solutions. Consideration should be given to ensuring that any works which are constructed upstream do not adversely affect this area.

5.6 West Arm (west of the Willoughby Road Bridge) (Area 5)

There are no buildings inundated above floor level in a 1% AEP flood in this area.

5.7 Farrand Crescent (Area 6)

There are 16 buildings in this area with floor levels below the 1% AEP flood level, with 14 of these below the 20% AEP flood level. The following floodplain management measures have been considered:

- levees,
- house raising.

5.7.1 Levees

The compact nature of the subject area, the existence of a public reserve around the lagoon foreshores, together with a lack of road crossings, make a levee worthy of consideration. This needs to be weighted up against the reduction in public amenity and the possible obstruction to views of the lagoon. This issue should be canvassed with the residents. Preliminary investigation suggests that it would not be supported by all residents.

Detailed costing would be required to properly evaluate a levee including internal drainage, but a cost of the order of $300 000 would be expected for a 400 m levee to protect the 16 buildings inundated above floor level in a 1% AEP flood. An indicative total cost which includes landtake costs, the relocation of services or resolution of the internal drainage, is $500 000. An indicative B/C ratio is 2.6. The relatively high B/C ratio is because the majority of the buildings are inundated in small floods.

Construction of a levee at a lower level than the 1% AEP was considered, but is also unlikely to be supported by all residents. The main reasons for this are that any levee is likely to be visually obtrusive and affect access. Furthermore a lower levee would result in a lower B/C ratio which may not be sufficient to attract funding.

5.7.2 House Raising

Preliminary investigation indicates that up to two buildings may be suitable for house raising. It is thought that some of the remaining two storey buildings may not have approval for ground floor habitation and this issue has not been considered further at this stage.

A detailed survey and interview with the residents should be undertaken to determine the exact number of buildings suitable for house raising. Voluntary purchase of the remaining buildings is not socially or financially viable.

5.8 Ogilvie Street (Area 7)

There are 2 houses with floor levels below the 1% AEP flood level in this area. The properties adjoin each other and are located near the intersection of Ogilvie Street and Willoughby Road. Although the crest level of Ogilvie Street is approximately 6 mAHD at this location, the lots fall steeply to the lagoon and the floor levels of the houses are more than 3 m below the road.

One house has a floor level approximately 0.1 m below the 1% AEP flood level and the other house has a floor level 0.4 m below. The former may be suitable for house raising but will have a B/C ratio of 0.1 or less. The latter is of brick construction and cannot be raised. Voluntary purchase cannot be justified on financial or social grounds.

5.9 Golf Course (Area 8)

The majority of the land in this area does not contain any development as it is occupied by a golf course. The 3 buildings in this area with floor levels below the 1% flood are located at Selma Close (2 houses) and the cellar of the Terrigal Memorial Country Club.

The Country Club is a commercial establishment and may be insured for flood losses. Recently a new clubhouse (circa 1994) has been constructed in accordance with Council's minimum floor level policy.

In a 1% AEP event both houses in Selma Close are inundated by approximately 0.4 m of water. Both houses are brick, two-storey, of slab-on-ground construction and unsuitable for house raising.

Council should check that approval has been given for ground floor habitation of these two buildings prior to recommending any works to protect them.

5.10 Windsor Road (Area 9)

Sixteen buildings in Windsor Road are flooded above floor level in a 1% AEP flood. One building is inundated at the 20% AEP flood level. This assumes that floodwaters overtop the levee on the western side of Willoughby Road. The levee appears to have performed reasonably well since it was constructed following the January 1978 flood, but has not been tested in a larger than (say) 10% AEP event. The crest height at Willoughby Road is 4.9 mAHD which is 0.4 m above the 1% AEP flood level of 4.5 mAHD. Council should ensure the continued performance of the structure by implementing a thorough and regular maintenance program. This should include inspections and grass cutting.

The flooding regime in this area is complex and the following need to be considered:

- the effects of further earthworks within the golf course,
- the effects of floodwaters flowing across Willoughby Road north of the levee, and into Windsor Road. This could flow behind the levee and then exit to the lagoon through the two flood channels. This would only occur in major floods greater than (say) a 20% AEP event,
- the effect of local runoff behind the levee. Section 3.2.9 describes how local runoff has reached 3.0 mAHD and inundated at least one house above floor level.

Minimum floor levels in this area should be established based on the assumption that the levee will be outflanked in a 1% AEP flood.

The location of the Golf Course in the upstream reaches of the lagoon represents excellent flood compatible usage of the floodplain. In order to minimise flood damage to the course, raising of tees and greens may be considered. Care should be taken to ensure that there is no extensive raising of fairways as this could lead to a reduction in flood storage volume. Maintenance of the main channel should be encouraged, and it should be inspected and if necessary cleared, annually. Any major re-design of the course should be submitted to Council's Floodplain Management Section for approval.

The following floodplain management measures for this area have been considered:

- additional levees,
- house raising or permanent sealing of openings,
- local drainage study and diversion of local drainage,
- clearing and widening of the North Arm Creek downstream of the Willoughby Road causeway.

5.10.1 Levees

Preliminary investigation suggests that it is probably not practical to construct a levee along the entire Golf Course side of the Windsor Road properties (from Willoughby Road to high ground in the east) because of the problems of internal drainage. The questionnaire and field interviews have shown that flooding from local runoff (rather than raised lagoon levels) is more common. Impeding the runoff from this area by constructing a levee could well exacerbate the problem, particularly as the majority of houses are of slab-on-ground construction.

The use of pumps to remove water from behind a levee is likely to be too expensive and there is a risk they could fail during floods. A cost of the order of $350 000 would be required to construct a 500 m long levee to protect the 16 houses in a 1% AEP flood. An indicative B/C ratio is 0.3. This does not include costs for internal drainage, landtake or relocation of services. Of particular concern is the problem of internal drainage which may prove to be impractical to resolve. It is considered that other floodplain management options will be more cost effective and prudent.

Appendix C details an investigation into the integrity of the existing levee running from Willoughby Road into the golf course. This revealed that the levee is likely to be overtopped in relatively frequent flood events (say 10% AEP and greater). Appendix C proposes a number of measures to reduce the frequency of overtopping.

5.10.2 House Raising or Permanent Sealing of Openings

As the buildings are generally all of brick construction, house raising is not possible. Permanent sealing of the openings to a house (doors, windows, vents in brickwork) is generally not viable (Section 4.3.1). However for a small number of houses (say 4) this measure would be a cost effective means of reducing the effects of inundation from local runoff. In these events the depth of inundation is shallow (less than 0.1 m) and flood damages could be prevented in this way. This measure would have to be discussed with the residents as funding from the DLWC is generally not available.

5.10.3 Diversion of Local Drainage

Local runoff from the catchment (19 hectares) exits to the Golf Course through the two concrete lined channels (Figure 2). As the major cause of flooding in this area (since 1978) is local drainage, a specific local drainage study was undertaken (Appendix C). This study concluded that major capital expenditure could not be justified and proposed a series of measures to control the existing problem (Appendix C).

5.10.4 Stream Clearing/Channel Works

The possible benefits of stream clearing and channel works downstream of the causeway was considered. Currently the creek and overbank floodplain are reasonably well maintained. Downstream of Section T18 (Figure 4) there is little benefit in undertaking works as the flood levels are largely due to backwater from the lagoon. Upstream of Section T19 the creek narrows (to say 10 m wide) and the channel and overbank have a moderate cover of shrubs and trees. Clearing of this length of creek would lower flood levels, but would offer no benefit if the existing levee was maintained above the 1% AEP flood level.

5.11 Upstream of Willoughby Road Causeway (Area 10)

Four buildings within this area are flooded above floor level in a 1% AEP flood. The buildings are rural residential homes on large lots. The only available measure to protect these homes is house raising. However, preliminary inspection suggest that this measure may not be possible (houses unsuitable and residents unwilling to participate). An alternative is for residents to seal the entrances to their houses (waterproof doors and windows, seal air vents in brickwork). These works should be funded by the owner. Residents and Council should also ensure that flood levels are not increased in this area through blockage of drainage paths by excessive vegetation, fences or filling.

5.12 Summary

The most appropriate floodplain management measures can be compared in the matrix provided in Table 6. The measures are presented as applying to the whole of the study area rather than to each Floodplain Management Area. This facilitates comparison of a measure such as *lowering of design lagoon levels* with *levee construction.* Relevant quantitative measures are given for each case (where applicable) in addition to a qualitative ranking (High, Medium, Low, None) so that different options can be readily compared.

Table 6: Comparison of Floodplain Management Measures

Criteria / Option		Lowering of Rainfall Induced Design Lagoon Levels	Flood Warning Scheme	Increasing Flood Awareness	Levees	House Raising	Voluntary Purchase
BENEFITS							
Reduction in 1% Level	A	0.1 m (up to 0.5 m)	Nil	Nil	Up to 1.0 m	Nil	Nil
	B	Low/Medium	None	None	High	None	None
Reduction in Number of Buildings Inundated at the 1% Level	A	17 (11%)	0 (0%)	0 (0%)	104 (66%)	25 (16%)	157 (100%)
	B	Low	None	None	High	High	High
Reduction in AAD ($'000's)	A	149 (22%)	70 (10%)	Up to 10% initially	560 (82%)	Varies depending upon the floor level	680 (100%)
	B	High	Low	Low	Medium/High	Medium	Very High
Benefit-Cost Ratio	A	(say) 15	Unknown	Unknown	2.7	Ranges from 1.5 to <0.1	0.2
	B	Very High	High	High	High	Medium to Low	Low
DISBENEFITS							
Cost of Option	A	(say) $10000/annum	Unknown	(say) $1000/annum	$2.4M*	$40 000 per house or a total cost of $1M.	$47M
	B	Low	Low	Low	Medium	Medium/High	Very High
Environmental Impact	B	Low	None	None	Medium	None	None
Social Impact	B	None	Low	None	High	Medium to High	High

NOTES:
1. Line A shows a quantitative measure and Line B a qualitative ranking describing the Benefit or Disbenefit. A High Benefit is good, but a High Disbenefit is not good.
2. The options are shown on a catchment-wide basis rather than within each Floodplain Management Area.

* The costs of levee construction cannot be accurately estimated at this stage. At some locations costs may rise as a result of internal drainage issues, landtake or roadworks.

6. DEVELOPMENT CONTROL MEASURES

6.1 General

Apart from floodplain management measures a number of development control measures have been considered. These encompass changes to the existing catchment or creek system which have been proposed by various bodies, and include the effects of future development of the catchment. These measures have been considered in order to ensure that they will not significantly affect the flooding regime, or if they do, that consideration is given to addressing their potential impacts.

6.2 Maintenance of a Minimum Water Level in the Lagoon

Public interaction through the questionnaire, field interviews, and discussions with Council, has shown that there is a desire to maintain a minimum water level in the lagoon. This issue has already been canvassed in Section 5.2.3. The main arguments for maintaining a minimum water level are for aesthetic reasons, such as eliminating the unsightly sand/mud flats, and supporting recreational use of the lagoon for fishing and boating.

6.2.1 Construction of an Artificial Weir

One option that has been proposed is the construction of a weir near the entrance to maintain the water level at, say, 1.0 mAHD. The weir would have to include some form of flap-gated culverts to ensure that the lagoon could be fully drained, if required. The preferred location of the weir would be downstream of the Ocean View Drive bridge at the end of Pacific Street. The length of a weir at that location would be approximately 100 m. An order of cost to construct a sand-filled weir at that location, including flap-gated pipe culverts, is $100 000. An alternative would be to provide a "fabri-form" dam under Ocean View Drive bridge. This could be collapsed during a flood or for full flushing of the lagoon, and then reconstructed following a flood to "trap" the floodwaters.

The weir would have no significant impact on peak flood levels in the lagoon as it has been assumed that the starting water level would be 1.2 mAHD and above the level of the proposed weir. If the ocean entrance had a greater waterway capacity than the weir, the weir would act as a hydraulic control and raise flood levels upstream. This situation would only occur in rare circumstances and would generally be when the lagoon levels were (say) around 2.0 mAHD. In such circumstances the afflux caused by the weir would cause few additional problems. The drawbacks of constructing such a weir are:

- significant cost with very little tangible benefit,
- possible disruption to the aquatic ecosystem and fish migration both during construction and in operation,

- the weir may be eroded or outflanked in a major flood event or ocean surge event unless it is constructed to a high engineering standard and consequent additional cost,
- likely effect on the natural estuarine and coastal processes.

6.2.2 Management of the Entrance Berm by Council

Council's management of the entrance berm can also play a role in maintaining a minimum water level and this is discussed in Section 5.2.3. Council is appreciative of the various issues involved with managing the berm. One of the major areas is maintaining a minimum water level. Council's management of the berm has been discussed by the Floodplain Management Committee, the local community and other interested parties (DLWC) and adopted by Council.

6.3 Upstream Catchment Development

The catchment of the lagoon is a developing area. There are increasing pressures for Council to:

- permit further subdivisions in the upper catchment which is predominantly rural (Area 11),
- permit infill development in the urbanised catchment surrounding the lagoon.

Catchment development has the potential to impact on the drainage system in a number of ways including:

- decreasing catchment infiltration by increasing the impervious area. This increases peak flows and volumes,
- a likely increase in the amount of pollutants generated within the catchment. This occurs due to a number of sources including: use of fertilisers, oil spillage from motor vehicles and increase in dog faeces. The decrease in pervious areas and increase in lined channels generally means that there would be an increase in pollutants reaching the lagoon with further development,
- a likely increase in erosion and consequent sediment load in the catchment runoff as a result of construction activities. As with the pollutants, this is likely to enter the lagoon,
- filling of the floodplain surrounding the lagoon or dredging of the lagoon sediments.

6.3.1 Increase in Peak Flow and Volume

The effect of catchment development was simulated using the WBNM hydrologic model and RUBICON hydraulic model. It was assumed that the catchment would be developed as follows:

- the maximum likely extent of catchment development was assumed,
- the development would predominantly consist of residential development and would be constructed in accordance with current Council guidelines.

The 1% AEP peak lagoon level was shown to increase by less than 0.01 m. The increase in peak flows could still stress the existing urban drainage system downstream of the development unless additional drainage works were implemented. On the North Arm, flood levels would increase by up to 0.06 m.

6.3.2 Increase in Pollutants and Sedimentation

An increase in pollutants and sedimentation is unlikely to significantly affect the peak flood level within the lagoon. Such issues are addressed in Reference 3. There has been no evidence of any significant infilling of the lagoon in recent times for reasons such as:

- the dredge holes created in the 1960's are still present,
- fine sediment transported in suspension from upstream is generally carried to the ocean if the entrance is open during a major flood.

6.3.3 Filling of the Floodplain and/or Dredging in the Lagoon

Dredging of the lagoon below 1.2 mAHD would have no impact upon the design flood levels (refer Section 4.2.2). Filling of the floodplain surrounding the lagoon was simulated by adjusting the hydraulic model and the results are provided below.

A reduction of 23 000 m^3 in the storage capacity of the lagoon was simulated for the 1% AEP storm to attain a measure of the possible impact. This represents an area of 2.5 hectares filled to a depth of 0.9 m and was assumed to be the likely maximum filling which could occur. The results showed that the peak level in the lagoon increased by 0.01 m. If the storage capacity was reduced by 90 000 m^3 (10 hectares filled to a depth of 0.9 m), the peak lagoon level was increased by only 0.05 m.

Any project involving large scale filling will require a detailed hydraulic investigation and should be treated on its merits.

Care should be taken with the placement of fill for future development to ensure that it does not constrict flow paths and consequently exacerbate any local drainage problems. It would be preferable if the fill was obtained from the floodplain rather than imported to the site (this may not always be possible). Building pads should be filled to at least the 1% AEP flood level plus 0.3 m with batters no flatter than 1 vertical to 6 horizontal.

Whilst filling of land, apart from its use as a building pad, is not recommended, there is merit in allowing fill on land to (say) 0.2 m above the let-out level of 1.2 mAHD. The hydraulic impacts of this fill would be negligible and this would allow owners full use of their land when the lagoon is "full". Council should consider each application for fill in this manner on its merits.

Consideration should be given to the consequences of permitting dual occupancies on land located within the 1% AEP flood extent. Approval of dual occupancies will increase the number of people living on the floodplain and consequently the number of people requiring evacuation or assistance during a flood.

6.3.4 Recommendations

The following recommendations are given regarding future catchment development:

- the use of retarding basins or on-site detention measures to control peak flows from new developments and thus reduce the impact upon the peak lagoon level cannot be justified because of the limited benefits that would accrue. However these measures may be required in order to negate any adverse impact immediately downstream of the proposed development. They may also be appropriate in local areas in order to mitigate the increase in peak flows in the drainage system,
- water quality and pollution control measures should be an integral part of any upstream development in both the construction and post-construction periods,
- the increase in impervious area should be minimised as far as possible and measures promoting infiltration encouraged,
- a limited amount of filling on the perimeter of the lagoon floodplain (for building pads or to 0.2 m above the let-out level) may be undertaken subject to the aforementioned guidelines,
- consideration should be given to installing a flood warning system based on the lagoon water level. This may include a siren to warn residents or "totem poles" advising residents of the key flood levels.

6.4 Assessment of the Possible Consequence of the Greenhouse Effect

6.4.1 The Greenhouse Effect

The Greenhouse Effect results from the presence of gases in the atmosphere which allow the sun's rays to penetrate to the earth but reduce the amount of incoming energy being back radiated. It is this trapping of the reflected heat which has enabled life to exist on earth.

Recently there has been concern that increasing amounts of greenhouse gases resulting from human activity may be raising the average earth surface temperature. As a consequence, this may affect the climate and consequently the sea level. The extent of any permanent climatic or sea level change can only be established through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any proposed works.

6.4.2 Climatic Change

It has been suggested that one possible consequence of the Greenhouse Effect would be an increase in rainfall. However, the Bureau of Meteorology have indicated that there is no intention at present to revise design rainfalls to take account of the Greenhouse Effect, as the possible mechanisms are far from clear, and there is no indication that the changes would in fact increase design rainfalls for major storms. Even if an increase in rainfall does occur, the impact upon flood levels may or may not be adverse. Increased rainfall may lead to more frequent openings of the lagoon and possibly a lower average berm level. As shown in Figure 6, a lower berm level produces a lower peak lagoon level.

A 20% increase in the 1% AEP design rainfalls was analysed assuming no change in berm level. The results showed that there would be an increase of up to 0.13 m in the 1% AEP peak flood level in the lagoon.

It has also been suggested that the Cyclone Belt may move further southwards. However, the possible impacts of this on the design rainfalls cannot be ascertained at this time, as little is known about the mechanisms that determine the movement of cyclones even under existing conditions.

6.4.3 Sea Level Change

One possible consequence of an increase in the earth's average surface temperature would be a rise in sea level. This issue is complicated by other long term influences on relative mean sea level changes. As yet there are no definitive data proving that a rise due to the Greenhouse Effect will occur or its likely magnitude. Again, the possible implications of a rise in sea level for Terrigal Lagoon are difficult to assess. Higher ocean levels may be accompanied by greater wave activity which may affect the design beach berm level.

A rise in sea level (say +0.3 m) in the absence of a change to the design beach berm level would cause approximately a 0.02 m rise in the 1% AEP level in the lagoon (rainfall induced inundation). This is because the level of the beach berm is the main determinant not the peak ocean level.

A rise (or fall) in the design beach berm level (currently 2.5 mAHD) would translate to a similar rise (or fall) in the design flood level (rainfall induced) in the lagoon. Any rise would be unacceptable. At this point in time it is assumed that in the short term (less than 10 years) a general rise in the beach berm level, caused by the Greenhouse Effect, could be effectively counteracted by increased maintenance of the beach berm by Council. In the long term (say 50 years) the design beach berm level may rise in response to the rise in sea level. If this occurs there would be a corresponding rise in the rainfall induced flood level. A rise in sea level may also be associated with a recession of the coastline which may potentially cause significant changes to the entrance profile.

6.4.4 Conclusions

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change (UNIPCC) (Reference 13), evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing "greenhouse" gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase,
- the balance of evidence suggests human interference has resulted in climate change over the past century,
- global sea level has risen about 0.1 m to 0.25 m in the past century,
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

The UNIPCC best estimate projected sea level rise for the year 2050 is 0.2 m, with a range of between 0.07 m and 0.39 m.

On a regional basis the CSIRO Climate Change Group predicted increased air and water temperatures, and greater frequency and intensity of severe storms for the NSW coastline (Reference 14). According to these predictions, east coast lows, which are the main cause of storms and floods on the mid north coast, would be more intense, leading to increased occurrence of gale force winds and flooding. However, in a more recent paper by the same group (Reference 15) the effects of sulfate emissions have now also been considered. The inclusion of these emissions in climate models has resulted in a possible reduction in storminess and rainfall.

It is far from certain what the implications of the Greenhouse Effect will be. What will be the magnitude of the effect? How will this affect flood levels at Terrigal Lagoon? If the Greenhouse Effect does result in an increase in the design beach berm level the rainfall induced (and possibly the ocean induced) design flood levels will rise.

There are no means of lessening the Greenhouse Effect other than a world wide reduction in the production of greenhouse gases. Council should continue to monitor the available literature and reassess Council's Flood Policy as appropriate. At a minimum Council should obtain the most current information available from the Department of Land and Water Conservation every two years.

Other Councils in NSW have included a "Greenhouse" freeboard in addition to the usual (say) 0.5 m freeboard. This issue should be canvassed at the Floodplain Management Plan Stage.

7. ACKNOWLEDGMENTS

The study was carried out by Webb, McKeown & Associates Pty Ltd. It was funded by Gosford City Council and the Department of Land and Water Conservation. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Gosford City Council,
- Department of Land and Water Conservation,
- Residents of Terrigal Lagoon,
- Coastline Management, Lagoon Management and Coastal Planning Committee (CLP Committee).

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FIGURES

FIGURE 1

CATCHMENT MAP

MAP WITH COMPLIMENTS OF AUSLIG

LEGEND

WAMBERAL LAGOON CATCHMENT BOUNDARY

TERRIGAL LAGOON CATCHMENT BOUNDARY

2 0 2 4 8 8 10km

SCALE

FILE > J:\JOBS\92067\DRAWINGS\FIGURE 1.CDR DATE > 21-02-2001 10:15

FIGURE 2
Floodplain Management Areas Terrigal Lagoon

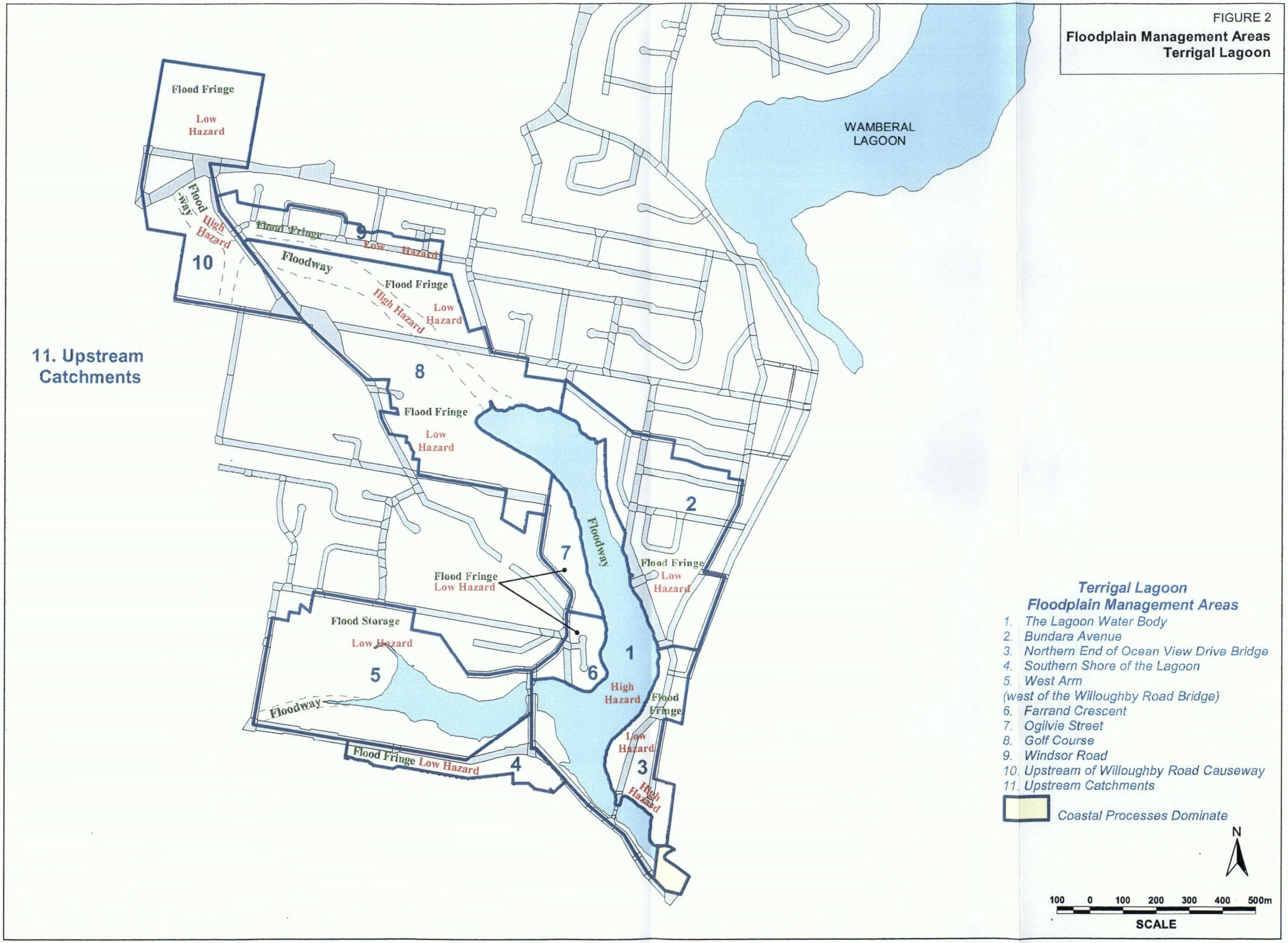
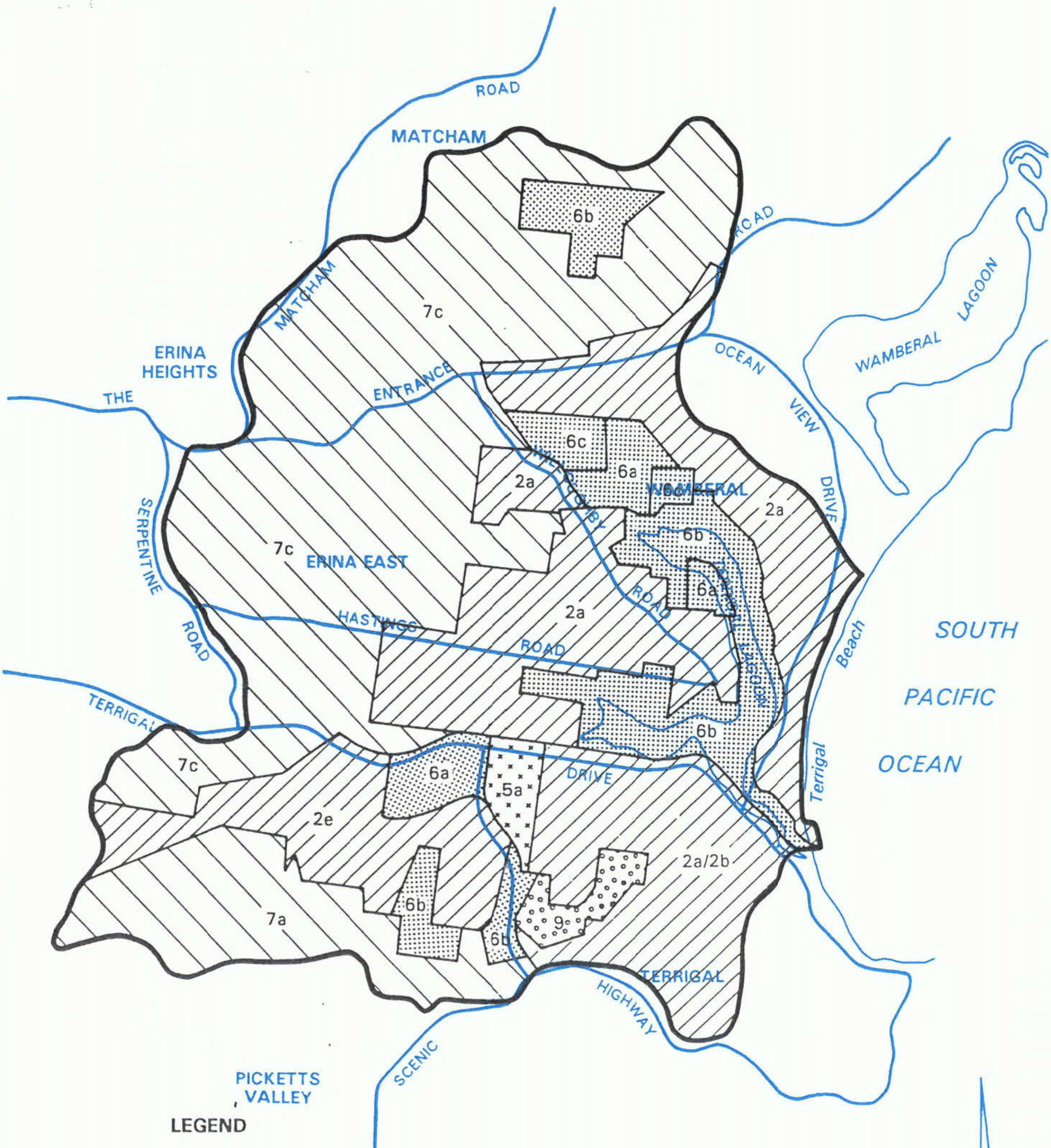


FIGURE 3

PROPOSED CATCHMENT DEVELOPMENT ZONING CONSOLIDATION PLAN

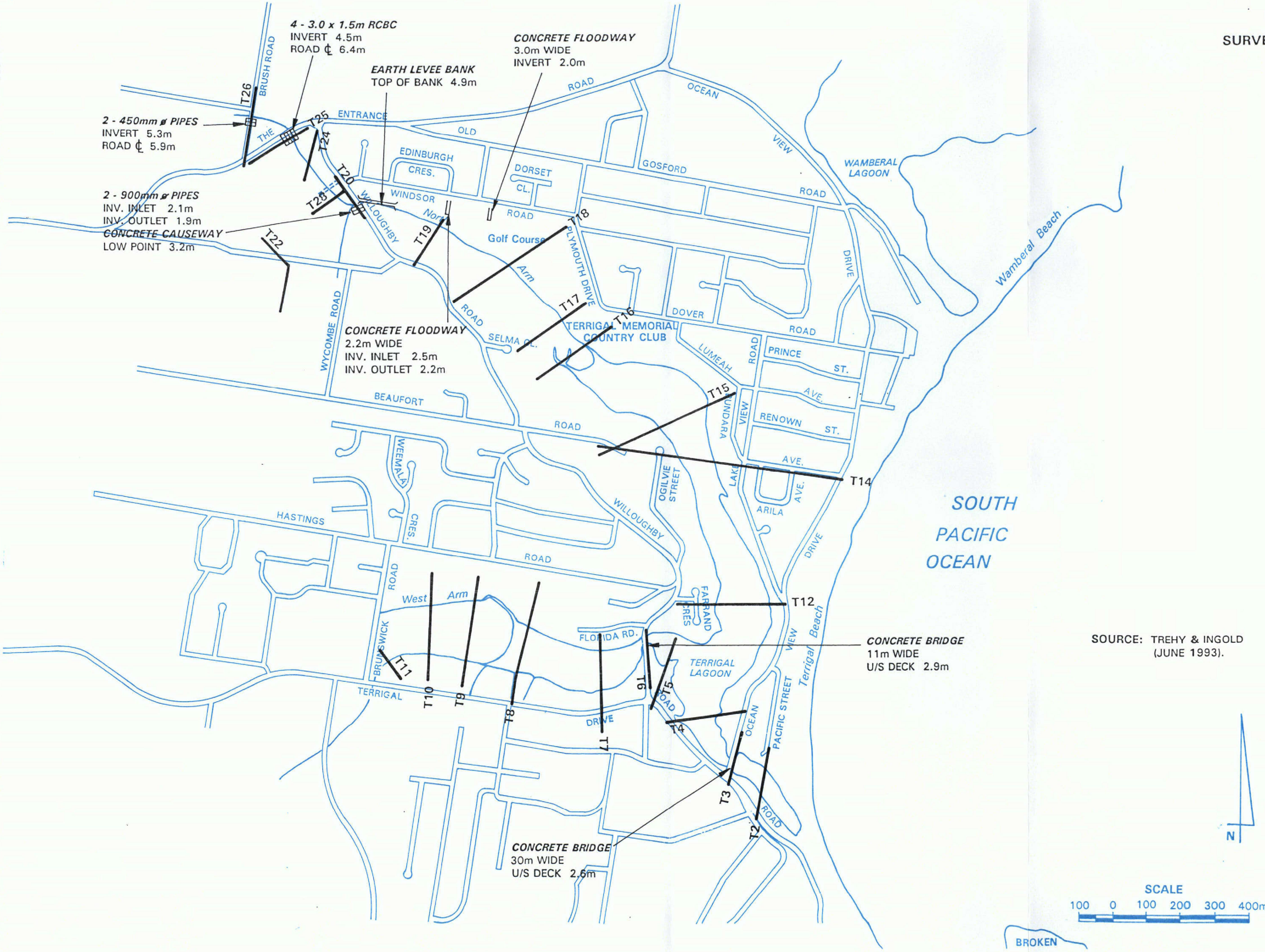


LEGEND

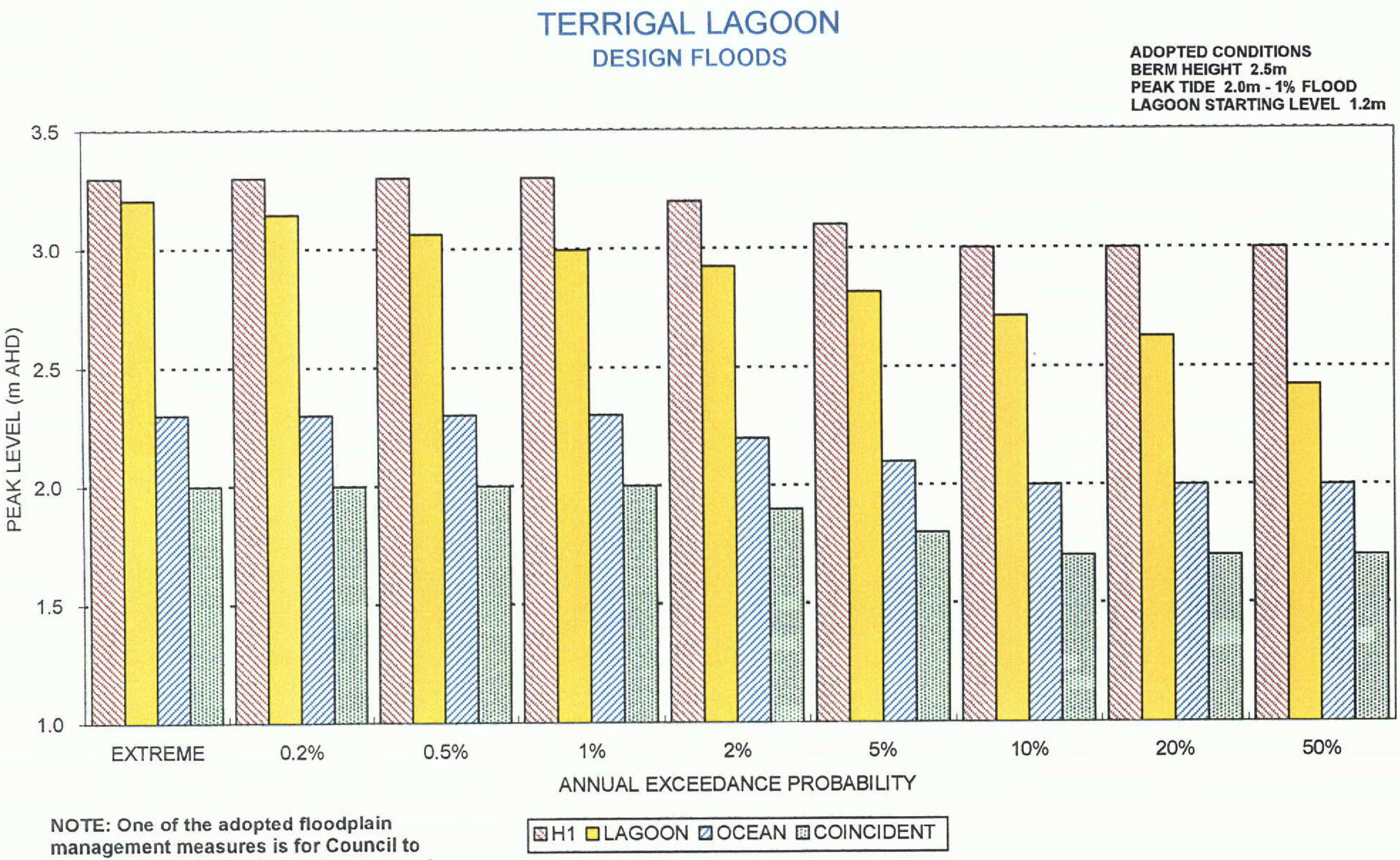
Residential		2a/2b 2e	
Special Uses		5a	
Open Space		6a 6b 6c	recreational environmental protection private recreation
Scenic Protection		7a 7c	conservation rural holdings
Restricted		9	

FIGURE 4

SURVEY DATA



SOURCE: TREHY & INGOLD (JUNE 1993).



NOTE: One of the adopted floodplain management measures is for Council to maintain the entrance berm. Consequently the resulting design flood levels will be lower than indicated on this Figure. For Terrigal Lagoon the 1% AEP level will be reduced from 3.0m AHD to 2.9m AHD.

For further details refer to Sections 2.3.6, 3.5.2 and 6.3.1 from the Terrigal Lagoon Flood Study.

FIGURE 5

PEAK LAGOON LEVELS DESIGN FLOODS

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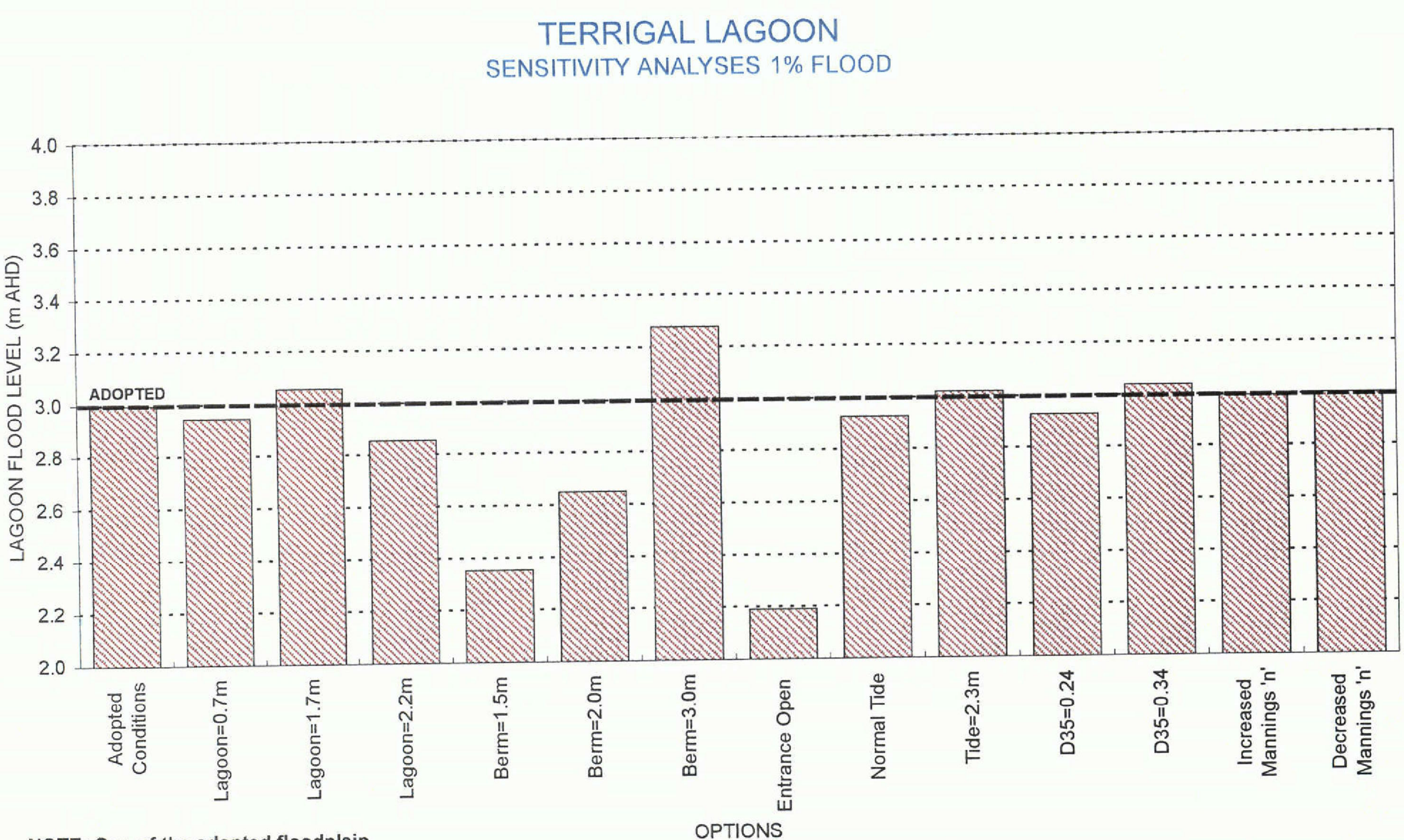


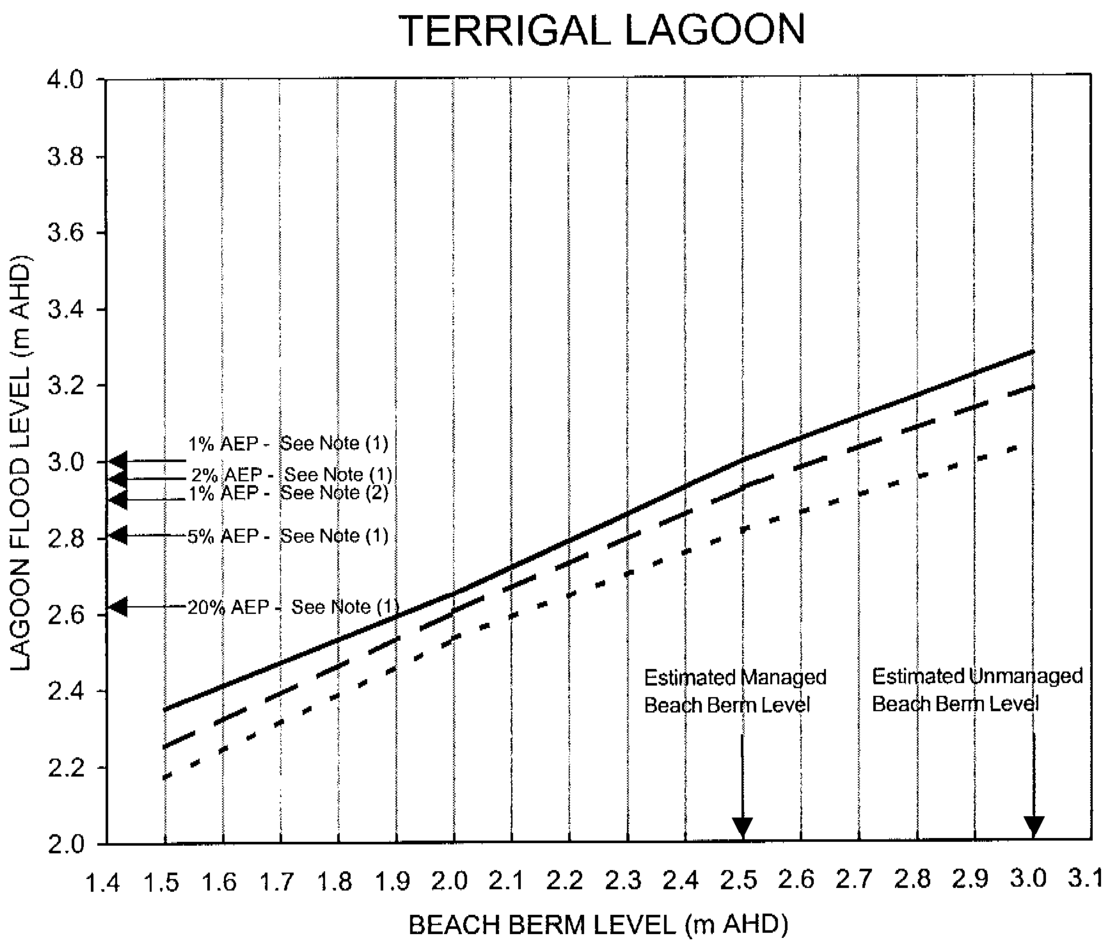
NOTE: One of the adopted floodplain management measures is for Council to maintain the entrance berm. Consequently the resulting design flood levels will be lower than indicated on this Figure. For Terrigal Lagoon the 1% AEP level will be reduced from 3.0m AHD to 2.9m AHD.

FIGURE 6

SENSITIVITY ANALYSES 1% FLOOD

FIGURE 7

SENSITIVITY OF DESIGN LAGOON LEVELS TO BEACH BERM LEVEL



NOTES:

(1) Flood heights determined in the Flood Study

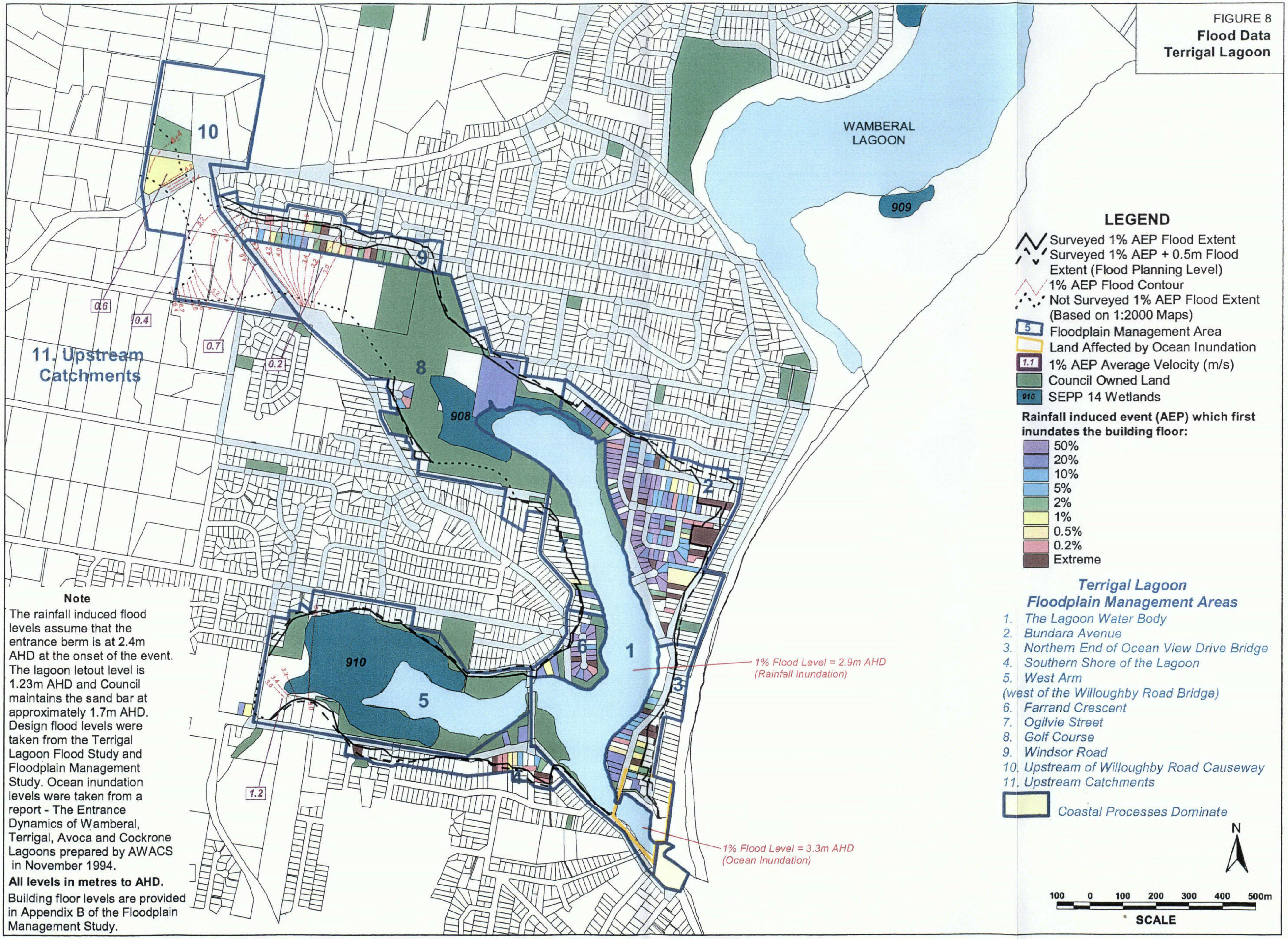
(2) Flood height detemined prior to the present Flood Study

1% Flood — 2% Flood - 5% Flood

NOTE: One of the adopted floodplain management measures is for Council to maintain the entrance berm. Consequently the resulting design flood levels will be lower than indicated on this Figure. For Terrigal Lagoon the 1% AEP level will be reduced from 3.0m AHD to 2.9m AHD.

FILE > J:\JOBS\92067\DRAWINGS\TFPMS\FIGURE7.CDR DATE > 10-01-2001 15:00

FIGURE 8
Flood Data
Terrigal Lagoon



Note

The rainfall induced flood levels assume that the entrance berm is at 2.4m AHD at the onset of the event. The lagoon letout level is 1.23m AHD and Council maintains the sand bar at approximately 1.7m AHD. Design flood levels were taken from the Terrigal Lagoon Flood Study and Floodplain Management Study. Ocean inundation levels were taken from a report - The Entrance Dynamics of Wamberal, Terrigal, Avoca and Cockrone Lagoons prepared by AWACS in November 1994.

All levels in metres to AHD.

Building floor levels are provided in Appendix B of the Floodplain Management Study.

APPENDIX A: DESCRIPTION AND ASSESSMENT OF FLOOD DAMAGES

APPENDIX A: DESCRIPTION AND ASSESSMENT OF FLOOD DAMAGES

A1. DESCRIPTION OF FLOOD DAMAGES

A1.1 General

Flood damages can be defined as being *tangible* or *intangible* and a schematic breakdown of the damage categories is provided in the main body of the text. Tangible damages are those for which a monetary value can be assigned, in contrast to intangible damages, which cannot easily be attributed a monetary value. The range of flood damages are categorised in Table A1.

A1.2 Tangible Damages

Tangible damages can be sub-divided into *direct* damages, which occur due to physical contact with the floodwaters, and *indirect* damages which occur as a result of the disruption of business, trade and other activities. Direct and indirect damages may be referred to as *Potential* or *Actual* damages. Potential damages are the assumed damages if no damage reduction measures are employed and are thus greater than the actual damages. The ratio of actual to potential damages depends upon a number of factors including:

- magnitude of the flood,
- prior flood experience of the community,
- length of warning time.

- **Direct Damages**

Direct damages can be sub-divided between the rural and urban sector. Under direct urban damages there are three broad categories: *Residential, Commercial* and *Public Sector.*

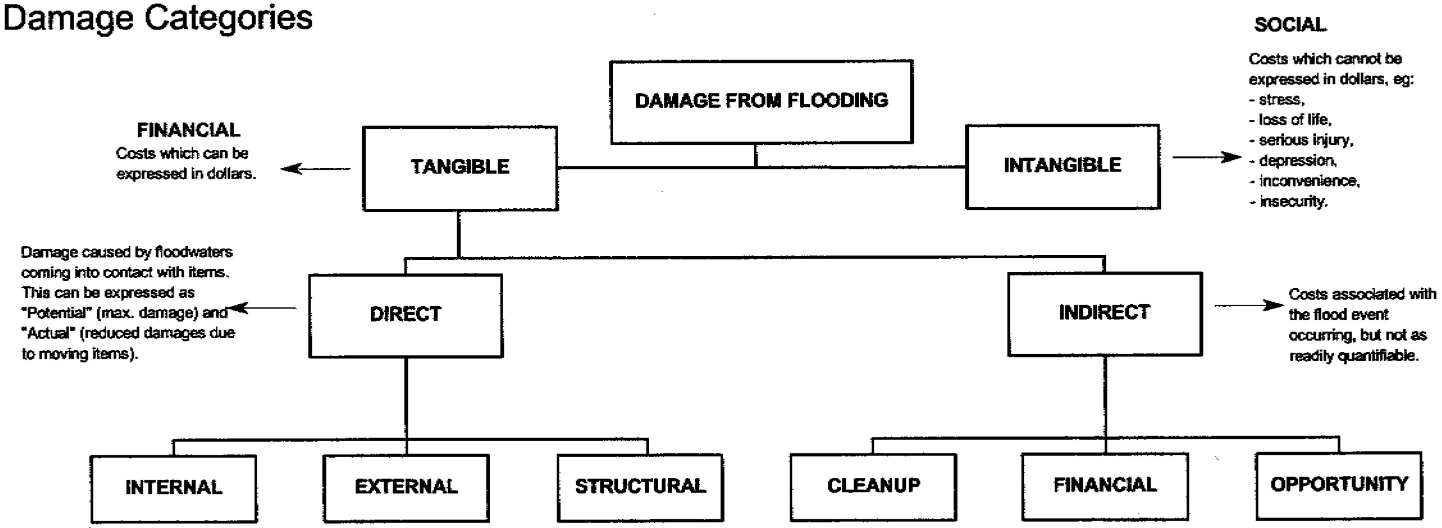
The direct damages under these categories can be grouped under the following headings:

- *Internal* - building contents,
- *Structural* - structure and building fabric,
- *External* - yard, garage, vehicle and other machinery (air conditioning).

Damages to commercial and industrial buildings are much more difficult to quantify for two reasons:

- damages to a given property vary much more than with houses, as they are heavily influenced by the type of business being carried out and the amount of stock carried. This will also vary over time as different businesses use the building,
- industrial enterprises in particular cannot simply be averaged out. Where large factories or warehouses are involved, the only way to get a good estimate of potential damages is to do a site specific survey of the enterprise.

Table A1: Flood Damage Categories



	INTERNAL	EXTERNAL	STRUCTURAL	CLEANUP	FINANCIAL	OPPORTUNITY
RESIDENTIAL	Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances	External Items: Vehicles, Laundries, Caravans, Sheds, Tools, Gardens, Fences	Physical Damage to Buildings: Gyprock, Cupboards, Scour of Footings, Houses becoming buoyant (floating off footings)	Clean Carpets, Walls, Clothes; Re-instate Furniture; Remove Mud and Debris	Loss of wages, Living costs (temporary accomodation and food), Time to repair/replace damaged items	Not Applicable
RURAL	Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances	External Items: Vehicles, Sheds (stables/barns), Machinery, Tools, Fences, Feed storage, Saddles, Crops &/or Stock, Irrigation Systems	Physical Damage to Structures: Damage to Homestead, Sheds, Access tracks, Protection levees	Clean Homestead and Out-buildings; Remove Debris; Dispose of affected crops &/or stock	Loss of Farm Production and Income, Re-instatement of Pastures, Supplementary feeding of stock (by hand or outside agistment), Stock movement/ transport, Living costs (temporary accomodation and food)	Sowing or harvesting of Crops, Sale of Stock (at depreciated value or dependent on market influences)
COMMERCIAL	Contents of Buildings: Products, Stock, Fittings, Tools, Machinery, Raw Materials	External Items: Vehicles, Machinery, Display, Raw Materials/Stockpiles, Fences	Physical Damage to Buildings	Dispose of damaged products, stock, materials; Cleaning and Re-instatement	Loss of Productivity and Income, Bank Interest Charges	Loss of existing &/or Potential Trade
PUBLIC AUTHORITIES	Contents of Public Buildings and Facilities	Public Property and Facilities: Parks, Signs, Machinery, Equipment	Physical Damage to Infrastructure: Electricity, Water, Telephone, Gas, Road & Rail Transport Links	Remove Mud & Debris from Facilities, Public & Private Property Repairs (temporary & permanent)	Disruption of Services, Community Service Relief Grants	Provision of Public Service

As flood damages can vary greatly between areas depending upon the type of buildings and contents, an average damages figure is estimated for each of the above categories (residential, commercial and public sector) following a flood. This is generally presented as a flood depth versus flood damages function. For residential buildings, the size, building fabric, condition of the house and whether it is single or two storey are also taken into account.

Public sector (non-building) damages include:
- recreational/tourist facilities,
- water and sewerage supply,
- gas supply,
- telephone supply,
- electricity supply including transmission poles/lines, sub-stations and underground cables,
- roads and bridges including traffic lights/signs,
- railway line and associated structures,
- costs to employ the emergency services.

Damages to the public sector can contribute a significant proportion of the total flood costs. In the Inverell flood of February 1991, direct costs to the local Council accounted for 10% of the total direct damages. A single item such as a bridge or a sub-station may account for a large proportion of the damages bill in a particular flood.

- **Indirect Damages**

Indirect damages are more difficult to quantify. They can be sub-divided into three broad cost categories:
- *Clean-up* - clean carpets, furniture, refrigerator, etc. It also includes the cost of alternative accommodation,
- *Financial* - loss of wages, loss of trade for the commercial/industrial sector,
- *Opportunity* - non-provision of public services.

In a particular locality it would require an extensive survey to evaluate the costs of lost working hours, disruption to business and trade. Nevertheless an indication of the damages can be obtained from previous studies. Generally the indirect damages have been expressed as a percentage of the direct damages. The figure varies greatly depending upon a number of factors including:
- magnitude of flood,
- time away from home/work,
- category (residential, commercial, industrial).

An average percentage (indirect as a percentage of direct) from a number of post flood surveys is:

- Residential - 15%,
- Commercial - 30%,
- Industrial - 50%.

A1.3 Intangible Damages

Intangible damages are those flood damages which by their nature are difficult to quantify in monetary terms. An example of a *direct* intangible damage is the "loss of visual quality" of an area or "loss of a heritage item". Most intangible damages are *indirect* and commonly occur after the flood peak has passed.

Intangible damages can be categorised as follows:

- **Residential**

  Post flood damages surveys have linked flooding to stress, ill-health and trauma in the residents. For example the loss of memorabilia, pets, insurance papers, etc., may cause stress and subsequent ill-health. In addition, flooding may affect personal relationships by contributing to marriage breakdowns and lead to stress in domestic/work situations. Residents may worry each time heavy rain occurs and there is a threat of flooding. This may be reflected in increased sickness or depression requiring psychiatric help. These effects can induce a lowering in the quality of life of the flood victims.

  Flood victims may also suffer injuries during a flood or during the clean-up process. Whilst the direct costs of the injuries may be accounted for in the flood damages survey, the physiological effect or discomfort may last for a long time.

  The most extreme "intangible damage" that can arise from flooding is death, and unfortunately this is not a rare occurrence. There are many examples of deaths of local residents and rescue workers during floods.

- **Commercial/Industrial/Rural**

  Whilst a large number of businesses carry insurance for loss of trade during and following a flood until the clean-up is complete, they may still suffer a financial loss. For example the confidence in the business of regular clients may be reduced permanently. Clients may take their business elsewhere during the flood/clean-up period and may never revert to the original supplier.

- **Services**

  The loss of services to customers, e.g., transport disruption, loss of education, loss of power, etc., occur as a result of floods and these are generally not costed within the tangible damages category.

- **Environmental**

  Environmental damage may occur as a result of flooding, for example flora and fauna may be lost. However the riverine environment is a natural system and it is difficult to quantify the effects of flooding on natural processes. Some flora and fauna can in fact benefit from flooding. Also in the short term there may be a deterioration in water quality or vegetation, which may recover in the long term. Wetlands develop over time as a result of flooding and require periodic flooding for their long term survival.

  Probably the most significant potential environmental impact is the release of pollutants as a result of flooding. Generally this is as a result of flooding of commercial/industrial establishments.

  The loss of man-made structures which have a "heritage" or non-replaceable value are a real cost which cannot be quantified. Modifications to the pattern of flooding through flood mitigation works may change the existing ecosystem. Although the changes can be beneficial or adverse.

In summary, there is a comprehensive body of available literature on intangible damages which provides many examples. However the costing of such damages in dollar terms is often not possible. These "costs" must not be ignored when determining floodplain management options. The literature suggests that the value of intangible damages may equal or exceed tangible damages. It is therefore often necessary to imply a value to the intangible damages to achieve a proper appreciation of proposed works and measures.

A2. ASSESSMENT OF FLOOD DAMAGES

A2.1 General

A2.1.1 Introduction

Quantification of flood damages is generally based upon post-flood damage surveys. An alternative procedure is to undertake a self-assessment survey of the flood liable residents. This latter approach is more expensive and may not accurately reflect what actually occurs in a flood. Floods by their nature are unpredictable and it is unlikely that a self-assessment survey would have predicted the scale of the damages which occurred in Nyngan in 1990. For this reason it was decided to use the post-flood damage approach in assessing flood damages. More recent information will become available from the November 1996 flood at Coffs Harbour. A listing of the most widely known post flood damage surveys is shown in Table A2.

Table A2: Residential Flood Damage Surveys

Location	Year of Flood	Comments
Brisbane	1974	400 residential properties.
Lismore	1974	100 properties. The data were obtained several years after the last major flood.
Forbes	1974	35 properties. The data were obtained several years after the latest major flood.
Sydney (Georges River)	1986	96 properties (2 studies undertaken)
Nyngan	1990	24 residential, 14 commercial and 6 public properties, 4-5 weeks after the flood.
Inverell	1991	4 residential, 20 commercial and 10 public properties, 2-3 weeks after the flood.

The most comprehensive surveys are those carried out for Sydney (Georges River), Nyngan and Inverell. Some of the problems in applying data from these studies to other areas can be summarised as follows:

- varying building construction methods, e.g. slab on ground, pier, brick, timber,
- different average age of the buildings in the area,
- the quality of buildings may differ greatly,
- inflation must be taken in account,
- different fixtures within buildings, e.g. air-conditioning units,
- change in internal fit out of buildings over the years or in different areas, e.g. more carpets and less linoleum or change in kitchen/bathroom cupboard material,
- external (yard) damages can vary greatly. For example in some areas vehicles can be readily moved whilst in other areas it is not possible,

- different approaches in assessing flood damages. Are the damages assessed on a "replacement" or a "repair and reinstate where possible" basis? Some surveys include structural damage within internal damage whilst others do not,
- varying warning times between communities means that the potential to actual damage ratio may change,
- variations in flood awareness of the community.

A2.1.2 Summary of Survey Data

Flood damages data from the following surveys are provided in Table A3:

- Inverell 1991 - Reference A1,
- Nyngan 1990 - Reference A2,
- Sydney (Georges River) 1986 - Reference A3.

References A1 and A2 were undertaken by Water Studies Pty Ltd and Reference A3 by the Centre for Resource and Environmental Studies (CRES) at the Australian National University, Canberra.

Table A3: Summary of Post Flood Damage Surveys
(Note: Costs quoted at the time of the flood)

	Nyngan	Inverell	Georges River
TOTAL FLOOD DAMAGES	$47 Million	$20.6 Million	$17 Million
Year	**1990**	**1991**	**1986**
Flooded Premises and Total Cost per section in $M (in brackets):			
Residences Commercial/Industrial Premises Public Authorities/Utilities	717 ($18.9) 98 ($11.3) 42 ($17.0)	126 ($2.3) 264 ($14.9) 36 ($3.4)	1000 215 Not Known
Total	857	426	
Damage ($M) per Category and % of Total Flood Damages (in brackets):			
Direct Indirect	28.6 (60%) 18.7 (40%)	10.7 (52%) 9.8 (48%)	16.9 (89%) 2.1(11%)
Average Damages per Premise and % of Total Flood Damages (in brackets):			
Average Residential Average Commercial/Industrial Average Public	$26 400(40%) $117 000(24%) $400 000(36%)	$18 000(11%) $54 000(72%) $93 000(17%)	$8 000(48%) $40 000(52%) Not Known
Average Residential Damages by Category and % of Total Residential Damages (in brackets):			
Direct - Internal Direct - External Direct - Structural Indirect - Financial Indirect - Clean Up Average depth of inundation above floor	$8 900(34%) $4 500(19%) $5 200(20%) $4 800(20%) $2 200(7%) 0.8m	$8 100(42%) $2 500(19%) $5 000(27%) $300(1%) $2 100(11%) 0.6m	Not Known $3 500 (44%) Not Known Assumed as 15% of Direct Not Known
Average Commercial Damages by Category and % of Total Commercial Damages (in brackets):			
Direct - Internal Direct - External Direct - Structural Indirect - Financial Indirect - Clean Up	$28 600 (25%) $1 100 (1%) $3 000(3%) $79 500 (70%) $2 000 (1%)	$17 100 (33%) $5 500 (12%) $750 (1%) $23 000 (45%) $4 900 (9%)	Not Known Not Known Not Known Assumed as 55% of Direct
Average Annual Damage	$0.63M	Unknown	$14.4M

NOTES:
- 93% of all properties in Nyngan were flooded above floor level.
- The AAD figure for Sydney (Georges River) is $0.88M for residential and $13.5M for commercial/industrial.

A2.2 Tangible Damages - Residential Properties

Tangible direct damages are generally calculated under the following components:
- Internal,
- Structural,
- External.

Tangible indirect damages can be subdivided into the following groups:

- accommodation and living expenses,
- loss of income,
- clean up activities.

All estimates are actual damages rather than potential damages.

A2.2.1 Direct Internal Damages

- **Water Studies**

In the Water Studies approach internal damages are based upon the following formulae provided in Reference A1.

$$\frac{D}{D_2} = 0.06+1.42H-0.61H^2 \qquad \text{for } H < 1.0\text{m}$$

$$\frac{D}{D_2} = 0.75+0.12H \qquad \text{for } H > 1.0\text{m}$$

where,

H	=	height of flooding above floor level (m)
D	=	damage at height (H) above floor level
D_2	=	damage at height of 2 m above floor level

At Nyngan and Inverell D_2 was $12 500 for small houses and $14 500 for medium/large houses. These values are in $1991's. The reference states that *"Damages to individual properties scatter widely around the relationship, which can only be used to reliably estimate the aggregated damage to a collection of flood prone dwellings and not the damage to a single dwelling."*. Structural damages are not included in the above figures.

- **CRES**

In the CRES approach (Reference A3) internal and structural damages are combined. Data are provided for three groups of buildings, namely Poor, Medium and Good. The data are shown in $1986's in Table A4.

Table A4: Residential Stage-Damage for Actual Direct Damage to Structure and Contents ($1986's)
(Taken from the Georges River Study: Reference A3 - Table A2.2.7)

Overfloor Depth	Poor	Medium	Good	Average
0.0m	370	1045	2400	1270
0.1m	740	2090	4799	2540
0.6m	3012	5713	10360	6360
1.5m	7102	7595	13190	9300
1.8m	7210	7711	13391	9440

A2.2.2 Direct Structural Damages

In the CRES approach internal and structural damages are combined. In the Water Studies approach structural damage was adopted as approximately $5 000 at both Nyngan and Inverell.

A2.2.3 Direct External Damages

The majority of external damages is attributable to vehicles. However there is a high likelihood that a significant percentage of the vehicles can be moved to high ground even with minimal flood warning.

At Nyngan external damages were estimated as $4 500, mostly for vehicles, and at Inverell at $2 500 of which $1 500 was for vehicles. In the Sydney 1986 data obtained by CRES an external damages figure of $600 was adopted per property experiencing over ground flooding. In addition a sum of $2 000 per property experiencing over ground flooding in excess of 0.6m was included.

A2.2.4 Indirect Damages

In the Inverell study the indirect damages were taken as $200 for accommodation, $100 for loss of income and $2 100 for clean up activities. The total indirect damages ($2 400) therefore, represented approximately 20% of the direct damages. At Nyngan indirect damages were high due to the extended period residents were away from their homes and were estimated at $7 700 per dwelling flooded above floor level. In this case the indirect damages amounted to approximately 40% of the direct damages. CRES adopted a figure for indirect damages of 15% of the direct damages (Georges River Study).

A2.3 Adopted Tangible Damages - Residential Properties

The adopted values used in this study are provided in Table A5 and documented in the following sections.

A2.3.1 Direct Internal Damages

The Water Studies approach to the determination of internal damages was adopted for use in this study. It was decided to adopt a single D_2 value of $20 000 for all residential buildings.

A2.3.2 Direct Structural Damages

Structural damages were assumed to be a linear relationship of $0 at 0 m to $8 000 at 0.5 m. Above this value it was considered that there would be no additional structural damages.

It is likely that in floods larger than a 1% event some buildings may collapse or have to be destroyed. The cost of this damage has not been included in the analysis.

A2.3.3 Direct External Damages

External damages (laundry/garage) was assumed to be a linear relationship from $0 at 0 m above ground level to $1 000 at 0.5 m. Vehicle damages were assumed to be $0 at 0.2 m and to increase linearly to $500 at 0.5 m above ground level.

A2.3.4 Indirect Damages

Indirect damages were assumed to be a linear relationship from $0 at 0 m to a maximum of $3 000 at 0.5 m.

A2.4 Tangible Damages - Commercial Properties

Damages to commercial properties cannot be estimated as accurately as damages to residential properties for a number of reasons, including:

- less post-flood surveys have been undertaken in Australia,
- some commercial properties are insured against flood loss, if this is the case the insurance premiums need to be considered in assessing flood damages,
- flood damages can vary greatly from building to building. For example an electrical retail shop may suffer more damages than say a sandwich shop, as the latter has less high value stock. On the other hand there is more opportunity to reduce this actual damage in the former as the items can be easily moved by staff if there is sufficient warning and awareness. In large premises the flood damages depends on the care taken in moving stock. Carpets are high value items and cannot be easily moved whilst the cars in a car showroom can be easily moved. In many floods there is no safe place to put the cars, yet carpets can be stacked on each other or raised,
- the damages can vary from year to year as the usage of a particular premises changes. Damages may also vary on a seasonal or weekly basis depending upon the type of business,
- indirect damages (loss of trade) may be significant and this is difficult to estimate.

In this study tangible direct commercial damages were estimated using data taken from Reference A1, where:

$$D = \mathcal{L} \log_e (H-B) + y$$

where, D = unit damage (\$ per m^2)
H = depth of flooding above floor level (m), and
$\mathcal{L}$, B and y are parameters determined from field survey at the time of the flood. The following parameters were adopted for use in this study: Commercial $\mathcal{L}$ = 14.6, B = 0.19, y = 86.9.

Indirect tangible damages were taken as 100% of direct damages. This figure includes external damages, structural damages, financial loss and clean up costs.

A2.5 Tangible Damages - Public Utilities

The damages to public utilities (excluding buildings which are taken as commercial properties) include:

- water and sewerage supply,
- telecommunications,
- road/rail transport,
- other public assets.

Little data are available for establishing costs to public utilities, and the data from Nyngan and Inverell show that it can vary from 17% to 36% of the total damages bill. In this study damages to public utilities were not estimated.

Table A5: Assumed Residential Depth/Damage Data

Depth over Floor/Yard (m)	Total	Internal Damages	Structural Damages	External Damages	Indirect Damages
0.1	6318	3918	1600	200	600
0.3	15989	8622	4800	767	1800
0.5	24850	12350	8000	1500	3000
1.0	29900	17400	8000	1500	3000
1.5	31100	18600	8000	1500	3000
2.0	32300	19800	8000	1500	3000

A2.6 Average Annual Damages

It should be emphasised that **these figures include only tangible (direct or indirect) damages to buildings and residents, the cost of intangible damages has not been evaluated**. Available literature suggests that the extent of **intangible damages may equal or exceed the tangible damages. Damages to the public sector have not been accurately assessed in this study**. Recent studies show that **damages to public property can vary significantly but may comprise 50% of the private tangible flood damages.**

While the total damage figure in a given flood is useful to get a "feel" for the magnitude of the flood problem, it is of little value for economic evaluation. When considering the economic effectiveness of a proposed mitigation option the key factor is the total damage prevented over the life of the option. This is a function not only of the high damage which occurs in large floods but also of lesser (but more frequent) damage which occur in small floods.

The standard way of expressing flood damage is in terms of *Average Annual Damages* (AAD). These are calculated by multiplying the damage that can occur in a given flood by the probability of the flood occurring in a given year. These numbers are then summed across the range of floods. By this means the smaller, more frequent floods are given a greater weighting than the rare, catastrophic floods.

A3. REFERENCES

A1. NSW Department of Water Resources
Inverell Flood Damage Survey February 1991 Flood
Water Studies Pty Ltd - November 1991.

A2. NSW Department of Water Resources
Nyngan 1990 Flood Investigation - Chapter 9
October 1990.

A3. Public Works, Department of Water Resources
Losses and Lessons from the Sydney Floods of August 1986 Vol. 1 and Vol. 2
Centre for Resource and Environmental Studies, Australian National University, and Environmental Management Pty Ltd Sydney - September 1990.

APPENDIX B: FLOOD DAMAGE DATABASE

APPENDIX B: FLOOD DAMAGE DATABASE

GIS Tag	FPM Area	Number Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
190834	2	1 Arila Avenue	2.45	2.15	20% AEP	possibly
190886	2	2 Arila Avenue	3.07	2.77	0.2% AEP	
190854	2	3 Arila Avenue	2.83	2.53	2% AEP	
190887	2	4 Arila Avenue	2.44	2.14	20% AEP	
190827	2	5 Arila Avenue	3.18	2.88	Extreme	
190862	2	6 Arila Avenue	2.83	2.53	2% AEP	
190826	2	7 Arila Avenue	2.77	2.47	5% AEP	
190864	2	8 Arila Avenue	3.00	2.70	0.5% AEP	
190838	2	9 Arila Avenue	2.24	1.94	50% AEP	
190863	2	10 Arila Avenue	2.71	2.41	10% AEP	
190828	2	11 Arila Avenue	2.19	1.89	50% AEP	
190888	2	12 Arila Avenue	2.69	2.39	10% AEP	
190829	2	13 Arila Avenue	2.80	2.50	5% AEP	
191052	2	14 Arila Avenue	2.73	2.43	5% AEP	
190856	2	15 Arila Avenue	2.11	1.81	50% AEP	
190842	2	16 Arila Avenue	2.30	2.00	50% AEP	
190823	2	17 Arila Avenue	2.81	2.31	5% AEP	possibly
190818	2	18 Arila Avenue	2.44	2.14	20% AEP	
190835	2	19 Arila Avenue	2.34	2.04	50% AEP	
190820	2	20 Arila Avenue	99.00	99.00	-	
190837	2	21 Arila Avenue	2.39	2.09	50% AEP	
190819	2	22 Arila Avenue	2.24	1.94	50% AEP	
190836	2	23 Arila Avenue	2.46	2.16	20% AEP	
190844	2	24 Arila Avenue	2.52	2.22	20% AEP	
190855	2	25 Arila Avenue	2.60	2.30	20% AEP	
190814	2	26 Arila Avenue	2.11	1.81	50% AEP	
190815	2	28 Arila Avenue	2.45	2.15	20% AEP	
190849	2	44 Arila Avenue	2.18	1.88	50% AEP	
190871	2	1 Bundara Avenue	4.82	4.52	-	
190885	2	3 Bundara Avenue	3.38	3.08	-	
190865	2	5 Bundara Avenue	3.39	3.09	-	
190866	2	7 Bundara Avenue	3.82	3.52	-	
190882	2	9 Bundara Avenue	3.40	3.10	-	possibly
190970	2	11 Bundara Avenue	2.50	2.20	20% AEP	
190971	2	13 Bundara Avenue	3.38	3.08	-	
191010	2	15 Bundara Avenue	2.79	2.49	5% AEP	
191005	2	17 Bundara Avenue	2.56	2.26	20% AEP	
190966	2	19 Bundara Avenue	2.73	2.43	5% AEP	
191015	2	21 Bundara Avenue	3.14	2.64	0.2% AEP	
190852	2	22 Bundara Avenue	2.62	2.32	20% AEP	
191044	2	23 Bundara Avenue	2.48	2.18	20% AEP	
190883	2	24 Bundara Avenue	3.09	2.79	0.2% AEP	possibly
191045	2	25 Bundara Avenue	2.50	2.20	20% AEP	
not found	2	26 Bundara Avenue	99.00	99.00	-	
190943	2	27 Bundara Avenue	2.76	2.46	5% AEP	
190848	2	28 Bundara Avenue	99.00	99.00	-	
190944	2	29 Bundara Avenue	2.66	2.36	10% AEP	

GIS Tag	FPM Area	Number Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
190847	2	30 Bundara Avenue	1.94	1.64	50% AEP	
190942	2	31 Bundara Avenue	2.28	1.98	50% AEP	
190899	2	32 Bundara Avenue	2.11	1.81	50% AEP	
190898	2	33 Bundara Avenue	3.23	2.93	Extreme	
190937	2	34 Bundara Avenue	2.52	2.22	20% AEP	
190935	2	35 Bundara Avenue	2.04	1.74	50% AEP	
190936	2	37 Bundara Avenue	2.27	1.97	50% AEP	
190900	2	39 Bundara Avenue	2.41	2.11	50% AEP	possibly
190938	2	40 Bundara Avenue	2.04	1.74	50% AEP	
190930	2	42 Bundara Avenue	2.10	1.80	50% AEP	
190931	2	43 Bundara Avenue	2.29	1.99	50% AEP	
190910	2	44 Bundara Avenue	2.16	1.86	50% AEP	
190919	2	45 Bundara Avenue	2.05	1.75	50% AEP	
190911	2	46 Bundara Avenue	1.80	1.50	50% AEP	
190960	2	47 Bundara Avenue	2.52	2.22	20% AEP	
190912	2	48 Bundara Avenue	1.93	1.63	50% AEP	
190965	2	49 Bundara Avenue	2.68	2.38	10% AEP	
190951	2	50 Bundara Avenue	2.30	2.00	50% AEP	
190924	2	51 Bundara Avenue	2.65	2.35	10% AEP	
190915	2	52 Bundara Avenue	3.13	2.83	0.2% AEP	
190926	2	53 Bundara Avenue	2.59	2.29	20% AEP	
190916	2	54 Bundara Avenue	2.20	1.90	50% AEP	
190914	2	56 Bundara Avenue	99.00	99.00	-	
229339	2	10 Lake View Drive	3.21	2.91	Extreme	
190810	2	12 Lake View Drive	2.89	2.59	2% AEP	possibly
190840	2	16 Lake View Drive	2.36	2.06	50% AEP	
190845	2	18 Lake View Drive	1.93	1.63	50% AEP	
190841	2	20 Lake View Drive	1.83	1.53	50% AEP	
190816	2	22 Lake View Drive	1.97	1.67	50% AEP	
191046	2	24 Lake View Drive	2.33	2.03	50% AEP	
190824	2	26 Lake View Drive	1.91	1.61	50% AEP	
190858	2	28 Lake View Drive	1.82	1.52	50% AEP	
190857	2	30 Lake View Drive	2.17	1.87	50% AEP	
190832	2	34 Lake View Drive	2.08	1.78	50% AEP	
190850	2	35 Lake View Drive	3.20	2.90	Extreme	
190833	2	36 Lake View Drive	2.37	2.07	50% AEP	
190822	2	37 Lake View Drive	2.11	1.81	50% AEP	
190949	2	44 Lake View Drive	3.25	2.95	Extreme	
190906	2	46 Lake View Drive	2.17	1.87	50% AEP	
190905	2	48 Lake View Drive	2.12	1.82	50% AEP	
190918	2	52 Lake View Drive	2.67	2.37	10% AEP	
190993	2	2 Lumeah Avenue	7.05	6.75	-	
190994	2	4 Lumeah Avenue	10.31	10.01	-	
190992	2	6 Lumeah Avenue	10.52	10.22	-	
191006	2	8 Lumeah Avenue	99.00	99.00	-	
190988	2	10 Lumeah Avenue	9.64	9.34	-	
191029	2	14 Lumeah Avenue	8.98	8.68	-	
190986	2	16 Lumeah Avenue	8.56	8.26	-	
191033	2	18 Lumeah Avenue	8.35	8.05	-	
191034	2	20 Lumeah Avenue	7.41	7.11	-	

GIS Tag	FPM Area	Number Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
190923	2	22 Lumeah Avenue	6.89	6.59	-	
190922	2	24 Lumeah Avenue	6.43	6.13	-	
190957	2	26 Lumeah Avenue	5.38	5.08	-	
190963	2	30 Lumeah Avenue	99.00	99.00	-	
190950	2	32 Lumeah Avenue	2.79	2.49	5% AEP	possibly
190913	2	34 Lumeah Avenue	2.91	2.61	2% AEP	possibly
190809	2	36 Lumeah Avenue	3.10	2.80	0.2% AEP	
191265	2	38 Lumeah Avenue	2.62	2.32	20% AEP	possibly
191236	2	40 Lumeah Avenue	2.62	2.32	20% AEP	possibly
191261	2	42 Lumeah Avenue	2.60	2.30	20% AEP	possibly
191069	2	44 Lumeah Avenue	2.60	2.30	20% AEP	possibly
191068	2	46 Lumeah Avenue	3.52	3.22	-	
191071	2	48 Lumeah Avenue	3.67	3.37	-	
191215	2	54 Lumeah Avenue	3.44	3.14	-	
191108	2	56 Lumeah Avenue	12.18	11.88	-	
191076	2	58 Lumeah Avenue	14.24	13.94	-	
190821	2	4 Minell Close	3.18	2.18	Extreme	
190817	2	6 Minell Close	2.17	1.87	50% AEP	
190839	2	8 Minell Close	2.68	2.38	10% AEP	
190813	2	10 Minell Close	2.16	1.86	50% AEP	
190096	2	12 Minell Close	2.25	1.95	50% AEP	
190060	2	40 Ocean View Drive	3.20	2.90	Extreme	
190058	2	42 Ocean View Drive	3.42	3.12	-	possibly
190062	2	44 Ocean View Drive	3.77	3.27	-	possibly
190068	2	46 Ocean View Drive	3.10	2.80	0.2% AEP	
190067	2	48 Ocean View Drive	3.45	3.15	-	
190066	2	50 Ocean View Drive	3.61	3.11	-	possibly
190065	2	52 Ocean View Drive	3.23	2.93	Extreme	possibly
190064	2	54 Ocean View Drive	3.34	3.04	-	possibly
190063	2	56 Ocean View Drive	3.25	2.95	Extreme	
consolidated	2	58 Ocean View Drive	3.21	2.91	Extreme	
consolidated	2	60 Ocean View Drive	3.08	2.78	0.2% AEP	
190876	2	62 Ocean View Drive	3.02	2.72	0.5% AEP	
190881	2	64 Ocean View Drive	2.81	2.51	5% AEP	possibly
190877	2	66 Ocean View Drive	3.45	3.15	-	possibly
191050	2	68 Ocean View Drive	3.07	2.77	0.2% AEP	possibly
190875	2	70 Ocean View Drive	3.20	2.90	Extreme	possibly
190874	2	72 Ocean View Drive	99.00	99.00	-	
consolidated	2	78 Ocean View Drive	3.55	3.25	-	
190872	2	80 Ocean View Drive	3.99	3.69	-	
191058	2	82 Ocean View Drive	3.20	2.90	Extreme	
191023	2	84 Ocean View Drive	4.23	3.93	-	
190981	2	86 Ocean View Drive	4.60	4.30	-	possibly
190980	2	88 Ocean View Drive	5.50	5.20	-	
not found	2	40A Ocean View Drive	3.20	2.90	Extreme	possibly
191048	2	74-76 Ocean View Drive	3.20	2.90	Extreme	
190982	2	1 Renown Street	4.46	3.46	-	possibly
190975	2	2 Renown Street	4.47	3.47	-	possibly
191011	2	3 Renown Street	4.27	3.77	-	
190976	2	4 Renown Street	3.41	3.11	-	

GIS Tag	FPM Area	Number Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
190973	2	5 Renown Street	5.35	3.35	-	
191024	2	6 Renown Street	3.81	3.51	-	
190968	2	8 Renown Street	3.62	3.32	-	
190967	2	10 Renown Street	3.65	3.35	-	
191012	2	11 Renown Street	3.50	3.20	-	
191007	2	12 Renown Street	3.47	3.17	-	
191060	2	15 Renown Street	3.53	3.23	-	
191009	2	16 Renown Street	3.59	3.29	-	
consolidated	2	17 Renown Street	3.53	3.23	-	possibly
191008	2	18 Renown Street	2.97	2.67	1% AEP	
190941	2	19 Renown Street	3.30	3.00	-	
191013	2	20 Renown Street	3.27	2.77	-	possibly
190945	2	21 Renown Street	3.73	3.23	-	possibly
191014	2	22 Renown Street	3.86	2.86	-	possibly
190987	2	23 Renown Street	3.38	3.08	-	possibly
191016	2	24 Renown Street	2.94	2.64	1% AEP	
190940	2	25 Renown Street	3.02	2.72	0.5% AEP	
190948	2	26 Renown Street	2.78	2.48	5% AEP	
190920	2	27 Renown Street	2.72	2.42	5% AEP	possibly
190907	2	28 Renown Street	3.49	3.19	-	
190921	2	29 Renown Street	3.24	2.94	Extreme	
190908	2	30 Renown Street	2.37	2.07	50% AEP	
190964	2	31 Renown Street	2.46	2.16	20% AEP	
190909	2	32 Renown Street	2.24	1.94	50% AEP	
190946	2	34 Renown Street	2.41	2.11	50% AEP	
190947	2	36 Renown Street	2.53	2.23	20% AEP	
190974	2	7-9 Renown Street	4.25	3.25	-	possibly
189848	3	1 Ocean View Drive	2.53	2.23	20% AEP	
189825	3	4 Ocean View Drive	2.56	2.26	20% AEP	
189831	3	5 Ocean View Drive	2.74	2.44	5% AEP	
189846	3	6 Ocean View Drive	2.48	2.18	20% AEP	possibly
189845	3	7 Ocean View Drive	2.98	2.68	1% AEP	
189844	3	8 Ocean View Drive	2.51	2.21	20% AEP	
190019	3	9 Ocean View Drive	3.18	2.88	Extreme	
190020	3	11 Ocean View Drive	2.95	2.65	1% AEP	possibly
190043	3	13 Ocean View Drive	2.83	2.53	2% AEP	possibly
190092	3	14 Ocean View Drive	3.01	2.71	0.5% AEP	
190042	3	15 Ocean View Drive	2.96	2.66	1% AEP	possibly
190093	3	16 Ocean View Drive	99.00	99.00	-	
190026	3	18 Ocean View Drive	3.10	2.80	0.2% AEP	
190037	3	19 Ocean View Drive	3.18	2.88	Extreme	
190025	3	20 Ocean View Drive	2.66	2.36	10% AEP	possibly
190091	3	21 Ocean View Drive	3.22	2.92	Extreme	
190029	3	22 Ocean View Drive	2.27	1.97	50% AEP	possibly
190032	3	23 Ocean View Drive	3.83	3.53	-	
190028	3	24 Ocean View Drive	2.70	2.40	10% AEP	possibly
190027	3	26 Ocean View Drive	2.75	2.45	5% AEP	possibly
190023	3	28 Ocean View Drive	2.76	2.46	5% AEP	possibly
190047	3	30 Ocean View Drive	2.51	2.21	20% AEP	

GIS Tag	FPM Area	Number	Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
190046	3	32	Ocean View Drive	3.18	2.88	Extreme	
190022	3	34	Ocean View Drive	2.85	2.55	2% AEP	
190045	3	36	Ocean View Drive	2.79	2.49	5% AEP	
190024	3	38	Ocean View Drive	2.82	2.52	2% AEP	possibly
189843	3	10-12	Ocean View Drive	2.55	2.25	20% AEP	
189841	3	1	Pacific Street	4.78	4.48	-	
189842	3	3	Pacific Street	7.40	7.10	-	
189864	3	5	Pacific Street	5.94	5.64	-	
189854	3	8	Pacific Street	3.85	3.55	-	
189829	3	10	Pacific Street	2.86	2.56	2% AEP	
189851	3	11	Pacific Street	7.56	7.26	-	
189830	3	12	Pacific Street	4.00	3.70	-	
190041	3	14	Pacific Street	3.80	3.50	-	
189833	3	15	Pacific Street	6.43	6.13	-	
190040	3	16	Pacific Street	99.00	99.00	-	
189832	3	17	Pacific Street	7.97	7.67	-	
190018	3	18	Pacific Street	3.78	3.48	-	
189850	3	19	Pacific Street	5.91	5.61	-	
190017	3	20	Pacific Street	3.81	3.51	-	possibly
190039	3	23	Pacific Street	5.95	5.65	-	
190034	3	29	Pacific Street	7.06	6.76	-	
190033	3	31	Pacific Street	8.47	8.17	-	
190031	3	33	Pacific Street	5.65	5.35	-	
189439	4	4	Anniversary Avenue	5.98	5.68	-	
189428	4	6	Anniversary Avenue	3.87	3.57	-	
189436	4	8	Anniversary Avenue	3.16	2.86	Extreme	
189163	4	10	Anniversary Avenue	5.13	4.83	-	
189878	4	??	Terrigal Dr (fire)	2.56	2.26	20% AEP	
190006	4	??	Terrigal Dr(scout)	2.49	2.19	20% AEP	
189500	4	41	Terrigal Drive	5.92	5.62	-	
189427	4	43	Terrigal Drive	8.01	7.71	-	
189502	4	45	Terrigal Drive	4.76	4.46	-	
189405	4	57	Terrigal Drive	3.64	3.34	1% AEP	
189408	4	59	Terrigal Drive	3.32	3.02	20% AEP	
not found	4	71	Terrigal Drive	3.89	3.59	Extreme	
not found	4	73	Terrigal Drive	5.06	4.76	-	
189740	4	194	Terrigal Drive	4.06	3.76	-	
189741	4	196	Terrigal Drive	3.57	3.27	-	
189724	4	198	Terrigal Drive	2.92	2.62	2% AEP	
189739	4	200	Terrigal Drive	2.70	2.40	10% AEP	
189744	4	202	Terrigal Drive	3.14	2.84	0.2% AEP	
189881	4	204	Terrigal Drive	2.78	2.48	5% AEP	
189877	4	206	Terrigal Drive	3.04	2.74	0.5% AEP	
189697	4	210	Terrigal Drive	2.93	2.63	1% AEP	
189700	4	212	Terrigal Drive	3.12	2.82	0.2% AEP	
189699	4	214	Terrigal Drive	3.13	2.83	0.2% AEP	
189698	4	216	Terrigal Drive	3.17	2.87	Extreme	
189696	4	218	Terrigal Drive	3.27	2.97	-	
189702	4	220	Terrigal Drive	4.50	4.20	-	
189670	4	222	Terrigal Drive	4.64	4.34	-	

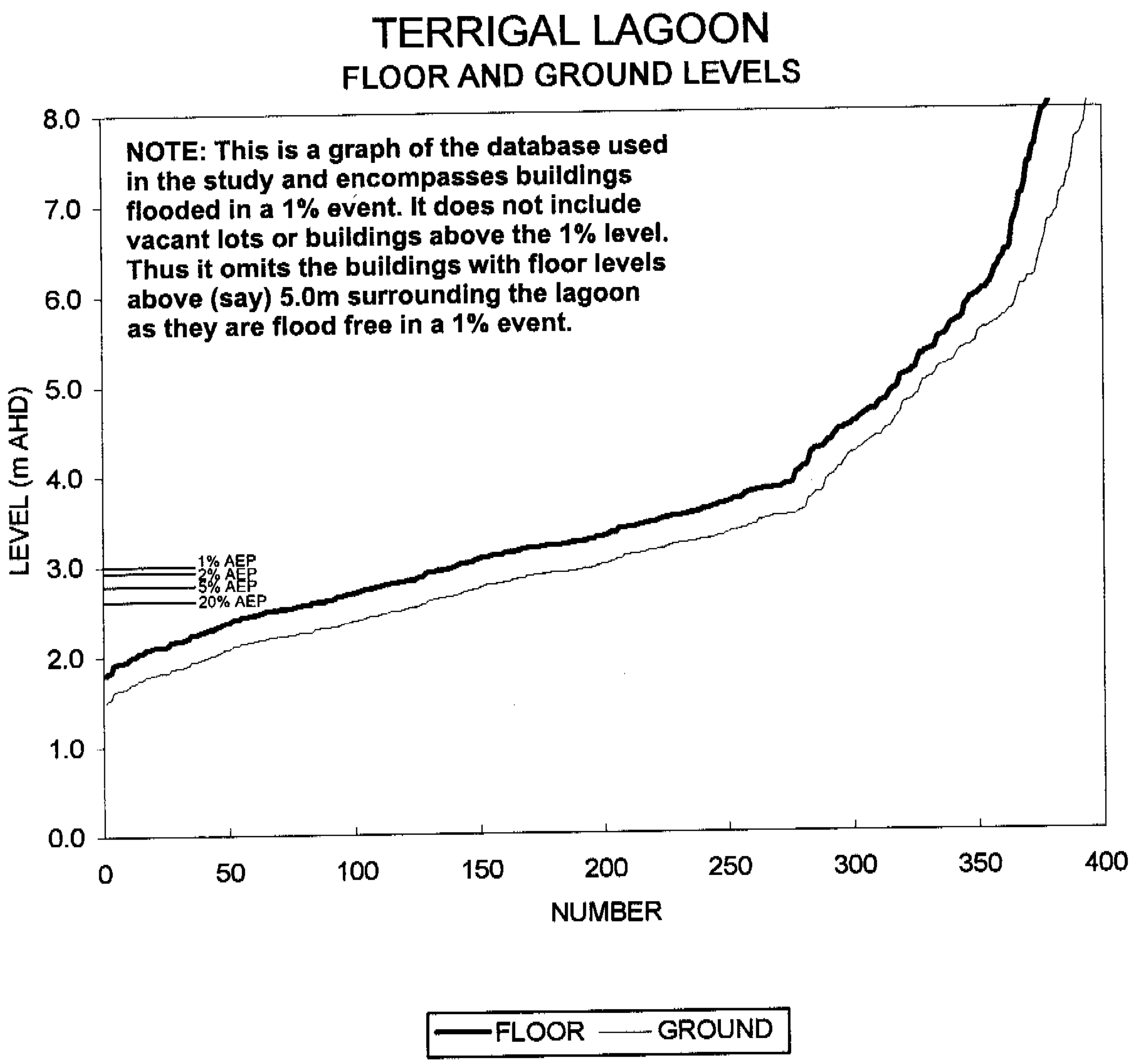
GIS Tag	FPM Area	Number Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
189524	4	232 Terrigal Drive	5.67	5.37	-	
189664	4	234 Terrigal Drive	5.68	5.38	-	
189694	4	238 Terrigal Drive	5.85	5.55	-	
189192	4	240 Terrigal Drive	4.51	4.21	-	
189195	4	242 Terrigal Drive	4.42	4.12	-	
189168	4	244 Terrigal Drive	5.29	4.99	-	
189174	4	246 Terrigal Drive	4.78	4.48	-	
189173	4	248 Terrigal Drive	3.82	3.52	-	
not found	4	?? Terrigal Drive	2.53	2.23	-	
not found	4	?? Terrigal Drive	3.48	3.18	-	
not found	4	?? Terrigal Drive	4.25	3.95	-	
not found	4	?? Terrigal Drive	6.36	6.06	-	
not found	4	?? Terrigal Drive	9.16	8.86	-	
189540	4	33-39 Terrigal Drive	8.08	7.78	-	
189433	4	2 Yarang Close	3.51	3.21	-	
189159	4	3 Yarang Close	4.09	3.79	-	
189432	4	4 Yarang Close	3.50	3.20	-	
189157	4	5 Yarang Close	4.26	3.96	-	
189504	4	6 Yarang Close	3.27	2.97	-	
189160	4	7 Yarang Close	4.34	4.04	-	
189437	4	8 Yarang Close	3.29	2.99	-	
189457	5	13 Brunswick Road	4.03	3.73	-	
189449	5	15 Brunswick Road	3.81	3.51	-	
189459	5	17 Brunswick Road	3.51	3.21	-	
189458	5	19 Brunswick Road	3.43	3.13	-	
189723	5	3 Junction Road	3.29	2.99	-	
189722	5	5 Junction Road	4.39	4.09	-	
189742	5	6 Junction Road	3.24	2.94	Extreme	
189745	5	7 Junction Road	5.33	5.03	-	
189743	5	8 Junction Road	3.07	2.77	0.2% AEP	
189443	5	2 Michaela Road	3.56	3.26	-	
not found	5	4 Raymond Terrace	4.94	4.64	-	
not found	5	6 Raymond Terrace	4.87	4.57	-	
not found	5	8 Raymond Terrace	5.14	4.84	-	
not found	5	10 Raymond Terrace	4.68	4.38	-	
not found	5	12 Raymond Terrace	6.01	5.71	-	
not found	5	14 Raymond Terrace	7.99	7.69	-	
not found	5	16 Raymond Terrace	5.22	4.92	-	
not found	5	18 Raymond Terrace	5.64	5.34	-	
not found	5	20 Raymond Terrace	5.08	4.78	-	
189942	6	2 Farrand Crescent	2.10	1.80	50% AEP	
189941	6	4 Farrand Crescent	2.08	1.78	50% AEP	
189943	6	6 Farrand Crescent	3.19	2.89	Extreme	
189976	6	8 Farrand Crescent	1.94	1.64	50% AEP	
189939	6	10 Farrand Crescent	1.92	1.62	50% AEP	
189884	6	12 Farrand Crescent	2.51	2.21	20% AEP	
190051	6	14 Farrand Crescent	2.32	2.02	50% AEP	
190050	6	16 Farrand Crescent	3.09	2.79	0.2% AEP	
190059	6	18 Farrand Crescent	3.19	2.89	Extreme	
190052	6	20 Farrand Crescent	1.99	1.69	50% AEP	

GIS Tag	FPM Area	Number Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
190053	6	22 Farrand Crescent	2.00	1.70	50% AEP	
190054	6	24 Farrand Crescent	2.63	2.33	10% AEP	possibly
190057	6	28 Farrand Crescent	2.01	1.71	50% AEP	
190056	6	30 Farrand Crescent	2.09	1.79	50% AEP	
189972	6	32 Farrand Crescent	2.54	2.24	20% AEP	
189951	6	34 Farrand Crescent	4.90	2.90	-	
189971	6	36 Farrand Crescent	2.41	2.11	50% AEP	
189883	6	2 Willoughby Road	2.60	2.30	20% AEP	
189975	6	4 Willoughby Road	2.93	2.63	1% AEP	possibly
189970	6	6 Willoughby Road	2.59	2.29	20% AEP	
189954	6	30 Willoughby Road	5.09	4.79	-	possibly
189956	7	6 Ogilvie Street	6.26	5.96	-	possibly
189991	7	8 Ogilvie Street	3.71	3.41	-	possibly
229337	7	10 Ogilvie Street	3.51	3.21	-	
189989	7	12 Ogilvie Street	3.31	3.01	-	
189990	7	14 Ogilvie Street	2.56	2.26	20% AEP	
189993	7	16 Ogilvie Street	2.92	2.62	2% AEP	possibly
189992	7	18 Ogilvie Street	3.01	2.71	0.5% AEP	
190012	7	20 Ogilvie Street	5.71	5.41	-	possibly
190013	7	22 Ogilvie Street	5.83	5.53	-	
190011	7	24 Ogilvie Street	7.18	6.88	-	
190114	7	26 Ogilvie Street	7.60	7.30	-	possibly
190113	7	28 Ogilvie Street	8.54	8.24	-	
190796	7	30 Ogilvie Street	7.85	6.85	-	
190797	7	32 Ogilvie Street	6.47	6.17	-	possibly
190757	7	34 Ogilvie Street	6.80	6.50	-	possibly
190758	7	36 Ogilvie Street	4.91	4.61	-	possibly
190759	7	38 Ogilvie Street	4.68	4.38	-	
190760	7	40 Ogilvie Street	99.00	99.00	-	
190798	7	42 Ogilvie Street	99.00	99.00	-	
190754	7	47 Ogilvie Street	99.00	99.00	-	
190752	7	51 Ogilvie Street	99.00	99.00	-	
190772	8	39 Beaufort Road	4.73	4.43	-	
191107	8	52 Dover Road	9.56	9.26	-	
191102	8	54 Dover Road	7.75	7.45	-	
191219	8	56 Dover Road	6.05	5.75	-	
191074	8	58 Dover Road	5.07	4.77	-	
191099	8	60 Dover Road	5.32	5.02	-	
191540	8	64 Dover Road (Club)	2.44	2.14	20% AEP	
190586	8	4 Selma Close	3.40	3.10	-	
190590	8	5 Selma Close	2.74	2.44	5% AEP	
190585	8	6 Selma Close	3.34	3.04	-	
190589	8	7 Selma Close	3.12	2.82	0.2% AEP	
190596	8	10 Selma Close	2.56	2.26	20% AEP	
189996	8	32 Willoughby Road	6.15	5.85	-	possibly
190523	8	92 Willoughby Road	5.47	5.17	-	
190510	8	100 Willoughby Road	6.72	6.42	-	
190591	8	110 Willoughby Road	5.61	5.31	-	
190544	8	96-98 Willoughby Road	6.08	5.78	-	
191562	8	Willoughby Road	5.51	5.21	-	

GIS Tag	FPM Area	Number	Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
192506	9	1	Pembrook Road	4.50	4.20	-	
192386	9	1	Somerset Close	4.66	4.36	-	
192389	9	174	Willoughby Road	4.62	4.32	-	
192382	9	176	Willoughby Road	5.29	4.99	-	
192612	9	3	Windsor Road	6.01	5.71	-	
192611	9	5	Windsor Road	4.47	4.17	-	
192620	9	7	Windsor Road	4.68	4.38	-	
191137	9	8	Windsor Road	5.55	5.25	-	
192475	9	9	Windsor Road	3.71	3.41	-	
190622	9	10	Windsor Road	4.55	4.25	-	
192476	9	11	Windsor Road	3.81	3.51	-	
191113	9	12	Windsor Road	3.86	3.56	-	
192504	9	13	Windsor Road	3.65	3.35	-	
190608	9	14	Windsor Road	3.78	3.48	-	
192474	9	15	Windsor Road	3.40	3.10	-	
190601	9	16	Windsor Road	3.66	3.36	-	
192509	9	17	Windsor Road	3.67	3.37	-	
190602	9	18	Windsor Road	3.59	3.29	-	
192492	9	19	Windsor Road	3.79	3.49	-	
190609	9	20	Windsor Road	2.91	2.61	2% AEP	
192473	9	21	Windsor Road	3.62	3.32	-	
190607	9	22	Windsor Road	3.53	3.23	-	
192498	9	23	Windsor Road	3.54	3.24	-	
190600	9	24	Windsor Road	3.34	3.04	-	
192448	9	25	Windsor Road	3.44	3.14	-	
190603	9	26	Windsor Road	2.93	2.63	2% AEP	
192445	9	27	Windsor Road	3.29	2.99	Extreme	
190604	9	28	Windsor Road	2.86	2.56	2% AEP	
192419	9	29	Windsor Road	3.43	3.13	2% AEP	
190606	9	30	Windsor Road	3.22	2.92	Extreme	
192447	9	31	Windsor Road	3.51	3.21	1% AEP	
192471	9	32	Windsor Road	3.16	2.86	0.2% AEP	
192440	9	33	Windsor Road	4.34	4.04	-	
192470	9	34	Windsor Road	2.83	2.53	2% AEP	
192439	9	35	Windsor Road	4.20	3.90	-	
192472	9	36	Windsor Road	3.70	3.40	-	
192441	9	37	Windsor Road	4.57	4.27	-	
192499	9	38	Windsor Road	3.13	2.83	0.2% AEP	
192414	9	39	Windsor Road	4.06	3.76	0.2% AEP	
192467	9	40	Windsor Road	2.95	2.65	1% AEP	
192388	9	41	Windsor Road	5.04	4.74	-	
192468	9	42	Windsor Road	3.05	2.75	0.5% AEP	
190619	9	44	Windsor Road	3.00	2.70	1% AEP	
192451	9	46	Windsor Road	3.24	2.94	Extreme	
192450	9	48	Windsor Road	3.45	3.15	2% AEP	
192415	9	50	Windsor Road	3.82	3.52	-	
192416	9	52	Windsor Road	3.06	2.76	20% AEP	
192452	9	54	Windsor Road	3.59	3.29	5% AEP	
192411	9	56	Windsor Road	3.55	3.25	10% AEP	
192412	9	58	Windsor Road	3.56	3.26	5% AEP	

GIS Tag	FPM Area	Number	Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
192436	9	60	Windsor Road	3.70	3.40	2% AEP	
192438	9	62	Windsor Road	3.76	3.46	1% AEP	
192442	9	66	Windsor Road	3.80	3.50	10% AEP	
192444	9	68	Windsor Road	4.54	4.24	-	
192399	10	1	Brush Road	6.33	6.30	1% AEP	
192561	10	22	Brush Road	6.24	5.14	2% AEP	
192408	10	30	Brush Road	8.61	5.17	-	
193468	10	40	Brush Road	11.36	5.58	-	
192554	10	44	Brush Road	9.12	6.05	-	
192545	10	50	Brush Road	23.88	23.58	-	
192407	10	-	Brush Road	9.39	5.42	-	
not found	10	-	Brush Road	18.60	11.67	-	
192409	10	-	Milina Road	12.85	5.79	-	
192550	10	12	Okanagan Road	13.13	6.78	-	
not found	10	591	The Entrance Road	37.97	7.06	-	
192143	10	593	The Entrance Road	11.08	6.14	-	
192562	10	599	The Entrance Road	13.47	5.38	-	
192557	10	631	The Entrance Road	9.62	5.17	-	
192558	10	633	The Entrance Road	13.46	5.58	-	
192556	10	635	The Entrance Road	9.25	5.58	-	
192555	10	647	The Entrance Road	27.02	6.05	-	
not found	10	-	Willoughby Road	5.34	5.04	50% AEP	
not found	10	-	Willoughby Road	5.49	5.19	50% AEP	
not found	10	-	Willoughby Road	8.11	7.84	-	
192387	9	70	Windsor Road	4.30	4.00	-	

BUILDING FLOOR AND GROUND LEVELS



NOTE: One of the adopted floodplain management measures is for Council to maintain the entrance berm. Consequently the resulting design flood levels will be lower than indicated on this Figure. For Terrigal Lagoon the 1% AEP level will be reduced from 3.0m AHD to 2.9m AHD.

APPENDIX C: INVESTIGATION INTO FLOODING AT WINDSOR ROAD, TERRIGAL

APPENDIX C: INVESTIGATION INTO FLOODING AT WINDSOR ROAD, TERRIGAL

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PHOTOGRAPHS

SUMMARY

Windsor Road, Terrigal, is located to the north of Terrigal Lagoon. It has a local catchment area to Windsor Road of approximately 18.9 hectares and comprises of mostly residential properties and roadways. The upper parts of the catchment drain in a southerly direction through several piped branches which continue past the properties on the south side of Windsor Road.

Several residential properties in Windsor Road have experienced flooding problems in the past. Flooding occurs at the two road low points along Windsor Road. The first is situated adjacent to property No's 26 and 28 and is the main low point of the road. The second low point is located adjacent to property No's 42 and 44. Both low points are drained by street drainage, with the excess surface flows conveyed via two channels located between adjacent properties and thence towards a branch of the North Arm of Terrigal Lagoon within the golf course.

Flooding of Windsor Road can occur as a result of elevated lagoon levels, intense rainfall over the local catchment or a combination of both. The Terrigal Lagoon Floodplain Management Study addressed the effects of elevated lagoon levels and this present study (Stage 1) has undertaken a preliminary investigation into the effects of intense rainfall over the local catchment. Stage II (if required) will provide detailed design of any proposed works. The main aims of this present study were to identify the cause of the past flooding problems and provide a preliminary review of available floodplain management measures as well as provide an assessment of the levee adjacent to Willoughby Road.

FLOODING FROM LOCAL DRAINAGE

Local inundation in the low points can occur as a result of surface runoff generated by intense short duration rainfall over the local catchment. Inundation of properties has occurred previously reaching a peak level of about 2.9 mAHD in a storm in 1990. This storm was estimated to be between a 10% and a 5% AEP event (assuming a low tailwater level in the golf course).

The main factors affecting the peak water level are the tailwater level in the golf course and the capacity of the pipes and channels taking runoff from Windsor Road to the golf course.

A preliminary ILSAX hydrologic analysis was undertaken to obtain the local catchment inflows and an indication of the existing pipe and channel capacities. The outcomes of this analysis are limited as the ILSAX model cannot adequately account for the complex hydraulic behaviour in the system (downstream tailwater levels, pressure flows, pipe losses) but it does indicate that inundation of Windsor Road will occur in 20% AEP and greater events. The maximum depth of inundation is limited by the fact that above (say) 3.0 mAHD, runoff can relatively easily enter the golf course across the properties (through fences, etc.).

The damages from floods caused by local runoff are generally intangible (safety, road blockage, inconvenience) although 6 buildings will be inundated above floor level (maximum depth of 0.2 m) in a 1% AEP event.

This study examined a range of floodplain management measures to address the problem including:

- removal of a building on the south side of Windsor Road,
- widening of the channels and/or forming new channels,
- upgrading of the pipe system connecting Windsor Road to the golf course,
- flood proofing of the buildings,
- improvement to flow entry into the channels,
- regular debris removal from the pipe network and downstream,
- development control.

Resident interviews indicate that they do not perceive flooding on Windsor Road as a major concern. The last significant event where a house was affected occurred in 1990, but there have been no problems since. Based upon the available information and the likely hazard, major capital expenditure cannot be justified for measures such as upgrading the existing drainage system.

RECOMMENDATIONS

The following measures are recommended, in approximate order of importance:

- review of development control procedures to ensure that future development will not exacerbate the problem or increase flood damages. This may require controls on the placing of fill and construction of fences together with the establishment and maintenance of overland flow paths,
- regular maintenance of the existing drainage system (clean pits and pipes regularly and ensure that the channels are well maintained),
- liaise with the golf club to ensure that the watercourses are maintained,
- monitoring of all future flood events (possibly with a questionnaire immediately after the event),
- undertake works to improve the entrances to the channels,
- flood proofing of houses. Initially this will require liaison with the residents and a detailed building inspection.

ASSESSMENT OF THE LEVEE ADJACENT TO WILLOUGHBY ROAD

Survey of the levee was undertaken which indicated that overtopping is likely to occur in the 10% AEP and greater events. A visual inspection of the levee showed that it is likely to experience "low spots" due to erosion or vegetation removal. Section C4.3 listed a series of High and Medium Priority recommendations.

C1. BACKGROUND

C1.1 Introduction

Questionnaires and field interviews undertaken as part of the Terrigal Lagoon Floodplain Management Study identified that several residential properties in Windsor Road have experienced flooding problems. Preliminary investigation indicated that this was not caused by elevated lagoon levels but occurred as a result of runoff from the local catchment ponding in Windsor Road.

This present study was commissioned by Gosford City Council in order to identify the cause of the problem and to investigate possible floodplain management measures.

C1.2 Available Data

Various sources of data were used in the investigation. These included maps and plans of the drainage system provided by Gosford City Council, and field inspection and interviews undertaken by the consultants.

C1.3 Catchment Description

The local catchment area to Windsor Road is approximately 18.9 hectares and comprises of mostly residential properties and roadways. The upper parts of the catchment drain to the south through several piped branches which continue past the properties on Windsor Road and empty into the watercourses within Terrigal Memorial Country golf course (part of the North Arm sub-catchment). Excess surface flows from Windsor Road are conveyed via the channels (lined escape paths constructed circa 1978 by Council) located between the properties on Windsor Road to the watercourses.

There are two road low points along Windsor Road. The first is situated adjacent to property No's 26 and 28 and is the main low point of the road (refer Photographs C1 & C2). The second low point is located adjacent to property No's 42 and 44. Both low points are drained by surface inlet pits on the road and the channels.

C1.4 Resident Surveys

The subdivision of Windsor Road is understood to have commenced around 1970. According to the residents, there have been several instances of flooding since that time.

Of the 14 returned questionnaires from the resident survey of May 1993, seven properties were identified as having experienced backyard inundation. At least three houses (No's 20, 26 and 28) have experienced above floor inundation. According to the residents, the problem occurred as a result of runoff from the local catchment and not by inundation from raised water levels in the lagoon. The residents however considered that the problem could be compounded by inadequate drainage within the golf course and elevated water levels in the lagoon.

According to one resident there have been about four occasions in the period between 1980 and 1994 in which Windsor Road was "covered in water". The highest water level experienced over this period appears to have occurred in February 1990, when water "just inundated" the floors of property No's 20, 26 and 28 Windsor Road (floor levels of 2.9, 2.93 and 2.86 mAHD respectively). It is not known whether property No. 34 Windsor Road (floor level of 2.83 mAHD) has been inundated during the period.

Recent interviews were conducted on the basis of the earlier resident survey at Windsor Road. The resident at property No. 14 has not experienced flooding on his property. He recalled that road flooding had occurred some time in the late 1970's to early 1980's, causing problems to the house further west of his property (about property No. 26). The resident at property No. 16 also had not experienced flooding, but he did recall that sandbagging of other houses was required in 1973 and 1977.

The resident at property No. 20 recalled that a problem occurred in January 1990 which caused water to just enter his property without causing much damage. During that time, the resident noted that the golf course was covered by water and that the water on Windsor Road ponded in the road for about two to three hours (although this may have been longer). He also noted that water flowed southwards between the houses towards the golf course. Since that time he recollected that there had been a couple of instances in which water had ponded over the road. The resident suggested that recent drainage works had improved the situation.

The resident at property No. 42 has not experienced inundation at his property. He was aware of water being a problem on the road in the late 1980's, however there had not been a problem since that time. He suggested that the construction of the channels had improved the drainage situation.

C1.5 Drainage Works

The Council has at various times addressed the problems of flooding in the Windsor Road area by implementing drainage and flood mitigation works. The main features of the current drainage system at Windsor Road include:

- the concrete lined causeway (circa 1978) and twin 900 mm RCP's (under the causeway) on Willoughby Road. The pipes have an upstream invert at approximately 2.1 mAHD, and a downstream invert at 1.9 mAHD. The low point in the causeway is at 3.2 mAHD,
- an earthen levee (circa 1978) adjacent to property No's 70 to 54 Windsor Road which has a crest at 4.9 mAHD,
- two concrete lined channels which extend 40 metres from Windsor Road to the golf course (circa 1978). The trapezoidal shaped channel between property No's 26 and

28 is 3 metres wide and has an upstream invert of 2.5 mAHD and a downstream invert of 2.1 mAHD (refer Photograph C3). The U-shaped channel between property No's 42 and 44 is 2.15 metres wide and has an upstream invert of 2.5 mAHD and a downstream invert of 2.2 mAHD (refer Photograph C4),

- seven drainage pipes which collect runoff from the local catchment. The pipes pass through the properties to the south of Windsor Road, except for one pipe which passes behind Windsor Road property No's 2 and 4 from Plymouth Road. The locations and pipe details are provided in Table C1.

Table C1: Drainage Pipe Details

Location (Property No's)	Pipe Details
No's 68/70	525 mm RCP
No's 56/58	450 mm RCP
No's 42/44	675 mm RCP
No's 26/28	twin 675 mm RCP's
No's 12/14	825 mm RCP
No's 4/6	750 mm RCP
No's 2/4	375 mm RCP

The pipe between property No's 4 and 6 was upgraded from a 600 mm RCP in 1993 together with additional pipes and inlet pits in Plymouth Road and Windsor Road. The total waterway area of the pipes exiting to the golf course (Table C1) is approximately 2.6 m^2,

- Council has undertaken flood related development control through introduction of a minimum floor level policy. The adopted levels have been revised in the Terrigal Lagoon Flood Study.

C2. FLOOD INVESTIGATION

C2.1 Causes of Inundation

There are three mechanisms which can cause inundation of Windsor Road. These can act independently of each other but are most likely to occur at the same time with the relative impacts on each occasion varying during the course of the rainfall event. The mechanisms are:

- ***Intense short duration rainfall over the local catchment.*** The catchment has a relatively short time of concentration as a result of its rectangular shape and short flow distance to the outlet. It is approximately 800 m long in the east-west direction but only 200 m wide in the north-south direction. The furthest distance runoff must travel to reach Windsor Road is of the order of 200 m (straight line distance). The time of concentration is further reduced due to the steepness of the terrain from The Entrance Road to Windsor Road, the high density of development, and because the roads and driveways are all generally aligned in a north-south direction. Runoff from a large part of the catchment will reach Windsor Road in between 5 and 10 minutes. Runoff will exit through the pipe system or pond in Windsor Road until it exits down the two lined channels.

- ***Elevated levels in Terrigal Lagoon.*** Once the lagoon reaches 2.5 mAHD (approximately) the lagoon water will surcharge through the drainage pipes and up the two channels into Windsor Road.

- ***Flow down the North Arm.*** Runoff from upstream of Willoughby Road crosses the road in a causeway to enter into the golf course. The levee provides partial protection from overflow from the golf course into Windsor Road. If the levee is overtopped or outflanked, floodwaters will enter Windsor Road. It is understood that in the 1978 event floodwaters crossed Willoughby Road upstream of the channel and entered Windsor Road. It is not known if this has occurred subsequently.

C2.2 Terrigal Lagoon Floodplain Management Study

Floodplain management measures to reduce the impacts of mechanisms 2 and 3 above are discussed in the Terrigal Lagoon Floodplain Management Study and include:

- improved management procedures at the entrance to reduce the design lagoon levels,
- audit and maintenance of the levee,
- investigation and implementation of works to reduce the possibility of the levee being outflanked.

Investigation of the latter two issues is discussed in Section 4 of this report.

C2.3 Hydrologic Analysis

C2.3.1 Study Approach

The ILSAX model was used to simulate surface runoff from the catchment area and to route the runoff through the pipe network and overland flow paths to the golf course. The drainage network established in the model was based on the data provided by Council and the sub-catchment data were determined from orthophoto maps.

The ILSAX model parameters adopted for evaluation purposes were based upon recommended values used in previous studies in the area.

ILSAX is primarily a hydrologic model with limited hydraulic capabilities. The main limitations are its inability to accurately simulate pipe pressure flow, and the high bend and pit entry losses which would occur in this relatively short steep catchment. Also it cannot account for the downstream tailwater level in the golf course.

The results from this study are preliminary and a more rigorous hydraulic procedure (hydraulic grade line analysis) should be undertaken to accurately determine any drainage upgrading works (if required).

C2.3.2 Local Drainage

The ILSAX model was set up to estimate the 20%, 10%, 5%, 2% and 1% AEP peak flows at Windsor Road. The capacities of the pipes and channels and the peak water level are dependant upon the tailwater level in the golf course. This would also affect which storm duration is critical. For this preliminary investigation the capacities were determined using the normal depth calculation which assumes no limiting tailwater level. It also assumes that the exits of the pipes are not blocked by debris. This approach is likely to be unrealistic as generally a short duration intense burst of rainfall over the local catchment is preceded by several hours or days of rainfall, which would cause a rise in the tailwater level in the golf course. However, this may not always be the case if the lagoon entrance is open. The results provided in Table C2 are therefore only indicative.

Table C2: Peak Flows for Existing Conditions - 25 Minute Duration Storm

AEP (%)	Total Flow through Channels (m³/s)	Total Piped Flows from Windsor Road (m³/s)	Depth of Flow through Channels [1] (m)	Peak Water Level [3] (mAHD)	Estimated No. of Properties Inundated [2]	Terrigal Lagoon Design Flood Levels (mAHD)
20	1.7	4.2	0.3	2.8	1	2.6
10	2.2	4.4	0.4	2.9	2	2.7
5	2.8	4.7	0.4	2.9	4	2.8
2	3.5	4.7	0.5	3.0	5	2.9
1	4.3	4.8	0.5	3.0	6	3.0

Notes:
1. Calculated over the combined channel areas.
2. Above floor level
3. Assumes no backwater effect from the golf course.

From the resident interviews it was found that the highest recorded flood level (1990) causing inundation above floor level, was at No. 28 Windsor Road. To have reached this level, water would have been around 2.9 mAHD (the floor level of No. 28 is 2.86 mAHD). The upstream inverts of the channels are at 2.5 mAHD, making the depth of flow approximately 0.4 m. This observed inundation level when compared with the calculated depths in Table C2 is seen to be between a 10% AEP and a 5% AEP event. The level of Terrigal Lagoon or the water level in the downstream watercourses at the time of the 1990 event are unknown. It is known that the highest lagoon level in the period 1974 to 1993 was only 1.7 mAHD.

As noted in Section C2.1, this area is also affected by backwater inundation from elevated levels in Terrigal Lagoon and the North Arm. The design flood levels at the entrances to the two channels (there is no appreciable flood gradient between the two entrances when Terrigal Lagoon is in flood) resulting from elevated levels in Terrigal Lagoon are also provided in Table C2.

C3. POSSIBLE FLOODPLAIN MANAGEMENT MEASURES

C3.1 Discussion

The preliminary ILSAX analysis provided in Section 2.3 indicates that inundation of house floor levels can occur as a result of intense rainfall over the local catchment in the absence of an elevated tailwater in the golf course. The cause of ponding in Windsor Road is the limited capacity of the exits (pipes, channels and overland flow paths) to the golf course. The southern side of Windsor Road has generally been filled to approximately 2.9 mAHD or above (say 0.4 m above the roadway). Together with the construction of buildings, garages and fences this forms a barrier for overland flows reaching the golf course. The only exits for runoff below 2.9 mAHD are the pipes (Table C1) and twin channels.

The flood problem resulting from local runoff is therefore effectively capped at the upper end (i.e. larger events will not cause a significant increase in level). The 1% AEP design level from an elevated lagoon is approximately 3.0 mAHD at the channel between No's 42 and 44 with the Extreme level being 3.3 mAHD. Table C2 indicates that up to 6 buildings will be inundated in the 1% AEP event from local catchment runoff (3.04 mAHD).

The tangible and intangible damages resulting from flooding in this manner are difficult to accurately quantify. The relatively shallow depth of inundation (a maximum of 0.2 m in a 1% AEP event) and short duration means that the amount of water entering houses may be small. If residents were home and aware of the threat they may be able to effectively seal the entrances.

A range of floodplain management measures were investigated for managing the flood problem. Indicative costings have been provided however these need to be substantiated (if required) at the detailed design stage.

C3.2 Increase the Capacity of the Exits to the Golf Course

The results have indicated that water will pond in Windsor Road during an intense short duration rainfall event over the local catchment combined with a low level in Terrigal Lagoon. This occurs due to the inadequate capacity of the exits to the golf course (pipes, channels and overland flow paths). Three broad options are possible to alleviate the situation and these are discussed below.

C3.2.1 Building Removal

Removing (voluntary purchase) of a building and lowering the ground to the level of the golf course (say 2.1 mAHD) would practically eliminate the problem by making the water level in Windsor Road the same as in the golf course. The cost of this option would be approximately \$250 000 to \$300 000. From a social viewpoint it is unlikely that any resident would accept the voluntary purchase offer and there may be some concerns from other residents regarding the streetscape and the subsequent use of the vacant land. The vacant land may be used for open space or similar.

C3.2.2 Widen the Existing Channels or Provide New Channels

There is little opportunity for widening the existing channels or providing other channels unless additional land is purchased. This issue has not been addressed with the residents. Given the lack of concern about flooding it may be difficult to persuade a resident to accept voluntary purchase of part of their land to form a new channel.

C3.2.3 Upgrade the Pipe System

The benefits of upgrading the existing pipe system from Windsor Road to the golf course are limited by the capacity of the upstream pit and pipe network to deliver the required inflows to the pipes through the properties and the tailwater level downstream. Residents have already indicated that the existing pits in Windsor Road surcharge during heavy rainfall.

A preliminary investigation was undertaken into upgrading the pipes exiting to the golf course. The 825 mm pipe at No's 12/14 did not require upgrading and upgrading the 375 mm pipe at No's 2/4 would provide no significant benefit. The pipe sizes required to upgrade the system by pipe replacement to the capacity of the 20% and 10% AEP events are shown in Table C3 (assuming no tailwater effects). It should be noted that Council's policy is generally to upgrade pipes to 5% AEP capacity through private property.

Table C3: Upgraded Drainage System

Location (Property No's)	Existing Pipe Size (mm)	New Replacement Pipe Size (mm)	
		20% AEP	10% AEP
68/70	525	600	600
56/58	450	750	750
42/44	675	900	1050
26/28	2 x 675	2 x 825	2 x 900
4/6	750	825	900
Waterway area	1.9 m^2	3.0 m^2	3.5 m^2

The peak flows and corresponding depths of flow in the channels for the upgraded systems are shown in Tables C4 and C5.

Table C4: Peak Flows for the 20% AEP Upgraded System

AEP (%)	Total Flow through Channel (m^3/s)	Depth of Flow [1] (m)	Peak Water Level (mAHD)	Estimated No. of Properties Inundated AFL[2]
20	0	-	-	0
10	0.4	0.2	2.7	0
5	0.6	0.2	2.7	0
2	1.1	0.3	2.8	0
1	1.8	0.3	2.8	1

1. Calculated over the combined channel area.
2. Above Floor Level

Table C5: Peak Flows for the 10% AEP Upgraded System

AEP (%)	Total Flow through Channel (m^3/s)	Depth of Flow [1] (m)	Peak Water Level (mAHD)	Estimated No. of Properties Inundated [2]
20	0	-	-	0
10	0	-	-	0
5	0	-	-	0
2	0.1	<0.1	<2.6	0
1	0.4	0.2	2.7	0

1. Calculated over the combined channel area.
2. Above Floor Level

It should be noted that the estimates of pipe sizes were determined using a simplified model of the drainage system, and they would need to be verified by detailed modelling of the drainage system considering downstream outlet control and the ability of the upstream system (pits and pipes) to deliver the runoff to the new pipes.

An indicative cost for upgrading the drainage pipes (Table C3) to the 20% AEP or the 10% AEP capacities is $200 000 to $250 000 (excluding pit and pipe upgrades upstream).

Given the high costs of upgrading the system, and the reduced effectiveness of the pipes when water levels in the lagoon limit outflows, the option of upgrading the pipe system is not recommended.

C3.3 Flood Proof Properties

Flood proofing of buildings by preventing the ingress of floodwaters (sealing of ground level windows, air vents and doors) is possible for residential buildings but rarely (if ever) applied. It is a relatively inexpensive measure (say $10 000 per house) and is likely to be effective in this location because of the shallow depths and short duration of inundation. The total cost for this measure (say $60 000) is much less than pipe upgrading or building removal. It would also provide some benefit in flooding from elevated lagoon levels. The main disadvantages of this measure are that in time any flood proofing is likely to be either removed by the owner or fall into disrepair (rubber seals). These could be partially negated by a flood awareness program and a regular inspection (say every two years).

C3.4 Improve Flow Entry into Channels

A preliminary inspection indicated that the configuration of the entrances to the channels in Windsor Road may limit their capacity to take runoff into the golf course. The entrances to the channels could be improved by footpath lowering or slight lowering of the road pavement to allow water to gain easier access. The costs of such works would depend upon the amount of work undertaken but would be unlikely to exceed $20 000 per channel. The hydraulic benefit of this measure cannot be accurately defined at this stage. It would be a relatively inexpensive measure which would assist in taking runoff to the golf course with no social disbenefits. It would only provide a benefit in "low tailwater" events.

C3.5 Debris Removal from the Pits/Pipes and Downstream Watercourses

Many residents have complained about the presence of debris in the pits (and possibly the pipes) in Windsor Road and in particular the excessive vegetation growth in the watercourses within the golf course. Improved maintenance of the existing pit and pipe network will ensure that the existing system is functioning to its maximum capacity. This is a relatively inexpensive measure and will be supported by all residents. Clearing the downstream watercourses will assist the problem when the tailwater becomes a limiting factor. At the time of the inspection the watercourses were relatively clear of excessive vegetation and it is understood that the golf club is in the process of upgrading the course and the water features. This would be an ideal opportunity to ensure that the exits of all the pipes and channels are cleared of vegetation and a program of maintenance established.

C3.6 Development Control

Redevelopment of the existing buildings is unlikely to occur in the short to medium term and there are no vacant lots of land to be developed. In the long term there is the potential that future development - housing construction, fence realignment or land filling - may raise flood levels or redirect flows elsewhere. As far as possible Council should ensure that any future development does not adversely affect existing residents. Council has little control over the placing of fencing but any proposals for minor building works (pool construction, room additions) should be considered with regard to their impact upon flooding.

C4. ASSESSMENT OF THE LEVEE ADJACENT TO WILLOUGHBY ROAD

C4.1 Background

A levee was constructed by Council, following the 1978 flood (exact details are unknown), to prevent flow from the North Arm entering Windsor Road across Willoughby Road. It consists of three components:

- an earthen levee, approximately 1 m above natural surface with a 2 m crest width, running from Willoughby Road east to No. 58 Windsor Road. The crest grades from 4.4 mAHD immediately east of Willoughby Road to 3.5 mAHD at No. 58,
- a raised section of roadway across Willoughby Road (crest at 4.9 mAHD),
- a raised embankment near the tree line on the west side of Willoughby Road. The crest varies from 5.0 mAHD at the causeway to 5.1 mAHD, approximately 100 m north of the Windsor Road entrance. There is a low section (at 4.9 mAHD) opposite the entrance to Windsor Road where a private access track enters.

C4.2 Levee Audit

A full levee audit, which would need to include a geotechnical investigation, has not been carried out as part of this study. No construction details or design drawings for the levee are available (Council to advise). During this study the following measures were implemented:

- detailed survey to identify the levee dimensions,
- comparison of the crest level versus the design flood levels,
- visual inspection of the levee.

C4.2.1 Detailed Survey

Detailed survey of the levee was undertaken by Bissett & Wright, Consulting Surveyors in October 1999 and 4 - A1 drawings were provided to Council.

C4.2.2 Crest Level Versus Design Flood Levels

The design flood gradients were calculated in the Terrigal Lagoon Flood Study. Whilst these are the most accurate estimates of design levels available, the lack of historical flood data in the area means that these levels have an error band of ±0.4 m. Table C6 provides a comparison of the levee crest versus the design flood levels.

Table C6: Levee Crest versus Design Flood Levels

Cross-section / Location (refer Fig. 4)	Crest Level (mAHD)	Design Flood Levels (mAHD) AEP (%)					
		Extreme	1	2	5	10	20
T24 - 120m upstream of Windsor Rd	5.1	5.7	5.3	5.2	5.1	5.1	4.9
T28 - opposite Windsor Road entrance	4.9	5.4	5.1	5.0	5.0	4.9	4.8
T20 - causeway	4.9	4.8	4.5	4.5	4.4	4.4	4.3
20m downstream of the causeway	4.2	4.6 *	4.3 *	4.3 *	4.2 *	4.2 *	4.1 *
T19 - 230m downstream of the causeway	No levee. Ground level at 2.3	3.3	3.0	2.9	2.8	2.7	2.4

* estimated from the gradient between T20 and T19.

The design flood levels (Table C6) indicate that there are only small differences in height between the 1% AEP and the 50% AEP events (generally <0.3 m between the 1% AEP and the 10% AEP). This is because the low flow channel has only a small capacity and the relatively wide and flat nature of the overbank means that a large increase in flow represents only a small increase in level. This makes it difficult to accurately establish the level at which overtopping of the levee will first occur. Table C6 indicates that at the causeway (T20) there is a 0.4 m freeboard above the 1% AEP level. Elsewhere the levee is likely to be overtopped in events greater than the 10% AEP event. Some overtopping may also occur in smaller events due to wind/wave action or the presence of "low points" not identified in the survey. Generally flood mitigation levees are constructed with a freeboard of (say) 0.5 m above the design standard to account for these factors.

In conclusion the survey indicates that the levee does not provide an adequate level of protection (including a freeboard allowance) for events larger than (say) a 90% AEP event.

C4.2.3 Visual Inspection of the Levee

The levee (apart from the Willoughby Road section) is of earthen construction and covered by grass or shrubs. Low spots have and will develop in time due to vegetation removal, weathering or human activities. This is particularly the case in the section parallel to Willoughby Road where the embankment is less well defined and close to or within the tree line. It would appear that the private access road has already created a "low point" in the crest.

Levees must be regularly inspected to ensure that low points do not develop and that activities likely to cause failure (trees falling over) are monitored.

C4.3 Recommendations

The levee was constructed to prevent overland flow from the North Arm crossing Willoughby Road and entering Windsor Road. No details of the design are available. Since construction (post 1978) there is no evidence that it has been overtopped (the last significant flood event was in February 1990). Design flood data indicates that overtopping will occur in a 10% AEP and greater events and possibly in smaller design events due to wind/wave actions.

The earthen levee is grass covered and is likely to develop low spots unless regular maintenance is carried out. One significant low spot is the private entrance access track opposite the Windsor Road entrance. Failure or overtopping of the levee will result in increased flood damages (inundation of buildings and increased risk to life) in Windsor Road. The attached Figure C1 details the available survey and the likely change in extent of inundation following the proposed levee upgrading works.

It is recommended that action be taken to upgrade the levee to a higher engineering standard. At this stage the following actions (prioritised) should be considered and from this a preferred strategy adopted.

High Priority

- Liaise with the Golf Club to establish their plans for the course immediately downstream of Windsor Road.
- Install maximum height gauges to ensure that in future events the flood gradient in this area is accurately recorded.
- Establish whether the private high level access track across the North Arm is appropriate. Lowering the track would reduce flood levels upstream whilst raising the entrance would eliminate the major low point.
- Determine if hydraulic investigations have been undertaken for the earthworks within the floodplain (house construction) immediately downstream of The Entrance Road.
- Ascertain why slashing of the vegetation has recently occurred (1999-2000) upstream of the private access track. This is likely to have a large impact upon the assumed Manning's 'n' values of the North Arm.
- Establish who owns or maintains the earthen levee.
- Review Council records to see if design plans are available.
- Seek the residents' views on the likely visual and social impacts of raising the existing earthen levee (public meeting or questionnaire).

Medium Priority

- Review the design flood height data and establish whether further survey and modelling should be undertaken to more accurately establish the hydraulic gradient.
- Undertake benefit/cost analysis to determine the viability of levee upgrading.
- Prepare a preliminary design to raise the levee to (say) the 1% AEP level + 0.5 m. Detailed survey will be required.

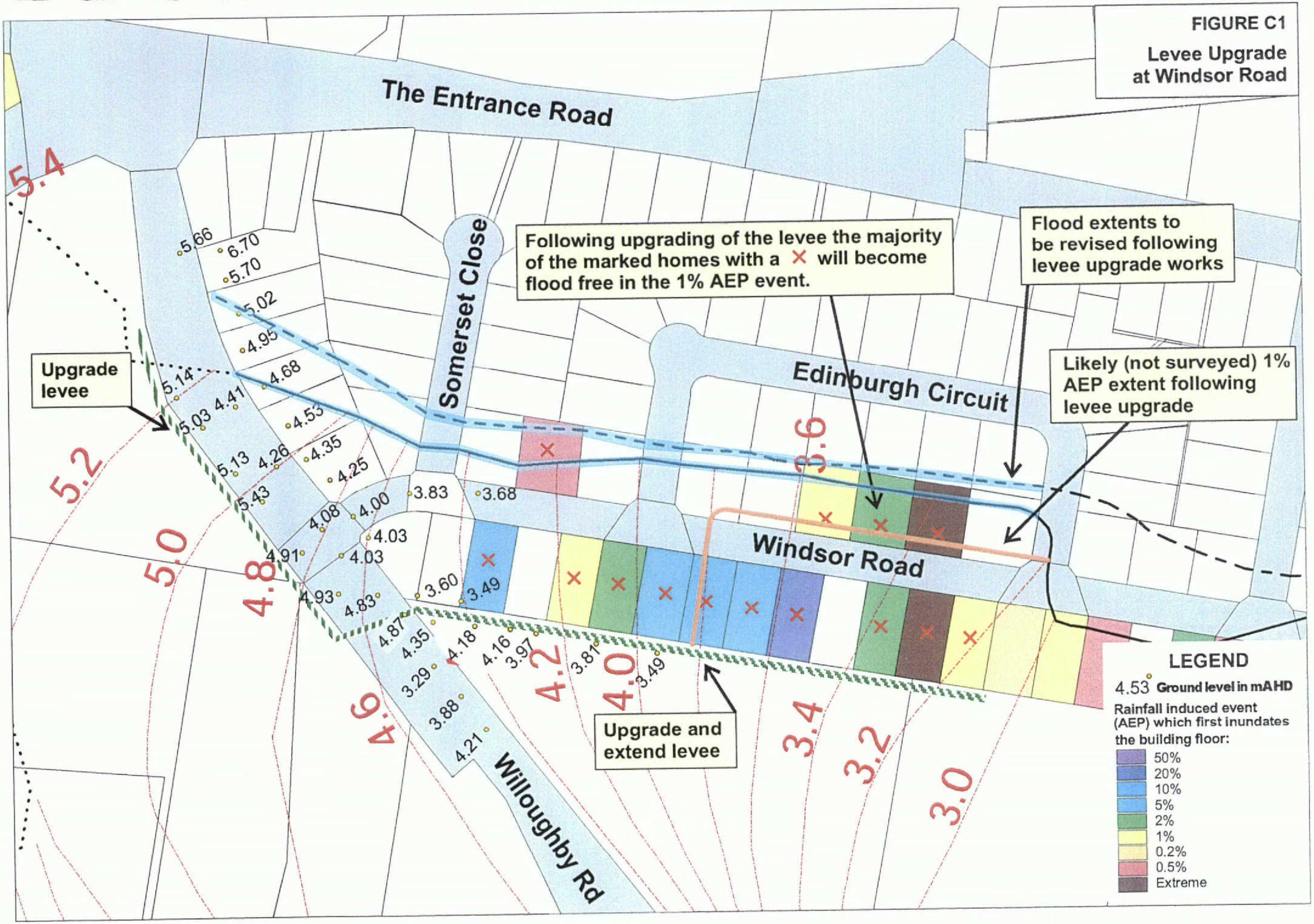
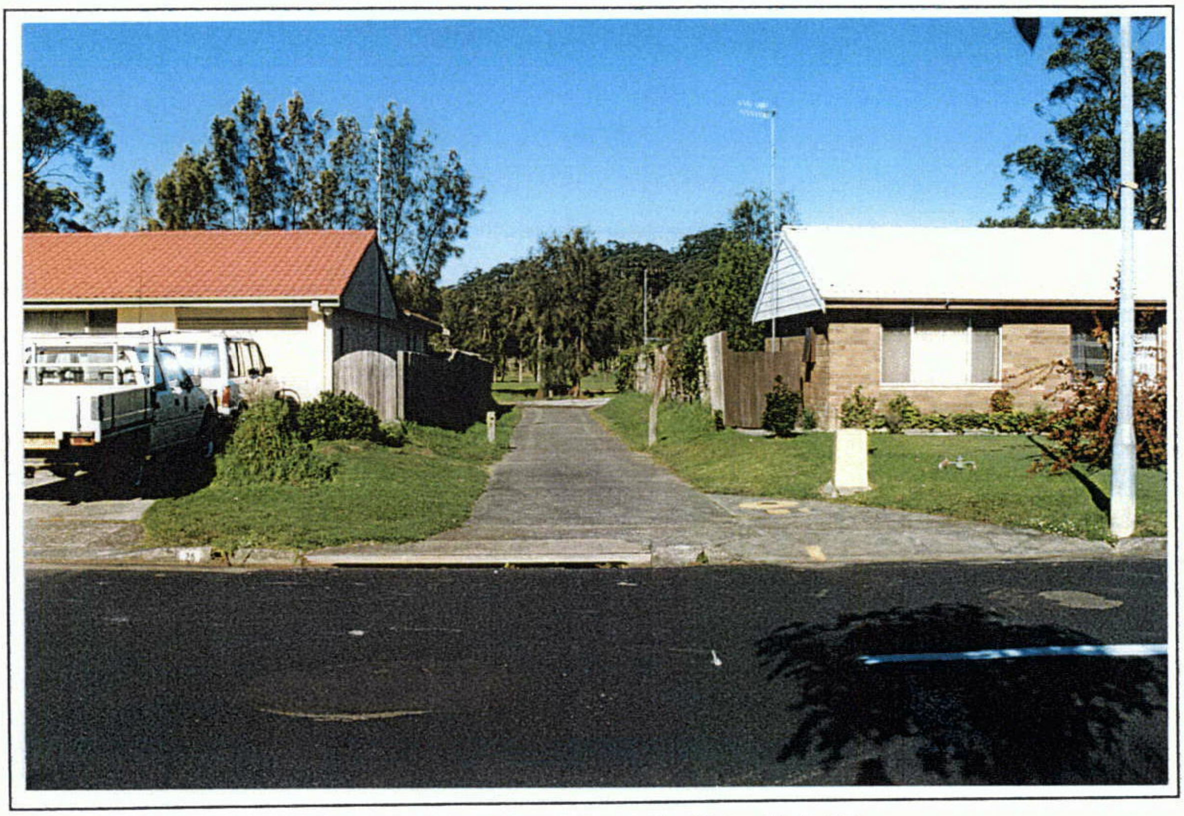


FIGURE C1
Levee Upgrade at Windsor Road
The Entrance Road
Somerset Close
Edinburgh Circuit
Windsor Road
Willoughby Rd
Following upgrading of the levee the majority of the marked homes with a × will become flood free in the 1% AEP event.
Flood extents to be revised following levee upgrade works
Likely (not surveyed) 1% AEP extent following levee upgrade
Upgrade levee
Upgrade and extend levee
5.4
5.2
5.0
4.8
4.6
4.2
4.0
3.6
3.4
3.2
3.0
5.66
6.70
5.70
5.02
4.95
4.68
5.14
5.03
4.41
4.53
4.35
4.25
5.13
4.26
5.43
4.08
4.00
3.83
3.68
4.03
4.03
4.91
4.93
4.83
3.60
3.49
4.87
4.35
4.18
4.16
3.97
3.81
3.49
3.29
3.88
4.21
LEGEND
4.53 Ground level in mAHD
Rainfall induced event (AEP) which first inundates the building floor:
50%
20%
10%
5%
2%
1%
0.2%
0.5%
Extreme

Photograph C1: Windsor Road Facing West of Main Low Point

Photograph C2: Windsor Road Facing East of Main Low Point



Photograph C3: Causeway between Property No's 26 & 28

Photograph C4: Causeway between Property No's 42 & 44

End of Report