

# **Great Mackerel Beach Flood Study**

**Report Prepared For**

**Pittwater Council**

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## FOREWORD

The State Government's Flood Prone Lands Policy is directed towards providing solutions to existing flood problems in developed areas utilising ecologically positive methods wherever possible and ensuring that new development is compatible with the flood hazard and downstream impacts are minimised.

Under the policy, the management of flood prone land is the responsibility of Local Government. To achieve its primary objective, the policy provides for State Government's financial assistance to Councils for flood mitigation works to alleviate existing flooding problems. The policy also provides for State Government's technical assistance to Councils to ensure that the management of flood prone land is consistent with the flood hazard and that future developments do not create or increase flooding problems in flood prone land.

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

- |                                     |                                                                                                                                                                                                                               |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Flood Study                      | Determines the nature and extent of the flood problem.                                                                                                                                                                        |
| 2. Floodplain Risk Management Study | Evaluates management options for the floodplain in respect of both existing and proposed development.                                                                                                                         |
| 3. Floodplain Risk Management Plan  | Involves formal adoption by Council of a plan of management for the floodplain.                                                                                                                                               |
| 4. Implementation of the Plan       | Implementation of works and measures such as construction of flood mitigation works to protect existing development, use of environmental planning instruments to ensure new development is compatible with the flood hazard. |

The Great Mackerel Beach Flood Study is the first stage of the management process for the Great Mackerel Beach catchment. This study, which has been prepared for Pittwater Council by Cardno Lawson Treloar Pty Ltd, defines flood behaviour under existing catchment conditions.

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## EXECUTIVE SUMMARY

A flood study of the Great Mackerel Beach catchment has been undertaken to define the nature and extent of flooding in the area for a range of design rainfall events. The study has been carried out for existing catchment conditions.

Great Mackerel Beach catchment has an area of 263.5 hectares. It is a small beach on the western foreshore of Pittwater, with only practical access by boat. There are approximately 130 residential properties in the area. The catchment is mostly forested and drains into Mackerel Beach Creek (herein referred to as the creek). In its lower reaches the creek forms a lagoon behind the beach dune that is commonly brackish. The lagoon area is vegetated by dense aquatic and riparian vegetation. The lagoon discharges into Pittwater estuary via a berm at the northern end of Great Mackerel beach.

In the past, flooding in the area has caused property damage and posed a high hazard to the residents living close to the major drainage channels in the area. Flood waters from the catchment also accumulate in residential areas and roadways. The area has experienced major flood events in 1974, 1987, 1992, 1998 and 2003.

### *Aim*

The aim of the Great Mackerel Beach Flood Study is to conduct a comprehensive technical investigation of the flood behaviour in the catchment and to define the nature and extent of the flood risk through three main components:

- Determination of flood discharges for floods of various severity (hydrological aspects);
- Determination of water levels and velocities (hydraulic and hazard aspects); and
- Assessment of the lagoon entrance and preparation of a management assessment of the entrance.

### *Community and Stakeholder Consultation*

A questionnaire was distributed to the residents of the Great Mackerel Beach floodplain in order to obtain flood related information such as whether the residents have experienced flooding, the nature and depth of flooding and the timing of such floods. The residents were also asked whether they could identify any historic flood levels.

Residents who had experienced flooding, as identified by the returned questionnaires, were contacted and asked if they could identify the flood level on their property or in the floodplain. Two residents had a good recollection of the November 1987 flood and were able to identify flood levels which were later surveyed.

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## *Methodology*

Estimation of flooding behaviour was undertaken by developing mathematical models to simulate the hydrologic and hydraulic aspects of flooding. The hydrological modelling package RAFTS (XP Software, 2000) was utilised to determine catchment runoff and for routing flows through the catchment. Predicted hydrographs from RAFTS were then input to the coupled one dimensional two dimensional (1D/2D) hydraulic model SOBEK (WJDELFT, 2004) for the determination of peak flood level, velocity and discharge for various design rainfall events. The design rainfall events investigated for this study were 1%, 2%, 5% and 20% Annual Exceedence Probability (AEP) together with the Probable Maximum Flood (PMF).

Flood levels within the catchment for the storm event of November 1987 were available for calibration of the hydraulic model. This event was chosen on the basis of flood level information obtained from the resident survey and the available rainfall data. The rainfall event resulted in a peak flood flow similar to the 1%AEP flood flow and flood levels of the order of the observed 1%AEP flood levels.

Design rainfall intensities and temporal patterns for the required rainfall events were obtained from Australian Rainfall and Runoff (AR&R). The Probable Maximum Precipitation (PMP) was estimated using the Generalised Short Duration Method recommended by the Bureau of Meteorology.

## *Flood Situation*

The model results reflect the observed flooding behaviour in Great Mackerel Beach. Properties adjacent to Monash Avenue and those on the valley floor are the most flood-affected properties in the area. Flooding in the area is primarily controlled by backwater effects (such as storage and ponding) as a result of the restricted outlet conditions, caused by the sand dune and berm height along the ocean beach.

## *Findings*

Limits of predicted flood extents for the 1%, 2%, 5% and 20% AEP events and the PMF are provided on a cadastral plan (Figures 7.1 - 7.5). Tabulated modelling results, which include predicted flood levels, velocities and flows at a number of locations in the floodplain, are also provided.

Provisional flood hazard has been determined for the 1%, 2%, 5% and 20% AEP events and the PMF. The hazard categorisation has been provided on the cadastral plan of the study area.

The Floodplain Development Manual (NSW Government 2005) defines flood prone land to fall within three hydraulic categories – floodway, flood storage and flood fringe. The hydraulic categories for the 1%, 2%, 5% and 20% AEP events and the PMF have been provided on the cadastral plan of the study area (Figures 7.17 - 7.21).

The impact of varying significant model parameters has been assessed by carrying out a sensitivity analysis. Model parameters such as bed and over bank roughness, inflow hydrographs, downstream boundary conditions and the effect of culvert blockage have been checked for sensitivity.

This study has produced flood behaviour information and provides a management tool in the form of a hydraulic model for future assessment of floodplain management options in the study area.

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## GLOSSARY OF TERMS

|                                            |                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Annual Exceedence Probability (AEP)</b> | Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be relatively large. |
| <b>Australian Height Datum (AHD)</b>       | A common national plane of level corresponding approximately to mean sea level.                                                                                                                                                                                                                                                                                              |
| <b>Cadastre, cadastral base</b>            | Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.                                                                                                                                                                                                                                               |
| <b>Catchment</b>                           | The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.                                                                                                                                                                                                                      |
| <b>Design Flood</b>                        | A significant event to be considered in the design process; Various works within the floodplain may have different design events: some roads may be designed to be overtopped in the annual flood event.                                                                                                                                                                     |
| <b>Development</b>                         | The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.                                                                                                                                                                                                                                             |
| <b>Discharge</b>                           | The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.                                                                                                                                                            |
| <b>Flash Flooding</b>                      | Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain, which causes it.                                                                                                                                                                       |
| <b>Flood</b>                               | Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river or drainage system.                                                                                                                                                                                                                                                |
| <b>Flood Hazard</b>                        | Potential risk to life and limb caused by flooding.                                                                                                                                                                                                                                                                                                                          |
| <b>Flood Liable Land</b>                   | Land inundated by designated flood events (DFE's) and which is subject to the provisions of a floodplain management plan. Note that the extent of flood liable land varies with the DFE.                                                                                                                                                                                     |
| <b>Flood Prone Land</b>                    | Land susceptible to inundation by the probable maximum flood (PMF) event, ie. The maximum extent of flood liable land. Floodplain management plans may encompass all flood prone land, rather than being restricted to land subject to designated flood events.                                                                                                              |
| <b>Floodplain</b>                          | Area of a river valley adjacent to the river channel, which is subject to inundation by the probable maximum flood event.                                                                                                                                                                                                                                                    |
| <b>Floodplain Management Measures</b>      | The full range of techniques available to floodplain managers.                                                                                                                                                                                                                                                                                                               |

|                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Floodplain Management Options</b>          | The measures which might be feasible for the management of a particular area.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Flood Storages</b>                         | Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Floodway Areas</b>                         | 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 significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas. |
| <b>Geographical Information Systems (GIS)</b> | A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Hydraulics</b>                             | The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Hydrograph</b>                             | A graph that shows how the discharge changes with time at any particular location.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Hydrology</b>                              | The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Integrated Survey Grid (ISG)</b>           | ISG is a global co-ordinate system based on a Transverse Mercator Projection. The globe is divided into a number of zones, with the true origin at the intersection of the Central Meridian and the Equator.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Mainstream Flooding</b>                    | Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Management Plan</b>                        | A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, problems, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.                                                                                                                                                                                                                                                                                                                                          |
| <b>Mathematical/ Computer models</b>          | The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

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|                               |                                                                                                                                                                                                                                                          |
|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Peak Discharge</b>         | The maximum discharge occurring during a flood event.                                                                                                                                                                                                    |
| <b>Probable Maximum Flood</b> | The flood calculated to be the maximum that is likely to occur.                                                                                                                                                                                          |
| <b>Probability</b>            | A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Annual Exceedence Probability.                                                                                                                   |
| <b>Pluviometer</b>            | Rainfall gauge which records the time history of rainfall.                                                                                                                                                                                               |
| <b>Runoff</b>                 | The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.                                                                                                                                                      |
| <b>Stage</b>                  | Equivalent to 'water level'. Both are measured with reference to a specified datum.                                                                                                                                                                      |
| <b>Stage Hydrograph</b>       | A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.                                                                                                                                      |
| <b>Stormwater Flooding</b>    | Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow. |
| <b>Topography</b>             | A surface which defines the ground level of a chosen area.                                                                                                                                                                                               |

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## 1. INTRODUCTION

Great Mackerel Beach is a small coastal catchment on the western shore of Pittwater, in the Sydney northern beaches area. The Great Mackerel Beach area is subject to influences of both catchment flooding and wave action and tidal inundation from Pittwater Estuary. The catchment is mostly forested and drains into Great Mackerel Beach Creek (herein referred to as the creek). The lower reaches of the creek forms a lagoon behind the dune that holds brackish water and discharges to the ocean via a berm at the northern end of Great Mackerel Beach.

The catchment contains approximately 130 properties near the beach front and has a total area of 263.5 ha.

Great Mackerel Beach has experienced major flood events in 1974, 1987, 1992, 1998 and 2003. Flooding in the area has caused property damage, hinders property access and poses a high hazard to the residents living close to the major drainage channels in the area.

This has prompted Pittwater Council, through the Land Water and Coastal Committee, to undertake a flood study including a section on management of entrance dynamics in the event of flooding, in the area extending from the most upstream residential dwelling through to the near shore zone. Floodplain management is part of the State Government's program to manage major flood impacts and hazards in floodplains, in accordance with the State Government's Floodplain Development Manual (2005).

The aims of the flood study were to:

- Determine flood discharges for floods of various severity (hydrological aspects);
- Determine water levels and velocities (hydraulic and hazard aspects), and
- Assessment of the lagoon entrance and preparation of a management assessment of the entrance.

The various components of the flood study can be grouped together in three stages. Firstly, all available data was compiled for the study. This involved the collection of available historical rainfall and flood level data. Historical flood data was gathered through an extensive resident survey and community consultation. Secondly, a full hydrologic investigation was carried out for the catchment using a hydrologic computer model. Thirdly, a hydraulic computer model of the major drainage paths in the catchment was established and calibrated using the historical flood level data. The hydraulic model was then used with design rainfall conditions to simulate flood behaviour in the catchment.

The hydraulic model developed in this study simulates flooding which may occur under existing catchment conditions. The model may be used to investigate various management and flood mitigation options and can assist in defining long term Floodplain Management Strategies.

In the evaluation of design flood behaviour for Great Mackerel Beach the term Average Recurrence Interval (ARI) is the more technically correct term for the design event evaluation (as the events have been derived from an assessment of rainfall runoff relationships where the ARI concept is utilised). For this report the term Annual Exceedance Probability (AEP) is utilised in the place of ARI to be consistent with the current range of Council's policies and mapping. The AEP concept is technically only used for flood studies where a flood frequency approach has been utilised (i.e. where there is a long history of stream gauge data where an annual or partial series can be assessed). Australian Rainfall Runoff (Pilgrim, 1999) provides further details of the specific differences between the approaches.

Additionally, the AEP concept has been adopted to further aid community understanding in order to reduce the misconception commonly associated with the term recurrence interval (eg that the 100 year event can only occur once in 100 years) and move to a more risk-based understand that essentially such an event has a 1% chance of occurrence in any one year.

## **2. BACKGROUND**

### **2.1 CATCHMENT DESCRIPTION**

The study area is located on the western foreshore of Pittwater in the Sydney Northern Beaches area (Figure 2.1). The 263.5 ha catchment is predominantly covered by the Ku-ring-gai National Park with residential properties located on the floodplain and immediately adjacent escarpment to the south of the floodplain.

The creek is located on the northern edge of the floodplain and in parts forms a lagoon behind the dune that holds brackish water and is vegetated by dense aquatic and riparian vegetation. The lagoon discharges into Pittwater via a berm at the northern end of Great Mackerel Beach (refer to Figure 2.2 for the catchment layout). The elevation varies from above 90 mAHD in the upper reaches of the catchment, down to mean sea level (0 mAHD) at the outlet to the ocean.

The residential area has no underground stormwater drainage system. Drainage is provided by overland flow to Mackerel Beach Creek. Eight private bridges have been constructed at various locations across the creek. Inspections indicate that five of these are likely to be unstable in a flood event.

### **2.2 DATA**

Data has been obtained from a number of sources and includes information required for input to the hydrologic and hydraulic models, together with information required for verification of model results and the adequate representation and presentation of those results.

#### **2.2.1 Previous Studies/Reports**

No previous flood studies for the Mackerel Beach catchment have been completed.

Related documents that were reviewed include:

- Pittwater Estuary Processes Study (Lawson and Treloar, 2002)
- Pittwater Draft Management Plan (WBM, 2003);
- Coastal Processes Study – Resolute Beach to the Basin (Kulmar, 1985);
- Mackerel Beach: Estimates of Dune Recession & Nourishment Demands Due to Raised Sea Levels & Sand Budget Variation (Cowell, 1992); and
- Advisory Report on Management of Beach Erosion at Mackerel Beach (Cowell, 1989).

#### **2.2.2 Survey Information**

Survey data was obtained to develop the hydraulic model for the study area. A survey brief was prepared to obtain survey data for parts of the study area to identify topographical features that influence flood behaviour.

The survey for the floodplain was completed by a council surveyor under the guidance of an engineer from Cardno Lawson Treloar in November 2003 and January 2004 (See Appendix A). The following survey details were obtained within the catchment:

- Cross-section survey information to enable definition of flow channels, significant overland flow paths and floodplain storage areas.
- Flow control structures such as bridges.

The survey was carried out to Australian Height Datum (AHD). All level data in this report is based on this datum.

Survey data for the area offshore of the beach and away from the floodplain (down to -2 m AHD) was derived from available charts of bathymetry of Pittwater outlined in Lawson and Treloar (2002).

The drainage system layout, modelled hydraulic structures and surveyed cross sections are shown on Figure 2.3.

A complete data set of survey data used in the study is provided in Appendix A.

### **2.2.3 Historical Storm Rainfall Data**

A pluviograph station is located nearby in Warriewood and the pluvio trace from this station for the 1987 event was obtained from Sydney Water. The location of the station is presented in Figure 2.4.

The storm event of November 1987 was used for model calibration, data was sourced from the pluviograph station and from the returned resident surveys (refer to section 3). The periods where flooding was identified by the residents was cross-referenced with historic rainfall data to determine the date of the flood and which floodmarks were relevant to the study.

The pluviograph trace from the Warriewood station was used to disaggregate the daily rainfall from the West Head station for use in the RAFTS model. The pluviograph is shown in Appendix B.

In addition, daily rainfall data was obtained from a gauge (West Head, #66143) within the catchment monitored by the Bureau of Meteorology (BOM). The station location is shown in Figure 2.4. The BOM data was used to define the rainfall isohyetal pattern for the above storm event. The isohyetal map for the storm is presented in Figure 2.4. This map shows the rainfall totals for the three days up to and including 12 November 1987.

The isohyetal pattern for the November 1987 storm event suggests that the epicentre of the storm event was centred around the Mackerel Beach catchment area, with daily rainfall totals in excess of 270mm at West Head.

## 2.2.4 Recorded Flood Levels

As described in Section 3, a questionnaire was distributed to the residents living in the floodplain of Great Mackerel Beach to collect historical flood information in November 2003. The residents who had experienced flooding as identified by the returned questionnaires were contacted and asked if they could identify the flood level on their property or in the floodplain. Two residents had a good recollection of November 1987 flood and were able to identify the flood levels. These levels were surveyed and are provided in Table 2.2. This information is also provided on a plan in Figure 2.5.

**Table 2.2: Recorded Flood Levels\***

| <b>Flood Event</b> | <b>Street Address</b>                                     | <b>Reported Flood Level*<br/>(m AHD)</b> |
|--------------------|-----------------------------------------------------------|------------------------------------------|
| November 1987      | 18 Monash Avenue                                          | 2.35 <sup>1</sup>                        |
| November 1987      | Electricity box near cnr Monash Avenue and Ross Smith Pde | 2.25 <sup>2</sup>                        |

\*No actual flood marks were recorded at the time of the 1987 storm event. The level has been estimated from photographs and responses received as part of the resident survey, with levels obtained from the 2003 survey undertaken by council and Cardno Lawson Treloar (Section 2.2)

<sup>1</sup>The level at 18 Monash Avenue is assumed to be 10cm above the surveyed floor level

<sup>2</sup>The level at the electricity box is assumed to be 75cm above the surveyed surface level

## 2.2.5 Cadastral and Topographic Data

Pittwater Council provided cadastral base information and 2m Land Information Centre contour files for use during the Flood Study in digital format. The data was input to the MapInfo mapping package.

Council also provided information about the land-use in the catchment through the Local Environment Plan and recent (2002) and historical aerial photographs.

The above information was utilised in the development of hydrology and hydraulic models.

### **3. RESIDENT SURVEY AND COMMUNITY CONSULTATION**

#### **3.1 RESIDENT SURVEY**

A resident survey was carried out to collate information about flooding from the local residents. A questionnaire, prepared in consultation with Council, was distributed to all the residents in the floodplain in November 2003 to seek information about the flooding behaviour in the catchment. The questionnaire sought information as to whether residents have experienced flooding, the nature and depth of flooding and the timing of such floods. The residents were also asked whether they could identify any historic flood levels.

Around 60 questionnaires were distributed and 12 responses received (for an example of the questionnaire and a summary of the responses see Appendix D). A few residents, who had either experienced flooding or had good knowledge of it, were selected for further interviewing. Personal interviews were carried out and further anecdotal information as well as photographs and newspaper clippings of flooding were collected.

The majority of the information was related to the November 1987 flood event, which was a major event in the flooding history of Great Mackerel Beach. The following information was obtained from interviews.

- Street front flooding results in access issues to properties, such events were quoted at occurring three times per year - the June event of 2003 caused flood levels to remain at knee height at the entrance to Diggers Crescent for approximately one week;
- Council relocated the creek entrance in 1974 after a severe flooding event
- The November 1987 event caused three houses to be washed from their foundations at the western end of Monash Avenue, flood waters remained ponded in the street for three weeks.

A number of residents identified flood levels from the November 1987 event, these were subsequently surveyed (Table 2.2).

Reports of flooding from the local newspapers are included in Appendix E.

#### **3.2 PUBLIC EXHIBITION**

As part of the study, this report was publicly exhibited for a period of eight weeks for public comment between 12 July 2005 and 6 September 2005. The draft report was exhibited at Council's Customer Service Centres at 1 Park Street, Mona Vale and 59A Old Barrenjoey Road, Avalon Level 2, the Coastal Environment Centre, Mona Vale and Avalon Libraries.

During the public exhibition period, a Public Information Stall was established to discuss the draft report at the Mackerel Beach Rural Fire Service shed on 6 August 2005 between 10am and 12pm. Representatives from Pittwater Council and Cardno

Lawson Treloar were present to discuss the matter with residents and approximately 20 residents attended the display.

Key comments received from the community at the Public Information Stall were:

- Residents report that in 1992 (possibly) there was a night event where residents had difficulty crossing the main bridge (this was prior to the bridge being replaced)
- The main bridge (identified as Bridge No 1 in Figure 6.1) acted as a dam in the 1987 flood event.
- Prior to the November 1987 event the creek entrance was opened on 25th October 1987
- Historically, NPWS used to come about once every four years to open out the entrance (using an excavator which is brought to the site by a barge)
- Creek maintenance is required - residents appear to undertake this on an ad-hoc basis which does not appear to be compatible with the environmental value of the site, the last time creek maintenance was carried out was approximately three years ago - residents could previously paddle up and down the creek in a canoe
- Electricity/phone services are below the FPL and during major flood events services are intermittent
- Residents of the area hold photographs of the Lagoon in the early 1970's when the creek used to break out through the centre of the beach
- RFS shed appears to be in the floodway
- NPWS have installed a diversion drain at the top of the Valley - residents have concerns about this diversion.

No written comments were received in response to the invitation for public submissions.

## 4. METHODOLOGY

Two numerical modelling tools were developed to model flood behaviour in the catchment:

- hydrological model (RAFTS)
- hydraulic model (SOBEK).

These are described in general below and in detail in Sections 5 and 6 respectively.

### 4.1 HYDROLOGICAL MODEL

A hydrologic model converts rainfall in the catchment into runoff. The hydrologic model combines rainfall information with local catchment characteristics to estimate a runoff hydrograph. Runoff hydrographs for the flood study were estimated using the XP-RAFTS (XP Software, 2000) rainfall-runoff modelling package.

### 4.2 HYDRAULIC MODEL

A hydraulic model converts runoff into water levels and velocities throughout the major drainage system in the study area. The model simulates the hydraulic behaviour of the water within the study area by accounting for flow in the major channels as well as potential flowpaths, which develop when the capacity of the channels is exceeded. It relies on boundary conditions, which include the runoff hydrographs produced by the hydrologic model and the appropriate downstream boundary.

SOBEK 1D/2D is a dynamic hydraulic-routing model developed by WL|Delft Hydraulics of the Netherlands (2004), which is used world-wide and has been shown to provide reliable, robust simulation of flood behaviour in urban and rural areas through a vast number of applications. The model allows addition of a two dimensional (2D) domain to a one dimensional (1D) network with the two components dynamically coupled and solved simultaneously using the robust Delft Scheme. The unique solution scheme is capable of handling steep fronts, wetting and drying processes and subcritical and supercritical flow. The wide variety of hydraulic structures which the model can handle (weirs, roads, levees, culverts, bridges etc) makes it a flexible and adaptable hydraulic analysis tool.

Another important feature of the model is the ability to model the hydraulic structures in the 1D component rather than in the 2D domain. The benefit of this approach is that structure hydraulics is modelled more precisely than the approximate representation possible in a 2D domain.

The establishment and calibration of the hydrological and hydraulic models are described in section 5 and 6 respectively.

## 5. HYDROLOGICAL MODELLING

### 5.1 CATCHMENT DEFINITION

The Great Mackerel Beach catchment is a coastal catchment with the majority of the land covered by Ku-ring-gai National Park and a small residential area of approximately 130 properties located in the floodplain. The upper catchment is characterised by steep slopes with an incised creek valley, which changes to a flat floodplain area prior to the outlet into the ocean. The total catchment area is 263.5 ha.

The following attributes were considered in the hydrological analysis of the catchment:

- Rainfall intensity-frequency-duration (IFD) relationships
- Sub-catchment divisions
- Slopes and overland flowpath lengths, and
- Land use (pervious and impervious areas).

The existing catchment condition (as at 2004) has been analysed in this study.

The subcatchments were defined based on the topographic features (using the 2-metre contour data), the likely flowpaths and the requirements of the hydraulic model. The study area was divided into a total of 13 subcatchments.

In cases where the slope of the subcatchment is greater than 30% (such as cliff faces), the 30% slope value was used, as this is the greatest slope that RAFTS will accept. However, the sub catchment areas where this slope has been applied are relatively small (Table 5.1) and therefore the impact of this assumption is not significant from a catchment wide perspective.

The subcatchments used an initial/continuing rainfall loss categorised as either forest or floodplain these are listed in Table 5.1. For rainfall loss data used in the model refer to Table 5.8 in section 5.6.

The sub-catchment layout is shown in Figure 5.1 and the details of these sub-catchments are provided in Table 5.1.

**Table 5.1: Sub-Catchment Details**

| Sub-catchment ID | Sub-catchment Area (ha) | Catch Slope (%) | % Impervious | Initial/Continuing Rainfall Loss |
|------------------|-------------------------|-----------------|--------------|----------------------------------|
| A1               | 7.471                   | 30.00           | 80           | Forest                           |
| A2               | 10.369                  | 15.52           | 10           | Forest                           |
| A3               | 3.710                   | 30.00           | 80           | Forest                           |

| Sub-catchment ID | Sub-catchment Area (ha) | Catch Slope (%) | % Impervious | Initial/Continuing Rainfall Loss |
|------------------|-------------------------|-----------------|--------------|----------------------------------|
| A4               | 48.535                  | 11.07           | 10           | Forest                           |
| A5               | 50.661                  | 11.40           | 10           | Forest                           |
| A6               | 83.863                  | 10.56           | 10           | Forest                           |
| A7               | 23.207                  | 13.44           | 10           | Forest                           |
| A8               | 5.411                   | 30.00           | 80           | Forest                           |
| A9               | 12.959                  | 0.73            | 10           | Floodplain                       |
| A10              | 4.239                   | 30.00           | 80           | Forest                           |
| A11              | 5.770                   | 23.69           | 80           | Forest                           |
| A12              | 6.010                   | 17.81           | 10           | Forest                           |
| A13              | 1.297                   | 30.00           | 80           | Forest                           |
| <b>TOTAL</b>     | <b>263.5</b>            | <b>-</b>        | <b>-</b>     | <b>-</b>                         |

Using the above categories, the impervious and pervious areas for each of the sub-catchments were determined based on available aerial photography (vertical for the lower portions of the catchment, Figure 2.1 and oblique for the remainder of the catchment, Appendix I) and knowledge of the catchment from site inspections. The total impervious area for the Great Mackerel Beach Catchment was estimated at approximately 46 ha, approximately 17% of the total area.

## 5.2 MODEL BOUNDARIES

The model boundaries are located at the model extremities. The upstream boundaries are defined as discharge boundaries, which are applied directly to the 1D branches of the model.

## 5.3 HYDROLOGICAL MODEL ESTABLISHMENT

Runoff hydrographs for the flood study were estimated using the XP-RAFTS (XP Software, 2000) rainfall-runoff modelling package. Based on the topographic features (2-metre LPI contour map) and land-use (2002 aerial photography), the catchment was divided into 13 sub-catchments. Each sub-catchment was further divided to account for different initial/continuing rainfall loss rates for pervious/impervious areas of the residential section of the catchment (i.e. a split catchment modelling approach was adopted in XP-RAFTS). Details of the sub-catchment parameters are provided in Table 5.1.

Important parameters used in the development of the RAFTS model are provided in Table 5.2.

**Table 5.2: RAFTS Model Parameters**

| <b>RAFTS Parameter</b>         | <b>Forests</b>                                                               | <b>Floodplain</b> |
|--------------------------------|------------------------------------------------------------------------------|-------------------|
| Manning's n for sub-catchments | 0.1                                                                          | 0.06              |
| Storage delay for parameter, B | 1.0                                                                          | 1.0               |
| Hydrograph Routing Lag         | Based on 'Main Roads Department Rational Method', (AR&R, Book IV, p11, 1999) |                   |

In RAFTS, a hydrograph lag is required for routing flows from a sub-catchment to the one downstream. The lag times were estimated using the Main Roads Department Rational Method (AR&R, Book IV, p11, 1999). For catchments of less than 5km<sup>2</sup> in area the method uses a table to approximate stream velocity based on the slope of the catchment surface, which is then used to calculate the hydrograph routing lag.

A variety of events were tested, ranging from 20% AEP to 1% AEP events. Different catchments were selected throughout the study area. The catchments were selected from various locations and with varying catchment characteristics.

#### 5.4 HYDROLOGIC MODEL CALIBRATION

The hydrological model was calibrated indirectly to the November 1987 flood event. A combined hydrology/hydraulics approach was adopted, where the hydraulic model was calibrated with input from the hydrology model (Section 6), thus validating the results of the hydrologic model.

The results of the hydrological model were further validated by comparison with the Probabilistic Rational Method for rural catchments. The method has been described in *Australian Rainfall and Runoff* (AR&R) (Pilgrim (ed), 1999). A comparison for the total catchment outflow was made to using the 60 minute duration (as  $t_c = 66$  minutes from the rational method) over the range of design events. The results are provided in Table 5.3. The Rational Method calculations are included as Appendix F.

**Table 5.3: Comparison of RAFTS Model and Rational Method (m<sup>3</sup>/s)**

| <b>AEP</b> | <b>Rational Method</b> | <b>RAFTS</b> |
|------------|------------------------|--------------|
| 1%         | 40.51                  | 46.97        |
| 2%         | 34.71                  | 39.01        |
| 5%         | 20.78                  | 29.51        |
| 20%        | 18.29                  | 16.92        |

The variations between the RAFTS and Rational method results shown in Table 5.3 are primarily due to the Rational Method not accounting for the slope of the catchment. The Rational Method makes no adjustment for the slope of the catchment and as there is a significant slope in the Mackerel Beach catchment (10-30% in all areas other than the floodplain), it is to be expected that the quantity of flow in RAFTS would generally be greater than that in the Rational method

calculation. The results generally show no greater than a 10% variation between values.

Additionally, the Rational Method makes no account for the longer times of concentration generally experienced in the smaller storm events (less than 10% AEP). In general, low flow rates increase the amount of time taken for water to reach the catchment outlet. This principle is included in the RAFTS hydrological model. This can be seen in the results for the 20% AEP in Table 5.3.

## 5.5 DESIGN RAINFALLS

The IFD data was generated based on the method outlined in Australian Rainfall and Runoff (Pilgrim, (ed), 1999). Temporal patterns for the region are classified as zone 1. The IFD coefficients utilised are shown in Table 5.4.

**Table 5.4: IFD Coefficients**

| Parameter     | Value |
|---------------|-------|
| $^2I_1$       | 38    |
| $^2I_{12}$    | 8.6   |
| $^2I_{72}$    | 2.6   |
| $^{50}I_1$    | 78    |
| $^{50}I_{12}$ | 17    |
| $^{50}I_{72}$ | 5.5   |
| G             | 0     |
| F2            | 4.298 |
| F50           | 15.88 |

Design rainfall depths and temporal patterns for the 1%, 2%, 5% and 20% AEP events were developed using standard techniques provided in AR&R. Design storm rainfall intensities for the full range of storm frequencies and durations are presented in Table 5.5.

**Table 5.5: Design Rainfall Intensities (mm/h)**

| <b>Frequency →<br/>Duration ↓</b> | <b>1% AEP</b> | <b>2% AEP</b> | <b>5% AEP</b> | <b>20% AEP</b> | <b>Probable<br/>Maximum<br/>Precipitation</b> |
|-----------------------------------|---------------|---------------|---------------|----------------|-----------------------------------------------|
| 15 min                            | 184.1         | 164.2         | 138.4         | 103.8          | 653                                           |
| 30 min                            | 129.3         | 115.5         | 97.5          | 73.4           | 469                                           |
| 1h                                | 87.2          | 78.0          | 66.0          | 49.8           | 348                                           |
| 1.5h                              | 68.4          | 61.2          | 51.8          | 39.3           | 298                                           |
| 2h                                | 57.4          | 51.4          | 43.5          | 33.0           | 261                                           |
| 3h                                | 44.6          | 40.0          | 34.0          | 25.8           | 211                                           |
| 6h                                | 29.0          | 26.1          | 22.2          | 16.9           | 140                                           |
| 9h                                | 22.6          | 20.3          | 17.3          | 13.2           | *                                             |
| 12h                               | 18.9          | 17.0          | 14.5          | 11.1           | *                                             |

\*Not calculated.

As detailed in Section 7.3, for storm events smaller than the 2%AEP event the 9 hour event was the critical duration. For the 1%AEP event the 2 hour event was the critical duration. Consequently the range of durations considered (as listed in Table 5.5) is appropriate.

The storm intensities for the Probable Maximum Precipitation (PMP) are also shown in Table 5.5 and were estimated using the Generalised Short Duration Method (BoM, 1994 and 2003 update). All subcatchment areas were contained within the area encompassed by the 'A' PMP ring (BoM, 1994) and therefore a uniform rainfall pattern was applied for the PMP for the entire catchment. Table 5.6 shows the total design rainfall that occurs for the various design PMP events.

**Table 5.6: PMP Rainfall Totals**

| <b>Duration</b> | <b>PMP 'A' Total<br/>Rainfall (mm)</b> |
|-----------------|----------------------------------------|
| 15min           | 163.3                                  |
| 30min           | 234.3                                  |
| 45min           | 298.2                                  |
| 1 hour          | 347.9                                  |
| 90 min          | 447.3                                  |
| 2 hour          | 521.85                                 |
| 3 hour          | 631.9                                  |
| 6 hour          | 841.35                                 |

The rainfall temporal pattern used for the PMP is shown in Table 5.7. The distribution was sourced from BoM (1994).

**Table 5.7: Temporal Distribution of PMP**

| % of time | % of PMP |
|-----------|----------|
| 5         | 4        |
| 10        | 6        |
| 15        | 8        |
| 20        | 7        |
| 25        | 7        |
| 30        | 7        |
| 35        | 7        |
| 40        | 6        |
| 45        | 7        |
| 50        | 5        |
| 55        | 6        |
| 60        | 5        |
| 65        | 5        |
| 70        | 5        |
| 75        | 4        |
| 80        | 3        |
| 85        | 3        |
| 90        | 2        |
| 95        | 2        |
| 100       | 1        |

## 5.6 DESIGN FLOWS

Design rainfall estimates were applied to the calibrated hydrologic model in order to predict design runoff hydrographs. The rainfall losses were assumed in accordance with AR&R guidelines. The loss values are provided in Table 5.8.

**Table 5.8 Design Rainfall Losses Used in RAFTS**

| Catchment Type | Initial (mm) | Continuing (mm/hr) |
|----------------|--------------|--------------------|
| Forest         | 20           | 2.5*               |
| Floodplain     | 30           | 5**                |

\*A conservative estimate

\*\* Given the sandy nature of soils in the floodplain area a continuing loss at the upper end of the ARR recommended range has been adopted.

For PMF estimates, zero initial and continuing rainfall losses were assumed (Section 5.5) as per the recommendation of AR&R.

The design flows for various storm events at critical duration are provided in Table 5.9 for the total catchment. The critical duration for each event for the total catchment was established from model runs for the 15min, 30min, 45min, 1hr, 1.5hr, 2hr, 3hr, 9hr and 12hr storm events.

**Table 5.9: Design Flows, Critical Durations and Rainfall Intensities**

|                                    | Storm Event |        |        |         |     |
|------------------------------------|-------------|--------|--------|---------|-----|
|                                    | 1%AEP       | 2% AEP | 5% AEP | 20% AEP | PMF |
| <b>Critical Duration (hours)</b>   | 2           | 2      | 2      | 2       | 1   |
| <b>Rainfall Intensity (mm/h)</b>   | 57.4        | 51.4   | 43.5   | 33.0    | 261 |
| <b>Peak Flow (m<sup>3</sup>/s)</b> | 52          | 44     | 35     | 21      | 275 |

The critical durations are based on the results of RAFTS modelling and are therefore critical in terms of peak flows. In hydraulic modelling the critical duration is generally defined in terms of peak water levels and can be different to the above values.

The design hydrographs are provided in Appendix C. The hydrographs have been provided at the outlet of those catchments that formed inflows to the hydraulic model and also for the 1987 calibration event (Section 6.4). Hydraulic model details and location of inflow hydrographs have been discussed in Section 6.

## 6. HYDRAULIC MODELLING

### 6.1 MODEL SCHEMATISATION

The creek (up to the top of bank) has been modelled in SOBEK as a typical one-dimensional (1D) channel with cross-sections defining the channel geometry. Once the channel capacity is exceeded, flow is able to spill into the two-dimensional (2D) overland flow grid. During the flood recession, flow is also able to drain from the overland areas back into the defined channel.

The open channel section was included in the 1D component of the model, until it became wide and undefined, just behind the dune system in the 'lagoon' area. In addition, the two-dimensional nature of flow through the mangrove swamp area is best represented in the 2D component of the model.

The extent of the hydraulic model is from the top of Monash Avenue eastwards to the confluence with Pittwater (Figures 6.1 and 6.2). This area covers a total of 15 hectares, being 6% of the total catchment.

#### 6.1.1 1D Model Set-up

The layout of the 1D component for the model was developed after a detailed site visit and thorough review of reports of historical floods and available mapping. The physical shape of the land, in addition to hydraulic controls such as grassed accessways and embankments were also taken into account. As there is no pipe drainage in the area, the creek was the only formal drainage system in the model. The 1D model branch layout is shown in Figure 6.1.

The location of cross sections in the model was determined from field inspections. The cross sections were located so that flow controls on the floodplain could be modelled satisfactorily, with cross sections spaced to adequately represent variations in the channel definition. The location of cross sections in the model is shown in Figure 6.1. The model cross sections are provided in Appendix G.

All other major flowpaths in the study area were modelled, including the streets, as part of the two-dimensional model domain.

#### 6.1.2 2D Model Set-Up

The major component of a two-dimensional (2D) model set-up is the model grid or topographic grid. The model topography was developed from the survey data described in Section 2.2. The civil and surveying package 12D was used to generate a detailed three dimensional surface (digital terrain model) of the hydraulic model area.

Important hydraulic controls such as road levels that act as flow paths for flood waters, need to be correctly represented in the topographical grid as used in SOBEK.

A comparison between the surveyed levels and the model grid was undertaken to ensure the generated grid would accurately represent these.

SOBEK dynamically links cross sections represented within the 1D domain (Section 6.1.1) and 2D components of the model to ensure a high level of detail and accurate conveyance calculations. The flood waters flow into the 2D topographical grid when the level of the grid cell is reached. To ensure the creek flow is calculated within the 1D domain, the creek must not be represented in the 2D grid. A three dimensional surface of the 2D area was therefore developed with the creek removed by using the top of creek bank breaklines. The 2D grid was then developed from this three dimensional surface.

The topographic grid used in the model had a grid size of 5 metres by 5 metres, which is suitable for providing details of the significant catchment features while allowing a moderate size grid with reasonable model computation time. SOBEK has the ability to accommodate parent/child grids, enabling grids of higher definition to be used in areas of interest. This feature can be utilised to assess any future developments in the 2D area. The grid details are outlined in Table 6.1. The modelled 2D grid is shown in Figure 6.2.

**Table 6.1: Two-dimensional Grid Parameters**

| <b>Grid Parameter</b>     | <b>Dimension</b>                   |
|---------------------------|------------------------------------|
| Origin *                  | 327262.500, 1281502.500            |
| Grid Size                 | 5 m                                |
| X-Dimension (east-west)   | 166                                |
| Y-Dimension (north-south) | 127                                |
| Rotation                  | 0 degrees (relative to Grid North) |

\* NSW ISG Zone 56/1 Co-ordinate System

The buildings in the floodplain were assumed to act as floodplain storage. They were assigned a high Manning's 'n' roughness to simulate their blockage of flow conveyance. This was considered reasonable due to the relatively low development density of the area, the general house construction methods at Mackerel Beach and reports of flooded houses by residents in the 1987 flood event.

## **6.2 HYDRAULIC ROUGHNESS**

The hydraulic roughness for the 1D cross sections and 2D grid were determined from a site inspection and aerial photography. In the 1D components the creek bed was classified as either 'brush' or 'sand' in the 2D components a range of land uses were assigned different roughness values. Table 6.2 lists the 'Manning's 'n' roughness values adopted for the creek and land after calibration (see Section 6.4). The roughness grid and classification is shown in Figure 6.3.

**Table 6.2: Hydraulic Roughness**

| <b>1D Creek Description</b>       | <b>Manning's 'n'</b> |
|-----------------------------------|----------------------|
| Brush bed                         | 0.1                  |
| Sand bed                          | 0.04                 |
| <b>2D Grid - Land Description</b> | <b>Manning's 'n'</b> |
| Creek channel                     | 0.06                 |
| Sand bed                          | 0.03                 |
| Urban grass                       | 0.05                 |
| Forest swamp                      | 0.12                 |
| Forest urban                      | 0.1                  |
| Buildings                         | 0.2                  |

The variation in the roughness definitions between the 1D and 2D domains is due to the varying relative contribution of the 1D and 2D components of flow in the creek area.

### **6.3 STRUCTURES**

Three bridges were modelled explicitly in the SOBEK model. Although nine small bridges were noted and surveyed during the survey and site inspection, it was considered that only three of the structures would be structurally stable in a flood event. Given that a dwelling was washed off its foundations in the event of 1987 this assumption is considered to be reasonable for the small, ad-hoc nature of the bridges identified to be unstable in flood events. The location of the three modelled bridges is shown in Figure 6.1.

Head loss at the bridges predicted by SOBEK were compared to results obtained from a simple one-dimensional steady state analysis using HEC-RAS (USACE, 2004). It was found that the head loss obtained from SOBEK was consistent with that predicted by HEC-RAS.

### **6.4 MODEL CALIBRATION**

The storm event of November 1987 was selected for the calibration of the SOBEK model (Section 3.1). Table 6.3 outlines the assessment of the recurrence interval (as an exceedance probability) for the event for different durations over the entire event. The event generally ranges somewhere between a 2% - 5% AEP with respect to rainfall intensities.

**Table 6.3 November 1987 storm event compared to design rainfall data**

| <b>Duration</b> | <b>Maximum Intensity<br/>(mm/hr)</b> | <b>Design Event<br/>(AEP)</b> |
|-----------------|--------------------------------------|-------------------------------|
| 30min           | 107.98                               | 5% AEP to 2% AEP              |
| 1hr             | 68.58                                | 5% AEP to 2% AEP              |
| 1.5hr           | 53.50                                | 5% AEP to 2% AEP              |
| 2hr             | 45.24                                | 5% AEP to 2% AEP              |
| 3hr             | 34.05                                | 5% AEP to 2% AEP              |
| 6hr             | 23.59                                | 5% AEP to 2% AEP              |
| 9hr             | 18.32                                | 5% AEP to 2% AEP              |
| 12hr            | 16.28                                | 20%AEP to 5% AEP              |

Inflow hydrographs for this event were developed in RAFTS from historical rainfall data (Section 2.2.3). A recorded water level time series at Fort Denison was used as the downstream boundary of the model as there are no similar gauges for Pittwater and this site is a good representation of the conditions observed in Pittwater (Lawson and Treloar, 2002) (see Section 6.5.2). The catchment and floodplain was assumed to be generally unchanged from the 1987 condition to the present, allowing generally for the present-day topographic data to be used. The only alteration for calibration was the details of the berm entrance conditions adopted.

The modified 2D grid is shown in Figure 6.4 and the roughness grid used for calibration is shown in Figure 6.5.

The initial roughness values selected for the roughness values did not require substantial adjustment to calibrate the model to the historic event. A sensitivity analysis was undertaken to determine the flood level impacts by varying the roughness as detailed in Appendix H. The sensitivity analysis indicated that slight changes in flood levels were evident in the top part of the catchment and minimal changes were seen in the lower lying areas of the floodplain.

Results from the model were compared against the recorded water levels and observed flow behaviour within the study area (Section 3.1). The comparison for the November 1987 event is provided in Table 6.4.

**Table 6.4: November 1987 Calibration**

| <b>Location of Historic Flood Level</b>                   | <b>Location ID</b> | <b>Estimated Historic Flood Level (mAHD)*</b> | <b>Modelled Flood Level (mAHD)</b> | <b>Difference (m)</b> |
|-----------------------------------------------------------|--------------------|-----------------------------------------------|------------------------------------|-----------------------|
| 18 Monash Avenue*                                         | 1                  | 2.35 <sup>1</sup>                             | 2.29                               | -0.06                 |
| Electricity box, cnr Monash Avenue and Ross Smith Parade* | 2                  | 2.25 <sup>1</sup>                             | 2.23                               | -0.02                 |

\*No actual flood marks were recorded at the time of the 1987 storm event. The level has been estimated from photographs and responses received as part of the resident survey, with levels obtained from the 2003 survey undertaken by council and Cardno Lawson Treloar (Section 2.2)

<sup>1</sup> The level at 18 Monash Avenue is assumed to be 10cm above the surveyed floor level

<sup>2</sup> The level at the electricity box is assumed to be 75cm above the surveyed surface level

The calibration results in Table 6.4 show that a reasonable match has been obtained between the recorded and modelled flood given the uncertainties associated with the nature of the beach berm behaviour during the event. The calibration storm event was not reported to have overtopped the berm at Ross Smith Parade. This behaviour was replicated in the model.

The anecdotal evidence of residents at Mackerel Beach (Section 3.1), who stated that water did not drain from the flooded areas for some time after the storm event, is also shown in the calibration modelling. This is likely due to the beach berm preventing ponded water from draining to Pittwater.

## **6.5 BOUNDARY CONDITIONS**

### **6.5.1 Inflow Hydrographs**

Inflow hydrographs for the design events were derived from those generated in Section 5. The hydrographs were applied at five locations as boundary conditions representing the overland flow nature of catchment flow to the creek system. The local rainfall on the township of Mackerel Beach was applied as a lateral inflow along the length of the creek.

### **6.5.2 Downstream Boundary Conditions**

The downstream boundary of the hydraulic model is the Pittwater estuary at Great Mackerel Beach. The estuary water levels were estimated for use with the design flood events. Detailed discussion of the methodology adopted to develop the appropriate estuary water levels is provided below. A discussion of 'entrance' conditions follows on from this discussion.

#### *Processes Affecting Great Mackerel Beach Levels*

The level of Pittwater at Great Mackerel Beach will often affect the catchment discharge through the creek mouth, especially at high tide. Water level variation

within Pittwater is a function of tides plus any combination of the following natural causes:

- Wind Set-up and the Inverse Barometer Effect
- Wave Set-up
- Wave Runup
- Fresh Water Flow
- Eustatic and Tectonic Changes
- Greenhouse Effect, and
- Global Changes in Meteorological Conditions.

During very severe ocean storms elevated ocean water levels occur within Pittwater. AWACS (1991) present estimates of the design still water levels in Pittwater for various return periods.

**Table 6.5: Design Still Water Levels for Mackerel Beach (AWACS, 1991)**

| <b>Return Period<br/>(ARI)</b> | <b>Water Level<br/>(mAHD)</b> |
|--------------------------------|-------------------------------|
| 20 year                        | 1.43                          |
| 50 year                        | 1.47                          |
| 100 year                       | 1.50                          |

Elevated ocean level events are very unlikely to occur during severe flood events of short duration in small coastal catchments, but form a component of potential ocean inundation levels for the lower parts of the catchment. That is, the lower parts of the catchment may be inundated due to ocean storms and/or catchment flooding. The matter of estuarine inundation is primarily addressed through the Estuarine Level Database established by Pittwater Council.

#### *Design Event Application*

The critical duration of flood events in the catchment is in the order of one to three hours, and peak estuary levels, which are dominated by the astronomical tide, have a similar duration around the peak water level. Ocean storms may cause elevated estuary levels for periods of up to four days. Therefore extreme estuary storm tides are not likely to occur at the same time as urban floods of this type. However, the elevated still water levels identified in the AWACS (1991) study (Table 6.5) are recommended for adoption for this investigation.

#### *Adopted Downstream Boundary Water Levels*

The design water levels for Great Mackerel Beach adopted were as follows:

- 1.5mAHD for the 1%AEP and PMF,
- 1.47mAHD for the 2%AEP,
- 1.43mAHD for the 5%AEP and

- 1.36mAHD for the 20% AEP.

The model sensitivity to variation in the downstream boundary condition is discussed in Appendix H.

For modelling of historic events, the recorded time series data at Fort Denison was used as the downstream boundary (Section 6.3). As a guide, the peak water level at Fort Denison during the course of the November 1987 event was 0.56mAHD (a normal spring tide level).

### *Entrance Conditions*

The state of the entrance berm has a major effect on flood levels. When the entrance is 'open' (i.e. a channel is scoured through the berm and the lagoon area is tidal) the full effect of the estuary water level influences peak flood levels. Water depth at the entrance is an important parameter for the wave set-up component. When the entrance is fully closed, the flood level rises until the berm is overtopped and then opens through scour action, or is opened artificially (e.g. by digging a pilot channel with a shovel).

The location and configuration of the berm is dependent on the sea level and flood condition and conditions shaping the berm prior to the flood (i.e. coastal processes such as wind and wave action).

For the calibration event of November 1987 no survey data was available for the shape and levels of the berm. Consequently, engineering judgement was used to represent the berm, based on available data for the 1987 event, other published data (e.g. Section 2.2) and historical aerial photography held by the Department of Lands. The topography of the berm adopted for the calibration event is shown in Figure 6.4.

For the design events, the berm was assumed to be in the condition as surveyed in November 2003/January 2004 (Section 2.2). The berm was assumed not to scour in design events to produce conservative results for peak flood levels.

A discussion of the implications of this study for the management of the berm is provided in Appendix I.

## 7. DESIGN EVENT MODELLING AND MAPPING

### 7.1 EXISTING FLOOD BEHAVIOUR

The flow generated in the forested part of the catchment is carried via overland flow paths and informal channels to the creek system within the floodplain. The creek flows down a steep slope and enters the residential area at the top of Monash Avenue, which acts as a grassed swale drain. When rainfall is excessive, floodwaters break out from Monash Avenue along Diggers Crescent and flood the surrounding properties.

As the floodwaters reach the mangrove swamp area to the east of the catchment the floodwaters slow and pond behind the sand dune until it is high enough to overtop the berm and flow into the ocean.

### 7.2 DESIGN FLOOD ESTIMATION

Design inflow hydrographs were obtained from the RAFTS hydrologic model and applied to the calibrated SOBEK 1D-2D hydraulic model. A range of hydrographs representing different storm durations was applied to the model in order to estimate critical flood levels for different areas of the floodplain. Design flooding behaviour was modelled for the existing catchment conditions.

### 7.3 RESULTS

The model results for all the durations of a design event were compiled into a single result list for each AEP event. The reported results are the envelope of results for all durations for each AEP event.

Flood extents for each AEP event and the PMF have been developed and are presented in Figures 7.1 to 7.5. The flood extent for the 1% AEP + 0.5m contour is shown in Figure 7.6, which represents Council's flood planning level. Model results for predicted flood behaviour at significant locations in the floodplain are summarised in Tables 7.1 (levels) and 7.2 (flows). The reporting locations are presented in Figure 7.7.

**Table 7.1: Design Peak Water Levels**

| Location ID | Type | Location Details                       | Peak Water Level (m AHD) |        |        |        |         |
|-------------|------|----------------------------------------|--------------------------|--------|--------|--------|---------|
|             |      |                                        | PMF                      | 1% AEP | 2% AEP | 5% AEP | 20% AEP |
| 143         | 2D   | 18 Monash Avenue                       | 3.16                     | 2.37   | 2.31   | 2.26   | 2.12    |
| 152         | 2D   | Monash Ave                             | 3.23                     | 2.39   | 2.32   | 2.27   | 2.13    |
| 153         | 2D   | Bridge 1 (Monash Ave)                  | 3.45                     | 2.44   | 2.36   | 2.31   | 2.17    |
| 154         | 2D   | Diggers Crescent                       | 3.40                     | 2.42   | 2.35   | 2.30   | 2.16    |
| 155         | 2D   | 38 Monash Avenue                       | 4.15                     | 2.69   | 2.59   | 2.47   | 2.31    |
| 156         | 2D   | Northern End of Diggers Crescent       | 3.05                     | 2.35   | 2.30   | 2.25   | 2.11    |
| 157         | 2D   | Outlet of Creek, Northern end of beach | 2.54                     | 2.16   | 2.12   | 2.08   | 1.98    |

| Location ID | Type | Location Details                               | Peak Water Level (m AHD) |        |        |        |         |
|-------------|------|------------------------------------------------|--------------------------|--------|--------|--------|---------|
|             |      |                                                | PMF                      | 1% AEP | 2% AEP | 5% AEP | 20% AEP |
| 158         | 2D   | Northern End of Swamp                          | 2.85                     | 2.32   | 2.27   | 2.22   | 2.09    |
| 159         | 2D   | North of 1 Ross Smith Parade                   | 2.90                     | 2.34   | 2.29   | 2.24   | 2.11    |
| 160         | 2D   | Middle of Swamp, rear 3 Ross Smith Parade      | 2.97                     | 2.35   | 2.30   | 2.25   | 2.11    |
| 2           | 2D   | Electricity Sub-station, Monash Avenue         | 3.05                     | 2.36   | 2.31   | 2.26   | 2.12    |
| 20          | 1D   | Stream Channel, near 69 Monash Ave             | 4.54                     | 2.97   | 2.86   | 2.73   | 2.53    |
| 30          | 1D   | Bridge 3, Downstream                           | 4.19                     | 2.76   | 2.67   | 2.56   | 2.41    |
| 40          | 1D   | Stream Channel, near 61 Monash Ave             | 3.97                     | 2.60   | 2.50   | 2.41   | 2.27    |
| 50          | 1D   | Stream Channel, near 53 Monash Ave             | 3.59                     | 2.48   | 2.39   | 2.33   | 2.19    |
| 60          | 1D   | Stream Channel, at 26 Monash Ave               | 3.33                     | 2.41   | 2.34   | 2.29   | 2.15    |
| 70          | 1D   | Stream Channel, at 20 Monash Ave               | 3.18                     | 2.38   | 2.31   | 2.27   | 2.13    |
| 80          | 1D   | Stream Channel, at 14 Monash Ave               | 3.09                     | 2.36   | 2.30   | 2.26   | 2.12    |
| 90          | 1D   | Stream Channel, rear of 24 Diggers Cres.       | 3.06                     | 2.36   | 2.30   | 2.26   | 2.12    |
| 100         | 1D   | Stream Channel, rear of 26 Diggers Cres        | 3.02                     | 2.35   | 2.30   | 2.25   | 2.11    |
| 110         | 1D   | Stream Channel, 20m north of 28 Diggers Cres.  | 2.99                     | 2.35   | 2.29   | 2.25   | 2.11    |
| 120         | 1D   | Stream Channel, 80m north of 28 Diggers Cres.  | 2.96                     | 2.34   | 2.29   | 2.24   | 2.11    |
| 130         | 1D   | Stream Channel, 120m north of 28 Diggers Cres. | 2.94                     | 2.34   | 2.29   | 2.24   | 2.11    |
| 140         | 1D   | End of 1D Channel section                      | 2.93                     | 2.34   | 2.28   | 2.24   | 2.11    |

**Table 7.2: Design Peak Flows**

| Section ID | Type    | Location Details                                                                        | Peak Flows (m <sup>3</sup> /s) |        |        |        |         |
|------------|---------|-----------------------------------------------------------------------------------------|--------------------------------|--------|--------|--------|---------|
|            |         |                                                                                         | PMF                            | 1% AEP | 2% AEP | 5% AEP | 20% AEP |
| 13         | 2D Line | Northern end of Swamp                                                                   | 114.21                         | 32.39  | 27.96  | 25.12  | 18.18   |
| 155        | 2D Line | End of 1D Channel Section                                                               | 13.09                          | 3.80   | 3.32   | 3.04   | 2.43    |
| 164        | 2D Line | Creek Outlet through dunes                                                              | 75.39                          | 33.07  | 29.96  | 27.28  | 19.87   |
| 165        | 2D Line | Top of Berm along Ross Smith Parade                                                     | 124.95                         | 4.12   | 1.76   | 0.75   | 0.00    |
| 167        | 2D Line | Western property boundary of 38 Monash Ave (house washed off foundations in 1987 event) | 124.33                         | 17.84  | 14.15  | 10.35  | 5.52    |

The results are also provided for the events along a longitudinal profile for the location shown in Figure 7.8. The long section profile of peak water levels is shown in Figure 7.9. Figures 7.10 and 7.11 show the provisional hazard (Section 7.5) and Figures 7.12 to 7.16 show the critical duration storm that causes the peak flood level at all points of the grid.

Results of design flood modelling indicate that the ponding and storage of floodwaters behind the sand berm is the key mechanism that determines water surface elevations at Mackerel Beach. This is evidenced in the long section plot (Figure 7.9) where the water surface profile is essentially flat, regardless of the slope of the natural surface. The 9-hour event causes the peak flood levels for the majority

of the study area for all events up to the 2% AEP event. The critical duration storm event for the 1% AEP event is the 2 hour storm, although analysis of the data indicates that over the majority of the catchment area, all the modelled storms record flood levels within 5cm of the maximum modelled level for this event.

It is noted that the Pittwater boundary conditions (Section 6.4.2) result in significant portions of the study area being inundated prior to the commencement of the modelled flood events. This effectively fills storage areas in the catchment and leads to a conservative approximation of flood levels in the study area. The sensitivity of modifying the downstream boundary is discussed further below.

## **7.4 SENSITIVITY ANALYSIS**

A sensitivity analysis was undertaken for the hydraulic model for the 1% AEP 2 hour event for the following cases:

- Increase/decrease in runoff (+/- 20%)
- Change in roughness (literature maximum and minimum, from Chow, 1973)
- Blockage of bridges/culverts (50% and 100%)
- A lower downstream boundary Pittwater water level (0.6 mAHD).

Manning's roughness was modified from the calibrated values (Table 6.2) to the minimum and maximum values for the land use or channel type in Chow (1973). An analysis was undertaken to determine the effect of lowering the tidal boundary level to 0.6m AHD (mean high water spring tide level). The hydraulic model was also analysed to ascertain the effect on flood levels for blockage of the three bridge structures equating to a reduction of 50% and 100% of the effective flow area.

Table 7.3 summarises the results from the sensitivity analysis at significant locations in the catchment (Figure 7.7). The tables indicate changes to the design levels (in metres) as a result of changes. Positive numbers indicate an increase in levels.

Table 7.4 summarises the results from the sensitivity analysis at significant locations in the catchment (Figure 7.7). The tables indicate changes to the design flows as a result of changes. Positive numbers indicate an increase in levels.

**Table 7.3: Model Sensitivity – Change in Peak Water Levels (m)**

| Location ID* | 1% AEP 2 hour Event |      |           |      |          |       |          |
|--------------|---------------------|------|-----------|------|----------|-------|----------|
|              | Flow                |      | Roughness |      | Blockage |       | Boundary |
|              | -20%                | +20% | Low       | High | 50%      | 100%  | 0.6mAHD  |
| 143          | -0.10               | 0.07 | -0.03     | 0.04 | 0.00     | 0.00  | -0.05    |
| 152          | -0.11               | 0.07 | -0.03     | 0.05 | 0.00     | 0.00  | -0.05    |
| 153          | -0.12               | 0.09 | -0.06     | 0.07 | 0.00     | 0.00  | -0.06    |
| 154          | -0.11               | 0.09 | -0.05     | 0.06 | 0.00     | 0.00  | -0.06    |
| 155          | -0.13               | 0.12 | -0.13     | 0.10 | 0.01     | 0.03  | -0.02    |
| 156          | -0.10               | 0.06 | -0.02     | 0.04 | 0.00     | 0.00  | -0.04    |
| 157          | -0.07               | 0.04 | -0.01     | 0.02 | 0.00     | 0.00  | -0.03    |
| 158          | -0.08               | 0.05 | -0.01     | 0.02 | 0.00     | 0.00  | -0.04    |
| 159          | -0.09               | 0.05 | -0.02     | 0.03 | 0.00     | 0.00  | -0.04    |
| 160          | -0.09               | 0.06 | -0.02     | 0.03 | 0.00     | 0.00  | -0.04    |
| 2            | -0.10               | 0.06 | -0.02     | 0.04 | 0.00     | 0.00  | -0.05    |
| 20           | -0.14               | 0.12 | -0.16     | 0.12 | 0.04     | 0.11  | -0.01    |
| 30           | -0.12               | 0.11 | -0.14     | 0.11 | -0.02    | -0.07 | -0.01    |
| 40           | -0.13               | 0.09 | -0.11     | 0.11 | 0.00     | 0.00  | -0.05    |
| 50           | -0.13               | 0.07 | -0.07     | 0.09 | 0.00     | 0.00  | -0.07    |
| 60           | -0.11               | 0.05 | -0.04     | 0.08 | 0.00     | 0.00  | -0.06    |
| 70           | -0.10               | 0.04 | -0.03     | 0.07 | 0.00     | 0.00  | -0.05    |
| 80           | -0.10               | 0.04 | -0.02     | 0.07 | 0.00     | 0.00  | -0.05    |
| 90           | -0.10               | 0.04 | -0.02     | 0.06 | 0.00     | 0.00  | -0.05    |
| 100          | -0.09               | 0.04 | -0.02     | 0.06 | 0.00     | 0.00  | -0.04    |
| 110          | -0.09               | 0.03 | -0.02     | 0.06 | 0.00     | 0.00  | -0.04    |
| 120          | -0.09               | 0.03 | -0.02     | 0.06 | 0.00     | 0.00  | -0.04    |
| 130          | -0.09               | 0.03 | -0.02     | 0.06 | 0.00     | 0.00  | -0.04    |
| 140          | -0.09               | 0.03 | -0.02     | 0.06 | 0.00     | 0.00  | -0.04    |

\*See Table 7.1 for location details

**Table 7.4: Model Sensitivity – Change in Flow (m<sup>3</sup>/s)**

| Location ID* | 1% AEP 2 hour Event |      |           |       |          |       |          |
|--------------|---------------------|------|-----------|-------|----------|-------|----------|
|              | Flow                |      | Roughness |       | Blockage |       | Boundary |
|              | -20%                | +20% | Low       | High  | 50%      | 100%  | 0.6mAHD  |
| 13           | -6.82               | 5.11 | 0.79      | -2.07 | 0.00     | 0.00  | -3.43    |
| 155          | -0.71               | 0.61 | -0.37     | 0.54  | 0.00     | 0.00  | -0.38    |
| 164          | -5.40               | 3.59 | 1.12      | -2.57 | -0.01    | -0.01 | -2.52    |
| 165          | -3.27               | 4.11 | -0.19     | 0.98  | 0.00     | 0.00  | -2.00    |
| 167          | -4.62               | 4.66 | -0.85     | -2.57 | 1.85     | 5.31  | -0.08    |

\*See Table 7.2 for location details

The characteristics of the majority of the floodplain areas are not particularly sensitive to changes in any of the modelled parameters, mostly due to the sand berm restricting outflows from the creek. The exception is the portion of the floodplain upstream of Bridge 2, where the backwater effect of the berm does not influence flow behaviour. Blockage of the bridges will cause greater flows across properties in the vicinity of Bridge 1 due to the flow diversion that will occur when the structure is blocked. Higher roughness generally causes flow to be slower, which is expected, and leads to the higher recorded flood levels, as indicated in Table 7.3.

Modification of the tidal boundary at 0.6 mAHD only caused an overall reduction in flood levels of approximately 5cm throughout the catchment.

Full details of the sensitivity analysis are found in Appendix H.

## **7.5 FLOOD HAZARD**

### **7.5.1 General**

Flood hazard can be defined as the risk to life and limb caused by a flood. The hazard caused by a flood varies both temporally and spatially across the floodplain. The Floodplain Development Manual (NSW Government, 2005) describes various factors to be considered in determining the degree of hazard. These factors are:

1. Size of the flood
2. Depth and velocity of floodwaters
3. Effective warning time
4. Flood awareness
5. Rate of rise of floodwaters
6. Duration of flooding
7. Evacuation problems
8. Access.

Hazard categorisation based on all the above factors is part of establishing a Floodplain Risk Management Plan. The scope of the present study calls for determination of provisional flood hazards only, which when considered in conjunction with the above listed factors, provides a comprehensive analysis of the flood hazard.

### **7.5.2 Provisional Flood Hazard**

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters (NSW Government, 2005). The Floodplain Development Manual (2005) defines two categories for provisional hazard - High and Low.

The model results were processed using an in-house developed program, which utilises the model results of flood level and velocity to determine hazard. Provisional flood hazard for the 1% AEP flood event and the PMF are presented in Figures 7.10 and 7.11 in plan view. The provisional hazard is based on the envelope of the hazard calculation (a function of depth and velocity) at each location. Hazard calculations are undertaken for the maximum velocity at a grid cell and the maximum depth at a grid cell. This approach is conservative, as it assumes the maximum depth occurs at the same time as the maximum velocity.

## 7.6 HYDRAULIC CATEGORISATION

### 7.6.1 General

The Floodplain Development Manual (NSW Government, 2005) defines flood prone land to fall into one of the following three hydraulic categories:

**Floodway** - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.

**Flood Storage** - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.

**Flood Fringe** - Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

### 7.6.2 Hydraulic Category Identification

Floodways were determined for the 1%, 2%, 5%, 20% AEP events and the PMF by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways was derived from Howells et al. (2003).

As a minimum, the floodway was assumed to follow the creekline from bank to bank. In addition, the following depth and velocity criteria was used to define a floodway:

- Velocity \* Depth must be greater than  $0.25 \text{ m}^2/\text{s}$  **and** velocity must be greater than  $0.25 \text{ m/s}$  **OR**
- Velocity is greater than  $1 \text{ m/s}$ .

In addition to the above hydraulic categorisation, any roadway that conveyed flow was considered a floodway. These roadways were considered floodway as the blocking of roads would cause a redistribution of gutter/full road flow into private property.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1 m and/or would cause peak discharge anywhere to increase by more than 10%. This criteria was applied to the model results as described below.

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for

flood storage would be satisfied. To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2m
- Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but still fell within the flood extent are represented as Flood Fringe.

The hydraulic categories for 1%, 2%, 5%, 20% AEP events and the PMF are provided as plans in Figures 7.17 - 7.21. The hydraulic categories are based on the envelope of the hydraulic categorisation at each location. The hydraulic categorisation was undertaken for each discrete time step for all durations for the events presented.

## 8. CONCLUSIONS

A flood study of the Great Mackerel Beach catchment has been undertaken to define the nature and extent of flooding in the area for a range of design rainfall events. The study has been carried out for the existing catchment conditions.

In the past, flooding in the area has caused property damage and posed a high hazard to the residents living close to the major drainage channels in the area. Flood waters from the catchment also accumulate in residential areas and roadways. The area has experienced major flood events in 1974, 1987, 1992, 1998 and 2003.

A questionnaire was distributed to the residents of the Great Mackerel Beach floodplain in order to obtain flood related information such as whether the residents have experienced flooding, the nature and depth of flooding and the timing of such floods. Two residents had a good recollection of the November 1987 flood and were able to identify flood levels which were later surveyed.

The estimation of flooding behaviour was undertaken by developing mathematical models to simulate the hydrologic and hydraulic aspects of flooding. RAFTS (XP Software, 2000) was utilised to determine catchment runoff and for routing flows through the catchment. Predicted hydrographs from RAFTS were then input to the coupled one dimensional two dimensional (1D/2D) hydraulic model SOBEK (WL|DELFT, 2004) for the determination of peak flood level, velocity and discharge for various rainfall events.

Flood levels within the catchment for the storm event of November 1987 were available for calibration of the hydraulic model. This event was chosen on the basis of flood level information obtained from the resident survey and the available rainfall data. The rainfall event resulted in a peak flood flow similar to the 1%AEP flood flow and flood levels of the order of the observed 1%AEP flood levels.

The model results reflect the observed flooding behaviour in Great Mackerel Beach. Properties adjacent to Monash Avenue and those on the valley floor are the most flood-affected properties in the area. Flooding in the area is primarily controlled by backwater effects (such as storage and ponding) as a result of the restricted outlet conditions, caused by the sand dune and berm height along the ocean beach.

The outcomes of the study include:

- Limits of predicted flood extents for the 1%, 2%, 5% and 20% AEP events and the PMF
- Tabulated modelling results including predicted flood levels, velocities and flows at a number of locations in the floodplain
- Mapping of provisional flood hazard has been determined for the 1%, 2%, 5% and 20% AEP events and the PMF
- Mapping of hydraulic categories for the 1%, 2%, 5% and 20% AEP events and the PMF.

The impact of varying significant model parameters has been assessed by carrying out a sensitivity analysis. Model parameters such as bed and over bank roughness, inflow hydrographs, downstream boundary conditions and the effect of culvert blockage have been checked for sensitivity.

This study has produced flood behaviour information and provides a management tool in the form of hydrologic and hydraulic models for future assessment of floodplain management options in the study area and the subsequent preparation of a floodplain risk management plan.

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- Pittwater Council
- Pittwater Land Water and Coast Committee
- The community of Great Mackerel Beach.

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## 11. QUALIFICATIONS

This report has been prepared by Cardno Lawson Treloar for Pittwater Council and as such should not be used by a third party without proper reference.

The report relies on the accuracy of the following information:

- Ground survey undertaken by Council (November 2003/January 2004)
- 2m LPI contours.

The investigation and modelling procedures adopted for this study follow current practice and considerable care has been applied to the preparation of the results. However, model set-up and calibration depends on the quality of data available. The flow regime and the flow control structures are complicated and can only be represented by schematised model layouts.

Hence there will be a level of uncertainty in the results and this should be borne in mind in their application.

Study results should not be used for purposes other than those for which they were prepared.