GOSFORD CITY COUNCIL

COCKRONE LAGOON
FLOODPLAIN MANAGEMENT STUDY

FINAL REPORT

May 2008

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POLICY BACKGROUND

NSW Government Policy

The New South Wales Government's Flood Policy (Reference 1) is directed at providing solutions to existing flooding problems in developed areas as well as ensuring that new development is compatible with the flood hazard and that it does not create additional flooding problems in other areas.

Under the policy, the management of flood-prone land remains the responsibility of local government. The state government subsidises flood mitigation works to alleviate existing problems, providing specialist technical advice to assist councils in the discharge of their floodplain management responsibilities.

The flood policy provides for technical and financial support by the government through the following four sequential stages:

* *Stage 1 - Flood study:*

  Determines the nature and extent of the flood problem.

* *Stage 2 - Floodplain management study:*

  Evaluates management options for the floodplain in respect of both existing and proposed development.

* *Stage 3 - Floodplain management plan:*

  Involves formal adoption by council of a plan of management for the floodplain.

* *Stage 4 - Implementation of the plan:*

  Involves construction of flood mitigation works to protect existing development and includes use of local environmental plans to ensure new development is compatible with the flood hazard.

The Cockrone Lagoon Floodplain Management Study constitutes completion of the second stage of the management process for Cockrone Lagoon and its associated catchment and has been prepared for Gosford City Council to determine an appropriate floodplain risk management strategy.

Gosford City Council's Approach

Cockrone Lagoon is one of the four major coastal lagoons in the Local Government area. The others are Wamberal, Terrigal, and Avoca. All the lagoons face similar issues and are affected by:

- NSW Government Floodplain Management Policy;
- NSW Rivers and Estuaries Policy;
- NSW Coastal Policy.

The coastal, estuarine and floodplain management issues overlap to varying degrees in each lagoon.

Council established a Coastal Lagoons and Coastal Planning Committee, which concurrently undertook:

- floodplain management studies for Wamberal, Terrigal, Avoca and Cockrone Lagoons;
- estuarine and water quality investigations of the four lagoons;
- coastline management investigations for the coastline and beaches on the seaward sides of the four lagoons.

Council adopted:

- a Coastline Management Plan in 1995;
- a policy for opening of the various lagoons in 1999 (reviewed March 2005).

The work on the Cockrone Flood Study, Floodplain Management Study and Plan were essentially completed over the period 1993 to 1995. However, their publication was delayed until similar projects at Terrigal and Wamberal were completed and the Coastline Management Plan was in place.

Publication Structure

The Floodplain Management Process comprises three stages (viz: Flood Study, Floodplain Management Study, Floodplain Management Plan). Each stage provides data for the Floodplain Management Plan. The most likely users of the reports on each stage are seen as differing. For example, the Plan will be of principal interest to Councillors, individual property owners and developers, while the Flood Study will be of principal interest to hydrologists, riverine and coastal engineers as providing the technical background to the Plan.

Accordingly, the Flood Study, Floodplain Management Study and Plan have been produced as three separate documents with the object of making the Plan as simple to use as possible.

The three stages of the floodplain management process have been completed (to “draft” stage) over a number of years as follows:

- Cockrone Lagoon Flood Study (1994 and 2003);
- Cockrone Lagoon Floodplain Management Study (1995 and 2003);
- Cockrone Lagoon Floodplain Management Plan (1996 to 2007).

Thus, the monetary sums quoted in each report represent the Australian dollar values at the time of preparation of the report.

SUMMARY

This floodplain management study has been prepared by Paterson Consultants and follows on from the Cockrone Lagoon Flood Study which was also carried out by Paterson Consultants.

The management study draws on the results of the flood study and uses this information, together with additional data collected for the management study to assess feasible floodplain management options for Cockrone Lagoon foreshore area and floodplain within the study area.

Preferred management options have been recommended based on a comparative evaluation of each option and a range of relevant criteria. These evaluation criteria include indicators of flood mitigation performance, economic considerations, environmental impacts and social issues.

Three distinct modes of flooding occur in the study area:

- inundation by ocean storm waves near the lagoon entrance;
- inundation by floodwaters ponded in the lagoon around the lagoon foreshores; and
- inundation by local runoff on the floodplain upstream of the lagoon and adjacent to drainage flowpaths.

Ocean inundation levels adjacent to the lagoon entrance are higher than the equivalent lagoon flood levels. Thus management of the entrance area is considered to be a coastal management issue and is not related to lagoon flood management.

The catchment of Cockrone Lagoon is some 7.1 square kilometres. Ninety percent of the catchment is natural bushland or under rural development. Urban development is essentially confined to a strip within 500 metres of the beach front to the Pacific Ocean.

Flooding in the tributary creeks to Cockrone Lagoon occurs from short duration, intense storms (durations of 3 hours or less) while the lagoon itself floods in longer duration events (durations in the order of 12 hours). The magnitude of flood water level rises in the lagoon is determined by conditions at the beach front.

Design one percent AEP flood levels within Cockrone Lagoon are of the order of RL 4.1 m AHD for a beach berm level of RL 3.8 m AHD. The berm level is some 0.5 metres above the average berm level deduced from Council records available since 1972 and represents some 10 percent of the time.

Ocean wave levels at the lagoon entrance have been assessed to reach RL 4.0 m AHD at one percent AEP. At the upstream end of the study area, design one percent AEP levels reach RL 4.82 m AHD.

Six flooding precincts have been identified around the lagoon foreshore.

These precincts have been classified for flood hazard as:

High Hazard - Floodways

- Cockrone Lagoon at its entrance to the ocean;

- Cockrone Gully, from the upstream study boundary to its confluence with Cockrone Lagoon; and

- an existing open drain through the residential areas bounded by Newell Road and Three Points Avenue.

Low Hazard - Floodway

- an overland flow path from the existing open drain between Newell Road and Three Points Avenue towards Three Points Avenue.

Low Hazard - Flood Storage

- Cockrone Lagoon and foreshores excepting high hazard areas above.

Council has adopted a policy of opening the lagoons when water level reaches RL 2.53 m AHD (identified as the let-out-level). Council has also adopted a policy that requires new buildings to have floor levels above RL 4.3 m AHD. These two policies effectively constitute Council's current floodplain management practice around Cockrone Lagoon. The adopted minimum floor level (RL 4.3 m AHD) provides only 21 centimetres clearance above the estimated one percent AEP design flood level for Cockrone Lagoon.

Cockrone Lagoon is a significant landscape and recreational resource in the Gosford area.

The foreshore vegetation generally consists of Melaleuca fringes with pockets of mature eucalypts. A significant rainforest area existing along Merchants Creek, a northern tributary to Cockrone Lagoon.

Land use around Cockrone Lagoon is essentially Residential 2(a) zoning near the beachfront with Open Space 6(a) and Conservation 7(a) zoning west of the residential area. Virtually all the western foreshore of Cockrone Lagoon is a designated wetland area under SEPP 14.

Future development potential with the current zonings is essentially limited to re-development of existing building with the existing subdivisions.

Flood-liable buildings within the study area have been identified by ground survey. There are nineteen (19) residences with floor levels below the design one percent AEP flood levels. Nearly two thirds of the flood-liable properties are at risk from ocean storm wave action which poses a greater risk to life and property.

Potential flood damages were estimated using the ANUFLOOD model (in 2003 dollars) as:

-	residential	- mean annual direct damage	$106,580
		- mean annual indirect damage	$15,980
-	commercial	- mean annual damage	Zero
-	public utilities		$95,080

Total mean annual damage is thus $217,640.

There are several practical floodplain management options, identified as:

- lagoon entrance management;
- levees;
- planning controls;
- floodproofing of buildings;
- voluntary acquisition; and
- flood warning and public education.

Each of the above options has been examined on the basis of:

- reduction in flood damages (that is benefits);
- environment effects (in broad scale);
- social impacts (as an overview); and
- economic analysis (principally benefit/cost ratio).

The capital costs for the six options above vary between zero and $5,112,000. The best benefit/cost ratio occurs for lagoon entrance management (15.5) while the worst benefit/cost ratio is voluntary acquisition (0.18).

The six floodplain management options have been compared employing a matrix approach using 19 criteria. The comparison shows levee construction to have a high cost and high reduction in flood damage but with adverse environmental impacts.

Lagoon entrance management and improved flood warning achieve reduction in flood damages of 20 and 6 percent respectively with virtually no environmental impacts and perceived high social acceptance.

The preferred floodplain management strategy involves:

Existing Development

- management of the beach berm level to maintain the berm below RL 3.3 m AHD;

- use of the telemetric recording of the lagoon water level to allow a faster response to rising water levels in the lagoon to create a faster let-out process.

- Construction of a small levee to prevent spillage from the open drain between Newell Road and Three Points Avenue

Future Development

- maintenance of minimum floor level controls for new development (and/or redevelopment) through the lagoon area for those areas identified as Flood Storage-Low Hazard;

- maintenance of building controls on minimum floor levels, maximum allowable increases in flood levels and general development controls on areas identified as Floodway-High Hazard.

1. INTRODUCTION

The New South Wales Floodplain Management Manual (Ref. 1) has been prepared to assist councils in the development of management plans for flood-liable lands. The principal objective of the floodplain management process is to reduce the impact of flooding and flood liability on individual owners and occupiers and to reduce private and public losses resulting from floods.

The floodplain management process comprises the following activities, as shown on Figure 1.1 which is derived from the Manual.

1. Establishment of a Floodplain Management Committee;
2. Development and implementation of an Interim Local Policy;
3. Completion of a Flood Study;
4. Selection of an appropriate Flood Standard;
5. Preparation of a Floodplain Management Study;
6. Adoption of a Floodplain Management Plan; and
7. Implementation of the Floodplain Management Plan.

The Cockrone Lagoon Floodplain Management Study has been prepared by Paterson Consultants Pty Limited on behalf of Gosford City Council as part of the floodplain management process for Cockrone Lagoon and other coastal lagoons within Gosford.

The floodplain management study follows on from the Cockrone Lagoon Flood Study (Ref. 2) which was also prepared by Paterson Consultants with additional modelling of ocean flooding by Australian Water and Coastal Services (AWACS).

Gosford Council has adopted the one percent Annual Exceedence Probability (AEP) design flood as the Flood Standard for floodplain management. The Flood Policy stipulates a minimum floor level of RL 4.3 m AHD, in accordance with the preliminary estimate of the one percent AEP flood level in Cockrone Lagoon.

Flooding of Cockrone Lagoon can result from runoff from the lagoon catchment, ocean inundation, or a combination of both. In order to limit the flooding of properties adjacent to the lagoon, Council has adopted a let-out-level of RL 2.53 m AHD for Cockrone Lagoon. The lagoon entrance is opened when the water level in the lagoon rises to let-out-level.

The adoption of the let-out-level and the resultant practice of opening the lagoon entrance together with the minimum floor level requirements constitute the existing floodplain management for Cockrone Lagoon.

Ecologically sustainable development (ESD) principles are now embodied through government policy (in particular the Environment, Planning and Assessment Act, Regulations 1994).

The floodplain management process seeks to satisfy ESD principles of:

* Intergenerational equity, that is the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;

* Conservation of biological diversity and ecological integrity;

* Active and meaningful community participation in identifying issues, responses and strategies and decision making;

* Precautionary principle in that lack of scientific certainty is not a reason for the lack of amelioration measures to prevent environmental degradation where a threat of serious or irreversible environmental damage exists; and

* Inclusion of valuations of environmental costs of activities and the costs of changes to biodiversity, ecological and cultural values.

Thus, the floodplain management process seeks to promote the adoption of an integrated approach to the management of all lands within the Cockrone Lagoon catchment.

This floodplain management study addresses the following issues:

- existing flood behaviour;
- environmental and planning considerations;
- future development;
- climatic change;
- flood damages;
- floodplain management options;
- floodplain management impacts;
- floodplain management economics;
- preferred floodplain management strategies.

The extent of lands included in the floodplain management study is shown on Figure 1.2.

2. EXISTING FLOOD BEHAVIOUR

2.1 Introduction

Cockrone Lagoon is the third largest of the four coastal lagoons within Gosford Council's administration area. The lagoon has a surface area of 43 hectares and a storage volume at let-out-level of RL 2.53 m AHD of 630 ML, yielding an average depth of approximately 1.5 metres. The lagoon entrance is normally closed due to the action of coastal dynamic processes, thus forming the lagoon which is perched approximately 2.5 metres above mean sea level.

The main body of the lagoon is located some 600 metres behind MacMasters Beach with a relatively confined entrance channel some 100 to 200 metres wide.

The eastern (seaward) half of the lagoon foreshore and adjacent areas have been extensively developed for residential purposes. The initial development comprised mainly holiday cottages. However, recent development has been primarily for permanent residences.

Gosford City Council has records of openings of the coastal lagoons, including Cockrone Lagoon commencing in 1972. These records show that the entrance has been opened 60 times since 1976 for flood control purposes. Openings have chiefly been for flood control purposes, with some natural break-outs. The entrance has also been opened by unauthorised persons when the lagoon level was close to let-out-level.

The records also contain limited information on inundation of Cockrone Lagoon by ocean storms. Major storms are recorded in May 1974, June 1978, July 1983 and August 1986.

The available flood information obtained from Council records, Department of Land and Water Conservation (DLWC) records and resident interview is summarised in Table 1 below and on Figure 2.1.

TABLE 1

Summary of Available Flood Level Data For Cockrone Lagoon

Flood Date	Flood Level (m AHD)	Location	Point*	Source
May 1974	3.15	49 Lakeside Drive	1	Resident
April 1988	3.45 (Peak)	622 Scenic Road	2	Resident
February 1990	1.85 (1735 Hrs on 2/2/90)	Gauge #		Council Records
	3.05 (Open) (0155 Hrs on 3/2/90)	Gauge Beach = 3.2	3	Council Records
	2.92 (Peak)	35 Lakeside Drive	4	Resident
	3.82 (Peak)	622 Scenic Road	2	Resident
June 1991	3.11 (Open) (1715 Hrs on 11/6/91)	Gauge Beach = 3.11		Council Records
February 1992	2.98	3 Lakeside Drive	5	Resident Peak
	2.90 (Open) (2345 Hrs)	Gauge Beach = 3.35	4	Council File 0650/9.2

Notes: * Refer to Figure 2.1 for locations.
"Gauge" refers to Gosford City Council gauge off Del Monte Place which is used to "trigger" mechanically assisted break-outs.
(Open) Refers to level and time at the initiation of opening.

A number of debris levels were surveyed following the severe ocean storm which occurred in July 1983. This data is presented in subsequent sections.

2.2 Previous Studies

The recently completed Cockrone Lagoon Flood Study details the investigations carried out to determine design flood levels for Cockrone Lagoon and the adjacent floodplain. Hydrologic and hydraulic models were established and jointly calibrated using available rainfall and flood level data for three flood events. The calibrated models were then used with design rainfall data to determine design flood levels for Cockrone Lagoon and the adjacent floodplain.

The Addendum No. 1 to the Flood Study presents a more detailed analysis of the existing open drain between Newell Road and Three Points Avenue. The Addendum indicates that spillage from the drain will occur in the design one percent AEP event, however this can be rectified by construction of a small earth levee.

This floodplain management study draws on the results obtained in the Flood Study.

The investigation of ocean dynamic processes and overtopping of the beach berm by ocean storm induced wave action were carried out by Geomarine P/L and are described in the report "Avoca Lake and Cockrone Lake - Coastal Engineering Advice for Flood Studies" (Ref. 3). This report was prepared as a working paper for the Flood Study.

The ocean dynamic processes were also investigated by AWACS (Ref. 4). The report provides estimates of wave runup levels near the lagoon entrance and estimated peak lagoon flood levels resulting from overtopping of the beach berm by storm induced waves. The results of this study were similar to those obtained by Geomarine.

"A Position Statement of the Coastal Lagoons of Gosford City Council" (Ref. 5) was prepared by Gosford City Council in 1984. This paper discusses Council management of the lagoon entrances and proposes a minimum floor level of RL 4.3 m AHD for the Cockrone Lagoon foreshore.

Data on the environment of Cockrone Lagoon is discussed in the report "Gosford Lagoons Environmental Study" (Ref. 6) prepared by P A Management Consultants in 1975. Prof. Cheng completed an ecological assessment of the coastal lagoons in 1992 (Ref. 7).

2.3 Flood Behaviour

Cockrone Lagoon has a catchment area of 7.1 square kilometres which drains to the Pacific Ocean via the entrance across MacMasters Beach. The lagoon entrance is normally closed as a result of coastal dynamic processes. The upper 60 percent of the catchment drains to the lagoon via Cockrone Gully, while the lower 40 percent of the catchment drains to the lagoon via numerous small creeks. An open drain has been excavated through the residential development between Newell Road and Three Points Avenue on the southern side of the lagoon.

The catchment topography is generally rough, with relatively steep slopes from the ridges down to the lagoon. Natural bushland and rural development cover some 90 percent of the catchment area. Urban development is confined to within 500 metres of the beachfront.

Floods in the tributary creeks draining to the lagoon result from short duration storms, typically less than three hours. The steep terrain results in short catchment response time to rainfall. The short response time, coupled with the confined nature of the creek channels leads to spilling of floodwaters onto the floodplain prior to a significant rise in lagoon water levels.

Flooding around the lagoon foreshores results from rainfall of much longer durations, typically 12 hours or longer. The large surface area of the lagoon requires a considerable volume of runoff to raise the water level. The extent of water level rises in the lagoon is determined by conditions at the entrance.

With the entrance opened, floodwaters are able to discharge quickly with little resultant increase in lagoon water levels. On the other hand, with the entrance closed, floodwaters are ponded in the lagoon until the beach berm is overtopped or the lagoon entrance is artificially opened.

Thus, flood levels on the floodplain upstream of Cockrone Lagoon are primarily dependent on rainfall intensity, while flood levels around the lagoon foreshores are dependent on the amount of rainfall and conditions at the lagoon entrance.

Properties adjacent to the entrance channel may be flooded by ocean storms. This occurred in March 1974 and July 1983 when high seas produced by severe ocean storms overtopped the beach berm and flowed into the lagoon.

The Cockrone Lagoon Flood Study modelled both short and long duration rainfall events for 1, 2 and 20 percent AEP and PMP (Probable Maximum Precipitation). The Flood Study also investigated oceanic inundation of the lagoon as the result of an extreme storm at sea.

The Flood Study found that the critical rainfall duration for lagoon flooding is primarily dependent on the level of the beach berm across the lagoon entrance. The critical rainfall duration is also dependent on the intensity of rainfall, as reflected in the probability of exceedence.

Thus, the critical rainfall duration was found to be 2 hours for the entrance open or the beach berm at below let-out-level. The critical rainfall duration increases with beach berm level to 9 hours at maximum beach berm level.

The intensity of rainfall in the PMP event is so great that the resultant runoff is much larger than the lagoon storage even at highest beach berm level. Thus, the critical rainfall duration for extreme rainfall events is 2 hours.

The one percent AEP design flood levels shown on Figure 2.2 have been determined from modelling results for short and medium duration rainfall events and a beach berm level of RL 3.8 m AHD. This beach berm level is some 500 millimetres above the average recorded beach level and has an estimated probability of exceedence of approximately 10 percent.

The general one percent AEP flood level is RL 4.09 m AHD, only 210 millimetres below Council's current minimum floor level for new buildings.

2.4 Ocean Inundation

Ocean waves may impact on Cockrone Lagoon and the foreshore by overtopping of the beach berm when the entrance is closed or by entering the lagoon through the open entrance.

When the entrance is closed, ocean waves overtopping the beach berm can propagate within the lagoon. These conditions will persist for as long as the ocean waves overtop the beach berm.

The ocean dynamic processes were investigated in the Flood Study to determine:

- the increase in lagoon water level resulting from overtopping of the beach berm by ocean waves; and

- the maximum level reached by wave action in the lagoon entrance.

These analyses were based on data recorded during the ocean storm which occurred in May 1974. This is the most severe ocean storm recorded along the Central New South Wales Coast. The wave height history has an estimated recurrence interval of some 50 years. However, its coincidence with spring lunar tides increases this recurrence interval, when based on water level, to well in excess of 50 years.

Australian Water and Coastal Studies (AWACS) has estimated that the average recurrence interval governing lagoon inundation, inclusive of wave and surge water level conditions, for the May 1974 extreme ocean storm event is approximately 100 years, ie. equivalent to one percent AEP.

The estimated maximum inundation level in the lagoon entrance for this event is RL 4.0 m AHD. This inundation level includes:

- wave setup;
- wave transmission into the lagoon;
- wave runup at the shoreline;
- lagoon storage filling; and
- berm overtopping.

This peak level is applicable to the lagoon entrance area which extends some 400 metres behind the beach. Once the storm waves pass through this section, the waves quickly dissipate in the storage of the lagoon. Thus, the estimated peak flood level in the lagoon caused by inflow from the ocean for this event is RL 2.7 m AHD.

An extensive survey of debris levels along the entrance channel was carried out after the ocean storm which occurred on 9 July 1983. The recorded levels varied from RL 4.08 m AHD 50 metres behind the beach to RL 2.89 m AHD some 350 metres from the entrance. The surveyed flood levels are shown on Figure 2.3.

In the July 1983 storm, the lagoon water level rose to RL 2.56 m AHD. The beach berm level after the storm was RL 2.66 m AHD. The lagoon opening log records that the beach had been built up by the wave action.

Unfortunately, no wave data is available for the 1983 event and there are no reports of significant ocean inflow at the other three coastal lagoons. The AWACS report suggest that it was not a significant storm event. Thus, the ocean inundation level should not be seen as unrealistically high.

2.5 Design Flood Levels

The scenarios that can lead to flooding of the lagoon foreshores and upstream floodplain are:

- short duration rainfall events. These events determine peak flood levels on the floodplain upstream of Cockrone Lagoon;

- medium duration rainfall events with lagoon entrance closed. These events determine peak flood levels in the lagoon in response to the volume of runoff entering the lagoon prior to breakout or opening of the entrance; and

- inundation by ocean storm induced wave action. The impact of ocean storm induced wave action is generally restricted to the lagoon entrance only, the volume of the water entering the lagoon being insufficient to produce a major increase in water level in the lagoon.

The estimated one percent AEP design flood levels for each of the above scenarios is presented in Table 2 below and shown on Figure 2.2.

TABLE 2

One Percent AEP Design Flood Levels
(m AHD)

Event	Upstream Study Extent	Lagoon	Entrance
2 Hour Storm	4.68		
9 Hour Storm	4.82	4.09	4.09
Ocean Storm	2.7	2.7	4.0

2.6 Extent of Flooding

The approximate extent of lands inundated by the appropriate one percent AEP design flood event is also shown on Figure 2.2.

Six specific areas of common flooding and topographical characteristics have been identified. The locations of the each of the following precinct areas are shown on Figure 2.4.

Specific areas or precincts affected are:

1. the northern side of lagoon entrance - comprising eight houses in Del Monte Place which are susceptible to inundation by lagoon floodwaters as well as wave action during severe ocean storms;

2. the northern foreshore of the lagoon - comprising open space and undeveloped rural land;

3. Cockrone Gully floodplain - comprising rural land, opens space and public reserve;

4. the southern foreshore of the lagoon - comprising the bird sanctuary, open space and five houses susceptible to lagoon flooding;

5. properties in Newell Road, Three Points Avenue and Tudibaring Parade backing onto the open drain - unaffected by lagoon flooding but may be affected by local runoff in extreme storms; and

6. southern side of the lagoon entrance - comprising four houses in Lakeside Drive and two houses in Three Points Avenue which are susceptible to lagoon flooding and wave action during severe ocean storms.

2.7 Flood Hazard Assessment

The New South Wales Floodplain Management Manual recognises three categories of flood-liable land:

* *Floodways - those areas where a significant volume of water flows during floods, where flow velocities are generally high and deeper flow may occur.*

* *Flood Storage - those areas of the floodplain which provide temporary storage of floodwaters and flow velocities are generally low.*

* *Flood Fringe - those areas of the floodplain not included in floodways or flood storage areas.*

The Manual also provides for two categories of flood hazard:

* *High Hazard - where floodwaters could cause structural damage to buildings, there could be danger to life and limb and social disruption and financial losses could be high.*

* *Low Hazard - where potential damage and risk to life and limb would be low.*

The flood hazard classification incorporates assessment of the depth and velocity of floodwaters, effective evacuation time and evacuation difficulties. The hazard classification is generally determined by assessment of the hydraulic variables - depth and velocity of floodwaters, as shown on Figure 2.5 which is reproduced from the Manual.

The preliminary hazard classification may be altered following a review of other significant factors including warning times, flood awareness, rate of rise of floodwaters and evacuation problems.

The Flood Study found that the depth of floodwaters in the one percent AEP flood adjacent to the lagoon shoreline and on the floodplain upstream of the lagoon would be generally in the range of 1 to 1.3 metres. The velocity of the floodwaters is generally less than 0.6 metres per second except at flow constrictions such as culverts.

Thus, the study concluded that the floodplain upstream of the lagoon and the lagoon foreshore area would be classified as "High Hazard" due to excessive depth of floodwaters. This classification is based on the assessment of hydraulic parameters only and the use of Figure 2.5.

The critical rainfall duration for flooding of the lagoon foreshore is relatively long (9 hours) due to the storage available in the lagoon. The rate of rise of the lagoon is relatively slow, taking 6 hours to peak.

This relatively drawn out flood period, coupled with the low velocities of floodwaters along the lagoon foreshore area would enable evacuation of persons and belongings from flood affected properties to be carried out with only relatively minor difficulties.

Accordingly, it is considered that the flood-liable lands around the lagoon foreshore can be revised to "Low Hazard".

It is considered that the "High Hazard" classification should be retained for the floodplain upstream of the lagoon due to early flooding of access routes by local runoff.

The Flood Study found that floodwaters in the open drain through the residential area on the southern side of the lagoon entrance would be approximately 1.5 metres deep and have a flow velocity of 1.0 to 1.2 metres per second. It is considered that the "High Hazard" classification is appropriate due to the depth of floodwaters. The open drain is considered to be classified as "floodway" by definition.

Therefore, the open drain and immediately adjacent areas are classified "High Hazard - Floodway" according to the Manual.

The Addendum No. 1 to the Flood Study indicates a break-out from the open drain towards Three Points Avenue. The hydraulic classification for this break-out would be "Low Hazard - Floodway". It is noted that the Addendum No. 1 to the Flood Study proposed a small levee system to prevent break-out. Thus, the area inundated by the break-out would not be flooded in a one percent AEP flood after the levee's construction.

The velocity of floodwaters flowing over the floodplain upstream of the lagoon is generally greater than 0.5 metres per second, while the depth is generally greater than 1.3 metres. Thus, flood-liable land upstream of the lagoon can be considered as being located in a floodway since little attenuation in peak discharge occurs due to storage routing.

On the other hand, flood-liable land around the lagoon foreshores can be considered to be located in flood storage. These areas are used for temporary storage of floodwaters and flow velocities are generally less than 0.1 metres per second.

The areas adjacent to the lagoon entrance are susceptible to inundation by ocean waves. There is generally a prolonged establishment period for ocean storms. However, storm intensity and the resultant wave climate can vary more rapidly. The destructive force of the waves is much greater than that of the rising floodwaters in the lagoon. The areas adjacent to the lagoon entrance present a number of difficulties in flood hazard assessment where the risks associated with ocean events are greater than flood events. The ocean wave height information for waves over the berm (see Cockrone Flood Study, Chapter 5 and

Reference 4) gives indicative wave heights. Land and Environment Court action in 2001 at Avoca Lagoon indicated more investigation is required to provide a more precise indication of extreme wave behaviour.

Therefore, due to the uncertainty associated with ocean storms and the potential for greater damage, it is considered that the "High Hazard" classification should be retained for the lagoon entrance until completion of further investigations.

The concept of floodwaters, flood storage and flood fringe areas is not normally associated with oceanic inundation. Due to high damage potential within areas susceptible to ocean wave action, it is considered that these areas have similar characteristics to floodways. Therefore, the flood-liable areas adjacent to the lagoon entrance can be considered to be located in a floodway. This would be subject to review after completion of more detailed investigations of waves overwashing the berm.

The proposed flood hazard classification for the lagoon foreshores and upstream floodplain is summarised in Table 3 below and presented in Figure 2.6.

TABLE 3

Flood Hazard Classification for Cockrone Lagoon

Location	Precinct Areas*	Hazard Classification
Entrance	1, 6	High Hazard - Floodway/Investigation
Lagoon Foreshores	2, 4	Low Hazard - Flood Storage
Upstream Floodplain	3	High Hazard - Floodway
Open Drain	5	High Hazard - Floodway

Notes: * Refer to Figure 2.4 for precinct locations.

3. ENVIRONMENTAL AND PLANNING CONSIDERATIONS

3.1 Lagoon Environment

Landscape Character

The visual characteristics of the lagoon and foreshore areas within the study area varies. However, in the main, the land around the foreshore is significant as a landscape element and for active or passive recreation. Existing residential development is generally low key and informal creating a pleasant beach-side atmosphere. There is no kerb and guttering through most of the area which adds to the informal streetscape and holiday character. Visually, the streets are unobtrusive and well vegetated.

Housing quality varies considerably ranging from new, substantial homes to older-style cottages.

Along the southern shore there has been some clearing and mowing of the foreshore but over a relatively short length. Similarly, on the northern foreshores selective mowing is carried out. This appears to have been done with some intention of keeping patches of reeds and foreshore vegetation in tact. A low-key walkway runs along the southern edge of the lake.

The *Melaleuca* forest along the southern shores, adjacent to the residential zone, is visually important in reducing the impact of housing. Towards the eastern end of the lake, native vegetation has been quite disturbed. Shores surrounding the western part of the lagoon have been subject to very little disturbance.

Flora and Fauna

Four separate environmental compartments have been identified around Cockrone Lagoon for the purposes of this report. The compartments are identified as:

A. Lagoon Foreshore, Copacabana Drive, Del Monte Place and Merchants Creek;

B. Lagoon Foreshore, Del Monte Drive;

C. Lagoon Foreshore, Southern side; and

D. Public Reserve, adjacent to Bounty Hill/Scenic Road intersection.

These areas are illustrated on Figure 3.1.

In the Copacabana Drive/Del Monte Place/Merchants Creek compartment, the environment comprises Swamp Gully rainforest of Cabbage Palm *Livistone australis, Melaleuca biconvexa*, Swamp Mahogany *Eucalyptus robusta* and Bluegum *E saligna*. The type of forest is particularly rare in the district with other sites only known at Pomona Road, Empire Bay. It is a closed forest comprised of reeds, sedges and rainforest elements in the understorey and, therefore, represents a diverse vegetation unit. In addition to the rainforest, mature habitat trees of Bluegum *E saligna* are present as are trees of Swamp Mahogany *E. robusta*. The Swamp Mahogany is a keystone species in the district and this vegetation unit may hold at least two endangered fauna species. This would require further investigation and would need to be addressed under the considerations of the Endangered Species (Interim Protection) Act Legislation.

In the Del Monte Place compartment, *Melaleuca* fringe forest occurs along the foreshore with pockets of *Phragmites australis*. Although the forest appears extensive, the understorey vegetation is disturbed to some extent. *Melaleuca* forests require inundation from floodwaters to perpetuate.

Along the southern foreshore of the lagoon, the bulk of the flora comprises *Melaleuca* fringe forest with pockets of Swamp Oak *Casuarina glauca* and *Baumea articulata* and *B. juncea* reedlands. Some trees of Swamp Mahogany *E robusta* also occur. Most of the understorey of the *Melaleuca* forest has been cleared for public areas to the foreshore area but some remnant littoral rainforest species do remain. These include Sandpaper Fig *Ficus rubiginosa* and Tuckeroo *Cupaniopsis anarcardiododes*.

In the larger public reserve near the intersection of Bounty Hill Road and Scenic Road, some remnant large mature trees of a mixed forest remain. These trees include Blackbutt *E. pillularis*, Bluegum *E. saligna*, Rough-barked Apples *Angophora floribunda*, Red Mahogany *E resinifera*, Grey Gum *E. punctata* and Grey Ironbark *E. paniculata*. Some understorey vegetation still remains which includes *Gahnia clarkei* and *Callistemon salignus*.

3.2 Landuse and Planning Controls

The existing development surrounding the lagoon is a mixture of older-style holiday cottages, particularly on the southern shores and more recent brick residences. On the southern shore, in MacMasters Beach, many of the older cottages have been renovated. The general character of the area is attractive, low density, residential in an informal setting.

The current landuse zonings at Cockrone Lagoon within the study area are illustrated on Figure 3.2.

The existing dwellings are within the Residential 2(a) zone. This zone permits, among other things, single dwellings. Dual occupancies are not permitted for this area under Council's DCP No. 126.

Other land in the study area is zoned as Public Open Space or Rural uses.

The southern arm of the lake is zoned part Open Space 6(a) and 6(b) and part Residential 2(a).

An extensive area of the foreshore of Cockrone Lagoon is affected under State Environmental Planning Policy No 14-Wetlands.

Gazetted Wetland No. 914 covers the entire western end of the lagoon. The western extremities of the study area encroach into the gazetted wetland along part of Lakeside Drive and adjoining Merchants Park. The gazetted wetlands are shown on Figure 3.1.

3.3 Recreational Values

There is little information on existing or projected recreation demands available for Cockrone Lagoon. Given the nature of Cockrone Lagoon and the similarities with Avoca Lake, the criteria proposed under the Avoca Lake Development Control Plan can be used as a guide.

The Avoca Lake Draft Development Control Plan proposes recreational uses based on the following criteria:

- compatible with the preservation of existing flora and fauna;
- require minimal works and facilities;
- can be enjoyed by participants but do not inconvenience other people;
- will not conflict with the conservation objectives of the plan of management; and
- existing uses that can be managed so their environmental impact is minimal.

From this list provided in the Avoca Lake Development Control Plan, the following uses are deemed to be suitable for Cockrone Lagoon:

- Picnicking;
- fishing;
- water craft;
- swimming;
- photography;
- bird watching; and
- walking, jogging and cycling.

These uses permitted in the Avoca Development Control Plan which are not considered suitable include games (playing fields) and caravaning/camping.

It would thus seem desirable to retain the low-key activities above for recreational interests around the foreshore of Cockrone Lagoon.

3.4 Future Development Potential

There are no known plans to intensify development densities within the study area. Because of the desirability of the foreshore areas, it could be expected that irrespective of any zoning controls, there will be demand to re-develop existing buildings as land values continue to increase and the sites become under-capitalised. There is some evidence of the occurring on various sites around Cockrone Lagoon.

The existence of the SEPP 14 designated wetland and extensive Rural 7(a) zoning is seen as limiting future development to the existing Residential 2(a) zoning.

3.5 Climatic Change

The Greenhouse Effect is the term used to describe a postulated warming of the earth resulting from the accumulation in the atmosphere of certain gases, in particular carbon dioxide produced by the burning of fossil fuel.

The current consensus of scientific opinion is that a global warming of 1.5 to 4.5^0 C could occur over the next 30 to 50 years. Such a global warming could lead to changes in climate, rainfall and ocean levels.

A range of ocean level rise scenarios of between 0.13 and 0.32 metres over the next 50 years have been postulated. An allowance of 0.2 metres for ocean level rises over the next 50 years is seen as a reasonable design assumption.

The effect of a general increase in ocean levels will be to increase the level to which the beach berms will build up and to increase the tailwater control level for runout from the lagoon by an equivalent height.

It is also predicted that the severity of storms will increase, rainfall intensities could increase and there could be a more severe wave climate.

The hydraulic model results for the flood study show that the height of the peak lagoon flood level above the beach berm level decreases with increasing beach berm height. This is due to the increasing storage available within the lagoon as the lagoon water level rises.

The net result of higher ocean levels producing higher beach berms is that flood levels in the lagoon will be increased by a marginally lesser amount than the rise in ocean level produced by the Greenhouse Effect.

Therefore, it is considered appropriate to adopt an allowance of 0.2 metres for the potential rise in flood levels produced by the Greenhouse Effect.

4. FLOOD DAMAGES ASSESSMENT

4.1 Flood Damages

Flood damages are divided into categories as follows:

- direct damages - the effects of flood inundation on buildings and contents;

- indirect damages - the costs of evacuation, temporary accommodation, clean-up, loss of income etc; and

- intangible damages - the effect of floods on the health and psyche of the community.

Flood damages have been assessed using the ANUFLOOD (Ref. 8) flood damages model which was developed at the Centre for Resource and Environmental Studies at the Australian National University. The model is designed to assess potential direct damages resulting from flooding of urban areas. Estimates of indirect damage are not produced as outputs from the model. Intangible damages, which are also relevant in floodplain management, are not specifically considered in the model.

The model assesses the potential direct, tangible damage to property. The actual damages resulting from a flood may be less than the estimated potential damage if sufficient warning is given to evacuate and house contents can be removed or relocated above flood level.

The catchment response time for flooding of Cockrone Lagoon is relatively short, therefore, it is considered that actual flood damages are unlikely to be significantly less than the estimated potential damages. Therefore, the assessment of flood damages was based on potential damage.

The ANUFLOOD model uses three sets of input data:

- a property database;
- a flood stage-frequency distribution for the study area; and
- stage-damage relationships specifying for different classes of property, the estimated potential direct damage to be sustained at differing depths of flooding.

The information for the property database was obtained as part of the floor level survey of properties which were located within the area inundated by the one percent AEP design flood, as determined in the flood study and shown on Figure 2.2.

The flood stage-frequency distribution was based on the results of the hydraulic modelling carried out for the flood study. The flood stage-frequency distribution adopted for the damages assessment is presented in Table 4.

TABLE 4

Cockrone Lagoon Flood Stage-Frequency

AEP (%)	Lagoon Level (m AHD)	Entrance Level (m AHD)
50	3.5	3.5
20	3.8	3.8
10	3.9	3.9
5	4.0	4.0
2	4.06	4.06
1	4.09	4.09
0.1	4.15	4.15
PMF	5.05	5.05

Note # Lagoon level refers to flood level through the body of the lagoon.
* Entrance level refers to water level in the entrance channel from either ocean storm levels or lagoon flood level.

The ANUFLOOD model contains stage height-damage relationships based on floods up to the mid 1980's.

More recent flood events, where flood damage data is available, occurred at Nyngan in 1990 and in Inverell in 1990. This flood damage information has been used after adjustment to 2003 dollar values for house contents and structural damage.

There has not been a significant recent flood in Cockrone Lagoon and it was thus considered that there was little value in attempting to estimate damages simply by resident interview.

The stage damage relationships were based on damages survey data collected for the 1990 flood at Nyngan. The damages estimates were corrected to 2003 dollar values.

The analysis of the information collected after the 1990 flood at Nyngan indicated that the indirect damages associated with flooding are:

- evacuation, temporary accommodation and loss of wages: $640/household/day.
- clean-up: $2,560 to $3,070/premises.
- loss of trade: $2,560/working day.

For a short duration flood, the indirect damages, based on the above figures, are equivalent to 15 percent of potential direct residential damage and 12 percent of potential direct damages for commercial properties.

Actual damage is defined as that damage which would occur after protective measures were undertaken. Protective measures include evacuation, raising or relocating contents to upper floors and removing vehicles to higher ground.

Considerable reduction in flood damages can be achieved with adequate warning and appropriate community response. The ratio of actual to potential damage depends primarily on flood magnitude, prior experience of flooding and warning times.

The hydraulic model results for the one percent AEP design flood show that the lagoon level rises approximately 600 millimetres to top-of-bank level over a period of 6 to 7 hours. This corresponds with the onset of higher intensity rainfall which produced a lagoon level rise of approximately 1 metre over a period of 4 hours.

Thus, the length of time available for mobilization and flood protection activities is unlikely to exceed 6 hours. This time may be significantly less if the flood occurs at night, when darkness will impede mobilisation of resources and observation of rising flood levels.

The highest recorded flood level for Cockrone Lagoon occurred on 3 February 1990 when the lagoon level reached RL 3.1 m AHD before the entrance broke out naturally. This highest recorded flood level is 0.3 metres above the top-of-bank level on the southern side of the lagoon.

The general community has no recent direct experience of flooding from the lagoon. A small number of residents in Lakeside Drive would appear to be the only members of the community with direct experience of lagoon flooding.

It is considered that actual direct flood damages will be only slightly less than potential direct damages due to the relatively short warning time available and general absence of community experience with flooding.

It is unlikely that any reduction in direct damages can be achieved by residents adjacent to the entrance due to the uncertainties in forecasting ocean storm conditions.

4.2 Residential Properties

The floor level survey revealed that there are 23 houses around the foreshores of Cockrone Lagoon with floor levels below the estimated one percent AEP design flood level. Fourteen of these houses are located within the area affected by wave action produced by an extensive storm at sea.

The height distribution of floor levels is presented in Table 5.

TABLE 5

Distribution of Floor Levels

Floor Level Equal to or Less Than (m AHD)	Number of Dwellings Equal to or Below Floor Level Specified					
	Precinct					
	1	2	3	4	5	6
3.0	0	0	0	0	0	0
3.2	0	0	0	0	0	0
3.4	3	0	0	0	0	0
3.6	7	0	0	1	0	2
3.8	7	0	0	4	0	2
4.0	**8**	0	0	**5**	0	4
4.1	9	0	0	8	0	5
4.2	10	0	0	11	0	5
4.4	12	0	1	18	0	5
4.6	16	0	1	19	2	7
4.8	18	0	1	22	3	7
5.0	19	0	1	26	3	7

Note: **Underlined bold** refer to 1% AEP flood levels in each precinct

The estimated potential direct flood damages to residential properties for a range of flood probabilities are shown in Table 6 below.

TABLE 6

Potential Direct Damages to Residential Properties

AEP (%)	Damages ($)
10	269,790
5	364,230
2	363,970
1	448,320
PMF	1,634,050

The estimated mean annual direct damages to residential properties is $106,590, equivalent to $5,610 per residential property.

There are no commercial properties within the flood-liable area.

4.3 Public Utilities

The extent of land inundated in the one percent AEP design flood covers 15 hectares of lagoon foreshore and floodplain upstream of Cockrone Lagoon. The inundated land comprises public reserve and open space areas, rural private property and residential development areas.

A number of public utility works are located within the inundated area, including:

- two sewerage pumping stations;
- roads;
- parklands; and
- underground water, sewerage, power and telephone services.

Public utility damages comprise replacement or repair of assets which suffer damage as a result of inundation and clean-up of debris deposited by floodwaters.

The lack of a recent flood at Cockrone Lagoon limits the opportunity to obtain actual utility damages. A suitable approach was thus seen as using the Nyngan flood data (which is well-documented) to ascertain a damage per unit area of developed land to estimate the public utility damages.

An analysis of public utility damage estimates for the Nyngan flood indicate that public utility damages were approximately $9,070 per hectare of inundated land. This public utility damage estimate is similar to that derived for the Narrabeen Lagoon Floodplain Management Study (Ref. 10). On this basis, the estimated mean annual damage for public utilities within the Cockrone study area is $135,340.

The estimated mean annual damages for public utilities is $95,080.

4.4 Total Flood Damage

The total tangible flood damage for the Cockrone Lagoon study area is $217,640 on a mean annual basis.

The total flood damage comprises:

-	Direct residential damage	$106,590	(as per section 4.2)
	Indirect residential damage	$ 15,990	(as 15 percent of direct damage)
-	Commercial/Industrial damage	Nil	(no properties so classified and affected)
-	Public Utilities	$ 95,080	
	Total	$217,660	

It is noted above that public utilities damage is some 40 percent of the estimated total flood damages in the study area.

5. FLOODPLAIN MANAGEMENT OPTIONS

5.1 Overview

Gosford City Council has adopted the one percent AEP as its designated flood for the purposes of floodplain management throughout its administration area.

This report concentrates on feasible options for protection against the designated or design flood but includes considerations of floods up to the Probable Maximum Flood (PMF) magnitude.

The flood-liable land around Cockrone Lagoon is comprised of:

- open space, public reserve around the shoreline of the lagoon;
- residential development abutting the above open space public reserve; and
- rural development of the floodplain upstream of the lagoon.

The Floodplain Management Manual lists a number of structural and non-structural flood mitigation measures with can reduce the impact of floods.

Structural flood mitigation measures control the extent and depth of floodwaters. These measures include:

- flood mitigation dams;
- levees;
- by-pass floodways;
- channel improvements; and
- detention basins.

Flood mitigation dams and by-pass floodways are not considered to be feasible options for Cockrone Lagoon due to the topography and size of the catchment area.

A detention basin would reduce the rate of rise of floodwaters in Cockrone Lagoon but would not reduce the volume of floodwaters entering the lagoon. It is the volume of runoff which is one of the primary factors which determine flood levels in the lagoon.

Therefore, it is considered that a detention basin option is not practicable for the Cockrone Lagoon foreshore and floodplain.

Addendum No. 1 to the Flood Study found that confinement of flow to the open drain between Newell Road and Three Points Avenue could be effectively achieved by construction of a small levee. The levee work is included in the Floodplain Management Plan.

The flood-liable properties around the foreshores of Cockrone Lagoon are located in relatively compact areas which could be protected by foreshore levees.

The flood study concluded that the level of the beach berm across the lagoon entrance was the major control for flood levels in Cockrone Lagoon.

Therefore, channel improvements, specifically at the lagoon entrance, and levees are considered to be feasible options and worthy of full investigation.

Dredging of Cockrone Lagoon is not seen as a practical option. Achievement of flood level reduction would require increasing the storage available above the current let-out-level. Whilst dredging would increase the total lagoon volumes, it would not increase storage above let-out-level and, consequently, no significant flood mitigation benefit is achieved.

Provision of a permanent opening from the lagoon to the ocean was briefly examined and discarded as not practical for several reasons, as follows:

- the coastal processes move sand along the beach relatively quickly to close any opening of the lagoon through the beach. The historical opening and closure regime of the lagoon to the ocean indicates there is insufficient tidal flows to maintain an open entrance without a significant Council intervention;

- the lagoon in its present form provides an important visual and recreational resources within the Gosford area. A permanent entrance would imply lowering of normal water levels by about 2.5 metres with attendant exposure of large areas of the lagoon bed; and

- significant lowering of the lagoon water levels would cause a major adverse environmental impact to the flora and fauna in the foreshores surrounding the lagoons.

5.2 Lagoon Berm Management

The Cockrone Lagoon Flood Study concluded that the level of the beach berm across the entrance was the primary control for flood levels in the lagoon. The hydraulic modelling results showed that the peak flood level in the lagoon is approximately 300 millimetres above beach berm level for natural breakouts.

Council has a management policy for Cockrone Lagoon whereby the lagoon entrance is mechanically opened when the water level reaches let-out-level, RL 2.53 m AHD. This policy was developed to minimise the risk of flooding of properties around the lagoon foreshore.

Analysis of the lagoon opening records shows that the beach berm level at the time of opening varied between RL 2.6 m AHD and RL 4.0 m AHD with a median beach level at RL 3.15 m AHD.

A beach berm level of RL 3.8 m AHD was adopted for the determination of design flood levels for the lagoon. The beach berm level can be expected to be higher than the adopted design level for approximately 10 percent of flood events.

A preliminary analysis of the lagoon opening records indicates that the beach berm would build up to RL 3.8 m AHD over a period of between 6 and 18 months after an opening of the lagoon entrance. The shorter period is similar to the average interval between flood control openings of the lagoon entrance.

The relationships between peak lagoon flood level and beach berm level is demonstrated on Figure 5.1 which shows the design flood envelopes determined by hydraulic modelling carried out for the Flood Study. Figure 5.1 shows that the peak flood level in Cockrone Lagoon in the one percent AEP flood is RL 4.1 m AHD for a beach berm level of RL 3.8 m AHD and is RL 3.81 m AHD for a beach berm level of RL 3.5 m AHD.

Thus, a 300 millimetre lowering of the beach berm produces a 280 millimetre lowering of the flood level in Cockrone Lagoon.

It would be necessary to lower the beach berm over a minimum distance of 60 metres to achieve this reduction in flood level.

It is estimated that a cutting through the beach berm 60 metres wide and 300 millimetres deep would be filled by wind-blown sand over a period of 10 to 12 weeks.

The record of lagoon entrance openings shows that the beach berm has built up above RL 3.5 m AHD on nine occasions over the period 1977 to 1992. The maximum recorded beach berm level is RL 4.0 m AHD.

It is estimated that it would have been necessary to remove sand from the lagoon entrance nine times over this period in order to maintain an effective beach berm level at RL 3.0 m AHD.

Similarly, it is estimated that it would have been necessary to remove sand from the entrance 18 times to maintain an effective beach berm level at RL 3.2 m AHD. The estimated one percent AEP flood level for this beach berm level is RL 3.50 m AHD, some 0.59 metres lower than the design flood level.

The cost for the periodic removal of sand from the beach berm is quite small when compared to the potential reduction in flood damages of this practice.

The analysis of the effectiveness of lowering the beach berm level was based on natural breakout of the entrance after the water level in the lagoon overtopped the beach berm. The hydraulic modelling indicates that peak lagoon flood levels are not significantly dependent on initial water level in the lagoon, provided that the volume of runoff is sufficient to fill the lagoon to beach berm level.

There is some minor variation in peak lagoon level dependent on the rate of inflow into the lagoon in the period following overtopping of the beach berm relative to the flow through the breakout. Thus breakouts on a rising inflow result in slightly higher lagoon levels than breakouts on a falling inflow after the flood peak inflow.

Thus, a change in the let-out level will have much less effect than a similar change in the beach berm level.

5.3 Levees

There are eight (8) residential properties in Del Monte Place, Copacabana, on the northern side of the entrance, which have floor levels below the design flood level. It would be possible to construct a levee 350 metres long and up to 1.5 metres high to protect these properties. The possible levee route is indicated on Figure 5.2.

The levee would be located in public reserve land along the shoreline. There could be significant impact on the local environment as a result of this levee construction.

There are 11 houses in Lakeside Drive and Three Points Avenue on the southern side of Cockrone Lagoon which have floor levels below the design flood level. It would be possible to construct a levee 550 metres long and up to 1.2 metres high to protect these properties.

This levee would be located in parkland along the lagoon shoreline and would cross over the outlet to the open drain from Precinct 5. It would be necessary to install flood gates on the drain outlet in order to prevent floodwaters from the lagoon passing under the levee.

5.4 Planning Controls

The Local Environmental Plan sets out the types of development permissible for land within each zone shown on Figure 3.2. The principal land zonings are summarised in Table 7 below.

TABLE 7

Principal Land Zonings
Cockrone Lagoon Environs

Zone	Permitted Development
Residential 2(a)	Single dwellings
Residential 2(f) Beach frontage	Detached dwelling houses, (with consent) amalgamation of lots, minor boundary changes.
Open Space 6(a)	Recreation
Conservation and Scenic Protection 7(a) 7(c2) 7(c3)	 Dwelling houses, parks and gardens. Rural small holdings. Tourist development.

Building floor levels are regulated through Council's flood policy. This policy sets a minimum floor level for new development around Cockrone Lagoon at RL 4.3 m AHD. This provides 210 millimetres clearance above the estimated one percent AEP design flood level for Cockrone Lagoon.

The western end of the lagoon foreshore is included in SEPP 14 - Coastal Wetlands Site 914. The gazetted wetlands are shown on Figure 3.1.

Examination of the zonings on Figure 3.2 shows the lagoon foreshores as essentially residential 2(a), Open Space 6(a) and Conservation and Scenic Protection 7(a). The presence of the SEPP 14 wetland effectively prevents major development around the western end of the lagoon foreshore. Future development within the confines of the current zonings are thus seen as essentially single dwelling construction, as infill or redevelopment with the Residential 2(a) zone and single dwellings on large lots in the Conservation and Scenic Protection zone.

Gosford City Council, in the application of floodplain management plans throughout their administrative area, identifies flood-liable land by hydraulic categories such as "Floodway" or "Flood Storage". In this case "Floodway" and "Flood Storage" apply.

The adopted definitions of "Floodway" and "Flood Storage" are:

> ***Floodways*** are those areas where a significant volume of water flows during floods. They are often aligned with obvious naturally-defined channels. Further, floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, which may, in time, affect other areas. They are often, but not necessarily, the areas with deep flow or areas where higher velocities occur.
>
> ***Flood Storage*** areas are areas which temporarily retain water during the passage of a flood. In these areas, the flow velocity, and therefore the flood hazard, is much less than the hazard within a Floodway.

The provision of Floodways has added benefits:

- Floodways allow retention of the existing stream environment;
- they can accommodate floods larger than the designated flood; and
- a clearly visible Floodway constantly provides flood awareness to the local community.

In the distant future, the Floodway may provide the opportunity for improvement of the stream conveyance if it is necessary following on-going development. However, once defined, the Floodway should never be compromised. Small changes occurring progressively would, in time, cause a significant change to the flow capacity.

A concise description of the general requirements for **Floodways** is as follows:

- Floodways should be maintained in perpetuity for the passage of floodwaters;
- no landscape planting should be undertaken where it would hinder the conveyance of water;
- no work that would impede the passage of floodwaters should be permitted in a Floodway;
- buildings should not be permitted to be constructed in the Floodway;
- filling is prohibited in the Floodway;

- fences likely to collect debris and/or impede floodwaters should not be permitted;

- all land uses should be flood-compatible; and

- proposals to cross the Floodway with services of major importance to the area could be permitted subject to conditions.

Floodways would need to be crossed by major service installations of importance to the area. These should be permitted in the Floodway provided they were investigated adequately and designed in a manner that did not significantly affect flood flow capacity or flood levels. They should also be designed so as to reduce damage potential to the services to the absolute minimum.

Application of Hazard to Cockrone Lagoon and Environs

The requirements for Flood Storage areas should be less rigid than the Floodways. New buildings, desirably, should not be located within the Flood Storage area. If, however, exclusion of individual buildings is not practical, development will be considered, providing such development satisfies all constraints including the specified minimum floor levels and controls on any fill for buildings.

Flood hazard categories have been assigned in Chapter 2 and illustrated on Figure 2.6. The classifications adopted are consistent with the definitions above.

The bulk of the lagoon study area is classified as "Low Hazard, Flood Storage" with "High Hazard Floodways" at the upstream end (Precincts 3 and 4) and at the lagoon entrance (Precincts 1 and 6).

The High Hazard Floodway/Investigation area at the lagoon entrance (Precincts 1 and 6) has been adopted due to the possible occurrence of ocean storms over-washing the beach. This area is considered best treated as a coastal hazard management process rather than a floodplain management process. Further investigation is required to detail the wave overwash hazard in better focus. Until such investigation is completed, it is prudent to classify the area as a high hazard floodway.

Within the **Flood Storage** areas, appropriate options are seen as:

- Council urge no further development within the floodplain areas;

- new buildings to be set with minimum floor levels of RL 4.3 m AHD (consistent with the current policy). Council strongly urge adoption of the higher levels given in the Flood Study as the current minimum floor level requires the successful continuation of Council's "let-out" policy; and

- filling for new development in Flood Storage area would be restricted to building footprint only, providing drainage of adjacent block is not affected;

- in areas where existing blocks have nuisance flooding, filling to 0.2 metres above the "Let-out-level" can be permitted;

- new buildings should have some form of emergency access so that if flooding does occur, the occupants can reach flood-free ground along a route with gradually reducing flood depths.

Within the **Floodway** categories, the most appropriate action is seen as:

- no new buildings be permitted in the Floodways;

- access bridges and roadways to be set nominally at existing floodplain levels such that flood levels are not increased by more than 10 millimetres in the design flood;

- fences on the floodplain to be of flood compatible variety such that their construction does not impede flood flows or debris;

- landscaping and plantings within the floodways, which restrict or impede flood flows beyond current conditions, should not be permitted; and

- proposals to cross the Floodway with services of major importance to the area would be permitted provided that the proposals are adequately investigated and designed in a manner that does not significantly affect flood-flow capacity and flood levels.

The aims of the above measures are seen as allowing limited works whilst retaining the Floodway status of the floodplain. Thus, landscaping and changes to the form of the floodway are possible, provided that flood flow capacity, and flood storage capacity are not reduced, nor flood flow velocities increased.

The measures above for both Flood Storage and Floodway areas are sufficiently general to enable site specific details to be determined at each block in the knowledge that the allowed developments will not aggravate flooding problems.

The minimum floor level recommendation option follows from the results of the Flood Study which indicated that flood levels within the lagoon are principally dependent on the beach berm level at the time of the flood. The Flood Study addressed the variable berm height by suggesting an appropriate berm height as one that was exceeded only 10 percent of the time, thus presenting a conservatively high flood level. An alternative argument is that the median level (that is the level which is exceeded 50 percent of the time) is appropriate. In the median berm level approach, the design one percent AEP flood level would fall to RL 3.6, where Council's current floor policy would provide 0.7 metres clearance to the design event.

5.5 Floodproofing of Buildings

Floodproofing of buildings in flood-liable areas is an effective method of reducing flood damage to the structure and contents. One of the most effective means of floodproofing for residential buildings is to raise habitable floor levels above flood level. However, this is only feasible with timber framed and clad construction or steel framed and clad construction.

Ten (10) of the 19 residential properties affected by lagoon flooding within the study area are of brick or brick-veneer construction and cannot economically be raised above flood level. These houses have been constructed over the past twenty years for permanent residences.

The remaining nine properties were primarily holiday cottages, although a number are now used as permanent residences. The nine residences identified are listed in Appendix A. These houses could be economically raised. It is noted that one building listed (Old Post Office, 49 Lakeside Drive) may appear on Gosford Council's Heritage Listing and thus house raising (flood proofing) may not be possible within the constraints of its heritage status.

5.6 Voluntary Acquisition

Voluntary acquisition of property is an option to virtually remove the flood damage potential. However, the high cost of this option implies that it is generally only used in High Hazard Floodways where no other solution exists.

Property acquisition would be an option for the High Hazard Floodway near the lagoon outlet (Precincts 1 and 6) though this can be expected to attract very high costs and strong opposition from landowners. Ten (10) houses would be involved in the acquisition programme and represents those in the "High Hazard" floodway areas that cannot be economically raised. In this instance it has been assumed land acquisition costs between $447,300 and $511,200 per block would be involved.

5.7 Flood Warning and Public Education

The last significant flood occurred in February 1990 when the lagoon water level rose to 600 millimetres above let-out-level before the entrance broke out naturally. The lagoon was well below let-out-level prior to the commencement of rainfall and rose 1.2 metres over a period of 2.5 hours. The lagoon overtopped the beach berm and natural break-out occurred.

It generally takes up to 3 hours to organise an emergency opening of the lagoon entrance. Hydraulic modelling results show that the water level in the lagoon can rise almost 1 metre during this time.

Council has recently installed automatic water level recorders on each of the coastal lagoons with telemetry to Erina Works Depot. This should enable improved monitoring of lagoon level rate of rise and enable earlier mobilization for opening of the lagoon entrance.

The earlier mobilisation and associated earlier opening of the lagoon outlet will achieve a reduction in flood levels and, consequently, flood damage. This occurs as earlier outflow from the lagoon on the rising limb of the flood prevents the lagoon rising as high.

A questionnaire was distributed to 40 properties within the study area during the Flood Study seeking information on flooding around Cockrone Lagoon. Of the 19 responses received, only 7 respondents had been affected by floodwaters on their property, while only one resident reported flooding in the house.

Thus, there appears to be a general lack of community awareness of the possible extent of flooding from Cockrone Lagoon. This is largely due to the effectiveness of Council's policy of opening the lagoon entrance when the level rises above the adopted let-out-level.

It is considered that public awareness of the potential flooding of the lagoon foreshores would be improved following a public education programme. A simple brochure outlining the relevant issues and distributed to all residents within the study area could be a satisfactory means of increasing the general awareness of the community.

The bulk of the flood liable properties in the Cockrone Lagoon area are within "Low Hazard - Flood Storage" classifications. There are no flood liable buildings within the "High Hazard Floodways" entering the lagoon area. Thus, flooding is seen as a potential threat to property and possessions but not to human life.

It is thus considered that:

- the threat to life is not sufficient to justify flood warnings by sirens and the like;

- public acceptance and knowledge of flooding could be enhanced by provision of a staff gauge in Cockrone Lagoon showing the "let-out-level" and design one percent AEP flood levels.

5.8 Future Upstream Development

There is the potential for future development in the catchment upstream of Cockrone Lagoon.

In assessment of upstream development, it is useful to note:

- future development can be expected to conform with the existing planning controls and thus development in "Floodways" should not occur;

- the future development will affect run-off potential over the full range of rainfall events;

- mitigation measures against increased run-off are essentially forms of detention basins which delay and reduce peak flows but do not reduce run-off volumes;

- Cockrone Lagoon essentially acts as a storage basin. The frequency of reaching its "let-out level" depends on the combination of rainfall and evaporation.

Thus, future upstream development can be expected to cause more frequent "let-out" of Cockrone Lagoon, though without a long term simulation of Lagoon behaviour, the change cannot be exactly quantified. The increase in frequency in "let-out" is not expected to be significant.

Conversely, the change in runoff from future development and its impact on Cockrone Lagoon itself (in a flooding sense) is unlikely to be mitigated by current technologies. Nonetheless, current technologies may need to be applied to protect the waterways reaching Cockrone Lagoon.

Significant erosion of the catchment (either naturally occurring or following future development) will have a major impact on Cockrone Lagoon.

The eroded material will be deposited in Cockrone Lagoon, thereby:

- reducing the storage available below the "let-out level" and thus increasing the frequency of reaching the "let-out level"; and

- reducing the storage available above the "let-out level", thus potentially giving higher flood levels.

6. FLOODPLAIN MANAGEMENT OPTIONS IMPACTS

The aims of floodplain management are to reduce:

- personal and public losses;
- risk to the safety of residents in flood-liable areas;
- post flood trauma in the local community; and
- impact of floods and flood mitigation works on the environment.

6.1 Reduction in Damages

Flood damages to existing private and public property can be reduced by providing protection for flood-liable development or by relocating existing development above flood level or to flood-free areas. Flood damages to future development can be minimised by ensuring that such development does not occur in flood-liable areas or is located above flood level.

Thus, reduction in flood damages is achieved by structural and non-structural processes. The estimated reduction in direct flood damages for the various floodplain management options considered feasible for Cockrone Lagoon are summarised in Table 8.

TABLE 8

Direct Flood Damages Reduction for Existing Development

Option	Reduction in Mean Annual Damages	
	Residential Direct ($)	Total Tangible ($)
Maintain Beach Berm Level at RL 3.5 m AHD	14,060	21,150
Maintain Beach Berm Level at RL 3.2 m AHD	21,150	43,320
Foreshore Levees RL 4.1 m AHD	102,880	138,980
House Raising	37,380	43,000
Flood Warning	8,630	13,290
Voluntary Acquisition	69,140	79,620

The values in Table 8 represent a reduction in damage, a benefit accruing as a result of implementation of the option.

The benefits accruing thus apply to existing developments on the basis that new development will be essentially flood-free.

6.2 Environmental Effects

Improved management of the beach berm level at the entrance to Cockrone Lagoon will not result in more frequent opening of the entrance but may result in a marginal increase in the volume of seawater entering the lagoon during ocean storm periods. This is expected to have a negligible impact on the water quality within the lagoon.

The established regime of the lagoon and foreshore areas will not be altered as a result of periodic lowering of a section of the beach berm. Therefore, this option is considered to have no impact on the lagoon environment.

The CLP Committee has suggested that the let-out-level be raised to RL 3.8 m AHD in order to allow the lagoon to revert to a more natural condition.

The lagoon could become a more diverse system if the lagoon water level was raised. This may cause some increase in the reedlands and sedgelands around the lagoon shoreline. In the aquatic zone, a more diverse flora and fauna could result.

However, the increase in lagoon water level is likely to result in less frequent flushing with the result that pollutant loads, derived from catchment runoff, may increase.

The routes of the potential levees to protect flood-prone properties on both sides of the lagoon are located in public open space land. Construction of these levees could result in the loss of significant foreshore vegetation and downgrade the visual amenity of the foreshore and adjoining properties.

The levees would be in excess of 1 metre in height and would reduce public access to lagoon. This could be partly overcome with careful design to enable the levee to provide a walkway through the foreshore vegetation and thus provide improved access to this recreation space.

Although no fauna study has been carried out, it is noted that the Green and Golden Bell frog has been found at nearby Avoca Lagoon and could commonly be found on the Cockrone Lagoon foreshore areas.

Raising floor levels as part of a co-ordinated programme will have negligible impact on the environment of the lagoon and foreshore areas. However, the general appearance of the residential development will be changed. Careful design of each house raising will be required in order to ensure minimal adverse visual impact on the streetscape. The implementation of such a programme will require the agreement of landowners.

6.3 Social Impacts

The options of beach berm management and improved entrance opening through flood warning are seen as having little social impact. In the main, these measures will be supported by the community and thus incur little social impact. The community acceptance of these measures is viewed as highly likely.

The levee construction would have an initial social impact during construction adjacent to the affected properties but this would diminish after construction completion. The affected landowners will probably feel a loss of amenity of their properties through the levee construction - their loss of views across the lagoon and its foreshores and their loss of access to the lagoon. The probable community acceptance of this measure is seen as low.

House raising, whilst providing flood benefits, can create a significant change to the lifestyle of the property owners.

The change flows from the raising of floors significantly with attendant access difficulties in reaching living areas from ground or street level. Such access difficulties are more acutely felt by the elderly and the disabled. The property owners may not see the benefit of flood protection as commensurate with the loss of access.

Similarly, the house raising will change the architectural style of the buildings and the general streetscape. Such changes may not be acceptable to all property owners.

The voluntary acquisition of houses would provide greater community access to the lake foreshores. However, strong opposition could be expected from the landowners given the location in an area generally perceived by the community as a prime location.

One of the difficulties faced by floodplain and coastal management planning is the rarity of major events. The community acceptance of floodplain management plans can be expected to be high if instituted immediately after a significant flood event. However, community acceptance would diminish with increasing time after the event.

6.4 Floodplain Management Options Economic Evaluation

The economic evaluation of alternative floodplain management options is most easily carried out using a benefit-cost analysis.

The benefits derived from floodplain management include:

- tangible benefits: reduced direct and indirect damages; and
- intangible benefits: reduced stress, trauma and improvements in numerous social factors.

It was concluded in Chapter 4 that actual direct flood damages are unlikely to be significantly less than estimated potential direct damages due to the relatively short warning time available in major floods. Hence, all direct damage estimates have been prepared on the basis of potential direct damages.

Previous damages studies have concluded that indirect damages for predominantly residential development are equivalent to 15 percent of direct damages. This ratio has been adopted for the current study.

The economic evaluation of options has been based on mean annual damages and annual costs of the options. This approach is considered appropriate as none of the options under consideration involved staged construction which would affect the cash flow and "net present value" of future costs.

The annual costs of the various options comprise annual operating and maintenance costs and interest and redemption payments over the economic lifetime of the options. The annual costs were estimated for discount rates of 7.5 percent, equivalent to the current interest rate, net of inflation, and 12.5 percent to test the sensitivity of the results to changes in economic conditions.

The estimated capital costs of structural works has been based on current construction rates. Annual operation and maintenance cost have been assessed at 2 percent of capital cost.

The economic comparison of the floodplain management options is summarised in Table 9. The analysis has been based on an economic planning period of 50 years.

TABLE 9

Economic Comparison of Floodplain Management Options

Economic Parameter	Management Option					
	Lower Beach Berm		Levees $	House Raising $	Flood Warning $	Voluntary Acquisition $
	RL 3.5	RL 3.2				
Capital Cost	-	-	498,420	287,550	12,780	5,112,000
Annual Interest and Redemption @ 7.5% Discount	-	-	38,470	22,110	1,850 [1]	395,030
Annual Interest and Redemption @ 12.5% Discount	-	-	62,490	36,040	2,300 [1]	640,280
Annual Operation and Maintenance	1,280	2,560	9,970	-	1,280	-
Total Annual Cost @ 7.5%	1,280	2,560	48,440	22,110	3,130	395,030
Total Annual Cost @ 12.5%	1,280	2,560	72,460	36,040	3,580	641,300
Reduction in Direct Residential Damages [3]	14,060	21,150	102,880	37,380	8,630	69,140
Reduction in Indirect Residential Damages [3]	2,110	3,200	15,230	5,620	1,280	10,420
Reduction in Damages Public Utilities	4,920	19,040	20,580	-	3,390	-
Total Reduction in Damages	21,150	43,320	138,980	43,000	13,290	79,620
Benefit-Cost @ 7.5% pa	16.55 [2]	17.00 [2]	2.87	1.94	4.24	0.20
Benefit-Cost @ 12.5% pa	16.55 [2]	17.00 [2]	1.92	1.19	3.71	0.12

Notes:
1. 10 year replacement period adopted for instrumentation
2. Benefit-cost does not vary with discount rate as no capital cost is involved
3. Based on average annual damage

The results presented in Table 9 show that house raising provides the greatest reduction in flood damages but also incurs the highest cost. The benefit-cost ratio is marginally greater than unity.

Lowering the beach berm at the entrance of Cockrone Lagoon is the least cost option and yields a very high benefit-cost ratio, in excess of 15.

7. COMPARISON OF FLOODPLAIN MANAGEMENT OPTIONS

7.1 Comparisons

The economic comparison of floodplain management options indicates that lowering the beach berm level and improved flood warning are options with very favourable benefit-cost ratios.

However, there are several other factors to be considered in the selection of the preferred management options. These factors include:

- environmental impacts;
- social impacts;
- effectiveness; and
- economic considerations.

One suitable method used to compare options is to prepare a comparison matrix. This enables direct comparison of all options against relevant criteria. The process can be carried out in stages, as follows:

- initial review of options to enable concentration on practical options;
- comparison of raw matrix data to determine options worthy of further consideration;
- applying weighting factors to evaluation criteria; and
- comparing weighted performance to select preferred option.

An initial review in Chapter 5 outlined several options that were discarded as not practical. These options were:

- retention/retarding basins in the catchment; and
- dredging of the lagoon.

These options have not been considered further.

The raw comparison matrix for feasible floodplain management options for Cockrone Lagoon is shown on Table 10 which illustrates six options against 19 criteria.

The evaluation criteria in the comparison matrix are defined as follows.

Properties Protected in Design Flood - number of existing flood-liable properties which would not be flooded in Design Flood as a result of option.

Properties Protected in PMF - number of existing properties in study area which would not be flooded in PMF as a result of option.

Reduced Flood Risk - assumed to be equivalent to the percentage reduction in mean annual damages as a result of option.

Localised Adverse Hydraulic Impacts - defined as increases in depth, velocity or rate of rise of floodwaters in or adjacent to protected area.

Capital Cost - estimated cost of investigation, design and construction of works option.

Operating Cost - annual operating and maintenance costs.

Damage Reduction - reduction in mean annual damages due to option.

Benefit-Cost Ratio - ratio of reduction in mean annual damages (direct and indirect) to full annual cost of option.

Economic Sensitivity - ratio of change in benefit-cost ratio for 1 percent variation in discount rate.

Financial Staging - ratio of initial capital investment in option to total capital investment.

Affordability - ratio of least-cost option to cost of option.

Access - ratio measure of serviceability of road network during flood periods.

Utility Services - ratio measure of failure of utility services during flood periods compared to existing conditions.

Safety - ratio measure of the reduced risk to life within flood affected areas derived from the reduction in properties flooded.

Community Acceptance - perceived relative acceptance of option by the community in general and those directly affected by option.

Flora - impact on existing flora due to option.

Fauna - impact on fauna and habitat due to option.

Visual Impact - impact of option on local landscape.

Recreation - impact of option on recreation use of lagoon and foreshore areas.

TABLE 10
Comparison Matrix For Floodplain Management Options

Criteria		Management Option					
		Lower Beach Berm		Levees	House Raising	Flood Warning	Voluntary Acquisition
		RL 3.5	RL 3.2	RL 4.1			
1.	**Function**						
1.1	Reduction in Design Flood Level (m)	0.28	0.58	0	0	0.13	0
1.2	Properties Protected in Design Flood	3	8	19 [(a)]	9	1	10
1.3	Properties Protected in PMF	4	8	-	27	3	26
1.4	Reduced Flood Risk	13%	20%	97%	35%	6%	65%
1.5	Localised Adverse Hydraulic Impacts	No	No	Possible	No	No	No
2.	**Economics**						
2.1	Capital Cost	-	-	498,420	287,550	12,780	5,112,000
2.2	Operating Cost	1,280	2,560	2,810	-	1,280	-
2.3	Damage Reduction	21,150	43,320	138,980	43,000	13,290	79,620
2.4	Benefit-Cost Ratio	16.5	16.9	2.87	1.94	4.24	0.20
2.5	Economic Sensitivity	0	0	0.17	0.14	0.10	0.01
2.6	Financial Staging	0	0	1.0	0.2 [(b)]	1.0	0.1 [(c)]
2.7	Affordability	1	0.5	0.026	0.058	0.41	0.003
3.	**Social Issues**						
3.1	Access	1.25	5.0	1.0	1.0	2.5	1.0
3.2	Utility Services	1.3	4.0	1.0	1.0	4.0	1.0
3.3	Safety	1.19	1.73	1.0	1.9	1.06	2.11
3.4	Community Acceptance	High	High	Low	Low	High	Very Low
4.	**Environmental Impact**						
4.1	Flora	No	No	Yes	No	No	No
4.2	Fauna	No	No	Yes	No	No	No
4.3	Visual Impact	No	No	Yes	Possible	No	Improve
4.4	Recreation	No	No	Yes	No	No	Improve

Notes: (a) flood-liable properties only.

(b) 5 year implementation program.
(c) 10 year implementation program.

The voluntary acquisition option is not seen as economically viable because of high cost and very low benefit/cost ratio. This option is unlikely to be acceptable to affected landowners or to the community at large. It has not been considered further.

The comparison matrix for feasible floodplain management options for Cockrone Lagoon in Table 10 shows that levee construction is the most effective option for reducing the impact of floods as measured by reduction in damages in the study area. It is also the most expensive feasible option and has a benefit-cost ratio greater than unity. This option protects properties from lagoon flooding and ocean waves. The environmental impacts of this option are unlikely to be acceptable to the community. The overall cost-effectiveness of this option is the second lowest of the options considered.

Improved management of the beach berm across the entrance to the lagoon is the most cost-effective option. This option has no adverse impacts on the lagoon environment. The option has the highest benefit-cost ratio and is likely to be widely accepted by the community.

The installation of a telemetry lagoon water level station will improve the flood control operations by enabling mobilization for mechanical opening of the entrance to begin earlier. The earlier opening of the entrance will result in lower flood levels in the lagoon.

7.2 Enhancements

The comparison in the previous section indicates the most attractive general floodplain management strategy is the management of the beach berms to RL 3.2 m AHD. The strategy effectively reduces the design one percent AEP flood level to RL 3.5 m AHD.

The proposed strategy, within the Cockrone Lagoon area, will create a situation where:

- the existing "minimum floor level" will provide 800 millimetres of freeboard to the design one percent AEP flood;

- no residences will remain at below the predicted one percent AEP flood level;

- three residences will have freeboard at less than 300 millimetres above the one percent AEP flood level;

- eight residences will have freeboard of less than 500 millimetres but greater than 300 millimetres above the projected one percent AEP flood level;

- seven residences out of the eight below the projected one percent AEP flood level or with less than 500 millimetres freeboard can be raised. The affected buildings are timber framed with "fibro" cladding.

- the remaining residence below the "cut-off" of the one percent AEP flood level plus 500 millimetres is brick veneer or double brick, which cannot practically be raised.

The above does not apply to the lagoon entrance area where coastal processes (principally wave action) dominate.

An enhancement of the proposed strategy would involve raising of the seven residences currently classed as "below the projected one percent AEP flood level plus freeboard" and "practical to raise".

The incremental benefit-cost ratio of this "enhancement" work is 2.3, based on:

-	Works cost	$223,650
-	Annual works cost @ 7.5% discount rate	$ 17,300
-	Reduction in annual damage (7 houses at $5,610 each)	$ 39,270
-	Benefit-cost ratio	2.27

Whilst the benefit-cost analysis for this exercise is attractive, the cost per individual dwelling is high. The benefits for the work accrue principally to the land owner through reduced flood damages. Thus, the funding opportunities and relative contributions from government and individual land owners should be explored.

The properties identified for this program of house raising are listed in Appendix A.

7.3 Extreme Floods

The floodplain management measures outlined earlier have been directed principally using the one percent AEP flood as the "benchmark". While floods of this magnitude are rare, larger floods can occur. Such extreme floods are represented by the Probable Maximum Flood (PMF).

The Cockrone Lagoon Flood Study examined PMF flood levels, assuming a berm level of RL 3.8 m AHD. The PMF levels are generally 1.0 metres above the one percent AEP flood levels in the lagoon storage area. Along upstream floodways, the PMF flood levels are up to 1.5 metres above the design one percent flood levels. The PMF flood behaviour is expected, given the lagoon is surrounded by relatively steep slopes falling to the lagoon foreshores, while lagoon flood levels are principally controlled by the beach berm break-out process.

The most appropriate response at this stage is ensuring that future development has access to flood free land (viz: above the PMF flood level) via gradually rising routes, such that persons escaping the PMF event traverse areas of decreasing flood depth.

Similarly, developments which are significant to post flood recovery (eg police stations, emergency services, hospitals) should be located outside the PMF flood extent.

Similarly, aged care facilities, where flood evacuation can cause considerable confusion and anguish, should be located above the PMF type event.

8. PREFERRED FLOODPLAIN MANAGEMENT STRATEGY

8.1 Existing Development

Analysis of the data presented in the comparison matrix for the floodplain management options investigated for Cockrone Lagoon indicates that the preferred management option is the improved management of the beach berm at the lagoon entrance.

This option has a low cost, requiring only periodic removal of sand from the beach berm area after the beach has built up above a critical level.

This management option has been assessed for maximum beach berm levels at RL 3.2 m and 3.5 m AHD. The maintenance of the lower beach berm level was found to be more cost-effective.

It is considered that this option, in combination with improved warning provided by telemetry of lagoon water level, will be widely accepted by all parties involved in the flood management process.

The peak lagoon flood level is primarily determined by the beach berm level, while the initial lagoon level has a minor impact on the peak lagoon flood level. Thus, raising the lagoon let-out-level by 0.3 metres is not counter-productive to the benefits to be achieved by lowering the beach berm level. Environmentally, raising the let-out-level is considered likely to result in a more diverse lagoon ecology. Raising the let-out-level would reduce the frequency of flushing of the lagoon and could result in higher pollutant loads derived from catchment runoff. The siting of development is such that an increase of 0.3 metres in let-out-level would not measurably increase flood damages.

Addendum No. 1 of the Flood Study has reviewed the trunk drainage options along the drain between Newell Road and Three Points Avenue. The preferred strategy is to construct a small levee to confine all drainage flows to the drain itself.

A flood awareness program is required to increase the level of knowledge of flood issues around Cockrone Lagoon. A single brochure outlining the issues and flood response is considered adequate in this case.

Flood awareness and flood warning can be improved by installation of a staff gauge in Cockrone Lagoon indicating the "let-out level" and design one percent AEP flood levels. This needs to be installed where easy public access is available.

The beach berm management option will provide increased protection for properties adjacent to the lagoon entrance against lagoon flooding only. However, these properties will remain exposed to inundation by ocean storm waves. The protection of these properties and adjacent beachfront properties is an issue to be addressed in coastal management.

8.2 Future Development

Council's Flood Policy requires that new buildings constructed around the foreshores of Cockrone Lagoon shall have a minimum floor level above RL 4.3 m AHD. This level is 210 millimetres above the estimated one percent AEP design flood level (assuming an "un-managed" beach berm).

The preferred floodplain management option to protect the existing development is to limit the beach berm level to below RL 3.5 m AHD. This option effectively reduces the one percent AEP flood level to RL 3.81 m AHD, thus providing 500 millimetres clearance to the current minimum floor level for the Cockrone Lagoon foreshore.

The minimum floor level requirement contained in Council's current Flood Policy, in conjunction with adoption of the preferred management option, will provide a generally acceptable level of protection for future development around the Cockrone Lagoon foreshore.

The minimum floor level of RL 4.3 m AHD is not applicable to Precincts 3 and 5, which are located upstream of the lagoon and adjacent to the open drain. Flood levels in those areas are determined by local flood discharges, not lagoon flood levels.

Therefore, it will be necessary to amend the minimum floor level for these areas to provide a satisfactory clearance above the one percent AEP design flood.

The flood-liable areas in Precincts 3 and 5 should be classified as Floodway in accordance with planning controls outlined in Chapter 5.

The proposed strategy for future development is thus a combination of the existing floor level policy and adoption of the preferred lagoon entrance management proposal for the protection of existing development around the lagoon foreshores.

New development within the catchment will require controls to ensure:

- flood flows into Cockrone Lagoon through Precinct 3 should not be increased, which would increase flood levels, if it were to occur;

- soil erosion control is required to prevent increased siltation in Cockrone Lagoon, which would reduce available storage and increase flood levels.

GLOSSARY

GLOSSARY - Terms and Abbreviations

Average Annual Damage (AAD): depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time. Refer Appendix H of Floodplain Management Manual (Ref. 1).

Annual Exceedence Probability (AEP): the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of *5%,* it means that there is a *5%* chance (that is one-in-20 chance) of a peak flood discharge of 500 m^3/s or larger occurring in any one year (see average recurrence interval).

Anti-dunes: erodible channels have bed forms. Anti-dunes are wave like bed forms which migrate upstream. They require high velocities to create the particular bed form.

Australian Height Datum (AHD): a common national surface level datum approximately corresponding to mean sea level.

Average Recurrence Interval: the long-term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.

Catchment: the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.

Critical flow: flow lies between sub-critical and super-critical flow conditions. Critical flow usually occurs at flow controls eg. at a weir.

Development: is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).

> *infill development:* refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.
>
> *new development:* refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.
>
> *redevelopment:* refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

Direct Damage: damage caused by contact with flood water eg. structural damage to building, water damage to furniture or house contents or damage caused by silt and debris.

Discharge: the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

DST: Day Light Saving Time (East Coast).

Effective warning time: the time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

EST: Eastern Standard Time.

Flash flooding: flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

Flood education, awareness and readiness:

> *Flood education* seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
>
> *Flood awareness* is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
>
> *Flood readiness* is an ability to react within the effective warning time.

Flood fringe areas: the remaining area of flood prone land after floodway and flood storage areas have been defined.

Flood liable land: is synonymous with flood prone land (ie) land susceptible to flooding by the probable maximum flood (PMF) event. Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level, as indicated in the 1986 Floodplain Development Manual (Ref. 11) (see flood planning area).

Floodplain: area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.

Flood planning area: the area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Floodplain Development Manual (Ref. 11).

Flood risk: potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in the Floodplain Management Manual is divided into 3 types, existing, future and continuing risks. They are described below.

existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.

future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

Flood storage areas: those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

Floodway areas: those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

Freeboard: a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted flood planning level and the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such and wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as "greenhouse" and climate change. Freeboard is included in the flood planning level.

Hazard: a source of potential harm or a situation with a potential to cause loss. In relation to the Floodplain Management Manual (Ref. 1), the hazard is flooding which has the potential to cause damage to the community. (Definitions of high and low hazard categories are provided in Appendix G of Floodplain Management Manual).

Hydraulics: term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

Indirect Damage: damage caused by flooding though not directly eg. loss of trade, cost of alternative accommodation or loss of wages.

Intangible Damage: damage that occurs but is difficult to quantify eg. increased ill-health in the community or disruption to community life.

Let-out-level: the water level in the lagoon used by Gosford City Council to initiate a mechanical break-out of the beach berm.

Mainstream flooding: inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

Mathematical/computer models: the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

Modification measures: measures that modify either the flood, the property or the response to flooding.

Peak Discharge: the maximum discharge occurring during a flood event.

Phreatic Line: free water surface line reached within the beach berm.

Probable Maximum Flood (PMF): the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP): the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to the estimation of the probable maximum flood.

Probability: a statistical measure of the expected chance of flooding (see annual exceedance probability).

Reduced Level (RL): a measured height above Australian Height Datum.

Risk: chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

Runoff: the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.

Sub-critical flow: flow in the channel is characterised by "mild" conditions featuring low velocities and reasonable depths.

Super-critical flow: flow in the channel is characterised by "unstable" conditions featuring high velocities and low depths.

Tangible Damage: damage that can be quantified in monetary terms.

Top Water Level (TWL): water level in the lagoon referenced by Council's opening records as existing prior to lagoon break-out.

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REFERENCES

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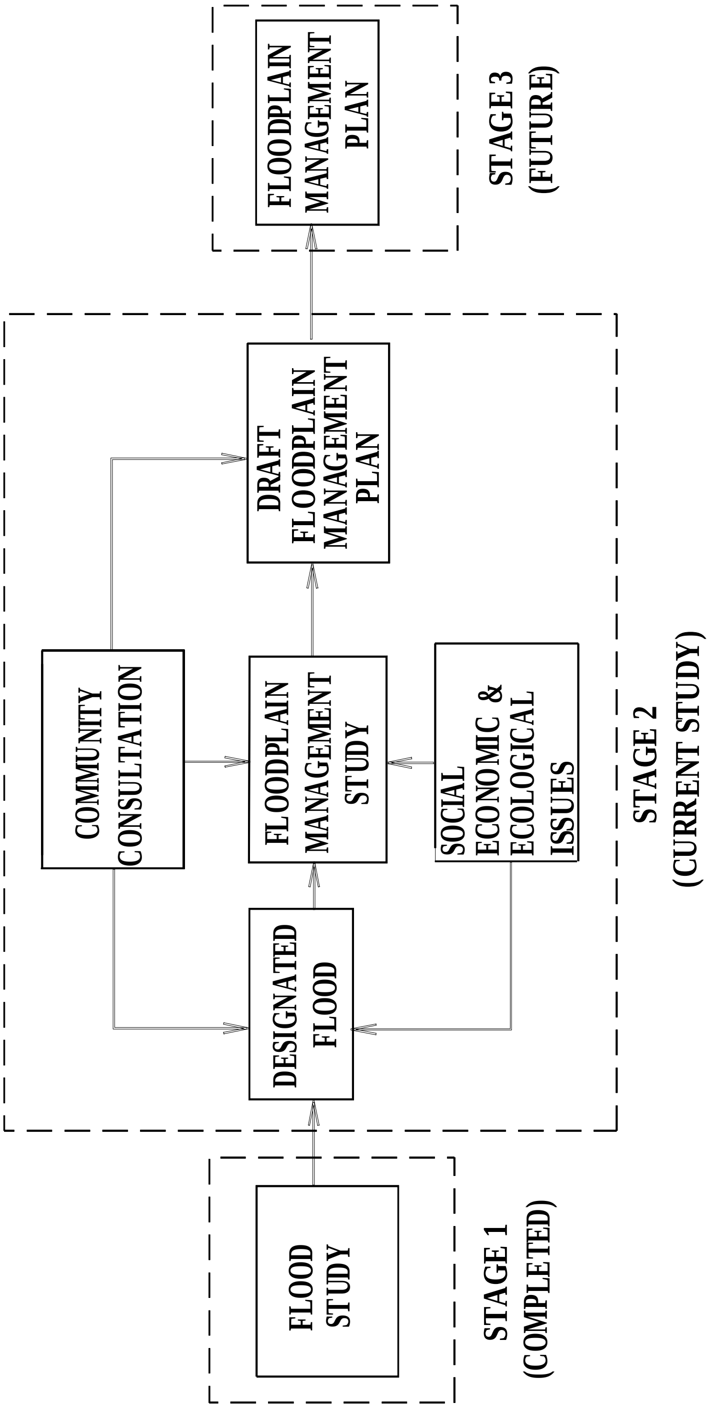
FIGURES

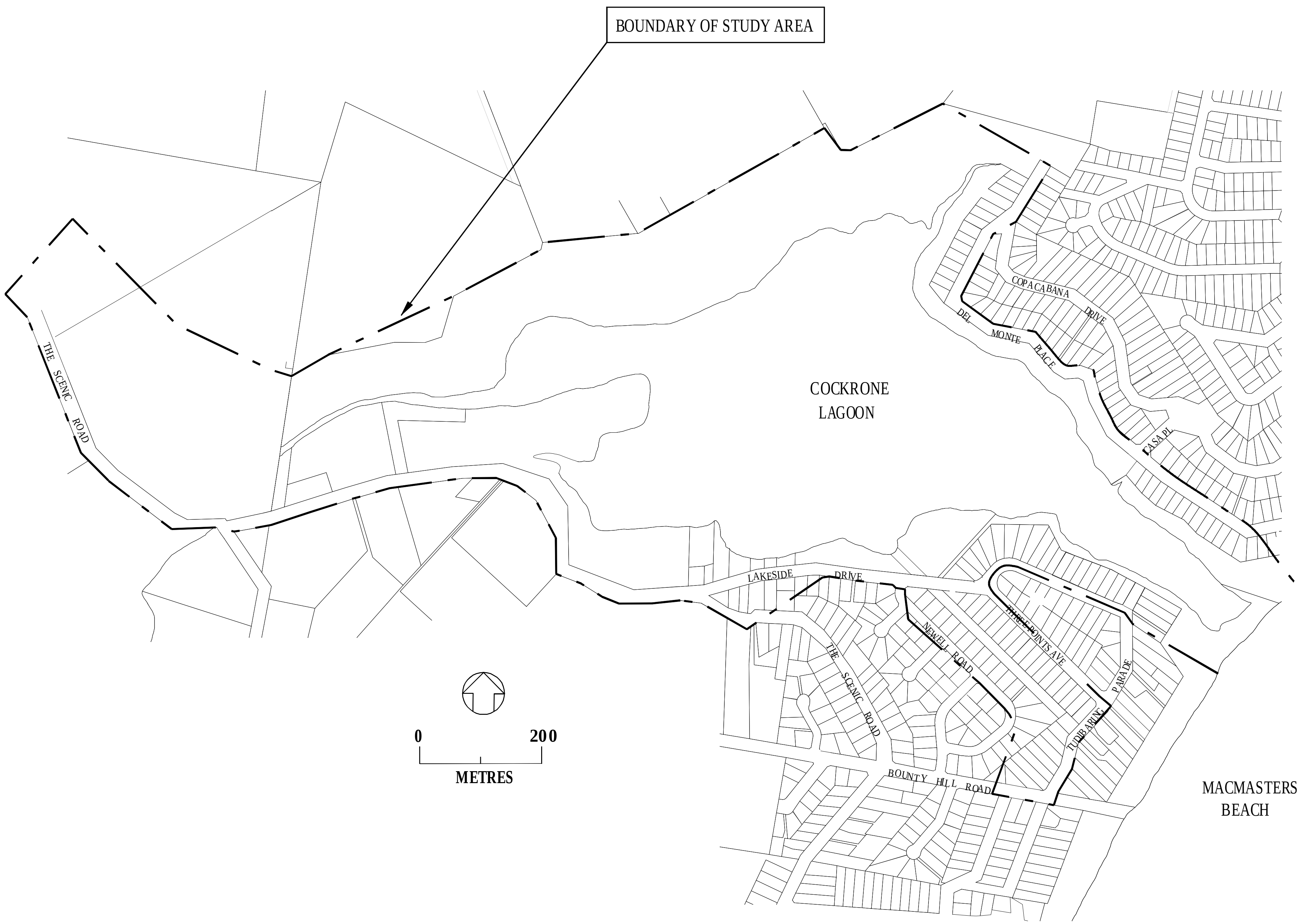
COCKRONE LAGOON
FLOODPLAIN MANAGEMENT STUDY



21 JULY 2003
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_1-1_PROCESS

FIGURE 1.1
FLOODPLAIN MANAGEMENT PROCESS

COCKRONE LAGOON
FLOODPLAIN MANAGEMENT STUDY



21 JULY 2003
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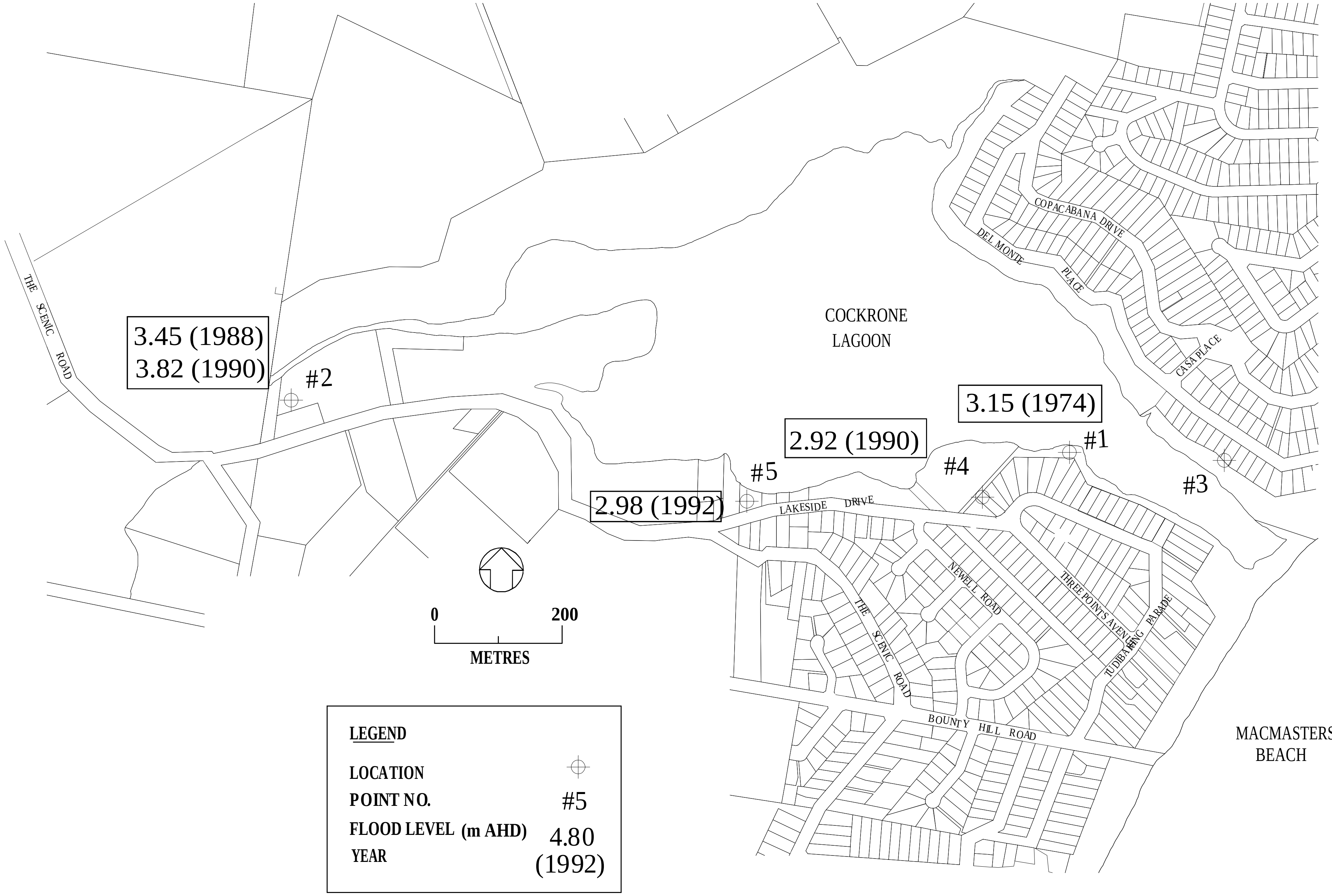
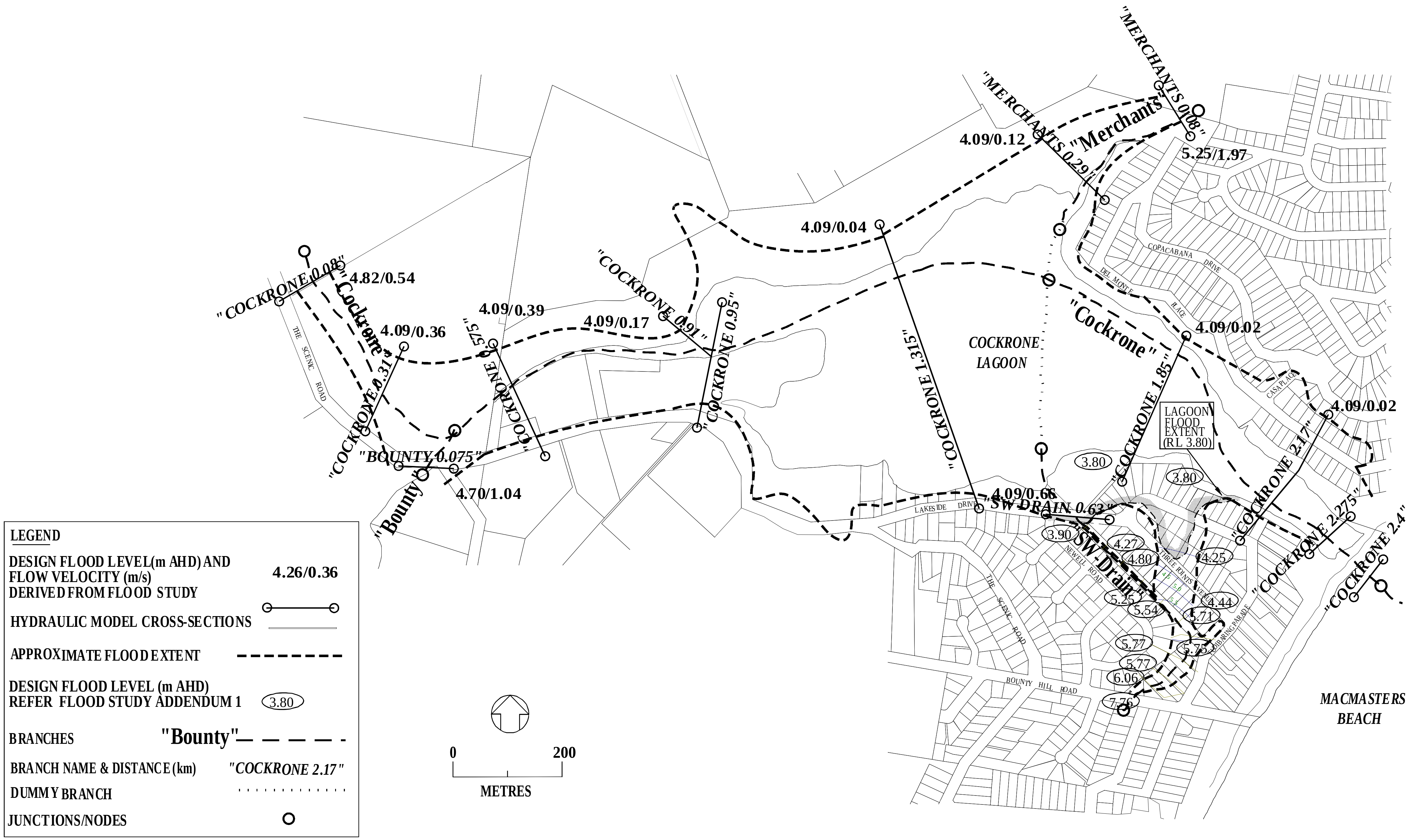
FIG REF: 93026_CFMS_1-2_SA

FIGURE 1.2
STUDY AREA



21 JULY 2003
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_2-1_REC FL LEVELS

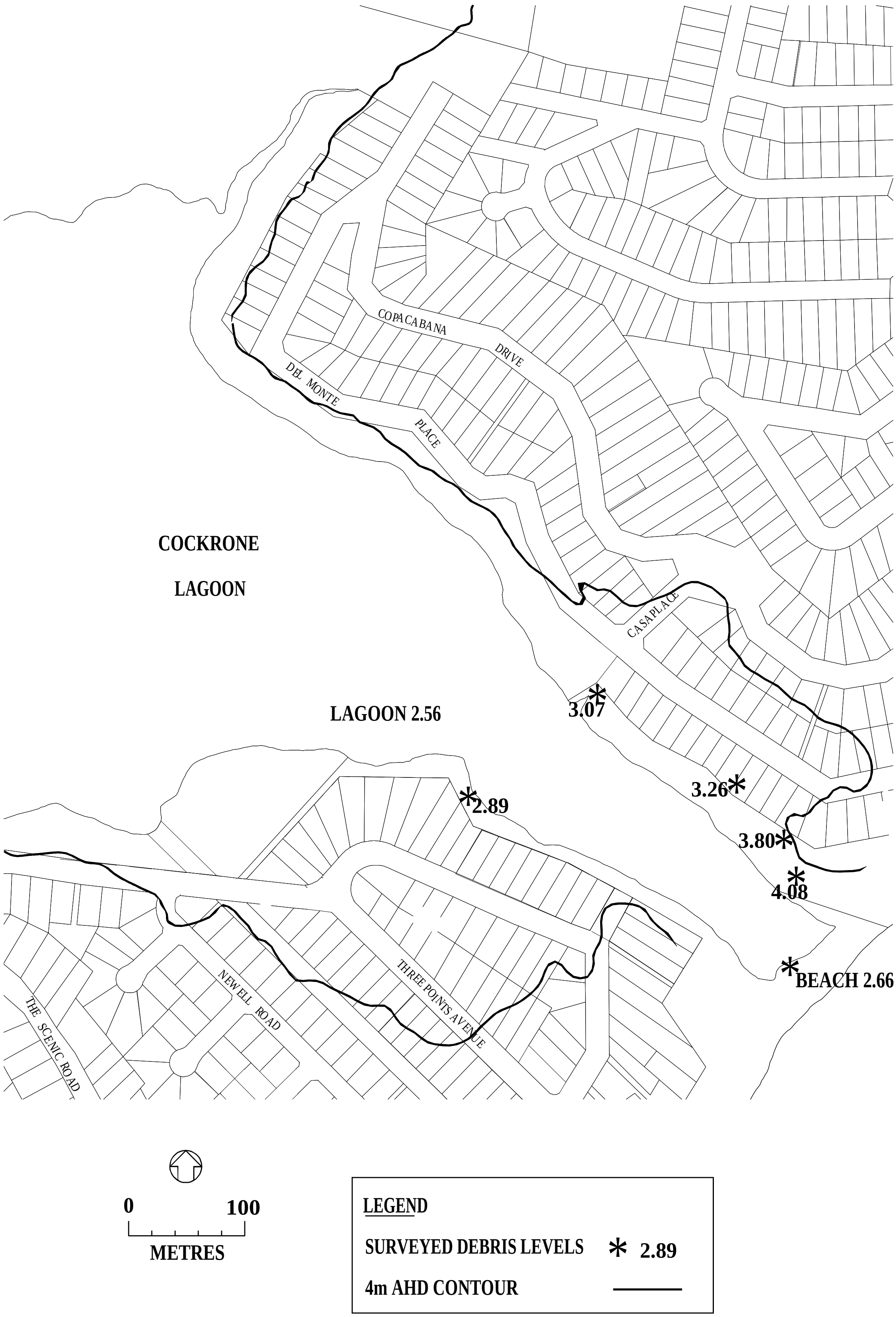
FIGURE 2.1
RECORDED FLOOD LEVELS



26 NOV 2003, KC
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_2-2_1%AEP

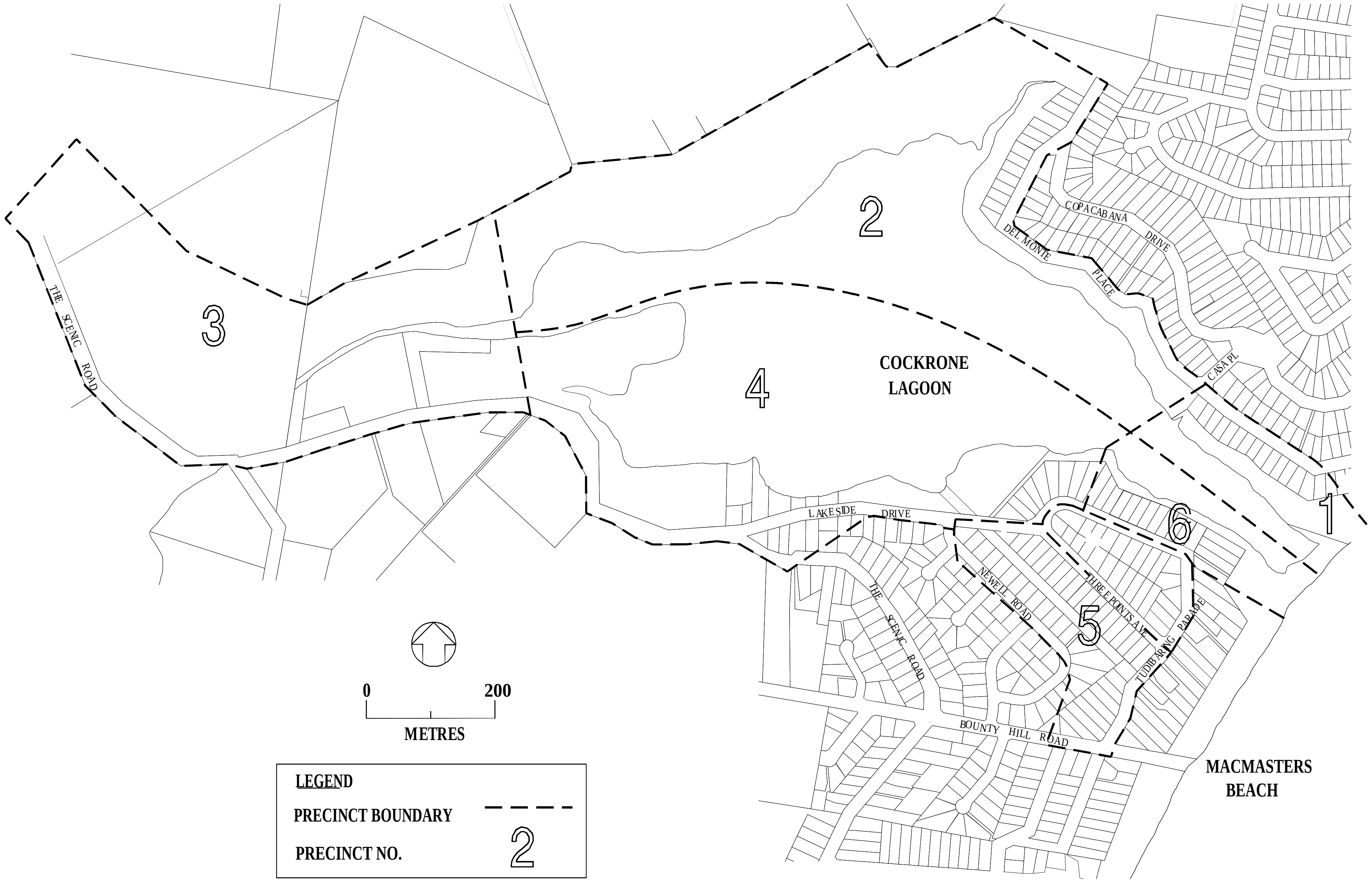
FIGURE 2.2
1% AEP DESIGN FLOOD LEVELS AND EXTENTS

COCKRONE LAGOON
FLOODPLAIN MANAGEMENT STUDY



21 JULY 2003
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_2-3_83 STORM LEVELS

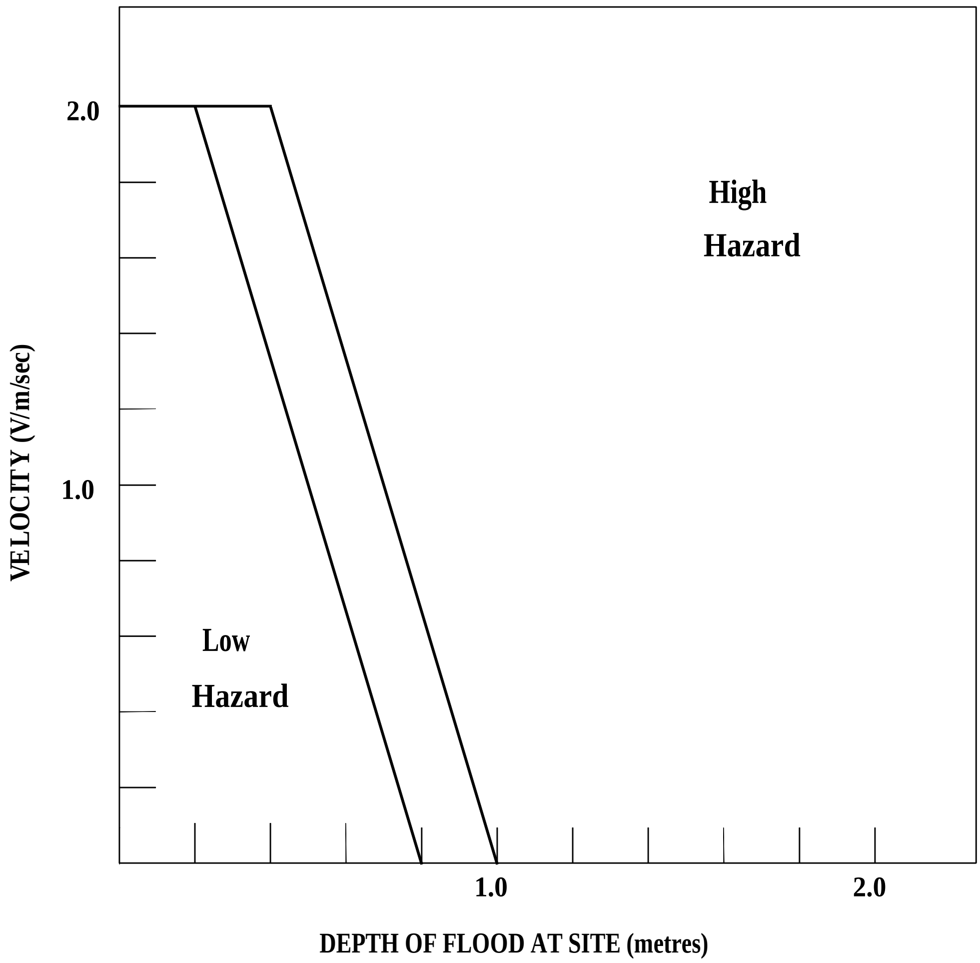
FIGURE 2.3
STORM LEVELS JULY 1983



21 JULY 2003
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_2-4_FL PRECINCTS

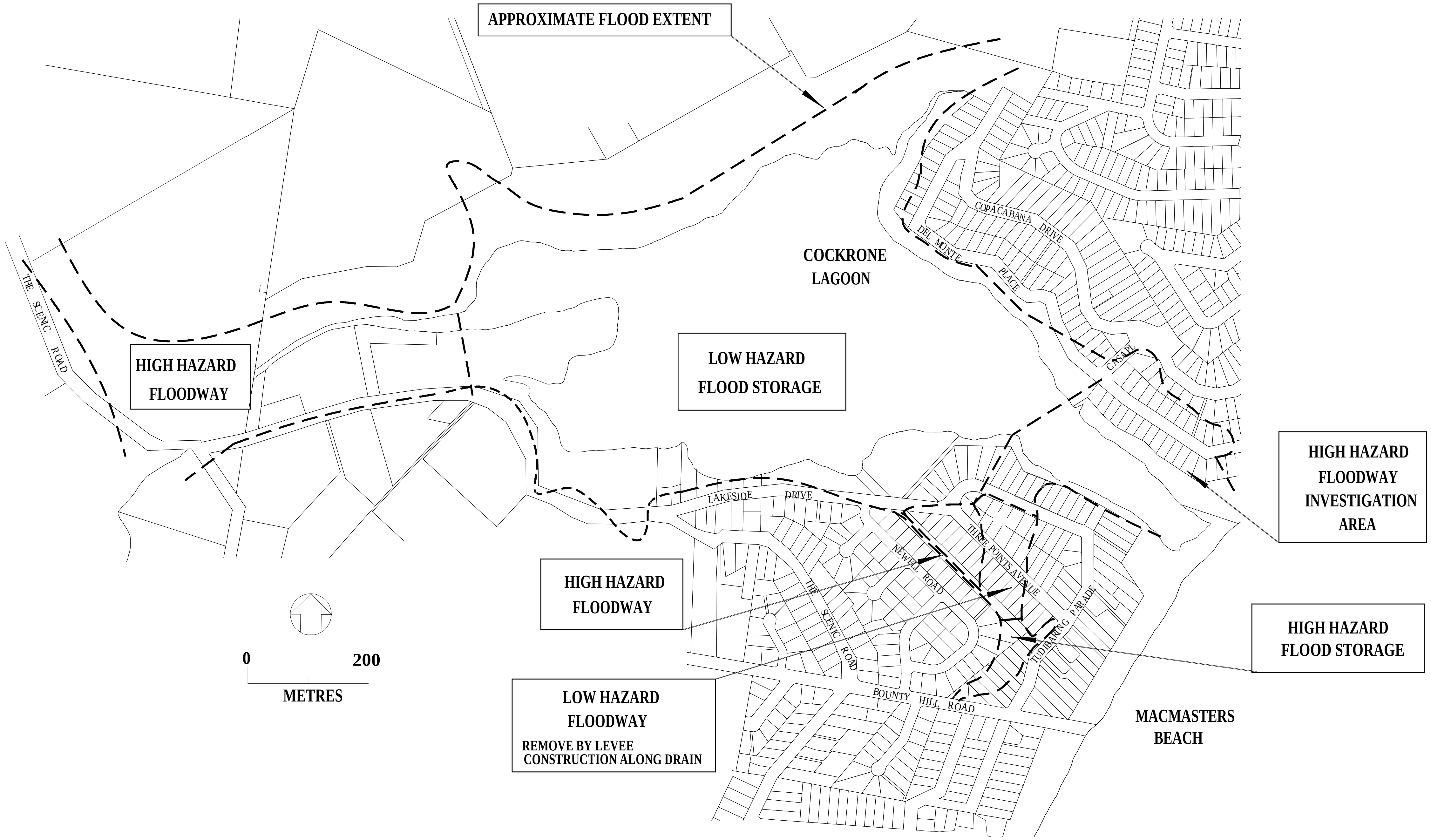
FIGURE 2.4
FLOOD EFFECTED PRECINCTS

COCKRONE LAGOON
FLOODPLAIN MANAGEMENT STUDY



21 JULY 2003
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_2-5_HAZ

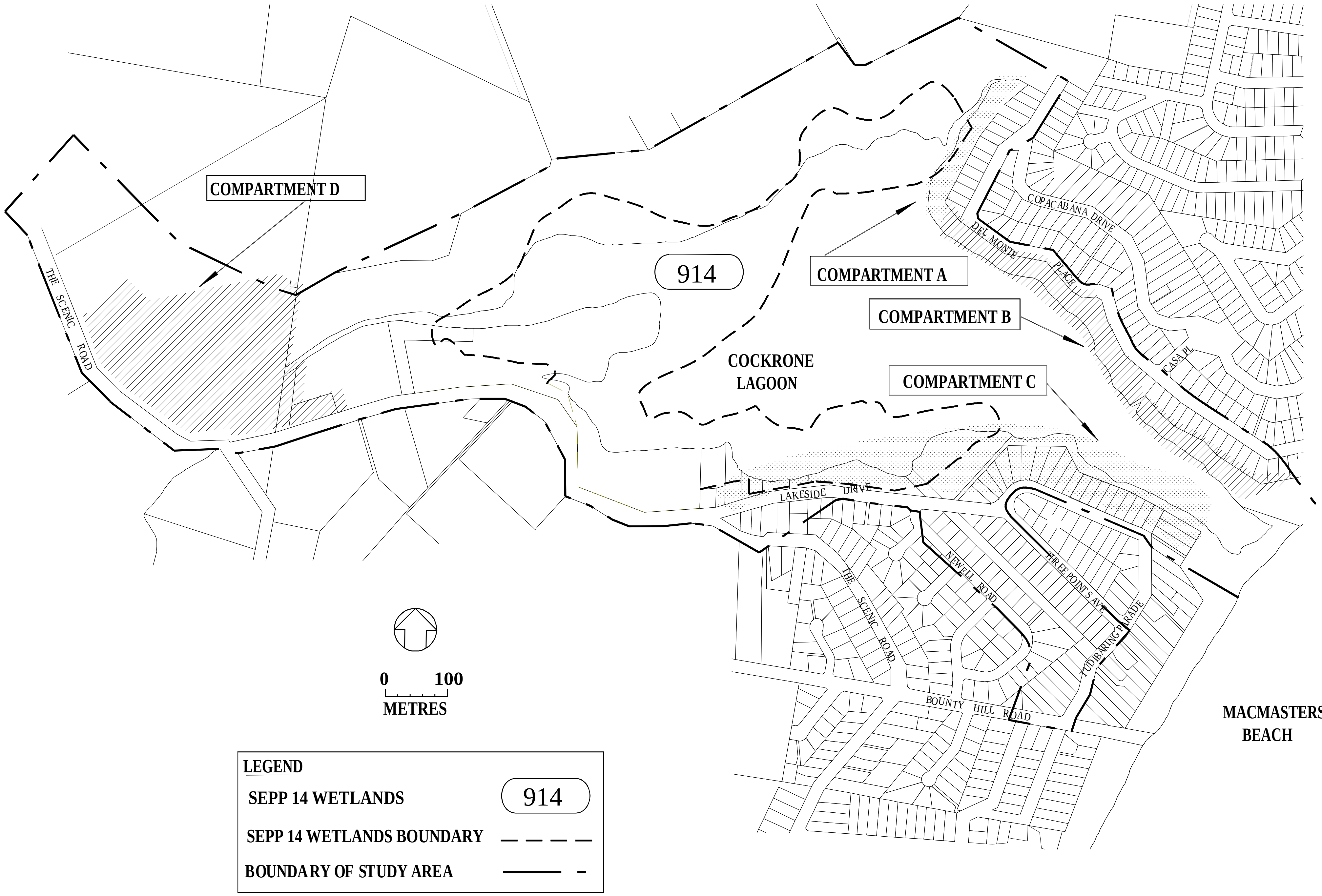
FIGURE 2.5
HAZARD DIAGRAM



11 AUG 2003, KC
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_2-6_HAZ-CLASS

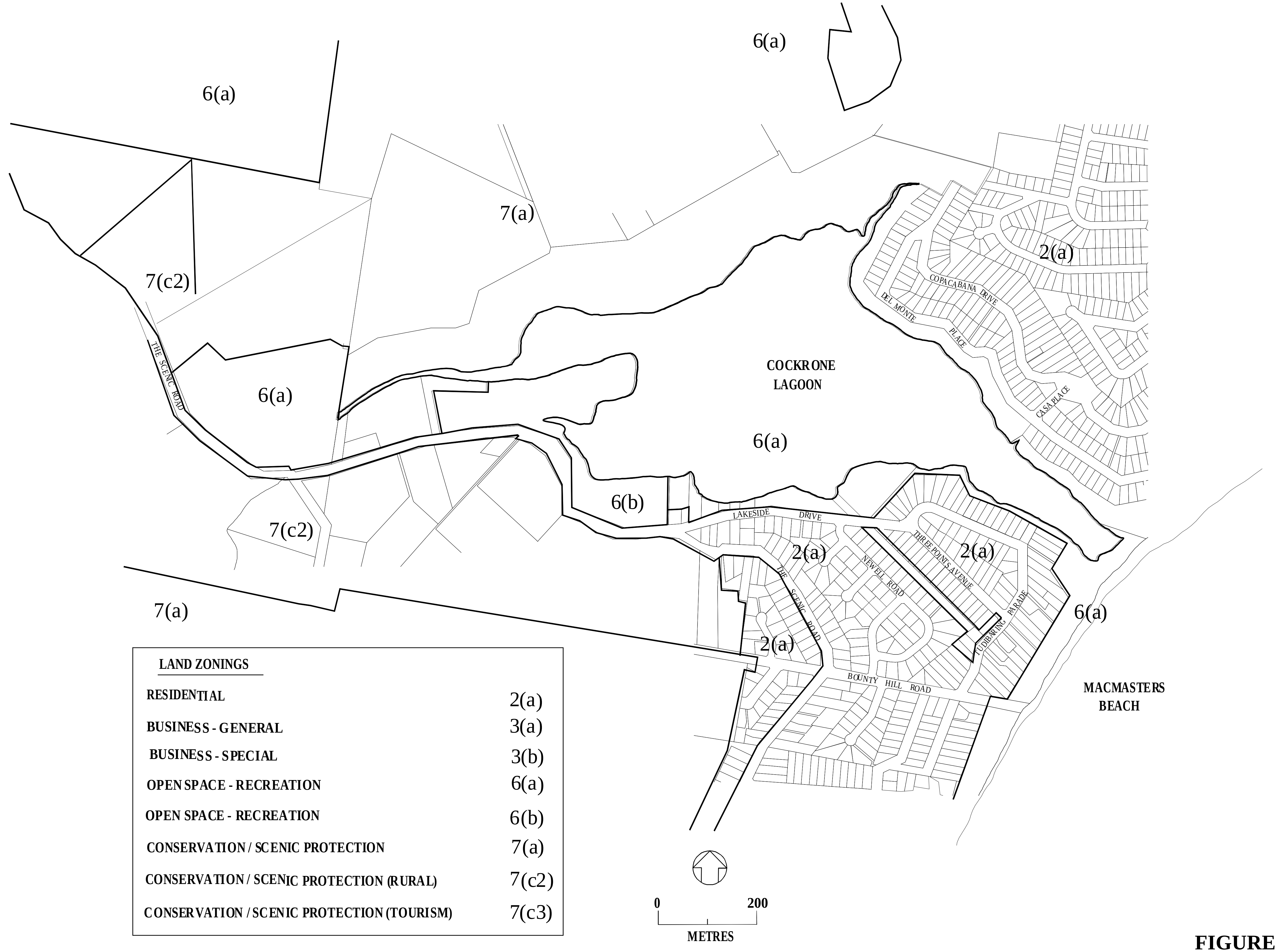
FIGURE 2.6
HAZARD CLASSIFICATION
COCKRONE LAGOON

COCKRONE LAGOON
FLOODPLAIN MANAGEMENT STUDY



21 JULY 2003
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_3-1_LANDSCAPE

FIGURE 3.1
LANDSCAPE COMPONENTS



21 JULY 2003
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_3-2_LAND ZONES

FIGURE 3.2
CURRENT LAND ZONINGS

COCKRONE LAGOON
FLOODPLAIN MANAGEMENT STUDY

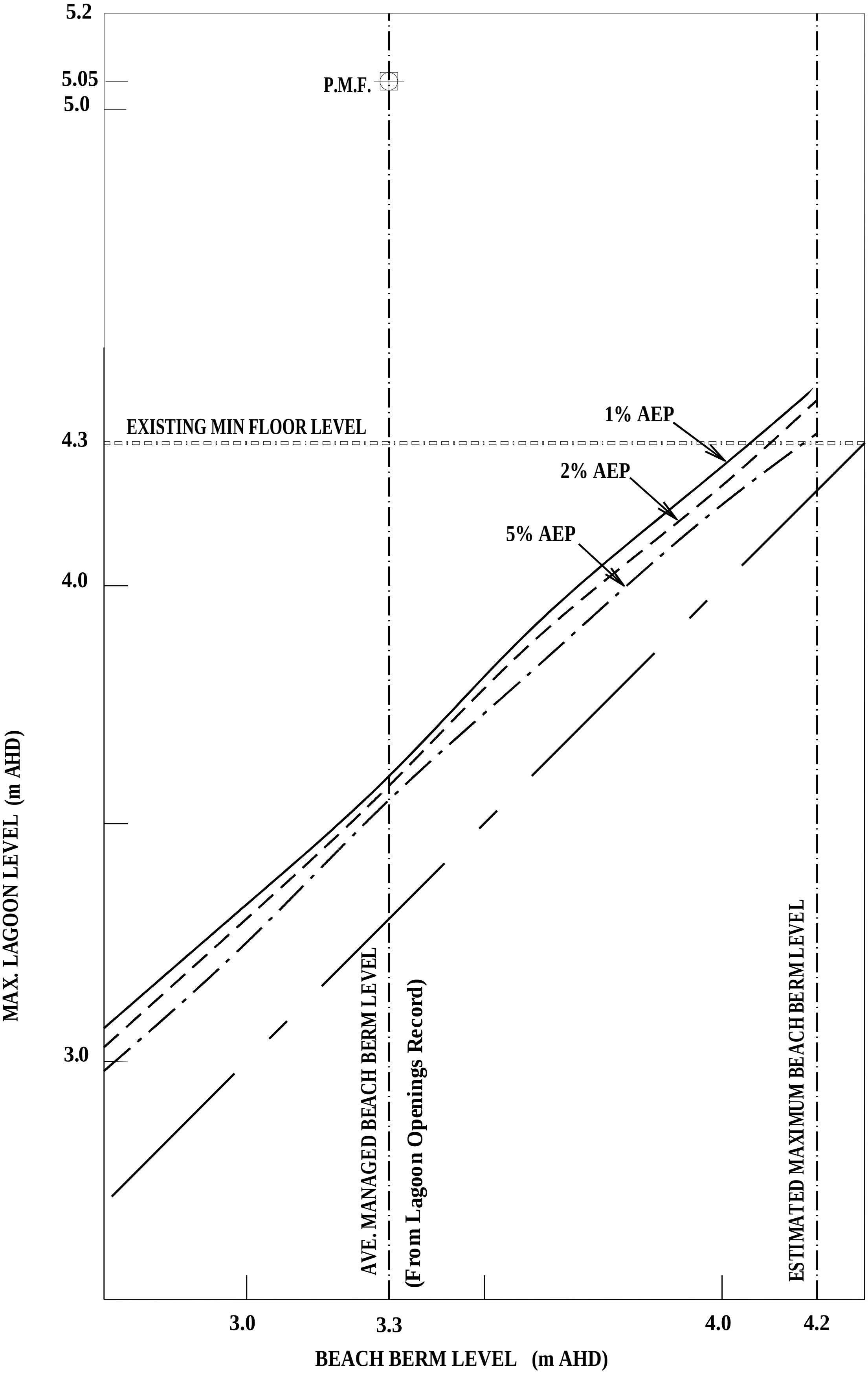
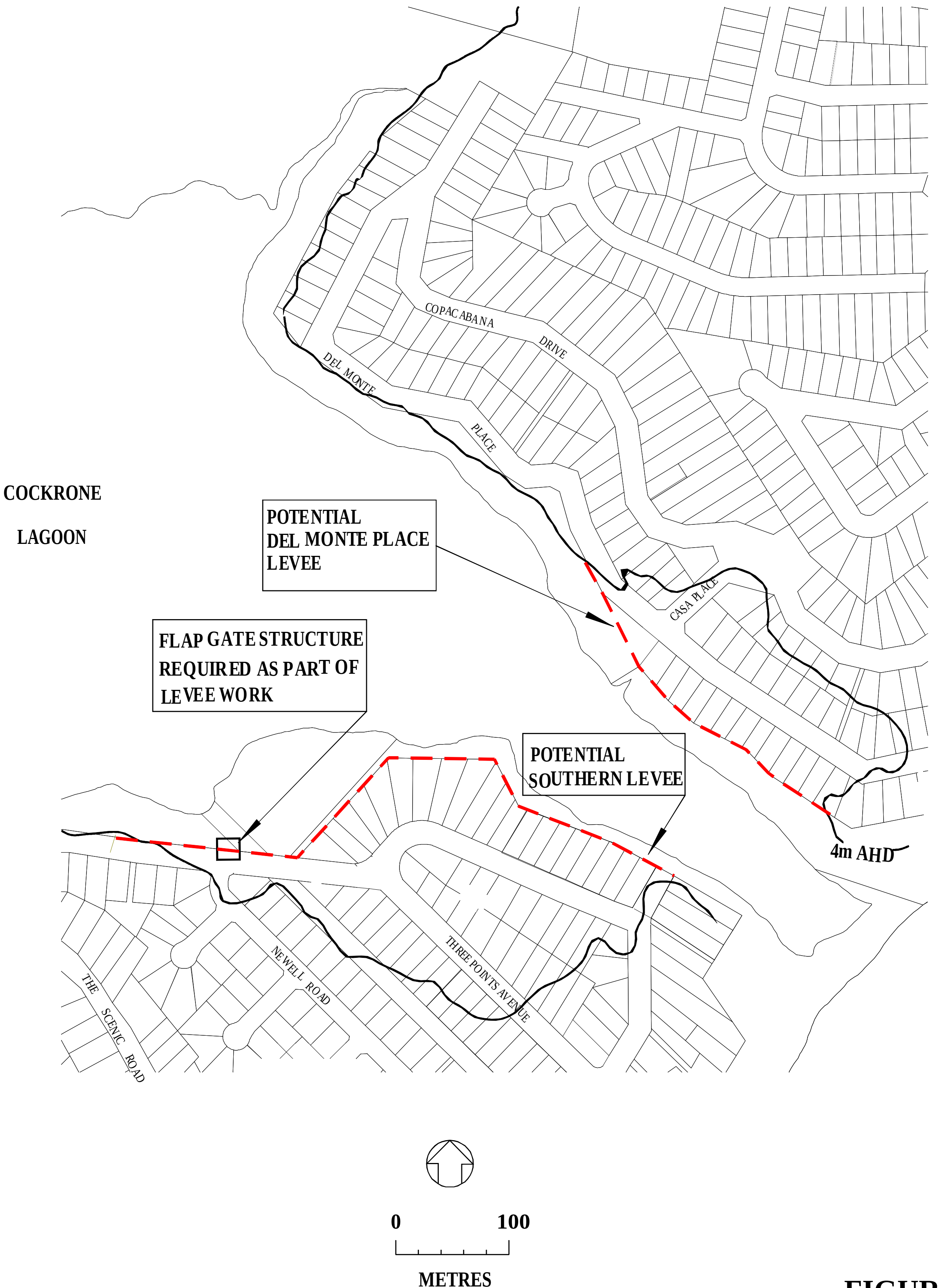


FIGURE 5.1
DESIGN FLOOD ENVELOPES

21 NOV 2003, KC
DISK REF: 93026_CFMS
FIG REF: 93026_CFMS_5-1_DES FL ENV

COCKRONE LAGOON
FLOODPLAIN MANAGEMENT STUDY



7 NOVEMBER 2007
DISK REF: 93026_CFMS
FIG REF:93026_CFMS_5-2_FL LEVEES_V2

FIGURE 5.2
POTENTIAL FLOOD LEVEES

APPENDICES

APPENDIX A

LIST OF HOUSES POTENTIALLY SUITABLE FOR HOUSE RAISING

TABLE A-1

Houses with Floor Levels less than RL 4.3 m AHD and Potentially Suitable for House Raising

Precinct	Street No.	Street Name	Existing Floor Level (m AHD)
4	49	Lakeside Drive	3.53
4	41	Lakeside Drive	3.79
4	11	Three Points Avenue	3.80
4	7	Three Points Avenue	3.91
4	45	Lakeside Drive	3.94
4	47	Lakeside Drive	3.95
4	46	Lakeside Drive	4.12
4	44	Lakeside Drive	4.17