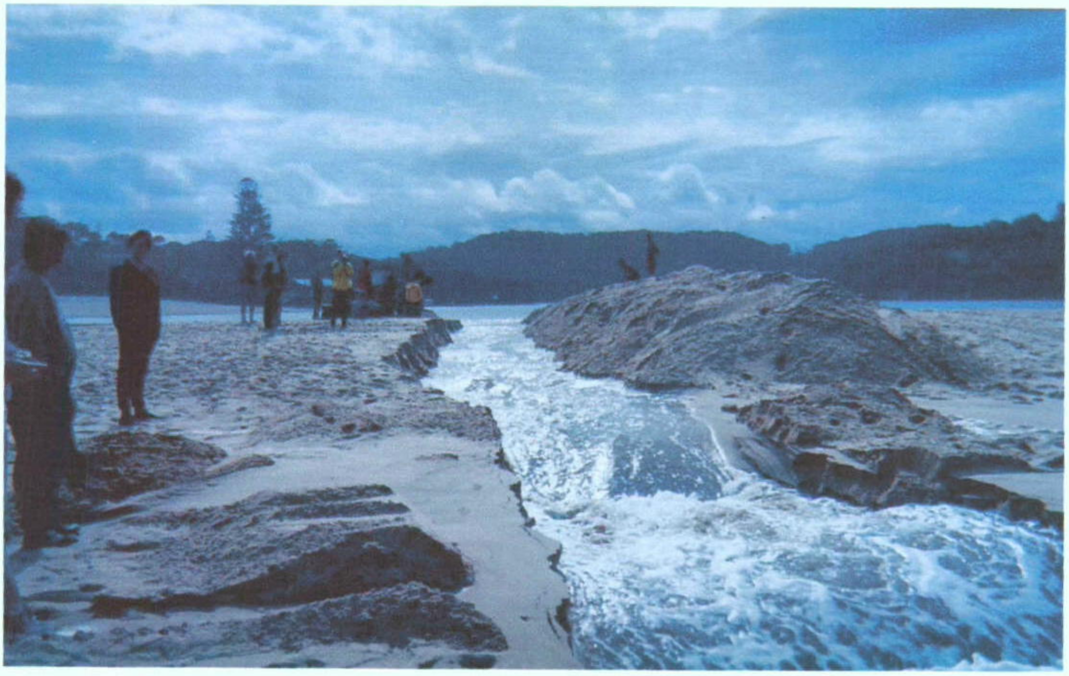
GOSFORD CITY COUNCIL

WAMBERAL LAGOON
FLOODPLAIN MANAGEMENT STUDY



NOVEMBER 2001

WEBB, McKEOWN & ASSOCIATES PTY LTD

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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 Wamberal Lagoon Floodplain Management Study constitutes the second stage of the management process for Wamberal 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 Wamberal 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 This manual was superseded by the Floodplain Management Manual which was introduced in January 2001 when this present report was nearing completion.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

Wamberal Lagoon has a catchment area of approximately 6.6 square kilometres, the majority of which lies within the boundaries of Gosford City Council. The remainder lies within the boundaries of Wyong Council. The area of the lagoon is approximately 0.5 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 Wamberal 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 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.	Remembrance Drive
3.	Loxton Avenue
4.	Wamberal Park and Blue Bell Drive
5.	Lavinia Street and Malkana Avenue
6.	North Arm (downstream of The Entrance Road)
7.	North Arm (upstream of The Entrance Road)
8.	Upstream Catchments

The number of buildings inundated above floor level in different flood events are 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**		
Extreme	6	1	0	28	0	0	35	596
1% AEP	3	0	0	5	0	0	8	110
2% AEP	2	0	0	5	0	0	7	80
5% AEP	2	0	0	3	0	0	5	50
10% AEP	0	0	0	3	0	0	3	29
20% AEP	0	0	0	1	0	0	1	18

Notes: Tangible damages do not include damages to public utilities (roads, reserves, etc.).
The average annual damages based on the above figures are $10 000.
Based upon existing design flood levels (1% AEP = 3.5 mAHD).

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

Floodplain Management Measures - Wamberal 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.
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.

Development Control Measures - Wamberal Lagoon

The following development control measures were examined.

STRATEGY	RESPONSE
Maintaining a minimum water level in the lagoon.	Rejected as not viable.
Council to initiate fewer lagoon openings.	Should be considered so that the lagoon will develop a more "natural" ecosystem.
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 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.

WAMBERAL LAGOON
FLOODPLAIN MANAGEMENT STUDY

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1. INTRODUCTION

1.1 General

Wamberal Lagoon is a small coastal lagoon within the Gosford City and Wyong Council Local Government areas (Figure 1). The lagoon has a surface area of approximately 0.5 square kilometres, and discharges to the Pacific Ocean at Wamberal Beach. The total catchment area to the Pacific Ocean is approximately 6.6 square kilometres with the lagoon representing 8% of the total catchment area.

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

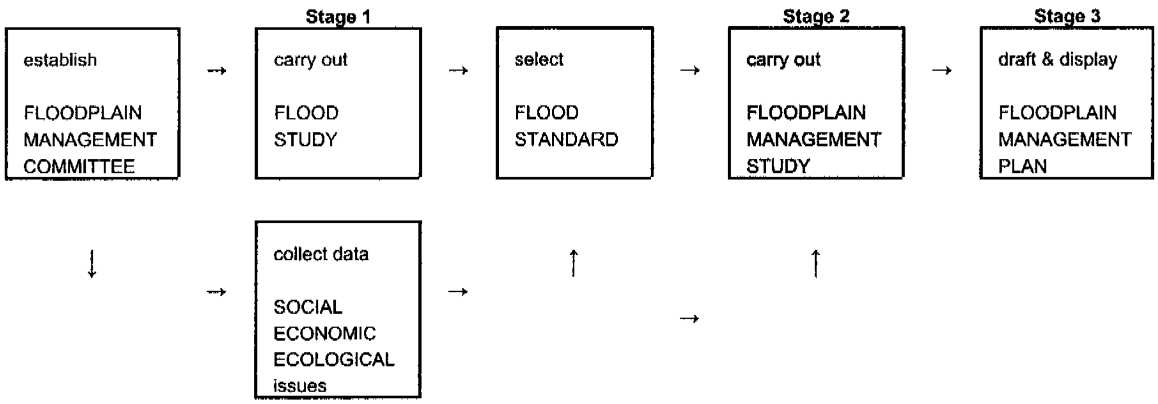
In the last 30 years the catchment has changed from being a predominantly rural community, to a more urbanised community. The lagoon and part of the adjoining foreshore have been dedicated as the Wamberal Lagoon Nature Reserve. There has also been an increase in population and a heightened awareness 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 Wamberal 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 Wamberal 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
2.	Remembrance Drive
3.	Loxton Avenue
4.	Wamberal Park and Blue Bell Drive
5.	Lavinia Street and Malkana Avenue
6.	North Arm (downstream of The Entrance Road)
7.	North Arm (upstream of The Entrance Road)
8.	Upstream Catchments

Note: Area 8 - Upstream Catchments - has not been examined in detail in this Study except for possible development in Area 8 affecting other Areas (Section 6.3).

2. BACKGROUND

2.1 Catchment Description

2.1.1 General

The majority of the catchment (over 95%) is within Gosford City Council, the remainder being within the Wyong Council boundary. All the flood liable areas lie within Gosford City Council.

The majority of the contributing catchment to the lagoon lies to the north and is largely undeveloped rural land. In the vicinity of the lagoon the southern and western parts of the catchment are entirely developed for residential usage. The north-eastern part of the catchment consists of the suburb of Forresters Beach. Wamberal Lagoon Nature Reserve (initiated in 1972 and gazetted in 1981) encompasses all the coastal escarpment to the east of the lagoon adjoining the Pacific Ocean. It has a area of 102 hectares and includes the lagoon itself. The coastal escarpment is at 10 mAHD to 30 mAHD and the only possible exit of the lagoon to the ocean is to the south.

The lagoon and surrounds contain a significant diversity of flora and fauna which are of major conservation value.

The main tributary to the lagoon is the creek which enters from the north (termed the North Arm) adjacent to Malkana Avenue (catchment area of 2.6 square kilometres). The other tributaries all have catchment areas less than 50 hectares and their main channels are largely ill-defined. The catchment areas of these residual creeks are described briefly below:

- *Carbeen Road* - downstream of Tumbi Road the creek is a lined channel through a proposed residential development,
- *Dalpura Road* - upstream of The Entrance Road a new roundabout has been constructed. Downstream an excavated channel has been formed,
- *Wamberal Park* - downstream of Wairakei Road the creek runs through Wamberal Park.

2.1.2 Description

The average bed level of the lagoon varies from +0.3 mAHD to +0.7 mAHD although there are localised holes to -1.5 mAHD. A cross-sectional survey of the lagoon was undertaken as part of the Flood Study. No other detailed survey of the lagoon is available. The outlet to the Pacific Ocean is generally blocked by a sand bar or beach berm. Thus the water level in the lagoon is generally not 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 available data the normal water level is approximately

1.5 mAHD. Variations in lagoon level of over 0.5 m within a day are reasonably common due to the effects of rainfall or opening of the entrance.

The lagoon area represents 8% of the total catchment area at 1.5 mAHD. At 3.0 mAHD the lagoon area represents 10% of the total catchment area. 90 mm of runoff (rainfall minus losses such as infiltration, storage, evaporation) produces 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 is of high environmental significance. No commercial tourist operators use the lagoon for activities. However, it is used by the local residents for fishing and boating. It is generally not used for swimming except near the outlet. Reduction in the aesthetic quality of the lagoon would have a significant impact upon the local area. There are no references to any significant filling or dredging activities within the lagoon environs.

2.1.3 Land Use

The land use zonings within the study area are mainly:

- residential "A",
- National Parks, Nature Reserves and State Recreation Areas (Wamberal Lagoon and foreshores),
- open space (recreation and environmental protection).

Other less significant zonings include special uses (cemetery), retail business and scenic protection. The houses along Remembrance Drive are zoned under "Restricted Development".

The zonings for the whole Wamberal Lagoon catchment are shown on Figure 3. The predominant zonings in each of the seven Floodplain Management Areas are given in Table 1.

Table 1: Predominant Land Use Zonings

Area	Predominant Zoning
1	8 - National Parks, Nature Reserves and State Recreation Area
2	9 - Restricted Development
3	2(a) - Residential "A"
4	2(a) - Residential "A"
5	2(a) - Residential "A"
6	8 - National Parks, Nature Reserves and State Recreation Area
7	7(c) - Scenic Protection - Small Rural Holdings

2.2 Study Limits

The hydrological investigations for this study considered the whole of the Wamberal 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:

- northern limit - Lavinia Street/John Street/Crystal Street/The Entrance Road,
- western limit - Tumbi Road/The Entrance Road,
- southern limit - Old Gosford Road/Ocean View Drive.

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:

- Wamberal 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 4).

A Compendium of Data used in References 1 and 3 has been published as Reference 5.

2.3.2 Wamberal Lagoon Flood Study

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

- determine the flood behaviour of Wamberal 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, and
- formulate the model such that the effects of 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.

Due to the paucity of historical flood data, the accuracy of the design levels within Wamberal Lagoon is considered to be ±0.4 m. The analyses show 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 the Gosford City Council area. The most important reports as far as this study is concerned are:

- *Wamberal Drainage Study (1989)* (Reference 6) undertook a hydrological and hydraulic analysis of two adjacent urbanised catchments lying upstream of Wamberal Park. The two catchments are loosely defined by:
    - Dalpura Road, Aldinga Drive (23 hectares),
    - Coreen Drive, The Entrance Road (17 hectares).

    The study was initiated due to complaints from the residents following the storms of April 1988 and January 1989. The proposed remedial works were costed (in $1989) at $125 600 or $181 400 for the first catchment and $81 100 or $113 000 for the second catchment depending upon the method of upgrading.

- *Wamberal Lagoon Catchment Study (1989)* (Reference 7) undertook a review of the natural environment of the lagoon and catchment. It discussed the existing and potential environmental problems and proposed the following management objectives:
    - to reduce and minimise the amount of erosion occurring in the lagoon catchment, whether resulting from natural processes or human activity,
    - to reduce and minimise the amount of sediment being deposited in wetland areas and on the lagoon bed and slow the ageing process of the lagoon,
    - to reduce and minimise bacterial pollution of the lagoon waters,
    - to reduce and minimise the level of plant nutrients entering the lagoon waters,
    - to minimise the impact of flood management procedures on residents and the lagoon's ecology,
    - to minimise the adverse impact of human activity in the lagoon catchment on lagoon ecology.

    No hydrologic or hydraulic modelling was undertaken as part of the study.

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 4) was commissioned in conjunction with the Wamberal 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 Wamberal 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 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 3.10 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 = 3.6 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 Wamberal Lagoon are provided below:

- the entrance berm is to be mechanically opened once the water level reaches approximately 2.4 mAHD. There is a nail in a concrete pole (opposite No.15 Remembrance Drive) to indicate this level (level = 2.365 mAHD as surveyed by Council in September 1993),
- 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 monitored 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 at approximately 3.0 mAHD (±0.5 m). Lowering of the beach berm by Council (without opening the entrance) has only occurred once since 1977. Opening of the lagoon 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.,
- 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 the 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. Whilst 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, and
- 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 covers approximately 50 hectares and includes only the areal extent of the lagoon at normal water level (say 1.5 mAHD) and the Wamberal Lagoon Nature Reserve. As there are clearly no buildings, and no proposals for future development within this area, there are no flooding problems. The major issues in this area are water quality, sedimentation, visual quality and the possible impacts of development, including dredging and recreational usage. Part of the Nature Reserve is designated as SEPP14 Wetland Nos. 909 and 907.

3.2.2 Remembrance Drive (Area 2)

Description: There are approximately 14 residential properties in Remembrance Drive fronting the lagoon. The land rises gradually from the lagoon and the houses are located on the slope to capture the views of the lagoon and entrance. The residents all appreciate the aesthetic appeal of the lagoon and are concerned about the quality of the lagoon (pollution, odour). There is minimal risk to life from flooding as all the residents can easily escape to higher ground. This area may experience flooding as a result of ocean inundation.

Flooding: There have been no recorded instances of buildings in Remembrance Drive being inundated above floor level. The lowest floor level is 3.3 mAHD (No. 15). The questionnaire indicated that the residents are concerned about the ponding of water in their front yards and the inconvenience caused by the roadway being flooded.

It was also noted that debris was placed in their front yards as a result of wave activity through the open entrance during the May 1974 storm. It would appear that waves were breaking inside the lagoon and running into the front yards of the properties (approximate ground level = 2.0 mAHD to 3.0 mAHD).

3.2.3 Loxton Avenue (Area 3)

Description: There are approximately 18 lots in Loxton Avenue and Ocean View Drive which possibly will be affected by an elevated lagoon. The lowest floor level is at 3.7 mAHD (No. 9) and is above the 1% AEP flood level of 3.5 mAHD. It is only in events greater than a 1% AEP flood that flooding of these buildings would occur. The buildings are all modern brick residences with the majority being slab-on-ground construction. The majority of residents of Ocean View Drive have views over the lagoon.

Flooding: A number of properties in Loxton Avenue have experienced above floor inundation in the past. Resident questionnaires and subsequent interviews revealed that water entered the homes of Nos. 7 and 9 Loxton Avenue, with probably more houses flooded for which there is no record. It should be noted that inundation has not occurred due to elevated lagoon levels. Rather, it has resulted from inadequate local drainage, although it has been claimed that flooding was exacerbated by an elevated lagoon level.

The resident of 9 Loxton Avenue (floor level = 3.7 mAHD and resident for 25 years), has had water enter the building in every major flood event since May 1974, except for February 1992. In February 1990 water reached the top of a coffee table in the living room, approximately 0.45 m above the floor (flood level of approximately 4.1 mAHD).

The present inhabitants of No. 7 (floor level = 3.9 mAHD) have reported water entering the building in 1988, 1989 and 1990. It should be noted that they have only resided at this address since late 1992 and their information was based on discussions with neighbours. An interview with the owner of 5 Loxton Avenue (resident since 1980) records that water has never entered the building (floor level = 4.1 mAHD). These data appear to be consistent with the 4.1 mAHD flood level recorded at 9 Loxton Avenue.

Most local residents believe that the cause of their flooding problems is inadequate local drainage rather than elevated lagoon levels. Council initiated a program of upgrading the local drainage system in the mid 1980's. Although part of the upgrading was completed by the late 1980's, inundation of the buildings still occurred in the floods of 1989 and 1990. A primary reason (identified by Council) for this problem was the lack of kerb and guttering in Old Gosford Road (upstream) causing significant overland flow across properties in Loxton Avenue and Ocean View Drive. The previous upgrading of the culverts under Ocean View Drive would appear to have raised the natural ground level (excessive backfilling). As a result, overland flow heading towards the lagoon from the upper parts of the catchment ponds in the back yards of the Loxton Avenue properties.

There have also been reports of water rising out of the drainage pit located at the rear of Nos. 154 and 156 Ocean View Drive. This pit was built as part of the upgrading works and features an irregular shape. Inflow to the pit occurs through twin 1350 mm pipes together with a smaller 750 mm pipe. Outflow is through triple 1200 mm pipes which are not aligned to any of the incoming pipes.

The upgrading works are now complete (1992), but as there have not been any subsequent flood events in the catchment, the adequacy of the improved system has not been fully tested. It would appear that the kerb and gutter work undertaken in Old Gosford Road (completed in 1990) has significantly improved flooding within the Loxton Avenue area as there were no reports of flooding in the February 1992 storm. This area should be closely monitored in future flood events to assess whether the flood problems have been eliminated.

Elevated lagoon levels have an effect upon this area by raising the tailwater level of the culverts under Ocean View Drive. The effect would appear to be less than that generally assumed as:

- the peak of the local runoff (1 hour duration) occurs prior to the peak lagoon level (a much longer duration of say 6 to 9 hours),
- flow through the culverts is most probably limited by the inlet capacity (size of inlet and debris blocking the pits) rather than the high tailwater level.

Lowering the lagoon water level would increase the capacities of the culverts.

3.2.4 Wamberal Park and Blue Bell Drive (Area 4)

Description: This area encompasses the residential lots adjacent to Wamberal Park and along Blue Bell Drive. It also include the lots in Tall Timbers Road fronting the lagoon. The lowest floor level of these buildings is 3.8 mAHD. Elevated lagoon levels have not inundated buildings in the past and are unlikely to even in an Extreme Flood. The residents all have pleasant outlooks across the lagoon and the adjoining Nature Reserve.

Flooding: Minor local drainage problems have been reported in the drain which is located between Blue Bell Drive and Tall Timbers Road. This has caused inundation of the yards of several properties and caused minor inconvenience. Flooding occurred due to inadequate capacity within the local drain and was not affected by elevated lagoon levels.

3.2.5 Lavinia Street and Malkana Avenue (Area 5)

Description: This area includes residential development located on the eastern bank of North Arm creek bounded by Lavinia Street, Malkana Avenue, Crystal Street and Noorong Avenue. The area can be subdivided into two parts separated by Binang Avenue. Upstream of Binang Avenue near Crystal Street, the ground is low-lying and there are approximately 40 lots which are flood liable including parts of John Street. The lowest building floor level is 3.9 mAHD. Downstream of Binang Avenue there are approximately 20 lots with the lowest building floor level also being 3.9 mAHD.

Flooding: Although there have been few recorded incidents of above-floor flooding, the area upstream of Binang Avenue has been identified as a problem area by Council, and this was also apparent in the questionnaire.

Questionnaire responses reveal that No. 5 Crystal Street was inundated above floor level in the February 1991 flood (floor level = 4.1 mAHD). The resident indicated that this was due to the failure of the local drainage system and not elevated lagoon levels. Similarly, the owner of No. 10 John Street has had water inside the building. The year is unknown but it is understood that the water ponded to a depth of approximately 0.05 m above the floor. The floor level of No. 10 John Street is above 5.0 mAHD, which means that it could not be flooded from the lagoon. The 1% AEP design flood level at this location is 4.5 mAHD.

Photographs accompanying the questionnaires, together with subsequent interviews, revealed that during the February 1990 event water inundated sections of Malkana Avenue and John Street, near Crystal Street. It is also likely that this occurred in January 1989. It would appear that in these instances flooding was caused by the North Arm creek overtopping its banks and flowing over Malkana Avenue. The water generally ponds in yards and dissipates slowly. Low lying depressions in the yards are inundated for several days.

Poor local drainage has been indicated as a problem in the northern part of John Street. The flood level at this location appears to have been much higher than the lagoon level at the time and lowering the lagoon level would not have eliminated the problem.

3.2.6 North Arm (downstream of The Entrance Road) (Area 6)

Description: This area includes all the flood liable land west of the North Arm and downstream of The Entrance Road. There are no buildings and no likelihood of development in this area. The concerns for this area are the same as for the lagoon (Section 3.2.1). One significant concern being the potential for erosion and pollution from the drain rising near Dalpura Road.

3.2.7 North Arm (upstream of The Entrance Road) (Area 7)

Description: Upstream of The Entrance Road there are no buildings which are flood liable within the study area (as at the time of the survey in 1994). The majority of the area consists of thickly vegetated rural land. The only exception is along Carbeen Road where a residential subdivision has been recently completed (1999). If further development occurs full consideration should be given to the possible impacts upon the flooding and water quality regimes.

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 flood height data were only for rainfall induced events and did not include the ocean induced inundation. This approach was taken as the ocean induced 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.

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

Design Flood	Inundation	Floodplain Management Areas (refer to Legend)						Total	Rainfall Induced Design Flood Level in the Lagoon (mAHD)
		2	3	4	5	6	7		
Extreme	Buildings	6	1	0	28	0	0	35	3.7
	Yards	11	3	3	44	0	0	61	
0.2% AEP	Buildings	3	0	0	8	0	0	11	3.5
	Yards	8	0	2	39	0	0	49	
0.5% AEP	Buildings	3	0	0	5	0	0	8	3.5
	Yards	8	0	2	35	0	0	45	
1% AEP	Buildings	3	0	0	5	0	0	8	3.5
	Yards	8	0	2	29	0	0	39	
2% AEP	Buildings	2	0	0	5	0	0	7	3.4
	Yards	8	0	1	25	0	0	34	
5% AEP	Buildings	2	0	0	3	0	0	5	3.4
	Yards	8	0	0	21	0	0	29	
10% AEP	Buildings	0	0	0	3	0	0	3	3.3
	Yards	8	0	0	16	0	0	24	
20% AEP	Buildings	0	0	0	1	0	0	1	3.2
	Yards	8	0	0	14	0	0	22	

LEGEND:

1. The lagoon water body
2. Remembrance Drive
3. Loxton Avenue
4. Wamberal Park and Blue Bell Drive
5. Lavinia Street and Malkana Avenue
6. North Arm (downstream of The Entrance Road)
7. North Arm (upstream of The Entrance Road)

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	
Extreme	80	4	2	510	-	-	596
0.2% AEP	40	-	-	140	-	-	180
0.5% AEP	30	-	-	100	-	-	130
1% AEP	30	-	-	80	-	-	110
2% AEP	20	-	-	60	-	-	80
5% AEP	20	-	-	30	-	-	50
10% AEP	9	-	-	20	-	-	29
20% AEP	8	-	-	10	-	-	18

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 $10 000, 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 8) 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 8).

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) 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, 5, 6 and 7 is generally flood fringe low hazard. The lagoon water body is a high hazard floodway. Lavinia Street and Malkana Avenue (Area 5) and the North Arm (Areas 6 and 7) contain the main tributary to the lagoon (North Arm) which is defined as a high hazard floodway.

The flood classifications are shown on Figure 2.

3.5 Discussion of the Existing Flood Problem

The developed part of the floodplain surrounding Wamberal Lagoon does not have a major flood problem. There are only 8 buildings inundated above floor level in a 1% AEP event and 39 yards. The buildings are located in Area 2: Remembrance Drive (3 buildings) and Area 5: Lavinia Street/Malkana Avenue (5 buildings). Flooding within Area 2 occurs as a result of ocean inundation as well as elevated lagoon levels resulting from rainfall. Flooding within Area 5 is due to a combination of elevated lagoon levels and runoff from the North Arm overtopping its banks.

Catchment runoff increases the lagoon water level (starting water level of say 2.4 mAHD) until it ultimately overtops the entrance berm (assumed to be 3.0 mAHD) and an ocean entrance is progressively eroded through the berm. The North Arm and the small creeks near Wamberal Park and the Entrance Road 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 causes flooding within the catchment at Area 3: Loxton Avenue and to a lesser extent at Area 2: Remembrance Drive, Area 4: Wamberal Park and Blue Bell Drive and Area 5: Lavinia Street and Malkana Avenue. It was of major concern at Loxton Avenue but recent works by Council may have solved the problem. At Wamberal Park the flooding from local drainage is not a major concern. At Areas 2 and 5 local drainage is an inconvenience but does not affect building floor levels.

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

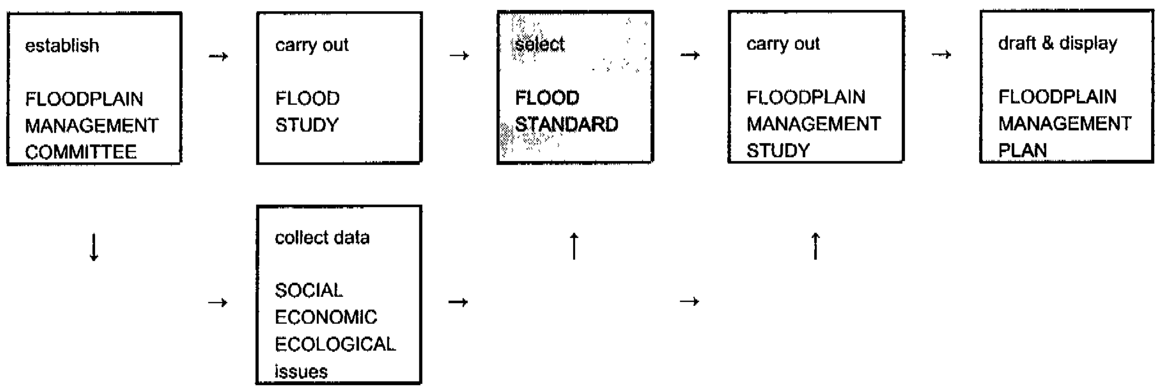
3.6 Review of the Flood Standard

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 8), 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 0.4 m increase in level from the 10% AEP event to the Extreme Flood with only a gradual 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 the majority of floodplain has already been developed in this catchment, changing the Flood Standard is unlikely to alter the amount of 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. In North Arm the difference is approximately 0.8 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 account the above considerations 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 could not be justified as the Extreme Flood is a maximum of 0.8 m above the 1% AEP level and therefore only 0.3 m above 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 all 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 Malkana Avenue.

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 has been undertaken in the past by Council. It is an effective means of assisting a man-made or natural opening. The possible environmental impacts of the works need to be considered.

- **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. This area is also an area of high environmental value.

- **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 previously as part of this study. 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 1.5 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 1.5 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 2.4 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. 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.

  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 Wamberal 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.

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

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 Wamberal 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. Funding is available from the State Government for house raising. 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).

  Preliminary analysis indicates that house raising has a benefit/cost ratio of 1 if the house is inundated in a 50% AEP event, 0.3 if inundated in a 20% AEP event and less than 0.1 if inundated in 5% AEP and greater events. Only three of the eight buildings inundated in the 1% AEP event could possibly be raised. Two are in Remembrance Drive and the other is in Crystal Street. None of these buildings provide a benefit/cost ratio greater than 0.3.

- **Permanent Measures - Permanent 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. 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 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 land 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 Wamberal 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 buildings (approximately 8) inundated above floor level in a 1% AEP flood is approximately $2 million (assuming an average of $250 000 per building). The high cost compared to the magnitude of the flood problem 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 issue is discussed 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 Wamberal 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 Wamberal 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 Wamberal 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 10). 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 equals less than 0.1% of the estimated capital cost. The benefit of the system to the Wamberal Lagoon catchment is small and cannot be justified. However for other catchments the benefits are much greater (for Terrigal Lagoon the benefit is 5% of the estimated capital cost).

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. High 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 Wamberal 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 9 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 main ones are Remembrance Drive (Area 2), Loxton Avenue (Area 3), Malkana Avenue/John Street/Crystal Street (Area 5) and The Entrance Road (border of Areas 7 and 6).

There are no practical solutions to this problem other than ensuring that the residents and the SES are adequately informed.

The most significant road inundation is at The Entrance Road upstream of Area 5. This is the main access route in the area and traffic disruption would cause considerable inconvenience. Flooding over the road occurs (say) once every year and generally traffic is able to pass through (albeit at a lower speed). The Entrance Road at this point has little fall and is therefore inundated to a shallow depth for a distance of up to 200 m. In a 1% AEP event the velocity is 0.5 m/s and the depth (say) 0.3 m.

Flood free access can only be provided by raising The Entrance Road over a large distance and providing the necessary waterway openings. The cost of these works would be in excess of $400 000 and could only be justified if undertaken in conjunction with other road and traffic works.

In the short term the problem should be managed by education and information. This would include provision and maintenance of depth indicators and notification of the hazard in the educational material.

4.6 Conclusions

A range of floodplain management measures has been canvassed for Wamberal Lagoon and assessments made of the 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 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 recommended level (2.4 mAHD at present) 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,
- 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. parks) 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,
- Council's present policy on providing information and education to residents regarding flooding is to be encouraged and could be expanded to include other 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 strategies, it is apparent that many measures are not practical for the Wamberal 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 lagoon level (and let out 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 4.

Lowering of the flood levels resulting from rainfall induced events will only provide benefit to the properties along Remembrance Drive and at Lavinia Street which are affected by elevated lagoon levels. Further upstream near John Street the flood levels are not influenced by the lagoon levels (refer Section 5.7).

5.2.2 Ocean Inundation

Along Remembrance Drive ocean inundation produces higher levels than rainfall induced events. The effect of ocean inundation rapidly diminishes upstream of Remembrance Drive (approximately 400 m from the Ocean). 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 will 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. The impact may 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 benefits that would occur if it was decided to undertake works which would change the adopted design scenario.

- **Altering the Lagoon Starting Level or Let Out Level (currently 2.4 mAHD)**

  Lowering the lagoon starting level (to 1.4 mAHD) or raising the lagoon starting level (to 2.9 mAHD) was found to reduce the lagoon flood level by 0.3 m and 0.2 m, respectively for the adopted design flood scenarios (for the adopted 9 hour duration storm).

  If the lagoon starting level was taken as 2.9 mAHD, the 2 hour becomes the critical storm duration and this produces a peak level similar to the adopted design level of 3.5 mAHD for the 9 hour duration. Thus, there is no tangible benefit 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 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 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 will be affected if there is insufficient water. This may affect the vegetation as well as the aquatic and avifauna balance of the lagoon,
  - maintenance of a lower starting water level can only be achieved by more frequent lagoon openings. This approach would conflict with the environmental groups who prefer less Council involvement in lagoon openings.

- **Reducing the Peak Inflow or Runoff Volumes**

  Reducing the hydrograph peaks (by using retarding basins or on-site detention) and runoff volumes (by increasing infiltration) will reduce the peak lagoon level. However, the substantial costs which would be involved (approximately $400 000 per basin) in providing this benefit would render this option impractical if it was for the sole purpose of reducing the peak lagoon level. Such a measure may be more attractive 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 2.4 mAHD (reduction of 1.1 m) is achieved if the entrance is open at the start of the flood-producing rains.

  The beach berm level adopted for all design events is 3.0 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). There is no way of changing the impact of the natural factors, but the management factors can be changed. (Council's existing opening policy has been 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**

    At present there is no formal system adopted by Council for maintaining the beach berm level. Only one lowering of the berm has been undertaken by Council in the 21 years of record (1977-1998). Currently Council expends approximately $3 000 per annum to open the lagoon.

    An indicative B/C analysis was undertaken to assess the economic viability of improved management of the berm, so that the berm level for design is reduced to 2.7 mAHD. It was assumed that the design flood levels could be reduced by 0.4 m in the 1% AEP (to 3.1 mAHD) through the introduction of this measure. The B/C analysis only considers the effects on rainfall induced inundation. The cost to Council to undertake these works cannot be accurately estimated at this stage. It costs approximately $1 000 per opening or lowering, but the number required each year is unknown. For this reason a range of costs have been included in Table 5. It should be noted that this is not a rigorous analysis as it has not taken account of the damage 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 an assumed 0.3 m reduction in the level may not result in a significant change to the peak level. Reference 3 suggests that lowering the berm may reduce the level of inundation. Further research is required in this area.

Table 5: Effect of Providing Increased Maintenance of the Berm so that the Design Berm Levee is Reduced from 3.0 mAHD to 2.7 mAHD

Additional Annual Cost to Council	Benefit/Cost Ratio
$2000	1.8
$5000	0.7
$10000	0.4

The results (Table 5) show that the indicative B/C ratio is approximately 1 (if the annual cost is $5000 or less) and thus on economic grounds this option may have some potential. Council may consider this measure desirable for social reasons as it could reduce the 1% AEP flood level of 3.5 mAHD from the Flood Study to the pre-Flood Study level of 3.1 mAHD (Figure 7).

However, this reduction has minimal impact upon the number of buildings inundated above floor level. At Remembrance Drive the design flood levels are from ocean inundation and would not benefit. At Lavinia Street and Malkana Avenue the benefit is reduced as the design levels are primarily a result of overflow from the North Arm and will only be slightly reduced with a lower lagoon level.

It is recommended that the following data collection and analysis 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 are 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 is 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 $5000 per annum for the increased berm maintenance and $1000 per annum for data collection.

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

This process is the most critical for determining the effective height of the beach berm level and resulting peak lagoon level. If this process is successful the lagoon will be open prior to the flood producing rains and so the flood levels will be much reduced (if the berm is open at the time of the flood the 1% AEP level is reduced by 1.1 m to say 2.4 mAHD). 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 wave 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 measure has rarely (if ever) been used in the past at Wamberal Lagoon due to environmental reasons (the community prefer a more natural opening regime and implementation of this measure would mean more frequent openings). This measure is used on Terrigal Lagoon. It is recommended that if any future openings of this type are undertaken they should be documented and the information collected used to reassess the opening strategy.

5.3 Remembrance Drive (Area 2)

Flooding in this area is caused by two mechanisms namely: *ocean inundation* (1% AEP level = 3.8 mAHD) and *rainfall induced* flooding raising the lagoon level (1% AEP level = 3.5 mAHD). Three buildings are inundated above floor at the 1% AEP rainfall induced level and six at the 1% AEP ocean induced level. Flooding from ocean inundation cannot be reduced unless some form of barrier is constructed at the lagoon entrance. This is not a practical solution and would be rejected on environmental, aesthetic and economic grounds. It is possible to reduce rainfall induced flood levels in this area by lowering the entrance berm and this is discussed in Section 5.2.

Apart from lowering the entrance berm the only other viable procedures for reducing flood damages are house raising or flood proofing. A levee was considered to be unsuitable because it would cause major access problems for the residents and is unlikely to be supported by the residents on aesthetic grounds.

The three buildings inundated in a 1% AEP event (rainfall induced) are No's 13, 15 and 17. No. 13 is a two-storey brick building and may have no habitable floor area on the ground floor. No's 15 and 17 are single non-brick buildings and can be raised for (say) $40 000 each. The B/C ratio for undertaking this work is less than 0.1.

Ponding occurs in the residents front yards several times a year and is largely due to local runoff. The ponding of water is of a very minor nature causing no significant damage to property or major inconvenience. However it is unsightly and can be readily solved by upgrading or cleaning out of the existing drainage pipe under the road which exits to the lagoon. Alternatively the yards of the properties can be filled to above (say) 2.5 mAHD. Care would have to be taken to ensure that the fill is not placed near the bases of the major trees.

It is proposed that specific advice and information be provided to the property owners located on Remembrance Drive regarding the effects of ocean inundation. This will ensure that the owners are fully informed of the risk to life and likely damages in a major ocean event. Council should satisfy themselves that there is an adequate evacuation procedure. Furthermore design standards should be introduced to ensure that all new buildings (within 100 m of the northern shore) are constructed to dissipate forces from inundation by ocean waves.

5.4 Loxton Avenue (Area 3)

A significant amount of work has been undertaken by Council (outlined in Section 3.2.3) in an effort to alleviate the problems in this area. As previously stated, the overall effectiveness of the improvements has not been fully tested and further investigation into the localised problems should be undertaken. This is beyond the scope of this study but should include assessing the performance of the pit between Nos. 154 and 156 Ocean View Drive as well as the possibility of removing the excessive backfill behind Nos. 7 and 9 Loxton Avenue.

Flooding from elevated lagoon levels is not an issue in the area as the floor level of the lowest house is 0.2 m above the existing 1% AEP rainfall induced flood level of 3.5 mAHD.

Since all the buildings which have in the past been inundated above floor level (from local catchment runoff and not elevated lagoon level) are of brick and slab-on-ground construction, house raising is probably not viable. Because the depth of inundation is shallow and of short duration sealing of the entrances to the buildings (waterproof doors) is likely to be a suitable floodplain management measure. It is possible that landscaping of the grounds may significantly reduce or eliminate the problem.

The following measures are recommended:
- an urban drainage investigation to be undertaken following the next period of heavy rain. This should allow an assessment to be made of the success of the recent drainage works,
- following completion of the above study consideration should be given to local landscaping of the resident's yards and/or flow diversion methods. Sealing of the entrances to No's 7 and 9 should be considered if warranted.

5.5 Wamberal Park and Blue Bell Drive (Area 4)

This area experiences no above floor inundation only yard damage. The only issue regarding flooding in this area is local runoff. It is recommended that the situation be monitored and addressed where appropriate.

5.6 Lavinia Street and Malkana Avenue (Area 5)

Flooding in this area is as a result of a combination of the following:
- local runoff ponding in low spots,
- elevated lagoon levels,
- runoff exceeding the capacity of the creek (North Arm).

The effect of each of the above depends upon location and the magnitude of the flood. For example, in short duration rainfall events local runoff will be the main contributor near Malkana Avenue and Crystal Street rather than elevated creek levels. For houses in Lavinia Street elevated lagoon levels are the major consideration. Further upstream the effect of the peak lagoon level decreases and flow from the North Arm becomes the dominant mechanism. In a 1% AEP flood in the North Arm the effects of local runoff and elevated lagoon levels will be minimal at Malkana Avenue near Crystal Street. The 1% AEP flood level is at this point is approximately 4.1 mAHD (the area will be inundated by up to 0.5 m of water) which is 0.6 m above the 1% AEP lagoon level of 3.5 mAHD.

Peak levels from the 1% AEP flood with the design entrance scenario (berm level at 3.0 mAHD) and with the entrance open conditions were compared to show the effect of elevated lagoon levels in this area. The results showed that 1% AEP flood levels upstream of Binang Avenue were reduced by less than 0.1 m. Downstream of Binang Avenue they were reduced by up to 0.3 m (no houses are inundated in the 1% AEP event). The entrance open condition is the "best possible" scenario and the reduction will be much less if the entrance is not fully open. An additional scenario which was considered was lowering the starting level of the berm by 0.1 m to 2.9 mAHD. The resulting reduction in flood level upstream of Binang Avenue was nil and downstream was only 0.07 m. It can be concluded that the flood levels upstream of Binang Avenue are largely independent of the lagoon level.

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

- levees,
- house raising,
- river improvement works.

For convenience the area has been subdivided into upstream and downstream of Binang Avenue.

5.6.1 Downstream of Binang Avenue

The lowest floor level of the houses in Lavinia Street and Malkana Avenue downstream of Binang Avenue is No. 36 (3.9 mAHD). This is approximately 0.4 m above the 1% AEP flood level. There is only a small risk to life from flooding in this area and cars are generally parked on ground above the 1% AEP flood level. Flooding of yards and Malkana Avenue will occur, but it is not considered warranted to undertake flood mitigation measures.

5.6.2 Upstream of Binang Avenue

Flooding from local runoff results in ponding in residents' yards. This causes inconvenience but no above floor level inundation. The lack of relief and sub-surface drainage within the area makes it difficult to resolve this problem. Further investigation will have to be undertaken if this is required. Possible solutions are sub-surface drainage or construction of a low flow channel through the properties. The disadvantage of these solutions are that they will exacerbate flooding when the North Arm is in flood. It is recommended that a local drainage study be undertaken to investigate these issues.

Flooding in this area is predominantly from the North Arm breaking its banks and spreading laterally across the floodplain. A levee near Malkana Avenue would cost approximately $150 000 for earthworks alone. There would be further costs including:

- landtake,
- roadworks. This is a major problem as a "hump" would be required on Malkana Avenue and possibly Crystal Street,
- resolution of internal drainage. Local runoff is a major problem at present and will be exacerbated if a levee was constructed.

An indicative total cost to construct this levee to the 1% AEP level would be approximately $600 000. This would give a B/C ratio of approximately 0.1. It is unlikely that the local residents would support a levee as it would detract from the aesthetics of the area. This would have to be canvassed in a public consultation program.

Stream clearing of the North Arm and removal of vegetation on the west bank was considered, but is unlikely to be acceptable to the community on environmental grounds. Dredging of the creek would also be environmentally unacceptable. These works would reduce flood levels, but unless major works were undertaken flooding would not be eliminated from Malkana Avenue (upstream of Binang Avenue), John Street and Crystal Street.

House raising is only possible for one building providing an indicative benefit/cost ratio of less than 0.3. The drawback of this option is that backyard damage and inconvenience/access problems would still occur. It is recommended that consideration be given to this measure and the residents consulted.

5.7 North Arm (Areas 6 and 7)

There are no flood liable buildings within this area. The main concerns are the two road crossings of the Entrance Road. The existing structures (Figure 4) are a 5 cell (3.6 m x 1.2 m) box culvert and a twin (1800 mm x 800 mm) box culvert. It is understood from the local residents that the road has been overtopped by floodwaters several times in recent years. The depth of overtopping is generally a maximum of 0.2 m and is trafficable (slowly) by most motor vehicles. The risk to life from being washed away is low as the depths and velocities (0.5 m/s) are low.

Since this road is the main access route to Bateau Bay and The Entrance, flooding causes a major inconvenience and the increased risk of motor accidents. Council should therefore give consideration to upgrading the bridge structures although an alternative route is available along Tumbi Road. One of the problems with making The Entrance Road flood free is the cost. Up to 200 m of road is inundated in a 1% AEP event. Upgrading the waterway structures without raising the road over this length will not make the road flood free. Further investigation of this option can only be undertaken in conjunction with a traffic study of the local area. In the short term a review (and upgrading if required) of the flood depth indicators should be undertaken in conjunction with notification of the issue in the flood education material.

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 Fewer Man-Initiated Lagoon Openings

Public interaction through the questionnaire, field interviews and discussions with Council have shown that there is a desire for less involvement of the Council in lagoon openings. The arguments for this are twofold. Firstly there are aesthetic reasons as residents prefer water in the lagoon and therefore less frequent openings. They accept that the lagoon will "break out" naturally, but consider that Council's involvement means that it occurs too frequently. Secondly, there are environmental reasons for less openings. It is considered that more frequent openings will cause the ecology of the lagoon and hinterland to change to a more salt water environment. Data on this issue are provided in Reference 3.

Residents have also requested the maintenance of a minimum water level. This can be achieved by constructing a weir or similar structure at the entrance. However this concept has been rejected as being too expensive and it would significantly affect the 'natural' aesthetic quality of the entrance and the ecology of the lagoon.

Since flooding is not a major problem around Wamberal Lagoon, consideration should be given to less involvement by Council in the lagoon opening procedure. For example there is no requirement to open the lagoon at say 2.5 mAHD (0.1 m above the let out level) if the rain has ceased and the forecast is for fine weather. As a safeguard a notch could be cut in the berm at say 2.7 mAHD to ensure that it can break out if the lagoon level does rise with further rain. There are problems with this approach as there is no easy access for equipment. Also if the berm is lowered too much there is the risk that the lagoon will be opened unnecessarily by others.

This issue has been discussed by the Floodplain Management Committee, the local community and other interested parties (DLWC) and already adopted by Council as a result of the work undertaken in Reference 3.

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 8),
- 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.

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

There are no proposals to dredge the lagoon at the present time. However should this situation change the impact of dredging should be examined in an Environmental Impact Statement. Preliminary investigation undertaken as part of this study suggests that dredging will not reduce flood levels and cannot be supported as a flood mitigation measure.

There are also no proposals for filling the floodplain surrounding the lagoon. Preliminary investigations undertaken as part of this study have shown that filling of (say) 1 hectare of floodplain will raise flood levels by 0.01 m. Filling of the floodplain surrounding the lagoon should be permitted subject to Council approval. Council should keep a record of the approvals and quantities of fill involved. Approval should only be provided if it is necessary to raise a structure or activity above flood level (e.g. house building pad) or if the filling is to 0.2 m above the let out level (to allow full use of the land when the lagoon is full).

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.

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.

Stricter controls on the placement of fill are required for the North Arm creek upstream of Binang Avenue. Filling in this area has the potential to restrict the floodplain and consequently raise flood levels upstream or compound the existing local drainage problem.

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 may be undertaken subject to the aforementioned guidelines.

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 increases of up to 0.03 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 Wamberal 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 (or fall) in the design beach berm level would translate to approximately a similar rise (or fall) in the design flood level in the lagoon. Any rise would be unacceptable. At this point in time it is assumed that in the short term 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 11), 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 12). 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 13) 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 Wamberal 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

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- Gosford City Council,
- Department of Land and Water Conservation,
- residents of Wamberal 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

N

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

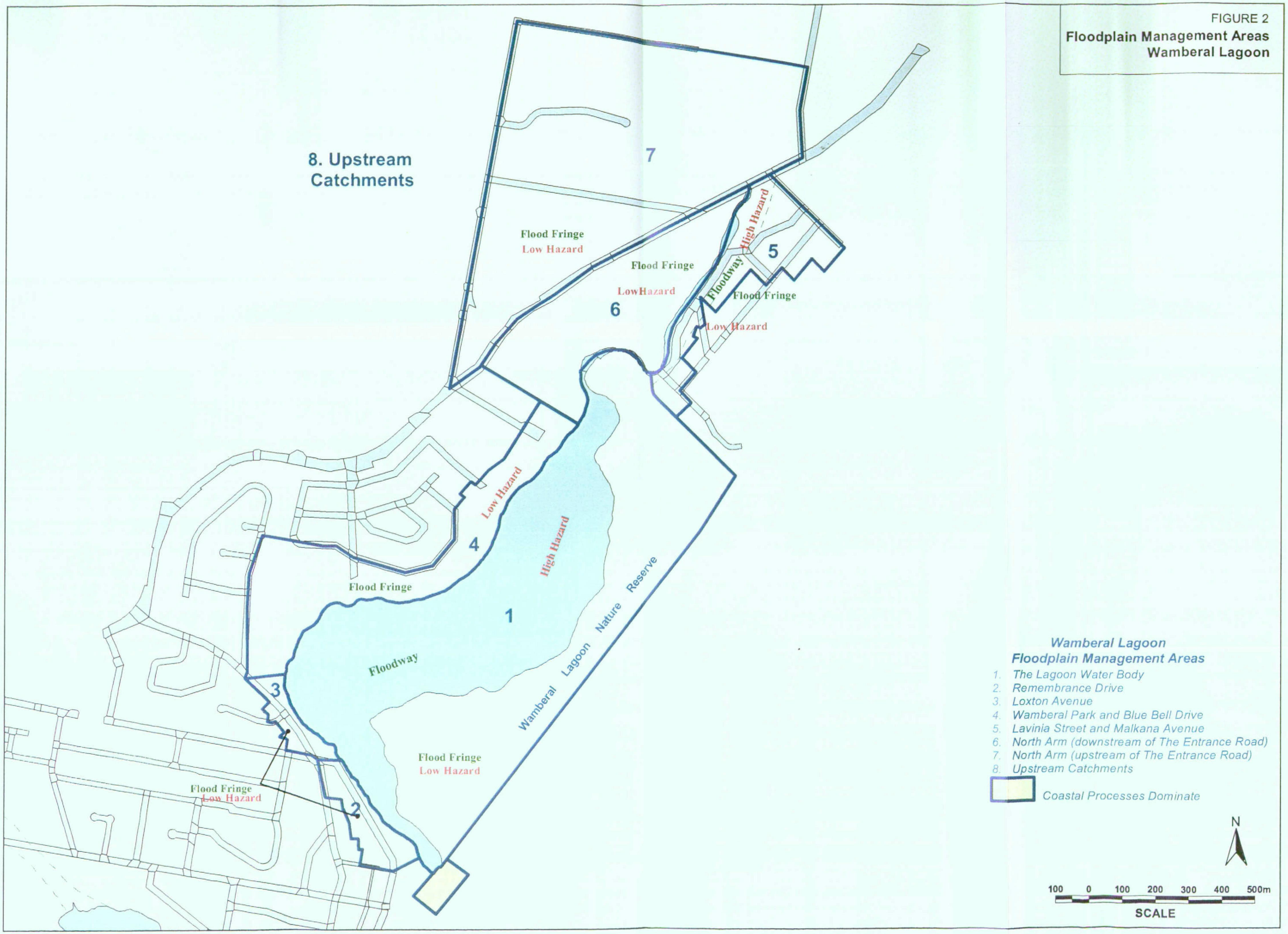


FIGURE 2
Floodplain Management Areas
Wamberal Lagoon
8. Upstream Catchments
7
Flood Fringe
Low Hazard
Flood Fringe
LowHazard
6
Floodway
High Hazard
5
Flood Fringe
Low Hazard
Low Hazard
4
High Hazard
Flood Fringe
1
Floodway
3
Wamberal Lagoon Nature Reserve
Flood Fringe
Low Hazard
Flood Fringe
Low Hazard
2
Wamberal Lagoon
Floodplain Management Areas
1. The Lagoon Water Body
2. Remembrance Drive
3. Loxton Avenue
4. Wamberal Park and Blue Bell Drive
5. Lavinia Street and Malkana Avenue
6. North Arm (downstream of The Entrance Road)
7. North Arm (upstream of The Entrance Road)
8. Upstream Catchments
Coastal Processes Dominate
N
100 0 100 200 300 400 500m
SCALE

FIGURE 3

PROPOSED CATCHMENT DEVELOPMENT ZONING CONSOLIDATION PLAN

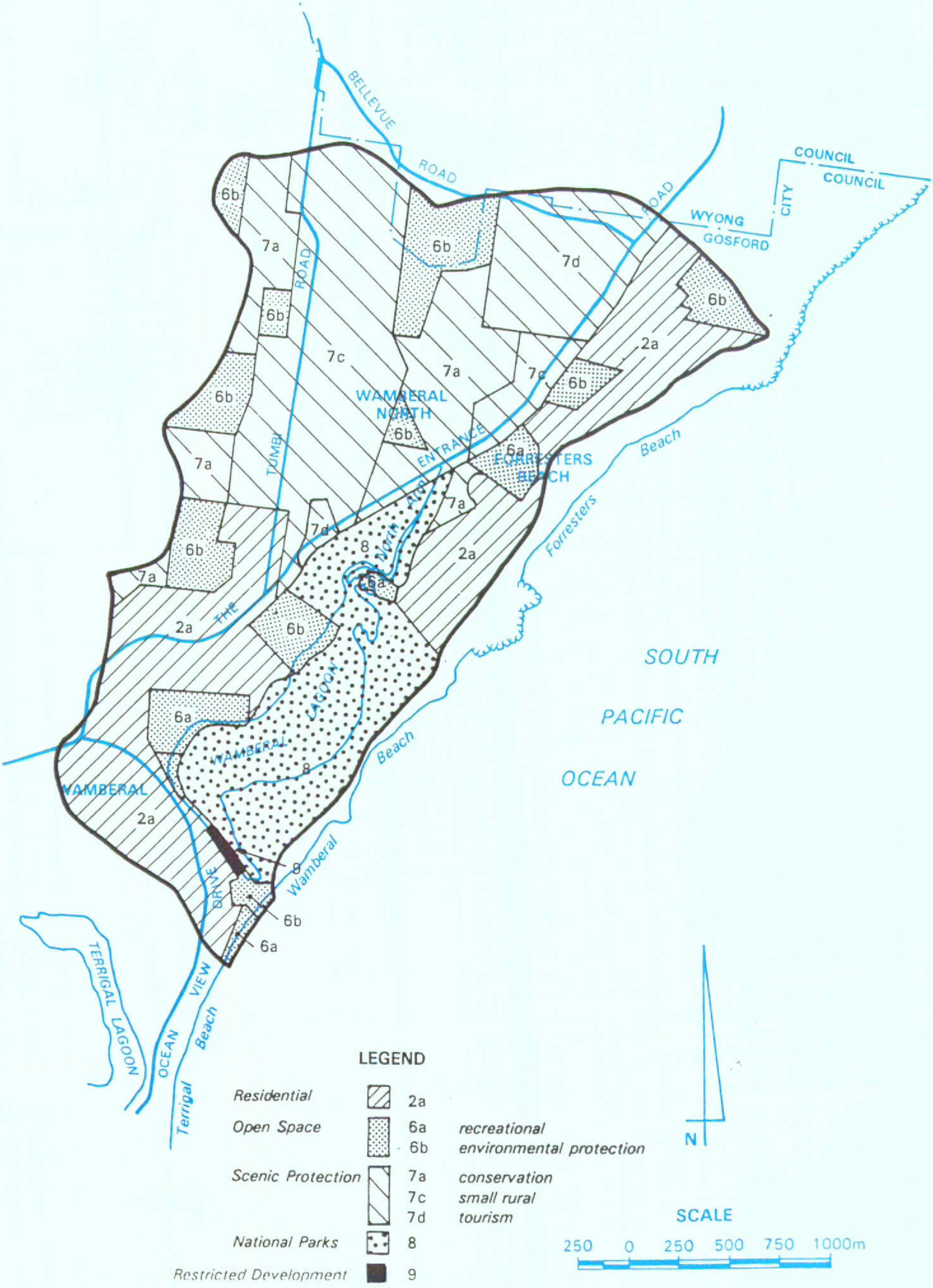
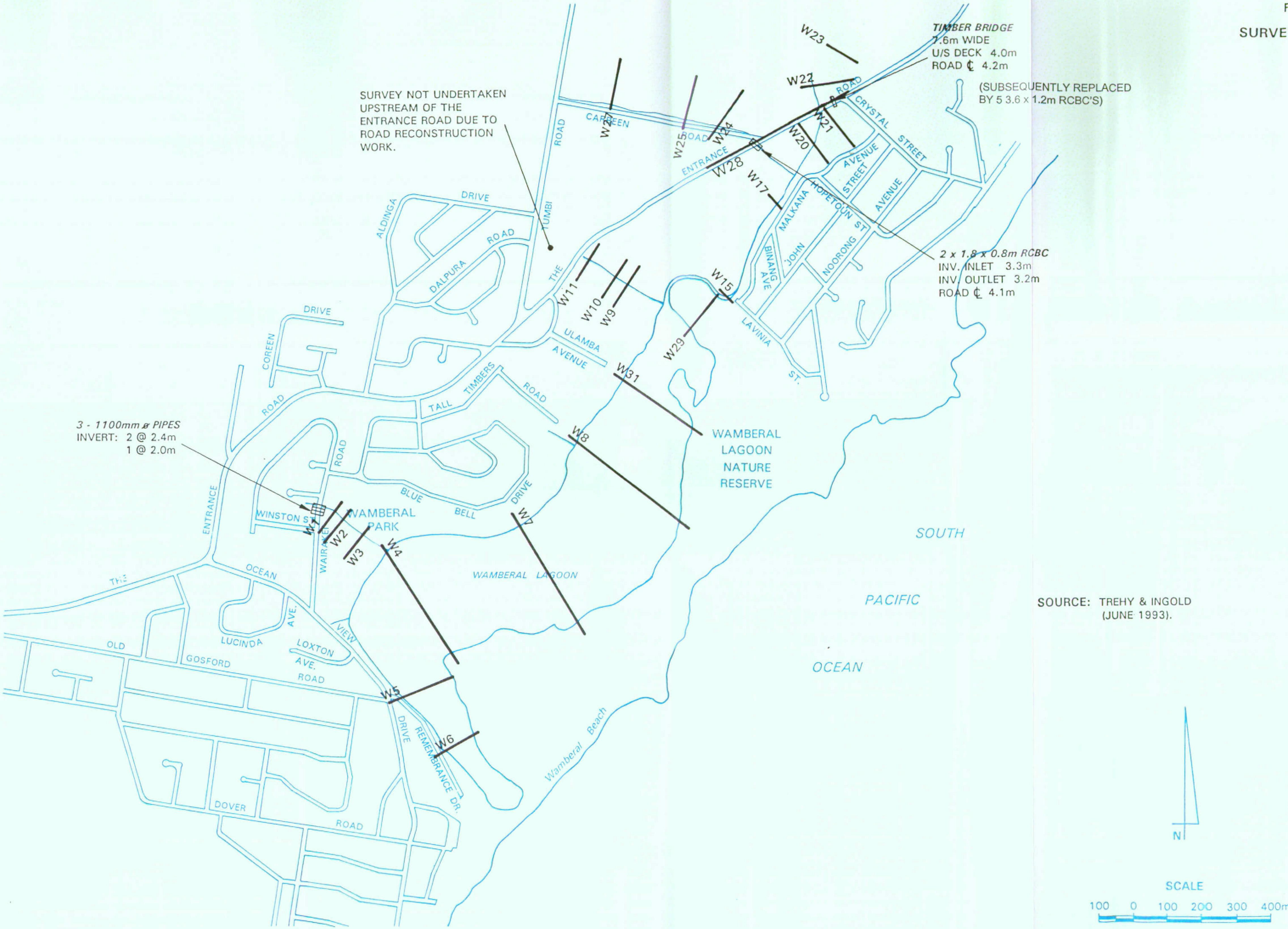


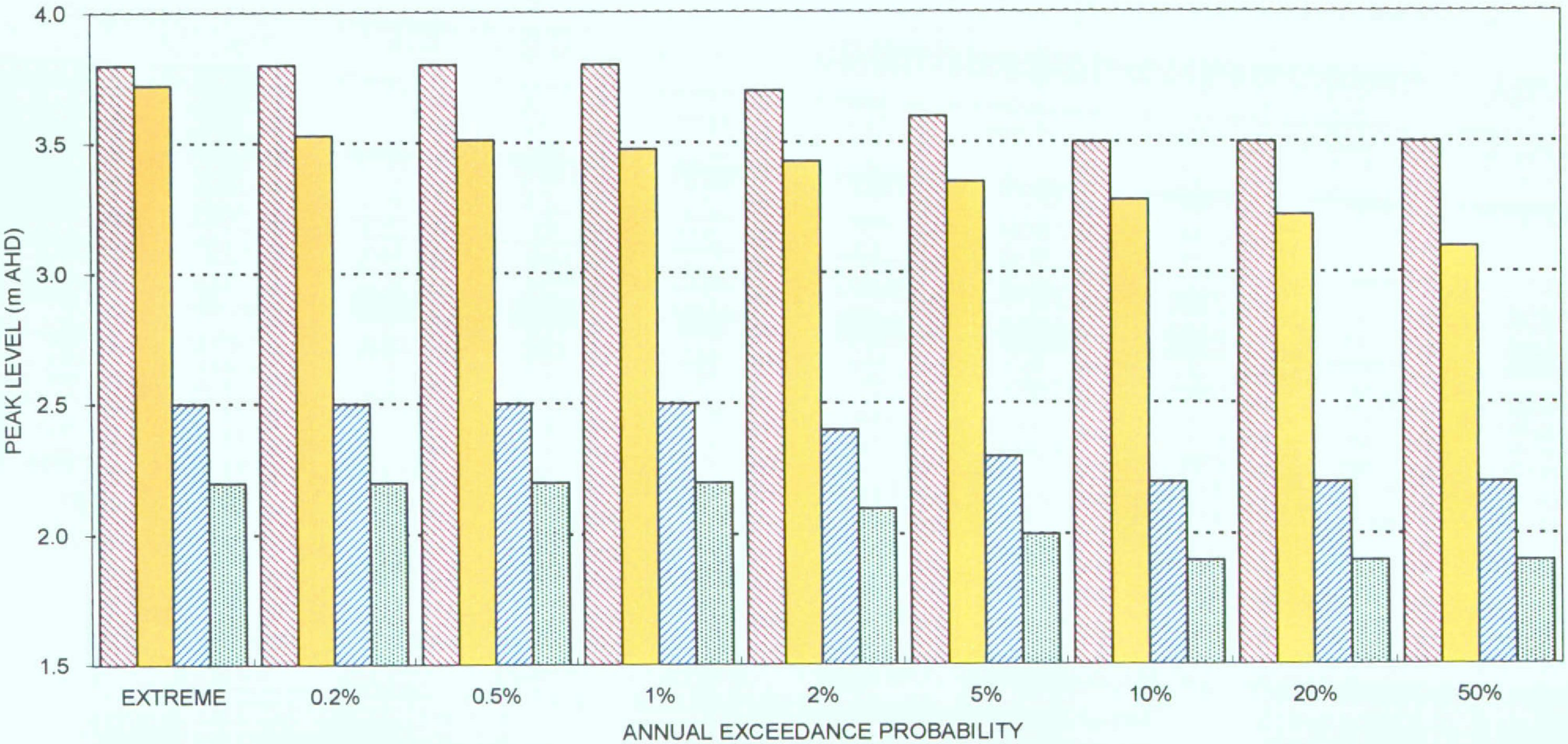
FIGURE 4

SURVEY DATA



WAMBERAL LAGOON
DESIGN FLOODS

ADOPTED CONDITIONS
BERM HEIGHT 3.0m
PEAK TIDE 2.2m - 1% FLOOD
LAGOON STARTING LEVEL 2.4m



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 Wamberal Lagoon the 1% AEP level will be reduced from 3.5m AHD to 3.1m AHD.

For further details refer to Sections 2.3.4, 3.5.2 and 6.3.1 from the Wamberal Lagoon Flood Study

FIGURE 5

PEAK LAGOON LEVELS
DESIGN FLOODS

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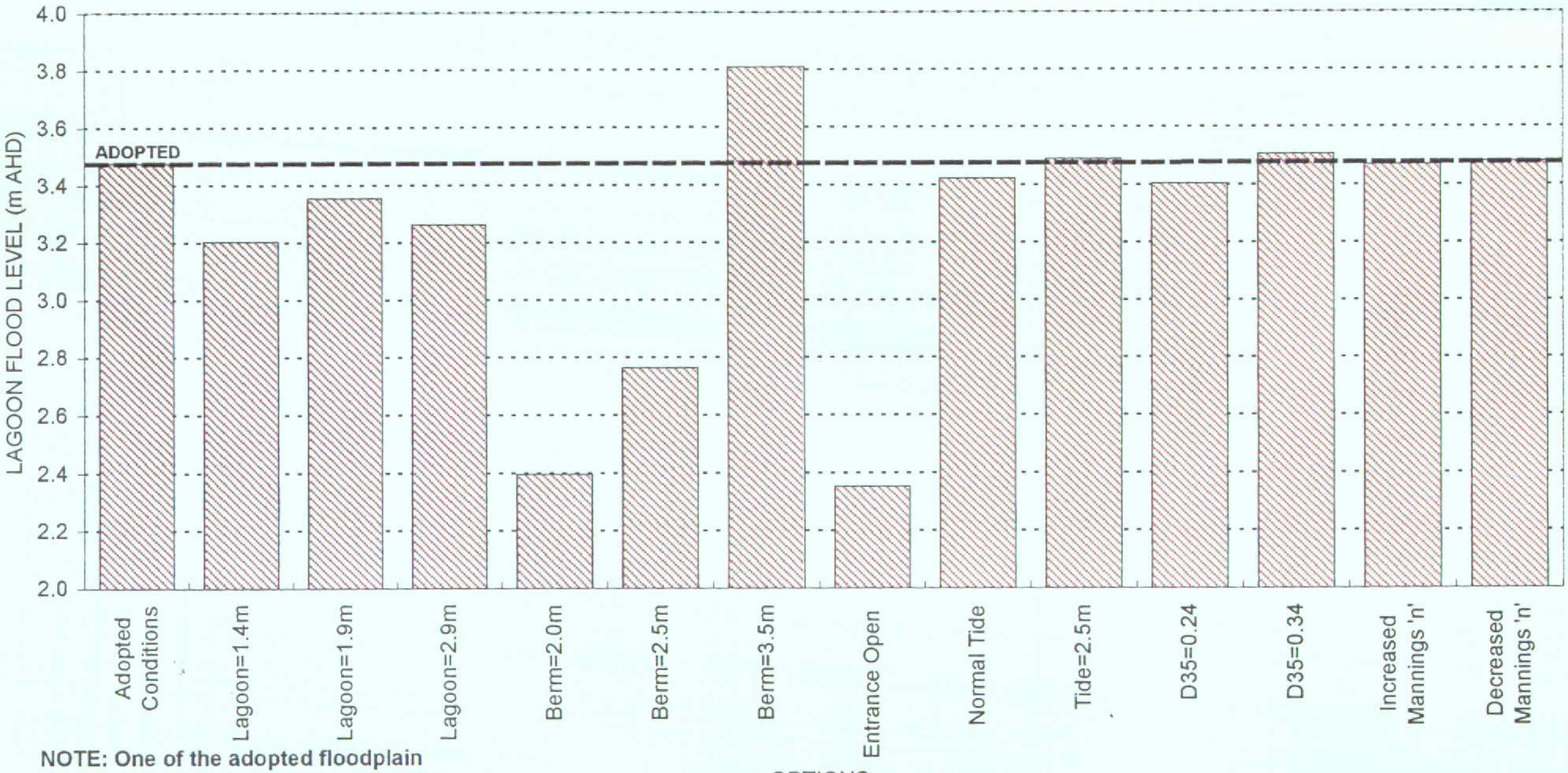
WAMBERAL LAGOON

SENSITIVITY ANALYSES 1% FLOOD



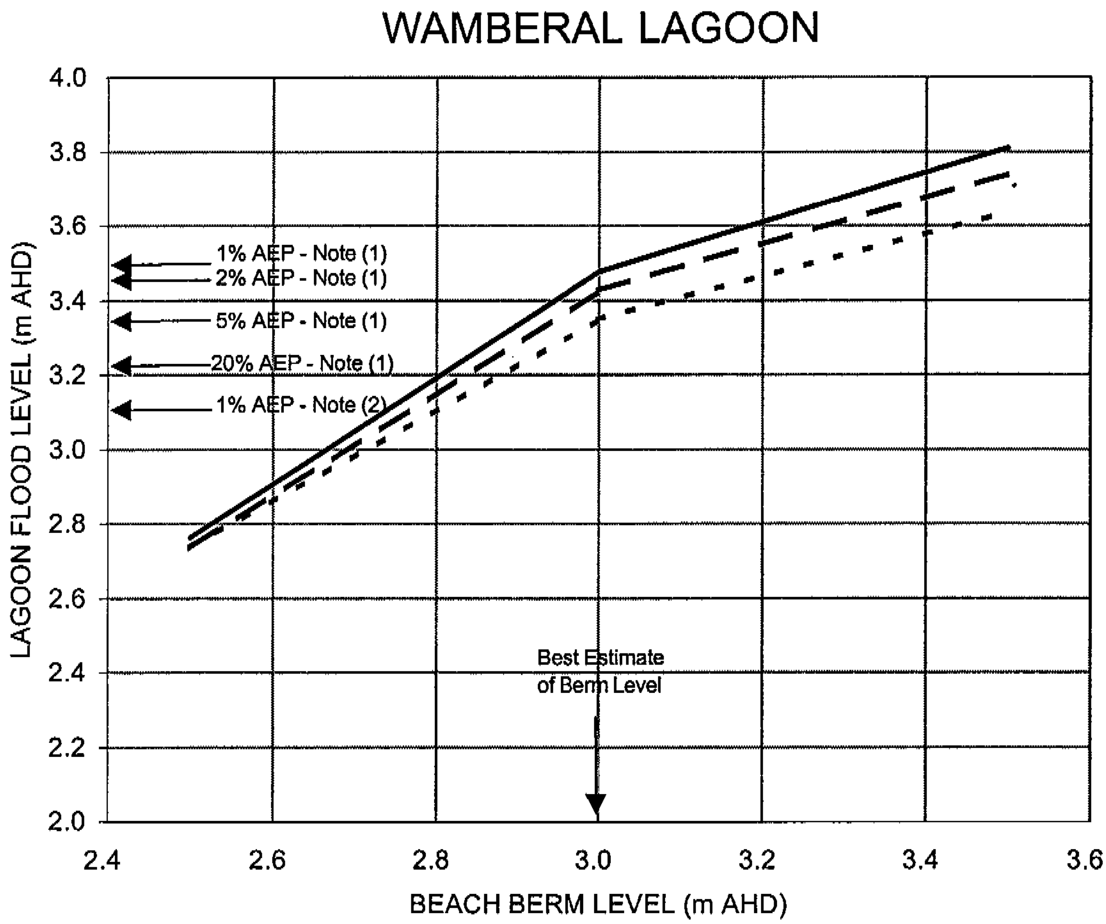
NOTE: One of the adopted floodplain management measures is for Council to maintain the entrance berm. Consequently the resulting design flood levels will be lower than indicated on this Figure. For Wamberal Lagoon the 1% AEP level will be reduced from 3.5m AHD to 3.1m AHD.

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

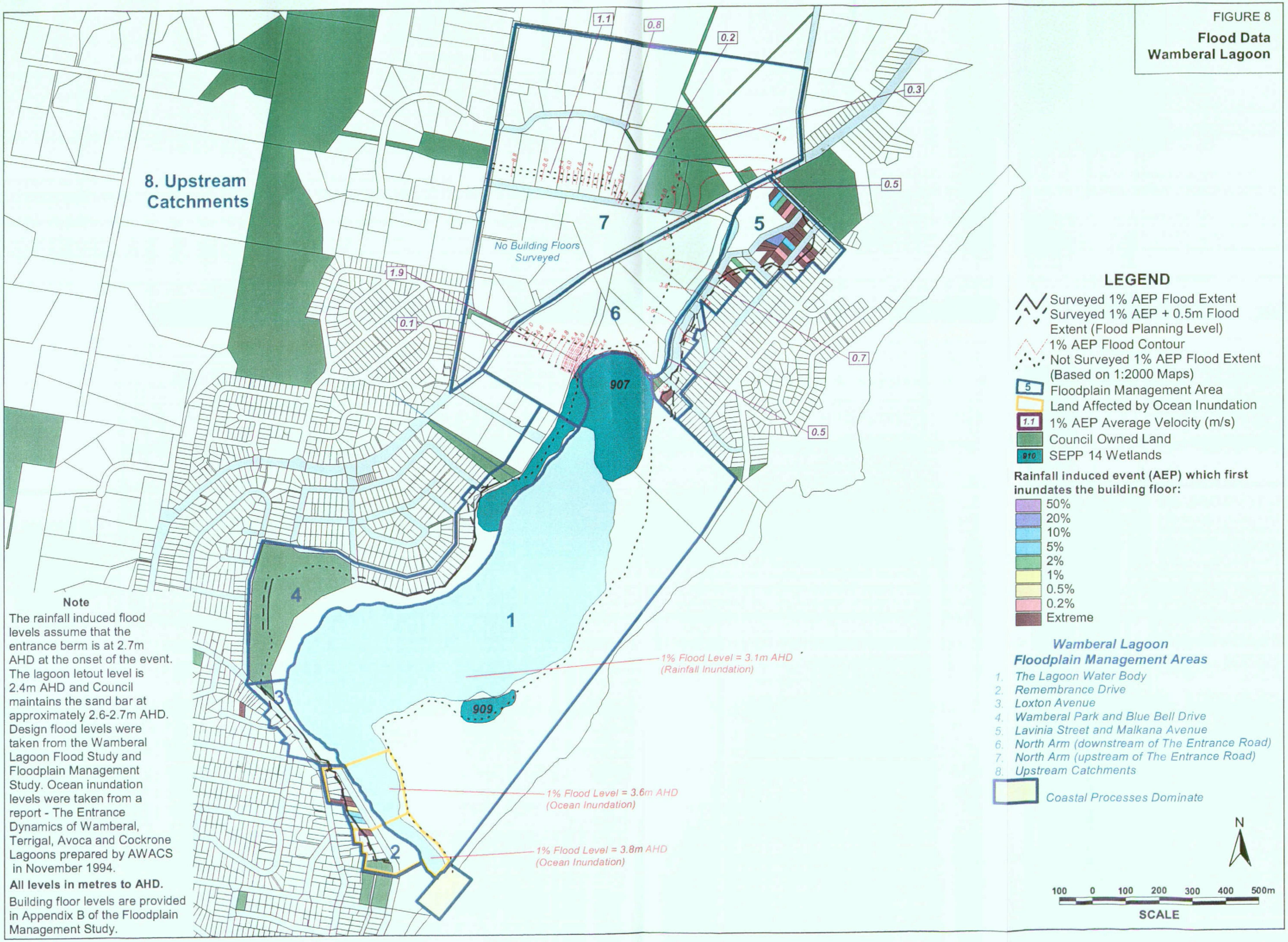
(2) Flood height detemined prior to the present Flood Study

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 Wamberal Lagoon the 1% AEP level will be reduced from 3.5m AHD to 3.1m AHD.

FIGURE 8

Flood Data Wamberal Lagoon



Note

The rainfall induced flood levels assume that the entrance berm is at 2.7m AHD at the onset of the event. The lagoon letout level is 2.4m AHD and Council maintains the sand bar at approximately 2.6-2.7m AHD. Design flood levels were taken from the Wamberal 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.*

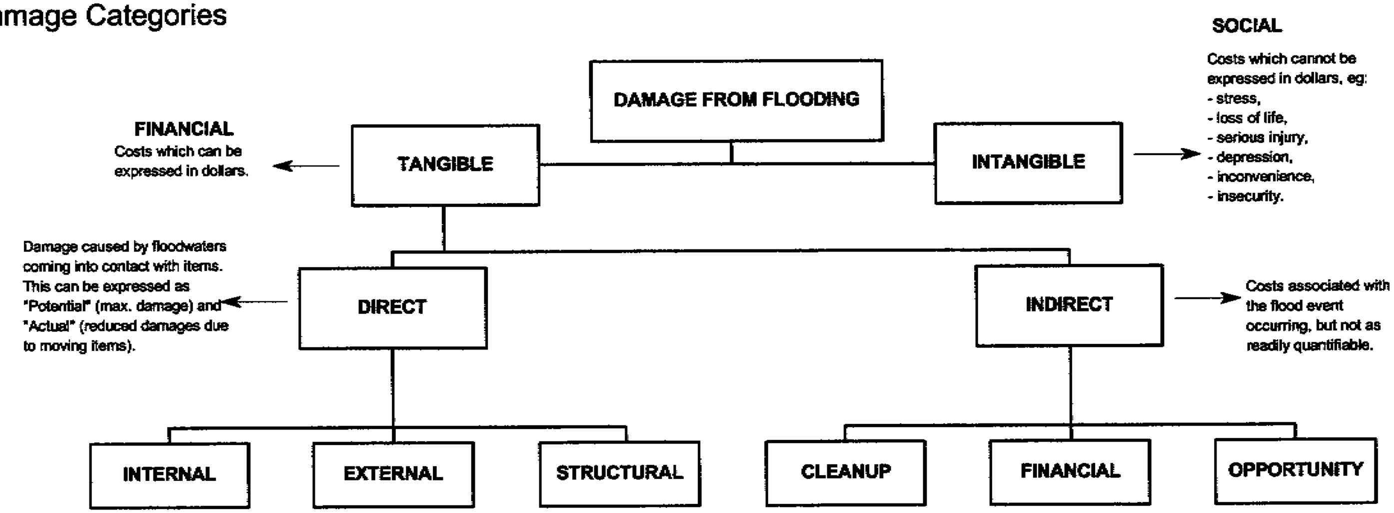
The direct damages under these categories can be grouped under the following headings:

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

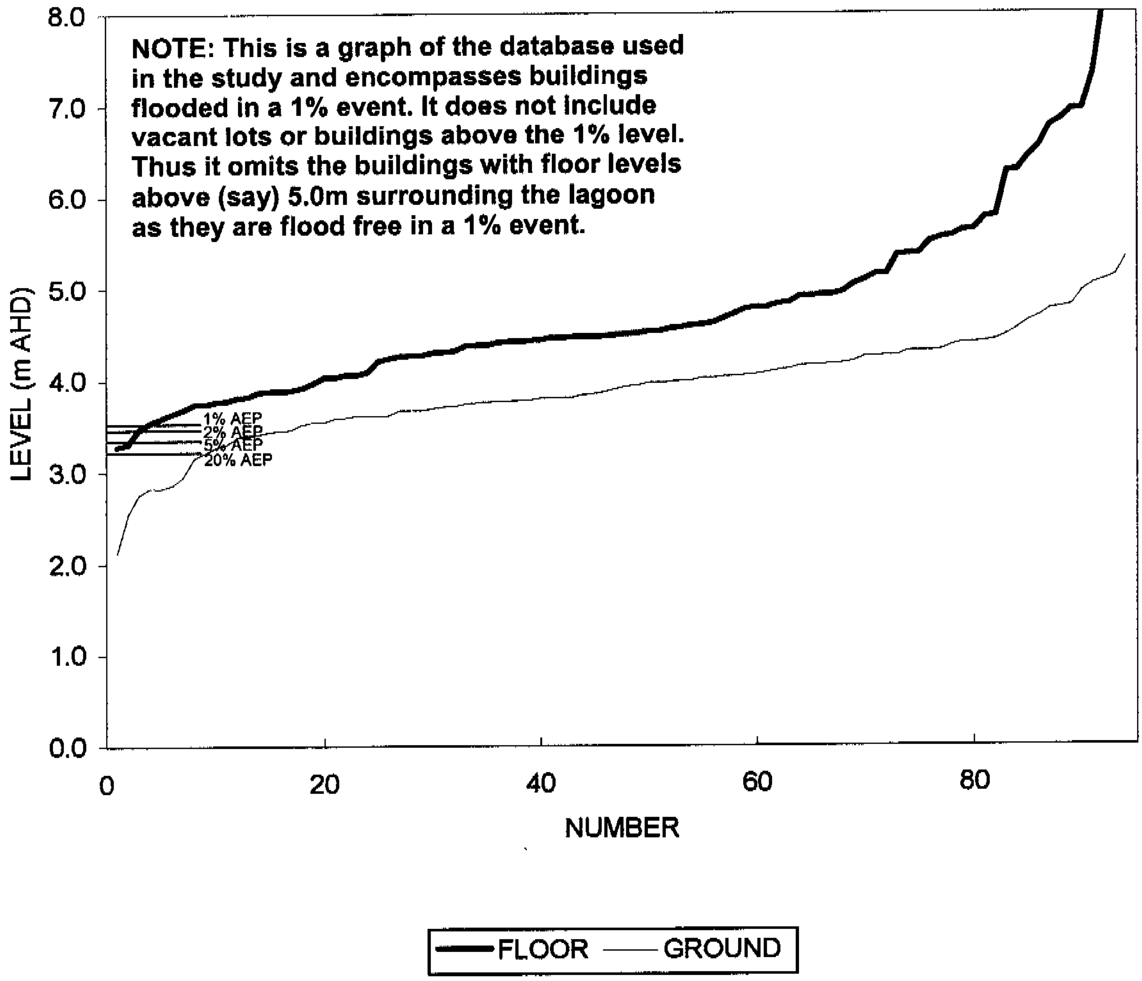
Tag	FPM Area	Number	Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
191827	2	3	Remembrance Drive	5.57	4.63	-	
191828	2	5	Remembrance Drive	4.91	3.97	-	
191829	2	7	Remembrance Drive	5.38	3.94	-	
191842	2	9	Remembrance Drive	3.64	2.76	Extreme	
191844	2	11	Remembrance Drive	99.00	2.12	-	
191846	2	13	Remembrance Drive	3.31	2.95	5% AEP	brick 2 storey
191847	2	15	Remembrance Drive	3.28	2.54	5% AEP	yes
191854	2	17	Remembrance Drive	3.47	2.83	1% AEP	yes
191525	2	19	Remembrance Drive	3.54	2.83	Extreme	
191841	2	21	Remembrance Drive	3.59	2.86	Extreme	
191520	2	23	Remembrance Drive	3.92	3.58	-	
191522	2	25	Remembrance Drive	99.00	3.71	-	
191495	2	27	Remembrance Drive	6.95	3.15	-	
191496	2	29	Remembrance Drive	4.30	3.61	-	
192885	3	5	Loxton Avenue	4.06	4.03	-	
192945	3	7	Loxton Avenue	3.87	3.80	-	
192877	3	9	Loxton Avenue	3.68	3.61	Extreme	
192876	3	11	Loxton Avenue	3.74	3.74	-	
192841	3	13	Loxton Avenue	4.09	3.87	-	
192872	3	15	Loxton Avenue	4.27	4.02	-	
consolidated	3	146	Ocean View Drive	8.14	6.09	-	
192952	3	148	Ocean View Drive	5.37	4.78	-	
192888	3	150	Ocean View Drive	4.21	3.99	-	
192895	3	152	Ocean View Drive	4.43	3.80	-	
192894	3	154	Ocean View Drive	4.03	3.59	-	
192896	3	156	Ocean View Drive	3.74	3.67	-	
192897	3	158	Ocean View Drive	99.00	3.75	-	
192871	3	164	Ocean View Drive	4.32	4.17	-	
229415	3	166	Ocean View Drive	4.46	4.31	-	
192875	3	168	Ocean View Drive	4.79	4.68	-	
192873	3	170	Ocean View Drive	5.51	5.51	-	
192946	3	160/162	Ocean View Drive	3.78	3.78	-	
193916	4	74	Blue Bell Drive	6.26	5.35	-	
193915	4	76	Blue Bell Drive	4.42	3.38	-	
193891	4	78	Blue Bell Drive	4.26	3.90	-	
193892	4	80	Blue Bell Drive	8.21	8.12	-	
193980	4	124	Blue Bell Drive	4.27	4.08	-	
193981	4	126	Blue Bell Drive	3.77	3.77	-	
193976	4	128	Blue Bell Drive	4.24	4.16	-	
194111	4	47	Tall Timbers Road	5.55	4.76	-	
194083	4	49	Tall Timbers Road	99.00	3.54	-	
194085	4	51	Tall Timbers Road	3.81	3.45	-	
194883	5	1	Crystal Street	4.77	3.97	Extreme	
194866	5	3	Crystal Street	3.88	3.46	10% AEP	yes small
194881	5	5	Crystal Street	4.06	3.99	2% AEP	no single brick
194882	5	7	Crystal Street	4.57	3.98	Extreme	
Tag	FPM Area	Number	Street	Floor Level	Ground Level	Flood first inundates floor	Raisable
194867	5	9	Crystal Street	4.38	3.93	0.2% AEP	
194868	5	11	Crystal Street	4.42	4.02	Extreme	
194859	5	13	Crystal Street	4.56	4.40	Extreme	
194690	5	1	Hopetoun Street	6.84	3.84	-	

194778	5	3	Hopetoun Street	5.63	5.08	-	
194686	5	1A	Hopetoun Street	4.79	3.77	Extreme	
194435	5	4	John Street	4.84	4.48	-	
194585	5	6	John Street	5.04	5.04	-	
194584	5	8	John Street	9.71	7.00	-	
194777	5	48	John Street	4.72	4.16	Extreme	
194877	5	50	John Street	4.31	3.78	0.2% AEP	
194874	5	52	John Street	4.48	3.71	Extreme	
194705	5	53	John Street	5.36	4.96	-	
194873	5	54	John Street	3.89	3.67	10% AEP	no single brick
194742	5	55	John Street	4.96	4.43	-	
194857	5	56	John Street	4.50	4.12	Extreme	
194743	5	57	John Street	99.00	4.32	-	
194895	5	58	John Street	4.49	3.67	Extreme	
194706	5	59	John Street	4.47	4.10	Extreme	
194876	5	60	John Street	4.53	4.03	Extreme	
194746	5	61	John Street	4.37	4.15	0.2% AEP	
194875	5	62	John Street	4.93	4.31	-	
194862	5	63	John Street	4.59	4.25	Extreme	
194861	5	65	John Street	4.53	4.31	Extreme	
194880	5	67	John Street	5.09	4.18	-	
194860	5	69	John Street	99.00	4.26	-	
194878	5	71	John Street	7.34	4.40	-	
not found	5	21	Lavinia Street	4.51	4.26	-	
194439	5	34	Lavinia Street	4.67	4.20	-	
194438	5	36	Lavinia Street	3.88	3.40	Extreme	
194451	5	38	Lavinia Street	4.03	3.30	-	
194440	5	1	Malkana Avenue	4.83	4.25	-	
194558	5	2	Malkana Avenue	4.38	3.54	-	
194449	5	3	Malkana Avenue	4.60	4.05	-	
194557	5	4	Malkana Avenue	99.00	99.00	-	
194671	5	5	Malkana Avenue	4.93	3.81	-	
194670	5	7	Malkana Avenue	4.91	4.55	-	
194659	5	9	Malkana Avenue	6.77	3.85	-	
194665	5	11	Malkana Avenue	5.15	4.41	-	
194669	5	13	Malkana Avenue	6.96	5.43	-	
194668	5	15	Malkana Avenue	5.79	5.32	-	
194667	5	17	Malkana Avenue	5.64	5.43	-	
194664	5	19	Malkana Avenue	6.43	5.13	-	
194663	5	21	Malkana Avenue	6.54	4.80	-	
194684	5	23	Malkana Avenue	5.77	4.37	-	
194683	5	25	Malkana Avenue	5.15	4.06	-	
194682	5	27	Malkana Avenue	4.41	3.81	Extreme	
194688	5	29	Malkana Avenue	4.44	3.76	Extreme	
194780	5	31	Malkana Avenue	99.00	3.44	-	
Tag	**FPM Area**	**Number**	**Street**	**Floor Level**	**Ground Level**	**Flood first inundates floor**	**Raisable**
194775	5	33	Malkana Avenue	3.97	3.52	2% AEP	no single brick
194689	5	37	Malkana Avenue	6.28	3.61	-	
194871	5	41	Malkana Avenue	3.82	3.41	20% AEP	no single brick
194858	5	43	Malkana Avenue	4.62	3.61	Extreme	
consolidated	5	45	Malkana Avenue	4.47	3.69	Extreme	
194685	5	39A	Malkana Avenue	4.46	3.27	Extreme	
194870	5	39B	Malkana Avenue	4.47	3.21	Extreme	

FIGURE B1

BUILDING FLOOR AND GROUND LEVELS

WAMBERAL LAGOON
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 Wamberal Lagoon the 1% AEP level will be reduced from 3.5m AHD to 3.1m AHD.

End of Report