SUTHERLAND SHIRE COUNCIL

OYSTER CREEK
FLOODPLAIN RISK MANAGEMENT STUDY

JUNE 2005

WEBB, McKEOWN & ASSOCIATES PTY LTD

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OYSTER CREEK
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FOREWORD

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

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

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

1. *Flood Study*
   - determine 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*
   - construction of flood mitigation works to protect existing development,
   - use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Oyster Creek Floodplain Risk Management Study constitutes the second stage of the management process for Oyster Creek and its catchment area. Webb, McKeown & Associates were commissioned by Sutherland Shire Council to prepare this study. The report documents the work undertaken and presents outcomes from an assessment of the available floodplain management measures.

SUMMARY

This report was prepared by Webb, McKeown & Associates on behalf of Sutherland Shire Council and details an assessment of the available floodplain management measures for the Oyster Creek floodplain. It represents the fourth step in the process to provide a formal Floodplain Risk Management Plan for the catchment.

Oyster Creek has a catchment area of approximately 3.5 km^2 to Oyster Bay on the Georges River and 2.4 km^2 to Bates Drive (1300 m upstream). The catchment is situated within Sutherland Shire Council's local government area and takes in parts of the suburbs of Sutherland, Kirrawee, Jannali, Kareela and Oyster Bay. Flooding of roads and residential properties between Box Road and Bates Drive has occurred in the past.

All relevant available rainfall, flood and topographic data were collected and analysed as part of the Flood Study. A WBNM hydrologic model was established to represent the entire catchment draining to Oyster Bay and the Georges River. A Mike-11 hydraulic model was created to represent the creek within the designated study area. The downstream limit of the model being Oyster Bay and the upstream limit approximately 200 m upstream of Box Road (some 1900 m upstream of Oyster Bay). Both models were calibrated (as far as possible) to historical flood data and subsequently used to determine design flood levels.

THE STUDY AREA

The Floodplain Risk Management Study identified that houses are only at risk of inundation by floodwaters within the reach from Bates Drive to approximately 200 m upstream of the Box Road footbridge. All the flood affected buildings are located in Buderim Avenue or Box Road. No management measures were considered outside this reach.

EXISTING FLOOD PROBLEM

Table (i) indicates the estimated number of buildings along Buderim Avenue and Box Road which are likely to be flooded for a range of event magnitudes and the corresponding tangible damages. No consideration has been given for damages to public structures or utilities (bridge, roads, pumping station).

Table (i): Buildings Inundated and Tangible Damages for Buderim Avenue/Box Road

Design Flood	Buildings Inundated		Tangible Damages	
	100% Blockage	**No Blockage**	**100% Blockage**	**No Blockage**
PMF	21	21	$1 140 000	$1 140 000
0.2% AEP	17	11	$620 000	$400 000
1% AEP	13	7	$480 000	$240 000
2% AEP	12	7	$430 000	$170 000
5% AEP	12	4	$360 000	$100 000
10% AEP	9	1	$200 000	$25 000

Note: The values are shown assuming 100% blockage at the Bates Drive and Box Road culverts as well as for no blockage.

The average annual damages were estimated to be $125 000 assuming 100% blockage.

STUDY AREA ISSUES

A range of issues relating to the Oyster Creek floodplain have been raised, discussed with Council and DIPNR Officers or the community as part of the consultation process, or were outlined in previous studies. These issues include:

- levees,
- stream clearing,
- dredging,
- replacing the Bates Drive culverts with a bridge or providing additional culverts,
- reducing the likelihood of blockage of the Bates Drive culverts,
- providing a slot in one of the Bates Drive culverts.

FLOODPLAIN RISK MANAGEMENT MEASURES

A list of all possible floodplain risk management measures which could be applied in the study area were initially developed for consideration. The measures were then assessed in terms of their suitability and effectiveness for reducing social, ecological, environmental, cultural and economic impacts. As part of this process, a number of measures were identified as not being worthy of further consideration.

A summary of the various measures considered during the course of the study is presented in Table (ii) together with a brief assessment of their viability for implementation as part of the Floodplain Risk Management Plan for Oyster Creek.

Table (ii): Summary of Floodplain Risk Management Measures

MEASURE	REFER SECTION	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
FLOOD MODIFICATION:					
FLOOD MITIGATION DAMS, RETARDING BASINS	Section 4.2.2	Reduce flows from upper catchment areas.	Many issues (cost, environmental, social) and not supported by residents.	Generally not viable from a purely flooding perspective.	Not appropriate.
DREDGING	Section 4.2.3	Increases the waterway capacity of the channel and in order to reduce flood levels.	Undertaken in the past but now rarely adopted due to high environmental impacts, with ongoing maintenance works required. Supported by all residents. Full benefit can only be obtained if also increase waterway at Bates Drive culverts.	High capital maintenance and environmental costs typically make this measure difficult to obtain funding.	To be considered further.
VEGETATION CLEARING	Section 4.2.4	Increase conveyance of creek.	Reduces flood levels if mangroves are removed from downstream of Bates Drive. Another area where benefits are derived is downstream of Box Road. Has high environmental implications and requires on going maintenance.	Greater benefit cost ratio than dredging. On going maintenance required.	Could be considered in limited areas.
SLOT AT BATES DRIVE CULVERTS	Section 4.2.5	Provides no hydraulic benefit by itself but would do so if it helps to reduce the accumulation of sediments upstream of Bates Drive.	Has potential to significantly alter the local ecosystem upstream from brackish to almost fully marine.	Exact benefit of this measure cannot be accurately assessed at this time. Relatively small cost but high environmental cost.	To be considered further.
ADDITIONAL WATERWAY AREA AT BATES DRIVE CULVERTS	Section 4.2.6	Remove hydraulic restriction caused by the culverts (raised invert at 0.7 m AHD) and high embankment on western side.	A variety of options are available to increase the waterway area. Difficult to obtain funding for road reconstruction works. Lowering the invert has the potential to significantly alter the local ecosystem upstream from brackish to almost fully marine.	All options are high cost with low benefit cost ratios.	Unlikely to obtain funding in the short to medium term. Should be considered when road is being upgraded.
WIDENING OF CHANNEL	Section 4.2.7	Similar purpose to dredging which increases waterway area.	The cost of this measure would be similar to dredging. Probably less environmental concerns, particularly if the excavated area could be used as a water quality control structure. Less support by the residents for this measure than dredging.	High capital maintenance and environmental costs typically make this measure difficult to obtain funding. May be attractive if developed as a water quality control structure.	To be considered further.
LEVEE	Section 4.2.9	Prevent or reduce the frequency of inundation of protected areas.	Viability of levees typically dependent on nature of flooding and physical situation. Can create problems in addition to solving them. A high economic cost and significant social consequences. Not supported by local residents.	One of the few measures that would eliminate inundation of all buildings (to the level of the crest).	Not considered further due to lack of support from residents.

MEASURE	REFER SECTION	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
REDUCE LIKELIHOOD OF BLOCKAGE AT BATES DRIVE CULVERTS	Section 4.2.10	Reduce possibility of blockage and thus help to reduce flood levels.	Well supported by residents. If successful it would be of significant benefit with few dis-benefits.	Varies depending upon measure. The simplest measure of removing existing debris has a low cost and would be greatly supported by the residents. Reducing blockage of the Bates Drive culverts has a high benefit/cost ratio (refer to damages figures in Table (i).	To be considered further.
		Increase the environmental quality of the creek.	Residents also strongly supported any measure to increase the environmental quality of the creek by reducing litter and debris entering along the drainage lines. Whilst these measures would have no tangible benefit in reducing blockage at Bates Drive they are of high environmental value.	Providing litter reduction devices may cost $5 000 per device and would not reduce flood levels. However they are of significant benefit in increasing the environmental quality of the creek.	Should be undertaken.
PROPERTY MODIFICATION:					
VOLUNTARY PURCHASE	Section 4.3.1	Purchase of the most hazardous flood liable properties.	High cost per property. Applicable for isolated high hazard residential buildings but cannot be economically justified to purchase all buildings. May introduce social problems.	High costs likely to far outweigh benefits.	Unlikely to obtain funding.
HOUSE RAISING	Section 4.3.2	Prevent flooding of existing buildings by raising habitable floor levels above the flood level.	All flood damages would not be prevented. House raising difficult and probably uneconomic to implement due to predominantly slab and brick construction.	Costs up to $100 000 per house. Benefit cost ratio of up to 0.3.	Not supported by local residents.
FLOOD PROOFING	Section 4.3.3	Sealing of entrances to buildings to minimise ingress of water and reduce the potential damage	Flood proofing should be considered but it is rarely (if ever) applied to residential buildings.	Local benefits can be high for relatively low cost.	Probably not supported by local residents.
PLANNING AND FUTURE DEVELOPMENT CONTROL MEASURES	Section 4.3.4	Ensure all new developments take into account flood hazard.	Council's existing policy outlined in recent Flood Risk Management Development Control Plan.	Measure already undertaken.	Recommended.
RESPONSE MODIFICATION:					
FLOOD WARNING	Section 4.4.1	Enable people to evacuate and take measures to reduce actual flood damages.	Catchment response time too small to implement effective system	Generally high benefit cost ratio for these systems.	Not relevant.
EVACUATION PLANNING	Section 4.4.2	To ensure that evacuation can be undertaken in a safe and efficient manner.	The SES Local Flood Plan could be enhanced to provide more detail on the particular problems along Oyster Creek. However it is doubtful if the SES would have the resources or ability to provide effective assistance before the flood peak.	Relatively low cost but only limited benefit likely.	Recommended as benefits should outweigh the costs.
EVACUATION ACCESS	Section 4.4.3	Ensures residents can safely evacuate	Existing access is satisfactory.		No works required.

MEASURE	REFER SECTION	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
FLOOD AWARENESS AND READINESS PROGRAM	Section 4.4.4	Educate people to minimise flood damages and reduce the flood risk.	A cheap effective method but requires continued effort. Examples of methods are provided.	Benefits likely to be significant for relatively low costs.	Recommended.

1. INTRODUCTION

1.1 Background

Oyster Creek has a 3.5 km^2 catchment which drains to Oyster Bay and the Georges River (Figure 1). The catchment area is predominantly occupied by urban development including both residential and commercial/light industrial development. There are no large areas of open space except for sporting fields and creek lines.

In July 2003 Webb, McKeown & Associates were commissioned by Sutherland Shire Council to undertake the Oyster Creek Waterway/Flooding Improvements Feasibility Investigation and Detailed Design Study. The overall scope of the study was to examine the feasibility of various waterway improvement and flood mitigation works in Oyster Creek. The study was to involve community consultation, review of environmental impacts, obtaining necessary approvals, and preparation of detailed designs and contract documents. The works as proposed by Council in the Brief were for the construction of a 1 m x 1 m slot in the base of the Bates Drive culverts, and the dredging of a channel some 0.5 m deep and 10 m wide for a distance of approximately 400 m upstream of the culverts.

A Draft Stage 1 Feasibility Assessment report (Reference 1), which was based on a Flood Study undertaken by Sutherland Shire Council (Reference 2), was subsequently completed in October 2003.

Reference 1 outlined the likely high cost of the proposed mitigation works and possible adverse social and environmental implications. In view of the complexity of the flooding problem it was decided to embark on the floodplain management process as outlined in the NSW Government's Floodplain Management Manual (2001) (Reference 3).

1.2 Floodplain Risk Management Process

Sutherland Council commissioned the following studies in accordance with the guidelines of the Floodplain Management Manual (Reference 3):

Stage 1: Flood Study - completed in 2004 (Reference 4),
Stage 2: Floodplain Risk Management Study,
Stage 3: Floodplain Risk Management Plan.

The Flood Study (Stage 1 of the process - Reference 4) established the design flood levels for the study area. The "1% AEP" or "1 in 100" flood has a 1 in 100 chance of being equalled or exceeded in any given year. On a LONG TERM average it will be experienced once in every 100 years, but it is wrong to think it can only happen once in a century. Because floods are random events there is still a 1 in 100 chance of the flood occurring next year no matter what happens this year.

This Floodplain Risk Management Study (Stage 2) seeks to fully identify the nature of the flood problem in terms of risks to floodplain occupants and their assets, and then to canvass various possible measures to mitigate the effects of flooding. The end product is the Floodplain Risk Management Plan (Stage 3) which will describe how the flood problem and flood liable lands in the Oyster Creek catchment are to be managed in the future. This process requires community interaction to ensure that the proposed measures are fully supported. Ultimately Council will complete the process through implementation of the actions identified in the Plan (depending upon financial and other constraints).

2. BACKGROUND

2.1 Description of Study Area

Oyster Creek (Figure 1) has a catchment area of some 2.4 km^2 upstream of Bates Drive and 3.5 km^2 to the Georges River. The catchment is steep and includes the suburbs of Sutherland, Jannali, Oyster Bay, Kareela and Kirrawee. The downstream reach between Box Road (unformed) and Bates Drive forms a narrow floodplain (see Figure 1 and Photographs 1 & 2). Downstream of Bates Drive the creek becomes a mangrove lined estuary leading into Oyster Bay and the Georges River. This reach is bounded by residential properties on either side (Loves Avenue, Oyster Bay and Siandra Drive, Kareela).

The study area for the Flood Study was taken as the reach of floodplain extending from approximately 170 m upstream of the Box Road footbridge down to Oyster Bay, a distance of some 1900 m. Further downstream the creek becomes part of Oyster Bay and the Georges River estuary. Upstream the creek becomes very incised with a narrow floodplain with development largely situated outside the floodplain. For this Floodplain Risk Management Study the study area was confined to the reach between the Bates Drive culverts and approximately 170 m upstream of the Box Road footbridge, a distance of some 600 m. This is because there are no buildings inundated in the 1% AEP event outside of this study area.

In the early 1960's, six (3000 mm x 1800 mm) box culverts were constructed across the creek at Bates Drive. The invert of the culverts is at approximately 0.7 mAHD and thus it acts as a weir across the creek. The creek upstream is consequently a semi-tidal, predominantly freshwater environment (refer Photographs 2 and 6) whilst downstream, it is a fully estuarine environment (Photograph 1).

In 1963, subdivision approval was given for Buderim Avenue and the adjoining streets in the area upstream of Bates Drive. The odd numbered residential properties (No's 1 to 39) in Buderim Avenue (Photographs 3, 4 and 5) were constructed between 1963 and 1971. To facilitate this development the floodplain adjoining and parallel to the creek was filled. At the time, the creek was excavated to form a 20 m wide x 1.5 m deep channel. Further filling of the floodplain occurred in the 1970's with a subdivision along Siandra Drive, Kareela.

The impounded part of the creek upstream of the Bates Drive culverts has been subject to high rates of ongoing siltation and is now very shallow with limited waterway area, see Photograph 6.

It is clear from historical photographs that the creek channel that exists today is significantly larger than what it was prior to 1960. A 20 m wide (approximately) channel up to 2.0 m deep has been dredged on the eastern side of the floodplain from 200 m downstream of the Bates Drive culverts. The original 2 m wide and 0.5 m deep channel still exists within the mangroves on the western side. Upstream of Bates Drive the dimensions of the original channel are unknown but it was probably only a few metres wide and a metre deep. Today it is up to 20 m wide but generally less than 1 m deep. No accurate records of the extent of dredging are available.

2.2 Photographs

Photograph 1: View downstream of Bates Drive

Photograph 2: View upstream of Bates Drive

Photograph 3: View upstream along Buderim Avenue

Photograph 4: View downstream along Buderim Avenue

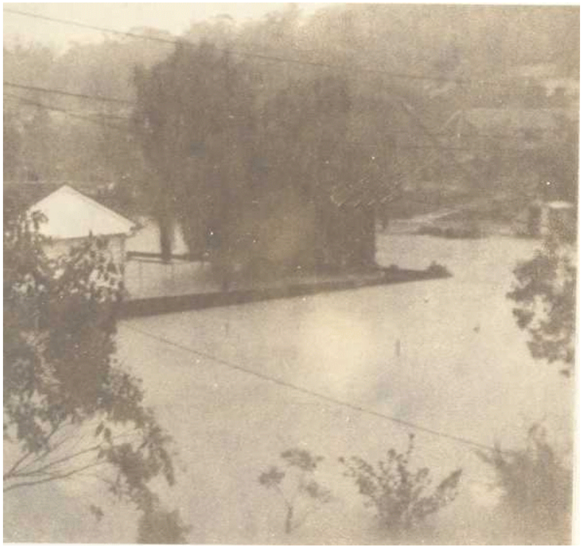
Photograph 5: No. 5 Buderim Avenue

Photograph 6: Carvers Road

FIG. 9. FLOODING OF NO. 5 BUDERIM AVENUE.
TAKEN AT PEAK OF MARCH, 1975 FLOOD.

Photograph 7: No. 5 Buderim Ave - March 1975

Photograph 8: Looking to Bates Dr - March 1975



Photograph 9: No. 5 Buderim Ave - March 1975

Photograph 10: Buderim Avenue - March 1975

FIG. 20 FLOOD MARK ON NO. 7 BUDERIM AVENUE AFTER
THE 1975 FLOOD.

Photograph 11: No. 7 Buderim Ave - March 1975

FIG. 27 THE BOX ROAD FOOTBRIDGE AT THE UPSTREAM END
OF THE STUDY AREA (NOTE FLOOD DEBRIS ON
BRIDGE INDICATING THAT IT PARTIALLY OBSTRUCTED
FLOODWATERS.

Photograph 12: Box Road - March 1975

*** Note: March 1975 photographs taken from M G Carleton's Project Report (Reference 5)**

2.3 Preliminary Environmental Assessment

2.3.1 Water Quality

The tidal range in Oyster Creek downstream of the Bates Drive culverts is similar to that in the Georges River and along the open coast generally. Based on a long term analysis of water levels at Picnic Point and with the culvert inverts at 0.7 mAHD, tidal overtopping causing inflows to upstream of the culverts would occur on approximately 50% of days.

Any inflows to upstream of the culverts would be predominantly marine, with salinities close to ocean conditions. The volume of water upstream of the culverts at low tide is less than 400 m^3 and the volume of inflows during a very high tide could exceed this amount. The resultant mixing of the waters would largely depend on the tide levels and catchment runoff flowing into the creek. However, it is reasonable to assume that at times the waters would be quite brackish (over 50%) ocean salinity, but generally would be closer to fresh water conditions.

In relation to other aspects of water quality such as dissolved oxygen, water acidity, water clarity, temperature, nutrients, phytoplankton, faecal coliforms and disease causing organisms, the existing waters upstream of the culverts are probably similar to other suburban catchment runoff waters mixed with marine waters. During low flow conditions the waters probably meet ANZECC standards, except for faecal coliforms, because of the large number of ducks which feed in the reach. During high flows the quality of the water probably deteriorates due to urbanised catchment runoff and sewer overflows, but resident times are likely to be short because of the high runoff volumes and subsequent tidal flushing.

2.3.2 Flora

The reach upstream of the Bates Drive culverts (see Photographs 2 and 6) is currently dominated by the Common Reed (Phragmites australis). Dense thickets of Phragmites extend along both banks of the creek and cover the full creek width in the upper limits near Box Road. In the lower half of the reach there are rafts of algae and several small River Mangroves (Aegiceras corniculatum) interspersed in the reeds. There is clear evidence that the mangroves are “kept in check” by local residents.

The presence of the mangroves indicates that although the area is predominantly a fresh water environment, the high tide connection between the mangrove dominated estuary section downstream of the Bates Drive culverts and the upstream section is sufficient to allow the introduction and establishment of mangroves.

In the upper half of the reach the reeds are interspersed with numerous different exotic plants such as kikuyu, privet and bananas. In places the kikuyu has been cultivated or has overgrown the reeds. Away from the immediate creek banks the area is grassed and mown. The western Carvers Road side has a number of large gum trees. The eastern side behind Buderim Avenue has a mix of gums, wattles and fruit trees.

2.3.3 Fauna

The predominant faunal feature of the existing creek environment is the flock of black ducks which feed and roost in the area upstream of Bates Drive. The ducks main food source is probably benthic organisms such as insect larvae, polychaete worms and molluscs (snails). Other wading birds also frequent the reach. The main, and possibly the only fish species would be mosquito fish (*gambusia Holbrooki*), although there may be short and long finned eels (*anguilla spp.*)

2.3.4 Visual Amenity

The visual amenity of the area upstream of Bates Drive is currently one of a predominantly freshwater lagoon/creek within a park setting, comprising permanent water, reeds and ducks. The ducks are one of the main visual elements. The brackish/estuarine components of the creek are kept minimal by human intervention such as mangrove removal, the cultivation of exotic plants and mowing of the grass. The quality of the view is reduced by the proximity of the properties along the eastern bank of the creek and the fact that they face away from the creek and often have high back fences. Exotic trees and creepers impact upon the view in the upper part of the reach.

2.3.5 Recreational Amenity

The area upstream of Bates Drive is currently used by local residents as a passive open space area for walking, exercising dogs (walking and swimming) and feeding the ducks. However, its main use is simply as a visual space for relaxation.

2.3.6 Analysis of Bed Sediments

The catchment area from which the bed sediments were derived is heavily urbanised. It includes the Kirrawee industrial estate and numerous main roads, including part of the Princes Highway. Based on sediment sampling from similar catchments in the Sydney region, there is a reasonable possibility that the sediments could be contaminated. Likely contaminants could be metals such as lead and zinc, and chemicals such as pesticides from white ant treatment, etc. There is also a strong possibility that the sediments of the original estuary floodplain could have an acid sulfate leachate potential.

In August 2003, four sediment samples were collected from the upper 0.5 m of bed sediments using polycarbonate push tube bores. The approximate locations were mid-stream at the 2 m, 100 m, 200 m and 300 m marks upstream from the Bates Drive culverts. Sediment samples were extracted from the tubes, placed directly into laboratory prepared glass jars and immediately capped, labelled and stored in an iced transport container. The samples were then couriered to ALS Environmental laboratory for testing. The testing included:

- total concentrations of metals (As, Cu, Ni, Pb, Zn and Hg),
- total polychlorinated biphenyls (PCBs),
- organochloride pesticides (OC),
- polynuclear aromatics (PAH).

The results of the testing are summarised in Table 1.

Table 1: Sediment Contaminant Test Results (mg/kg)

Contaminant	Location A (2 m)	Location B (100 m)	Location C (200 m)	Location D (300 m)	EPA Inert solid Threshold TC	ANZECC Low Threshold
Arsenic(As)	16	1	6	3	10	8.2
Copper (Cu)	14	7	18	22		34
Nickel (Ni)	3	3	3	13	4	21
Lead (Pb)	14	13	55	30	10	46
Zinc (Zn)	24	37	232	95		150
Mercury (Hg)	<0.1	0.1	0.2	0.1	0.4	0.15
Total PCB	<0.1	<0.1	<0.1	<0.1		0.02
OC*	<0.02	<0.02	<0.02	<0.02		0.02
PAH*	<0.05	0.48	<0.05	0.17		0.55

* Maximum individual compound concentrations.
- dark shaded results exceed threshold levels.

The A sample from the 2 m mark consisted entirely of an unconsolidated silty fine to coarse sand with some lithic particles. The B sample from the 100 m mark consisted of some 300 mm of similar unconsolidated silty fine to coarse sand overlying a firmer silty sand. The C and D samples from the 200 m and 300 m marks were similar to sample B, but with the unconsolidated sandy sediment layer decreasing down to around 150 mm at the 300 m mark.

For this preliminary assessment the samples were tested for total concentrations (TC) of pollutants rather than the leachable or bio-available concentrations. EPA (1999) and ANZECC (2000) guidelines provide for the testing of total concentrations as a guide to the possible level of contaminants in a sample. The guidelines are based on a range of contaminant levels for each of the specified contaminants. A TC level in the lowest range indicates that the sediments are not of concern for that contaminant. A TC above the lowest threshold limit (but below the next) indicates that sediments may possibly be contaminated and that further investigations are required. Sediments with TC levels above the next level are identified as likely to be contaminated, etc.

Comparison of the TC test results with EPA and ANZECC guidelines indicates that contamination levels for lead exceed the EPA threshold limits for all samples. Arsenic levels in the A sample and zinc levels in the C sample also exceed the EPA and ANZECC limits respectively. The levels of organic contaminants PCBs, OCs and PAHs appear to be below threshold levels.

2.3.7 Acid Sulphate Soil Potential

In May 2002 Council undertook an extensive ASS investigation of the study area including eight boreholes between 0.75 m and 1.3 m depth and 19 samples. A hand auger and piston suction were used.

Elementary testing for ASS potential was undertaken at Council's Materials Laboratory with more detailed POCAS testing undertaken externally. Details of the testing are summarised in Table 2.

Table 2: Acid Sulphate Soil Potential Test Results

Location	Depth (mm)	Natural pH	H_2O_2 pH	% S_{pos}	TAA	TPA
BH1	0-560	6.5	6.9			
BH1	560-750	6	6.4			
BH2	0-750	6.9	3.3	0.23	2	90
BH3	550-750	6.8	3.7			
BH3	750-1100	6.6	3	0.07	2	4
BH4	800-1100	6.8	3.1			
BH4	1100-1400	6.9	3.4	0.02	32	54
BH5	0-580	6.5	4.3			
BH5	580-820	6.4	3	0.22	2	104
BH6	0-250	7	6.9			
BH6	250-500	7	6.1	0,02	2	2
BH6	500-800	7	6.7			
BH7	0-520	6.2	3			
BH7	520-730	5.3	3	0.23	2	152
BH7	730-1100	5.9	3			
BH8	0-300	7	4.2			
BH8	300-650	7	5.6			
BH8	650-850	7.1	4	0.01	2	2
BH8	850-1150	6.9	5.6			

TAA - Total Actual Acid
TPA - Total Potential Acid
dark shaded results used in assessment

All the upper level samples are relevant to any measure which may lower ground water levels upstream of the Bates Drive culverts. Samples from BH4, BH6 and BH8 are not relevant to the proposed dredging as they are on the western floodplain. Of the samples collected, only BH6 and BH2 were submitted for detailed POCAS analysis.

Council's Materials Laboratory found that there were two zones of potential acid sulfate soils, a low zone along the left (western) bank and partially in the creek, and a medium zone within the creek. The laboratory found that soils from the low potential zone could be treated by the application of Aglime at a rate of 6.4 kg/tonne of soil, and that the moderate zone soils could be treated at a rate of 18.4 kg/tonne.

2.4 Causes of Flooding

Flooding within the Oyster Creek catchment may occur as a result of a combination of factors including:

- An elevated water level in Oyster Bay due to persistent rain over the entire Georges River catchment and an elevated ocean level.
- Elevated water levels within Oyster Creek as a result of intense rain over the Oyster Creek catchment. The levels experienced in the creek may also be affected by constrictions (e.g. culverts, blockages, vegetation).
- Local runoff over a small area accumulating (ponding) in low spots (such as may occur in Buderim Avenue). Generally this occurs in areas which are relatively flat with little potential for drainage. This type of inundation may be exacerbated by inadequate local drainage provisions and elevated water levels at the downstream outlet of the urban drainage system (pipe, road drainage) system. Detailed analysis of this type of flooding is outside the scope of the present study.

These factors may occur in isolation or in combination with each other. Generally the peak water level in the Georges River is more likely to occur several hours after the Oyster Creek flood peak. This is because the peak levels in the Oyster Creek catchment are generated by an intense short duration storm of up to two hours duration. In contrast, the peak levels in the Georges River result from a longer duration storm of up to 48 hours or longer.

The rainfall event causing flooding within the Oyster Creek catchment may occur as part of a long duration storm that causes flooding on the Georges River. Alternatively, it may occur as an isolated thunder storm that is not part of a long duration event causing flooding in the Georges River. Thus flooding in Oyster Creek and the Georges River do not necessarily result from the same period of rainfall.

2.5 Flood Information

2.5.1 Historical Flood Data

A data search was carried out in the Flood Study to identify the dates and magnitudes of historical flood events. The search concentrated on the period since approximately 1970, as it was considered that data prior to this date would generally be of insufficient quality and quantity. Unfortunately there is no stream height gauge in the Oyster Creek catchment or other means of determining the level of past flood events. Reliance must therefore be made on photographs and interviews with residents. A detailed review of rainfall records was also undertaken as this allows the possible dates of flooding to be established.

The only known recorded history of flooding in the Oyster Creek catchment is provided in M G Carleton's Project Report undertaken in 1977 (Reference 5). In summary, the report indicates that Oyster Creek broke its banks approximately 10 times in the period from 1969 to 1977 and floodwaters entered houses in Buderim Avenue on at least four occasions (refer Table 3).

Table 3: Flood History from M G Carleton's Report (Reference 5)

Event	No. of Buildings Inundated above floor	House No's * Inundated in Buderim Avenue	Approximate Peak Level at Bates Drive (mAHD)	Number of Recorded Flood Levels
?? 1969	approx. 8	unsure	3.0	nil
?? 1970	unknown	??	??	nil
26 March 1974	6	5,7,17,27,31,33	2.8	8
11 March 1975	10	5,7,15,17,23,25, 27,31,33,39	3.0	11
4 March 1977	nil	-	2.4	8

Note: * Some buildings may have been rebuilt since 1977.

Since 1977, Sutherland Shire Council has no record of houses or yards being inundated. A questionnaire survey undertaken as part of the Flood Study indicated that no overbank flooding or inundation of private property has occurred since 1977. Thus it would appear that the only documented period of flooding is from 1969 to 1977 as contained in Reference 5.

The following issues relating to floodplain management were described in Reference 5:

- a log may have partially restricted two of the six cells under Bates Drive in the 1974 flood,
- the event of March 1975 caused widespread flooding throughout Sydney. Based on rainfall and flood records at Miranda, it was estimated that this event may have approached a 1 in 1000 ARI for a 12 hour duration and a 1 in 400 ARI for a 2 hour duration,
- between 1963 and 1969 there were no reports of flooding.

2.5.2 Design Flood Data

The Flood Study (Reference 4) established design flood behaviour within the study area as indicated on Figures 3 to 6 and summarised in Tables 4 and 5. These data assume 100% blockage of the structures at Bates Drive and Box Road.

Table 4: Design Peak Discharges (m^3/s)

Location	Event					
	10% AEP	**5% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**PMF**
Upstream limit of MIKE-11 model	36	49	57	65	84	251
Bates Drive	40	54	64	73	95	282
Downstream limit of MIKE-11 model	46	61	73	84	108	327

Note: Assumes 100% blockage of structures at Bates Drive and Box Road.

Table 5: Design Flood Levels (mAHD)

Location	Event					
	10% AEP	**5% AEP**	**2% AEP**	**1% AEP**	**0.2% AEP**	**PMF**
Upstream limit of MIKE-11 model	4.9	5.2	5.4	5.5	5.8	7.6
Box Road	3.7	4.0	4.1	4.3	4.6	6.4
Bates Drive	3.4	3.5	3.6	3.6	3.8	4.9
550 m downstream of Bates Drive	1.6	1.7	1.8	1.9	2.1	3.0
Downstream limit of MIKE-11 model	1.2	1.2	1.2	1.2	1.2	1.2

Note: Assumes 100% blockage of structures at Bates Drive and Box Road.

2.5.3 Hydraulic Classification

The Floodplain Management Manual (Reference 3) defines three hydraulic categories which can be applied to define different areas of the floodplain. The hydraulic categories of flood prone land include:

> "*Floodways* are those areas where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow or a significant increase in flood levels."
>
> *"Flood storage* areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood."
>
> *"Flood fringe* is the remaining area of flood prone land after floodway and flood storage areas have been defined."

The above hydraulic classifications have been applied to the Oyster Creek floodplain based on a detailed assessment of flood behaviour, the available topographic information and interpretation of model results from the Flood Study. There can be some variation in the hydraulic classification depending upon the size of the flood. An overview of the classifications for the study area in the

1% AEP event is indicated on Figure 5. The figure has been prepared on a broad scale and should only be relied upon for a general indication of the classification.

2.5.4 Hazard Classification

Flood hazard is a measure of the overall adverse effects of flooding and the risks they pose to people and/or property. It incorporates threat to life, the danger and difficulty in evacuating people and possessions, as well as the potential for damage, social disruption and loss of production. Flood prone areas are typically classified as either *low* or *high* hazard for a range of flood events.

Aside from the technical Flood Study results quantifying design flood behaviour, the hazard classification for a given area is partially a qualitative assessment based on a number of factors as listed in Table 6. The accompanying Figure 5 defines the resulting low and high hazard classifications for the Oyster Creek floodplain in the 1% AEP event. It should be noted that the extent of inundation has not been accurately surveyed and is based on limited survey data.

In events larger than the 1% AEP some areas of low hazard will become high hazard. It is also possible that some areas which are not flooded in the 1% AEP event will become high hazard areas in the PMF event. These will only occur at the limits of the high hazard area and accurate identification of these areas would require additional survey data. In events smaller than the 1% AEP there may be a decrease in the area of high hazard. Again, additional survey is required to more accurately define these areas.

Table 6: Flood Hazard Classification

Criteria	Relative Weighting	Comment
Size of the Flood	High	Even in a 20% AEP event the majority of the floodplain is inundated (largely as a result of blockage).
Flood Awareness of the Community	Low to Medium	Based upon the results of community consultation.
Depth and Velocity of Floodwaters	High	Velocities will be low (up to 1 m/s) near the creek bank and will reduce further across the overbank areas of the floodplain. The depth of inundation in a 1% AEP will be approximately 1.0 to 1.5 m across the majority of the floodplain.
Effective Warning and Evacuation Times	High	There is no flood warning system and thus it is possible that while residents may be aware of rain falling during the night they are not aware that flooding has/is occurring. Each flood is different and there is insufficient information to provide a reliable estimate of the actual warning time in a future flood event.
Rate of Rise of Floodwaters	High	Residents may be aware that the creek is rising but could be surprised at how rapidly the floodplain becomes inundated following overtopping of the river banks.

Criteria	Relative Weighting	Comment
Duration of Flooding	Low	The duration of inundation will be typically less than 2 hours and the flood will generally have receded completely within 4 hours.
Effective Flood Access	Low	Access from every building should be relatively easy.
Evacuation Difficulties	Low	There are unlikely to be any significant problems.
Additional Concerns such as Bank Erosion, Debris, Wind Wave Action	Medium - Low	These are unlikely to significantly increase the level of hazard. Blockage of the Bates Drive culverts has been taken into account for the design analysis.

2.5.5 Flood Damages

The quantification of flood damages is an important part of the floodplain risk management process. By quantifying flood damages for a range of design events, appropriate cost effective management measures can be analysed in terms of their benefits (reduction in damages) versus the cost of implementation.

The extent of disruption to the community and overall cost of flood damages depend upon many factors which include:

- the magnitude (depth, velocity and duration) of the flood,
- land usage and susceptibility to damage,
- awareness of the community to flooding,
- effective warning time,
- the availability of an evacuation plan or damage minimisation program,
- physical factors such as erosion of the river bank, flood borne debris, blockage, sedimentation.

The estimation of flood damages tends to focus on the physical impact for the human environment but there is also a need to consider the ecological costs and benefits associated with flooding of the floodplain. Flood damages are often defined as being “tangible” or “intangible”. Tangible damages are those for which a monetary value can be assigned. This is in contrast to intangible damages (stress, injury and loss of life) which cannot easily be attributed a monetary value.

A summary of results obtained is included in Table (i). The number of buildings (at Buderim Avenue and Box Road only) likely to be flooded and the corresponding tangible damages were estimated for a range of events. Likely damages to public utilities were not considered. Additionally no allowance was made for potential losses associated with the complete destruction of buildings.

The standard way of expressing flood damages is in terms of Average Annual Damages (AAD). These are calculated by multiplying the estimated damages that can occur for a given flood by the probability of the flood occurring in a given year and then summing across the range of floods. By this means the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods. Based on the damages estimated for the different flood events as shown in Table (i), the average annual tangible damages (AAD) for the Oyster Creek floodplain are estimated to be of the order of $125 000 (assuming 100% blockage of the Bates Drive culverts).

Given the variability of flooding and property values, etc., the total likely damages figure in any given flood event (as shown in Table (i)) is useful to get a “feel” for the relative order of magnitude of the overall flood problem, but is of only limited value for precise economic evaluation. When considering the economic effectiveness of a proposed mitigation option, the key question is the relative difference in total damages prevented over the life of the option. This is a function of not only the high value damages which occur in the larger less frequent floods but also of the more frequent lesser damages which occur in small floods.

2.6 Previous Flood Mitigation Measures

Reference 5 indicates that Sutherland Shire Council undertook channel deepening works twice in the period from 1971 to 1975. Photographs of the March 1975 flood show the dredge in the creek (Photograph 9). Reference 5 also indicates that:

- residents noted that following dredging in 1972 the creek bed soon silted up,
- this was also confirmed by a comparison of creek surveys in December 1972 and July 1974,
- Roads and Transport Authority plans indicate up to 2 m of silting occurred,
- residents reported that boats had previously entered the inlet, suggesting a much greater depth than at the time of the report in 1977,
- Council may have infilled portions of the floodplain adjacent to the Bates Drive culverts,
- extensive land reclamation works on other inlets (Kareela Golf Course, Oyster Bay ovals) may have affected the tidal dynamics of the lower parts of Oyster Creek.

As indicated in Section 2.1 the creek has been extensively dredged since 1960.

3. FLOODPLAIN MANAGEMENT ISSUES

3.1 Community Consultation

A rigorous public consultation program was carried out as part of the floodplain management process and included:

- a letter of introduction,
- questionnaires,
- floodplain management committee meetings,
- newsletters,
- a public meeting,
- interviews and discussions with residents,
- public exhibition of material.

The direction of the study and emphasis placed upon the various management measures was influenced by the feedback obtained from the community consultation program.

3.2 Study Area Issues

3.2.1 Local Issues

The following issues/views were raised by the community:

- **Dredging:** Practically all residents were of the opinion that the creek channel must be dredged. Many are aware that it was dredged in the past and consider that dredging is required to eliminate the build up of sediment entering from upstream. Preliminary discussions with Fisheries indicated that they would consider dredging if it could be justified.
- **Stream Clearing:** Most residents consider that some form of regular stream clearing is required upstream of the Bates Drive culverts. Whilst the channel is mostly well maintained for 200 m upstream of the culverts, further upstream the channel has become overgrown with vegetation including some exotic species.
- **Removal of Man-made Debris and Vegetative Matter from the Bush Upstream:** Some bush clearing has been undertaken in the past and it would appear that this rubbish has not been removed. The residents are concerned that in a future flood this debris could exacerbate possible blockage of the Bates Drive culverts.
- **Removal of Mangroves/Stream Clearing Downstream of Bates Drive Culverts:** This measure was raised but it would appear that it is not considered by all residents to provide an appropriate solution.
- **Replacement of the Bates Drive Culverts with a Bridge:** All residents consider that this should be undertaken and that it would significantly reduce their flood hazard. Nearly all

residents are aware of the blockage of the culverts that has occurred in the past and that this risk would be minimised or eliminated with construction of a bridge.

- **Provision of a "Slot" in the Invert of the Bates Drive Culvert:** This measure is not seen as a mitigation measure but rather as a means of maintaining a lower bed level upstream of the culvert. It is assumed that with this slot the sediments washed down from the catchment would not accumulate upstream but rather they would travel downstream and be deposited in Oyster Bay.
- **Levees around Buderim Avenue Properties:** This measure has been raised in the past as a means of reducing flood levels within the Buderim Avenue properties. This measure is not supported by the local residents for a number of reasons including aesthetics, access and that they consider other measures more preferable.
- **Flood Affectation Notice on S149 Certificate:** This was a major issue when the notifications were first placed on the properties. However it would appear that the residents now accept the reasons why this has occurred and that no mitigation measure would reduce flood levels to the extent that the notice could be removed.
- **Blockage of the Bates Drive Culverts:** All residents who have lived in the area since 1974 are aware that blockage of one (or more) of the culvert cells occurred in the March 1974 event. Many residents would like some measure to reduce the likelihood of blockage. Surprisingly it would appear that blockage has not occurred at the Box Road footbridge and the residents do not consider it as a threat.
- **Activate Existing Management Plan for Oyster Creek:** A committee was previously formed to prepare and administer this plan. However it would appear that no works have been undertaken as part of the plan.
- **House Raising/Flood Proofing of Buildings:** These measures have been discussed but are considered impractical by most residents.
- **Flood Warning:** This measure has never been mentioned as it is presumed that if the residents were in their houses at the time it is likely that they would be aware of the possibility of a flood.
- **Flood Related Development Controls:** All residents are aware that new houses must be raised to a specific level in order to have their floors above flood level. There are already several examples along Buderim Avenue where this has occurred. There would appear to be no resistance to these measures.

3.2.2 Council Wide Flood Related Issues

There are a number of Council wide flood related issues that are normally examined in Floodplain Risk Management Studies. These include:

- Flood warning by the Bureau of Meteorology,
- Review of Council's flood related development controls, including Flood Planning Levels, Local Environmental Plans and Development Control Plans,
- Flood insurance,
- Impacts of future development on flood liable lands,

- Possible rezoning of flood liable lands,
- Council's On Site Detention policy and controls used by Council to minimise the increase in runoff as well as the possible reduction in water quality emanating from future developments.

These issues are currently or will be considered by Council as part of the Georges River Floodplain Risk Management Study and Plan or other similar large studies. The main focus of this present study has been to examine the local problems at Oyster Creek rather than to review Council's overall floodplain management strategies for the wider local government area.

4. FLOODPLAIN RISK MANAGEMENT MEASURES

4.1 Introduction

The floodplain risk management study aims to identify and assess risk management measures which will mitigate flooding impacts and reduce flood damages. The risk management measures must be assessed against the legal, structural, environmental, social and economic conditions or constraints of the local area. The potential floodplain risk management measures can be separated into three broad categories as follows:

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

Property modification measures modify the existing land use or building and development controls for future development. This is generally accomplished through such means as re-zoning, development control plans, flood access, flood proofing (house raising or sealing entrances), or voluntary purchase.

Response modification measures modify the community's response to the potential risks and hazards of flooding. This is achieved by informing flood-affected property owners as well as the wider community about the nature of flooding so that they can make better informed decisions. Examples of such measures include provision of improved flood information, awareness and education of the community, flood warning and emergency services, and provision of flood insurance.

A number of methods are available for judging the relative merits of competing measures. The benefit/cost (B/C) approach has long been used to quantify the economic worth of each option on a relative basis and also enable ranking (prioritisation) against similar projects in other areas. The benefit/cost ratio is the ratio of the Net Present Worth of the reduction in flood damages (benefit) to the cost of the works. The ratio generally only incorporates the reduction in tangible damages as it is difficult to accurately quantify and include intangibles such as anxiety, risk to life, ill health and other social or environmental effects. The reduction in tangible damage to all public utilities has not been included in this study.

The potential environmental or social impacts of any proposed flood mitigation works are often of great concern to society and these cannot be evaluated using the classical benefit/cost approach. The public consultation program has ensured that all identified social and environmental factors have been considered in the decision making process.

4.2 Assessment of Flood Modification Measures

4.2.1 Hydraulic Assessment Approach

The Mike-11 hydraulic model developed for the Flood Study was used (where appropriate) to assess the hydraulic benefits (reduction in flood level) of the various flood modification measures. For the design flood analysis adopted in the Flood Study the Bates Drive culverts were assumed to be 100% blocked. For the purposes of assessing the different flood modification measures, the culverts have been assumed to have NO Blockage. This approach was considered reasonable otherwise the hydraulic impacts of most measures would be negated due to the blockage assumption.

The following analyses therefore compare results for the No Blockage existing conditions to the No Blockage design (modification measure) case. The results of the hydraulic assessment using the Mike-11 model are provided on Figure 7 for the 1% AEP event.

4.2.2 Flood Mitigation Dams

Flood mitigation dams and their smaller urban counterparts termed retarding basins have frequently been used in NSW to reduce peak flows downstream. Retarding basins are still used today in developing areas as a means of reducing the impacts of new development but rarely as a flood mitigation measure for existing development on account of the:

- high cost of construction,
- high environmental damage caused by construction,
- possible sterilisation of land within the basin,
- high cost of land purchase,
- risk of failure of the dam wall,
- likely low benefit cost ratio,
- lack of suitable sites. A considerable volume of water needs to be impounded by the dam in order to provide a significant reduction in flood level downstream.

This measure was not considered further for the above reasons and also as it was not supported by the local community.

The Darling Mills Dam in the Upper Parramatta River catchment (constructed in the late 1990's) is an example of a recent structure constructed in an already developed urban area.

4.2.3 Dredging

Discussion: Dredging of accumulated sediment has been used in the past for flood mitigation purposes as well as for navigation in order to increase the waterway capacity of channels. Oyster Creek and other areas surrounding Oyster Bay were dredged in the 1960's to 1970's with the fill material used to construct playing fields (Kareela golf course, Oyster Bay soccer ovals). This measure is rarely used today as it is difficult to justify solely for flood mitigation purposes. This is due to:

- the likely high environmental damage caused by the works,
- the subsequent possible change in ecology. On Oyster Creek it is likely that dredging would change the ecology upstream of Bates Drive from freshwater/brackish to saline, particularly if combined with a lowering of the culvert invert at Bates Drive,
- the ongoing maintenance requirement,
- if maintenance is not undertaken and a flood occurs then there may be some liability issues for Council,
- there is no guarantee that the creek would have been "dredged" immediately prior to a flood. Also the early part of a flood or a period of heavy rain prior to the flood peak may bring down sediments that could largely negate the benefits of dredging,
- dredging rarely eliminates a flood problem altogether and merely helps to reduce the flood levels,
- the excavated material is likely to be contaminated and thus there may be significant additional costs to dispose of it. Rubbish tips (Lucas Heights) are now a lot more cautious with the material that can be dumped and will ban unsuitable material or demand that it be "cleaned". However if the dredged material can be used for some useful purpose (on playing fields or similar) then this issue may not be a factor,
- dredging would not eliminate the S149 certificate notation on the properties along Buderim Avenue.

Most residents are strongly in favour of dredging and consider that this is the most viable means of protection. Two dredging scenarios were investigated.

Scenario 1 - The creek was dredged to a level of 0.0 mAHD from the Box Road footbridge to the Bates Drive culverts (a distance of approximately 400 m). This would involve the removal of approximately 6000 m^3 of sediments.

Scenario 2 - Dredging to a level of 0.0m AHD from the Box Road footbridge to approximately 200 metres downstream of the Bates Drive culverts (a distance of approximately 600 m). Downstream of this point the creek channel becomes wider and deeper and little benefit would be achieved from further dredging. This would involve the removal of approximately 8000 m^3 of sediments.

Benefits: The largest impacts from Scenario 1 are evident in the vicinity of the Box Road footbridge (Figure 7) where levels would be reduced by up to 500 mm. However downstream of this area this effect quickly tapers off, becoming less than 50 mm after only 200 metres (at a point approximately in line with 11 Buderim Avenue). From 300 metres downstream of Box Road no significant reduction in level occurs due to the "restriction" caused by the Bates Drive culverts and associated embankments. The number of inundated houses in the 1% AEP event would be reduced from 7 to 6 (a further 2 houses are on the borderline of not being inundated in the 1%

AEP event). For the house with the greatest depth of inundation in the 1% AEP event there is little reduction in level.
The impacts from Scenario 2 were again greatest at the footbridge, reducing peaks by 500+ mm. The impacts were reduced to 100 mm near the Bates Drive culverts and became negligible 150 metres downstream of Bates Drive. The benefit of Scenario 2 is that it would provide up to 100 mm reduction for the two most flood affected buildings. A greater benefit could be achieved if the Bates Drive culverts were upgraded in conjunction with dredging.

Dis-benefits: There are several dis-benefits for dredging as indicated above. Potentially there may be some increase in flood level downstream of the works. This would need to be evaluated at the concept stage when the full extent of the proposed works can be accurately determined. An Environmental Impact Statement (EIS) would be required to justify the works and this could cost up to $50 000.

Costs: The cost of dredging largely depends on the cost to dispose of the excavated material from the site. This could cost up to $100 per tonne. The actual cost of the excavation may be only $30 000. Assuming a total cost of $200,000 the benefit/cost ratio would be 0.3. The true B/C ratio over the life of the project is likely to be less as the ongoing maintenance costs have not been included. It could be that a similar amount of expenditure would be required every 10 years (estimate).

Analysis of Sediments: The NSW Environment Protection Authority (EPA) regulate the disposal of liquid and non-liquid/solid wastes under the provisions of the Waste Minimisation and Management Act 1995 and the Protection of the Environment Operations (POEO) Act 1997. Regulations associated with this Act require that "wastes" such as dredged sediments meet certain standards in terms of contaminant levels which determine their classification and hence their suitability for different reuse or disposal methods. Information about the levels of contamination in the creek bed sediments (refer Section 2.3.6) was therefore required prior to determining a suitable disposal method.

Based on the results provided in Table 1, before the sediments could be dredged and removed from the site it would be necessary to undertake further leaching tests for lead and arsenic. The purpose of these tests would be to identify the suitability or otherwise of the sediments for use as land fill materials. Further investigation may find that the lead and arsenic present in the sediments are bound sufficiently to the particles for the material to be classified as an inert solid, and therefore suitable for use as general landfill. Disposal costs may only be $20 per tonne.

Alternatively, the testing may show that the contaminants are not bound to the sediments, and that the dredged material would need to be classified as a solid waste. If this were the case, the sediments would have to be disposed of at a licensed contaminant waste site. Disposal costs at such sites are of the order of $100 per tonne.

Conclusions: Dredging would reduce flood levels but would not eliminate flooding from yards. There are several significant issues that need to be resolved before dredging could be undertaken. These issues need to be examined in detail as part of an EIS. The ongoing maintenance requirement means that these works might have to be repeated every few years. Possibly the installation of a 1 m^2 slot in the culverts may reduce the need for on going maintenance.

4.2.4 Vegetation Clearing

Discussion: This measure involves removing the vegetation from the creek channel and banks to increase the hydraulic conveyance of the creek and thus reduce flood levels. Clearing was examined from Box Road to 200 m downstream of the Bates Drive culverts (a reach length of approximately 600 m).

Benefits: 1% AEP flood levels would be reduced by around 100 mm for most of the cleared length with up to 400 mm reduction in the vicinity of the Box Road footbridge. However it should be noted that the most significant benefit is achieved from clearing of the mangroves immediately downstream of the Bates Drive culverts. Vegetation clearing of the 200 m reach upstream of the culverts has only minor benefit as the existing vegetation is very sparse.

Dis-benefits: The dis-benefits associated with vegetation clearing are mainly environmental concerns as it would reduce habitat for wildlife, including birds and fish. It could also increase erosion of the creek banks due to higher velocities. As with dredging, the clearing would need to be maintained on a regular basis and there is no guarantee that it would have been undertaken before a major flood. A Review of Environmental Factors would be required to justify the works and removal of the mangroves downstream of Bates Drive may require an EIS.

Costs: The cost may be up to $30 000 but would be a lot less if the works did not include removal of the mangroves.

Conclusions: Clearing of the mangroves downstream of Bates Drive would probably require an EIS. Works upstream require less justification but also provide less hydraulic benefit except in the vicinity of the Box Road footbridge.

4.2.5 1 m^2 slot at Bates Drive Culverts

Discussion: This measure would involve creating a slot (0.7 m wide x 1.4 m deep) beneath one of the culverts at Bates Drive. The slot invert level would be set at 0.0 m AHD. The aim of this measure would be to reduce the accumulation of sediments upstream of the Bates Drive culverts.

Construction of the slot would change water salinity conditions upstream of the culverts from brackish to almost to fully marine. This would result in colonisation of the foreshores by mangroves, and a change in the aquatic fauna from freshwater/brackish to estuarine. The ducks which are currently a feature of the area may leave, but would be replaced by waders and other estuary birds. The visual and recreational amenity of the area would also change with extensive mud flats at low tide and the existing reeds would be restricted to the upper section of the area. Juvenile estuarine fish species would probably use the area.

It should be noted that whilst the above might be considered a dis-benefit by some it may considered a benefit by others.

Benefits: Construction of the slot would achieve little reduction in the 1% AEP flood levels (generally not exceeding 25 mm). However this assumes that the existing sediments upstream have not been removed. Implementation of this measure should therefore only be considered if it was thought that the upstream sediments would be removed. This could either occur naturally over time or initially as a result of dredging.

A Review of Environmental Factors would need to be undertaken to justify the works.

Costs: Based on previous estimates in 2002 and allowing for inflation, the cost of these works may be up to $100 000.

Conclusions: This measure is only of limited floodplain management value even if the sediments upstream were to be removed (either naturally or through dredging). It will result in a change in the ecology of the creek which may be considered a dis-benefit by some and a benefit by others.

4.2.6 Additional Waterway Area at Bates Drive Culverts

Discussion: A number of scenarios for widening the waterway area at the Bates Drive culverts are possible. These include providing additional culverts, constructing a bridge or removing the culverts altogether. Removing the six culverts and replacement with a natural channel has the benefit in that it would lower the creek “invert” producing greater waterway area. Constructing a bridge would have little hydraulic benefit unless the total waterway area is increased. This is because the culverts themselves are hydraulically efficient smooth walled structures which provide greater conveyance than the equivalent waterway area of a natural channel. Raising the roadway would provide some benefit but only in events where the floodwaters reach the deck (events greater than the 2% AEP - refer Figure 3).

The main obstruction caused by the culverts is the approach embankment on the western side where the road is up to 1 m above the surrounding land (on the eastern side Bates Drive rises quickly). Removal of this embankment as well as the raised land on the downstream side of Bates Drive will achieve the maximum reduction in flood level. The land on the downstream side is open space and preliminary investigations suggest that it could be lowered with no significant detrimental effect.

For the purposes of this assessment, we have assumed a scenario whereby the culverts are replaced with a natural channel and the floodplain on the western side is available for the passage of floodwaters. This could either be achieved by placing additional culverts beneath the roadway or constructing a bridge. The former would probably be the most cost effective measure.

Benefits: This scenario would achieve the greatest benefits directly upstream of Bates Drive by reducing levels in this area by approximately 150 mm in the 1% AEP event. This effect gradually decreases with little reduction noted after 300 m upstream of Bates Drive. There was minimal change in flood level downstream of Bates Drive.

A bridge option has the benefit of largely minimising the possibility of blockage during a flood event. Whilst in accordance with current best practice, the use of culverts would probably mean that the design flood levels should be established assuming 100% blockage. As shown in Figure 7 blockage has a significant impact on the 1% AEP design flood profile and the number of buildings inundated.

Dis-benefits: Under existing conditions the invert of the Bates Drive culverts acts as a weir which results in the upstream water being predominately freshwater and only semi-tidal. Removing the culverts would mean the upstream area would become tidal with brackish water. This change to the upstream creek environment would impact on the local flora and fauna. There may also be some slight increase in flood level downstream.

Costs: The costs will vary depending on the nature of the works undertaken. In order to achieve the maximum hydraulic benefit, the construction of a bridge from near the intersection with Carvers Road to high ground on the eastern side (an approximate distance of 100 m) would be required. Such a structure would cost in the order of $2.5 million and there may be further costs for utility adjustments. The works would also cause significant traffic disruption. A number of less expensive options are possible as indicated below:

- lower all or some of the culvert inverts to 0 mAHD (say $600 000),
- place additional culverts under the western approach (say $500 000),
- replace the six culverts with a bridge (approximate span of 20 m say $1 million).

It should be noted that any of these options would achieve a lesser reduction in level than the 150 mm (in the 1% AEP) for the bridge option.

The benefit/cost ratio assuming a total cost of $2.5 million is less than 0.01.

Conclusions: There is a significant cost in undertaking works to increase the waterway area at the Bates Drive culverts. Unless the works are combined with dredging, the reduction in flood levels quickly tapers off after 300 m upstream.

4.2.7 Widening of the Channel

Discussion: This measure was mentioned in previous studies and would involve widening the creek into the western floodplain. Possibly the works could be combined with a water quality control structure. The residents would probably prefer dredging to widening.

Benefits: Widening of the channel would produce a similar benefit to dredging as it increases the waterway area available. No hydraulic modelling was undertaken at this stage. If undertaken in conjunction with dredging there would be an additional reduction in level. It should be noted that dredging or widening can only "flatten" the water profile within the area where the works are undertaken. Thus additional works provide lesser marginal improvement. To achieve a greater reduction in flood level requires works to be undertaken downstream of Bates Drive.

Dis-benefits: If this measure was implemented then consideration would have to be given to the analysis of sediments and acid sulphate soil potential discussed in Section 4.2.3. Residents may consider this measure unattractive as it would remove part of the open space on the western side of the creek. There may also be some slight increase in flood level downstream.

A Review of Environmental Factors (REF) would need to be undertaken to justify these works.

Costs: The cost of this measure would be similar to dredging and would depend on where the excavated material can be placed.

Conclusions: Widening of the channel could be undertaken in conjunction with dredging or as an alternative. An REF would be required to justify the works. One advantage of this measure over dredging is that there would be less requirement for on going maintenance.

4.2.8 Combined Dredging Scenario 2 and Bridge at Bates Drive

Discussion: This combined measure of dredging Scenario 2 and a bridge at Bates Drive is intended to provide an indication of the maximum hydraulic benefit that could be achieved by flood modification measures.

Benefits: There would be approximately a 200 mm reduction in the 1% AEP flood level (Figure 7) for a distance of 300 m upstream of Bates Drive. This increases to nearly 500 mm near Box Road. There may also be some slight increase in flood level downstream.

Conclusions: This measure would cost in excess of $2 million (say $2.7 million) with an indicative benefit/cost ratio of 0.02. Therefore it cannot be justified on economic grounds.

4.2.9 Levee

Discussion: The construction of a levee was mentioned in previous studies as a means of eliminating inundation of yards as well as house floors. Previously it was thought that the existence of a levee would enable removal of the S149 notification from the properties protected but this is not the case. A levee is not supported by the residents on social (access, aesthetics) grounds. Therefore, it has not been investigated in detail in this study. The costings for the levee provided below were taken from the previous study undertaken in 2002 and thus would need to be increased for inflation.

- Levee on Buderim Avenue side - $1.45 million,
- Levee on Carvers Road side - $10 000,
- Gates within Buderim Avenue levee - $14 000 (manual or $112 000 if automatic),
- Internal drainage on Buderim Avenue side - $1.1 million (pump) or $746 000 (gravity),
- Internal drainage on Carvers Road side - $855 000 (pump) or $192 000 (gravity).

Benefits: This is the only flood modification measure that would eliminate inundation of yards and floors (to the height of the levee crest).

Dis-benefits: According to previous studies this measure would produce a slight (up to 60 mm) increase in the 1% AEP flood level along Carvers Road. For this reason, an additional levee and associated stormwater system were included on the west bank. There may also be some slight increase in flood level downstream at upstream of the works. This would need to be fully evaluated at the concept design stage.

A number of key points are relevant:

- a levee can always be overtopped by a larger flood event,
- the original levee design assumed gates in the wall. These are not recommended,
- there is little justification for construction of a levee plus gravity stormwater system on the Carvers Road side (estimated cost of $200 000) as all the houses on the Carvers Road side are elevated and the majority (if not all) of the land adversely affected is Council owned (this would need to be verified),
- failure of an internal drainage system behind a levee can cause as much damage as would occur if the levee had not been built. An alternative to a gravity or pump system is to eliminate the need for one. A preliminary investigation indicates that this could be achieved by raising the ground and driveways within the road easement to prevent runoff entering from Buderim Avenue. In effect all runoff entering Buderim Avenue would flow to the north and enter the creek in the Reserve between No's 3 and 5. The only runoff ponding within the leveed properties would be from the rain falling over the properties themselves. There would be some cost for these works but it is likely to be significantly less than $746,000 for the gravity system proposed for the Buderim Avenue side,
- the buildings upstream of Box Road are inundated in the 1% AEP flood but would be excluded from the levee protection,

- there would be no real benefit in undertaking dredging, creek widening, replacement of the Bates Drive culverts or construction of a slot in the Bates Drive culverts if a levee was constructed (apart from lowering the levee crest by approximately 200 mm).

Costs: The total cost for all the levee works was previously estimated to be at least $2.4 million. A significant proportion of this cost was for internal drainage (either pumps or a gravity system). The cost of this measure could be significantly reduced if the internal drainage requirements were reduced and no works were required on the western side. Based on previous estimates the cost could be reduced to the order of $1.5 million giving a benefit/cost ratio of 0.2.

Conclusions: This measure is probably the most preferable option in terms of hydraulic benefit as it eliminates flood damages (to the height of the levee crest) to all properties along Buderim Avenue. However it is not supported by the residents for access and aesthetic reasons. Additionally, the two houses upstream of Box Road footbridge would not be protected by the proposed levee.

4.2.10 Reduce Likelihood of Blockage at the Bates Drive Culverts

Discussion: All residents support measures that would reduce the likelihood of blockage of the Bates drive culverts. Examples of such measures include:

- channel clearing to remove tree trunks/branches,
- removal of man-made and vegetative debris from the upstream catchment area,
- provision of a debris blockage structure at the Bates Drive culverts.

Benefits: If successful the measures would reduce blockage potential and thus decrease flood levels (refer Table (i)).

Dis-Benefits: There are no significant dis-benefits. A minor dis-benefit is the possible reduction in aesthetic appeal of the creek/vista.

Costs: The costs would depend upon the nature of the works ultimately adopted for implementation. An indicative cost would be $50 000. A measure that would ensure that blockage does not occur would have a benefit/cost ratio of above 4.

Conclusions: Any measure of this nature would provide some hydraulic benefit.

Litter/debris reduction devices: Whilst these measures produce no tangible benefit in reducing blockage at Bates Drive and thus flood levels upstream, they are of high environmental value in enhancing the quality of the creek both physically and aesthetically. These measures are strongly supported by the community and can be readily installed on the outlet pipes entering the creek. They would work in conjunction with Sutherland Council's existing community education measures on litter reduction.

4.3 Assessment of Property Modification Measures

4.3.1 Voluntary Purchase

Discussion: Voluntary purchase involves the acquisition of flood affected properties (particularly those frequently inundated in high hazard areas) and demolition of the residence to remove it from the floodplain. Generally the land is returned to open space however there may be an opportunity for a new house to be built at a higher floor level.

Benefits: It is mainly implemented over the long term in the more hazardous areas over the long term as a means of removing isolated or remaining buildings and thus free both residents and potential rescuers from the danger and cost of future floods. It also helps to restore the hydraulic capacity of the floodplain (storage volume and waterway area).

Dis-Benefits: Many local communities do not accept voluntary purchase because it would have a significant impact on their way of life. Among their concerns are:

- it can be difficult to establish a market value that is acceptable to both the State Valuation Office and the resident,
- in many cases residents may not wish to move for a reasonable purchase price,
- progressive removal of properties may impose stress on the social fabric of an area,
- it may be difficult to find alternative equivalent priced housing in the nearby area with similar aesthetic values or features.

Costs: Voluntary purchase of all the Buderim Avenue dwellings inundated above floor level in the 1% AEP event (assuming blockage) would be around $7 million (say 10 buildings at $700 000 each). Generally, Government funding of voluntary purchase schemes is only available as a last resort for situations where buildings are located in a high hazard area and are frequently flooded (20%, 10% or 5% AEP events) where continual occupation presents a real risk to life and there are limited alternative options available to manage the situation. It is unlikely in this particular situation that this measure would meet the Government's criteria.

Conclusions: The adoption of a voluntary purchase scheme is unlikely to be embraced by the majority of affected property owners and the associated social and economic costs would not justify the benefits.

4.3.2 House Raising

Discussion: House raising is suitable for most non-brick single storey buildings on piers and is particularly relevant to those situated in low hazard areas of the floodplain. This approach provides more flexibility in planning, funding and implementation than the likes of voluntary purchase. A review of the building types suggests that house raising is not suitable for the affected buildings along Buderim Avenue as they are of slab and brick construction. These could still be raised but it would probably be more cost effective to demolish and rebuild at a higher level.

Benefits: Eliminates inundation of dwellings to the height of the floor.

Dis-Benefits: The grants for funding of this measure generally only cover the basic costs of raising the structure. Additionally, the subsidy is usually offered on a relative basis depending on the severity of the problem and potential damages cost. Residents would most likely have to contribute their own funds to make up any difference and to facilitate any associated works or modifications.
It should also be noted that house raising does not alter or reduce the flood hazard classification for a property and in fact residents tend to remain with their house rather than be evacuated early in the event. The main benefit of house raising is the reduction in flood damages experienced.

Costs: A widely accepted cost for raising a suitable house is $40 000. For the buildings along Buderim Avenue the cost may be up to $100 000 per house as they are of slab and brick construction.

Conclusions: House raising is not a viable measure for the buildings along Buderim Avenue. For the lowest building floor along Buderim Avenue this measure would have a benefit/cost ratio of 0.4 (assuming a cost of $100 000). It should be noted that this ratio would decrease if all inundated properties (1% AEP event) were included in the calculation. By just using the lowest house floor level, the highest ratio possible is obtained. For all other properties, the cost per house would remain the same though the benefits would be less, thus lowering the benefit/cost ratio.

4.3.3 Flood Proofing

Discussion: Flood proofing involves the sealing of entrances, windows, vents etc. to prevent or limit the ingress of floodwater. It is generally only suitable for brick buildings with concrete floors and it can prevent ingress for outside water depths up to approximately one metre. Depending on the nature of construction, greater depths may cause structural problems (buoyancy) unless water is allowed to enter.

This measure is rarely (if ever) used in NSW for residential buildings and is more suited to commercial premises where there are only one or two entrances and maintenance and operation procedures can be better enforced.

Benefits: Flood proofing requires the sealing of doors and possibly windows (new frame, seal and door); sealing and re-routing of ventilation gaps in brickwork; sealing of all underfloor entrances, and checking of brickwork to ensure that there are no gaps or weaknesses in the mortar and sealing of floor wastes and toilets. It will prevent inundation to the level of the flood proofing.

Dis-Benefits: Flood proofing would not reduce the flood hazard and in fact the hazard could be increased if the measure results in occupants staying in their premises and a large flood eventually inundates the building to high depths above floor level. There are no other significant environmental or social problems. One concern with this measure is that future renovations or a change in ownership may mean that the protection could fail when the next flood occurs.

Costs: An existing house could be sealed for approximately $20 000 while the cost to seal extensions could be much less. New buildings should have floor levels built at the appropriate Flood Planning Level and in a manner which reduces the risk of flood damage in greater events.

Conclusions: This measure generally costs much less than house raising thereby giving it a higher B/C ratio. However as noted above it is rarely (if ever) used for residential buildings. Further examination would include detailed inspection of buildings and interviews with the property owners. If it can be implemented then it is the least cost measure for minimising inundation of all buildings at risk in the 1% AEP event. It has none of the environmental concerns common to many of the flood modification measures.

It must be made clear that this measure would not completely protect the occupants or the house in large events, evacuation may still be necessary which could pose some hazard or risk.

4.3.4 Planning and Future Development Control Measures

These measures have not been investigated as part of this study as Council has recently prepared a Flood Risk Management Development Control Plan (DCP). This DCP is also recommended for application to the Oyster Creek floodplain.

4.4 Assessment of Response Modification Measures

4.4.1 Flood Warning

Discussion: Flood warning, and the implementation of evacuation procedures by the State Emergency Services (SES), are widely used throughout NSW to reduce flood damages and protect lives. The Bureau of Meteorology (BOM) is responsible for flood warnings on major river systems but does not have a system for small creeks such as Oyster Creek.

Benefits: Adequate flood warning gives residents time to move goods and vehicles above the reach of floodwaters and to facilitate organised evacuations from those areas at risk. The effectiveness of a flood warning scheme depends on:

- the maximum potential warning time before the onset of flooding,
- the actual warning time provided before the onset of flooding, this depends on the adequacy of the information gathering network and the skill and knowledge of the operators,

- the flood awareness of the community responding to a warning.

Even with an effective flood warning system, some tangible and intangible flood damages would still occur.

Dis-Benefits: There are no significant dis-benefits.

Costs: Studies have shown that flood warning systems generally have high benefit/cost ratios if sufficient warning time is available.

Conclusions: It is not possible to develop an effective flood warning system for a small catchment such as Oyster Creek due to the relatively short response time from the start of the rain to the time of the flood peak (say less than 3 hours). The situation may change in the future as the BOM develops radar based warning systems that can forecast where storms and the consequent flooding will occur.

4.4.2 Evacuation Planning

Discussion: A comprehensive Local Flood Plan prepared by the SES would assist in reducing flood damages and the risk to life. However it is likely that a flood on Oyster Creek would occur in conjunction with flooding in other localities across the Shire. Thus the SES would be involved or busy with many such emergencies (car crashes, roofs damaged, fallen power lines).

The rate of rise of the creek determines the amount of time the SES has to implement an evacuation plan. The small size of this catchment means the rate of rise in the creek is very fast (say less than 2 hours) which means that it would be unlikely the SES would arrive until after the peak (unless there is a risk to life and they are not dealing with an emergency elsewhere).

Conclusions: Whilst the SES are aware that flooding can occur on this creek it is unlikely that they would be able to offer any effective assistance until after the flood peak.

4.4.3 Evacuation Access

Discussion: One of the main ways of improving evacuation (apart from more SES equipment, personnel or training) is to ensure that there are adequate evacuation access routes available. The relatively shallow depth of inundation and small distance to travel to high ground indicates that evacuation access would be reasonable for most flood events along Buderim Avenue and Box Road at Oyster Creek. However there is always a risk in a flood that residents will stay inside their homes until the last possible moment, when the risk has increased significantly will they decide to evacuate.

4.4.4 Flood Awareness and Readiness Program

Discussion: The success of any evacuation and damage minimisation system depends on:
Flood Awareness: How aware is the community to the threat of flooding? Have they been adequately informed and educated?
Flood Readiness: How prepared is the community to react to the threat? Do they (or the SES) have damage minimisation strategies (such as sand bags, raising of possessions) which can be implemented?
Flood Evacuation: How prepared are the authorities and the evacuees to evacuate households to minimise damages and the potential risk to life? How will the evacuation be implemented, where will the evacuees be moved to?

The above can be improved upon though implementation of an effective Council or SES run flood awareness program. The extent of the program can vary from year to year depending upon the circumstances. An extensive program along the Woronora River was undertaken by Sutherland Council as an outcome to the Floodplain Management Plan for that area. Other Councils have mailed flood information pamphlets each year to residents.

Benefits: A community with high flood awareness will suffer less damage and disruption during and after a flood because people are aware of the potential risks of the situation. During a period of frequent flooding (such as the 1970's) the residents would probably have developed an unofficial warning network to effectively respond to imminent danger by raising goods, moving cars, lifting carpets, etc. Photographs and other sentimental or non-replaceable items are generally put in safe places. Some residents may have developed storage facilities which are flood compatible. The level of trauma or anxiety may be reduced as people have "survived" previous floods and know how to handle both the immediate emergency and the post flood rehabilitation phase in a calm and efficient manner.

The level of flood awareness within a community is difficult to evaluate and will vary over time depending upon the:

- frequency and impact of previous floods,
- history of residence,
- whether an effective public awareness program has been implemented.

Dis-Benefits: There are no significant dis-benefits. It is difficult to accurately assess the benefits of an awareness program but it is generally considered that the benefits far outweigh the costs. The perceived value of the information and level of awareness, diminishes as the time since the last flood increases. A major hurdle is often convincing residents that large floods will occur in the future. Some residents may oppose an awareness program because they consider it reduces the value of their property.

Costs: The costs associated with this measure will depend upon the nature of the awareness and readiness program.

Conclusions: Based on feedback obtained from the local residents, the majority have a low level of flood awareness. Their level of readiness is therefore probably medium to low. This can be improved upon with the implementation of an appropriate flood awareness program.

A suitable Council wide flood awareness program should be implemented by Council using appropriate elements from Table 7. The details of the program and necessary follow up should be properly documented to ensure that they do not lapse with time and to establish the most effective methods of communication.

Table 7: Flood Education Methods

Method	Comment
Letter/Pamphlet from Council	These may be sent (annually or bi-annually) with the rate notice or separately. A Council database of flood liable properties/addresses helps to make this a relatively inexpensive and effective measure. The pamphlet can inform residents of changes to flood planning levels or any other relevant information. These should also be handed out as part of rental property information.
School Project or Local Historical Society	This provides an excellent means of informing the younger generation about flooding. It may involve talks from various authorities and can be combined with water quality, estuary management, etc.
Displays at Council Offices, Library, Schools, Local Fairs	This is an inexpensive way of informing the community and may be combined with related displays. Include photographs, newspaper articles and information on development controls and standards, flood evacuation and readiness procedures.
Historical Flood Markers or Depth Indicators on Roads	Signs or marks can be prominently displayed in parks, on telegraph poles or such like to indicate the level reached in previous floods. This was undertaken along the Woronora River.
Articles in Local Newspapers	Ongoing articles in the newspapers will ensure that the problem is not forgotten.
Collection of Data from Future Floods	Collection of data assists in reinforcing to the residents that Council is aware of the problem and ensures that the design flood levels are as accurate as possible.
Notification of Section 149 Planning Certificate Details	Floodplain property owners were indirectly informed that they were potentially flood affected as part of the public consultation program and floor level survey. Future residential property owners are advised during the property searches at the time of purchase by details provided on the Section 149 certificate.
Type of Information Available	A recurring problem is that new owners consider they were not adequately advised, by the Section 149 Planning Certificate obtained during the purchase process, that their property was flood affected. Council may wish to advise interested parties, when they inquire during the property purchase process, of the flood information currently available, how it can be obtained and the cost.
Establishment of a Flood Affectation Database	The database developed from the information collated in this study could provide details on which houses are likely to be affected. This database should be reviewed after each flood event and could be maintained by the various relevant authorities (SES, Police, Council).

Method	Comment
Flood Readiness Program	Providing information to the community regarding flooding informs it of the problem. However, it does not necessarily prepare people to react effectively to the problem. A Flood Readiness Program would ensure that the community is adequately prepared for the event of flooding. The SES would take a lead role in this regard.
Foster Community Ownership of the Problem	Flood damage in future events can be minimised if the community is aware of the problem and takes appropriate actions to find solutions. For example, Council should have a maintenance program to ensure that its drainage systems are regularly maintained. Residents have a responsibility to advise Council if they see a maintenance problem such as fallen trees or overgrown vegetation. This can be linked to water quality or other water related issues including estuary management.

5. OUTCOMES

5.1 Residents' Overview

From the residents' viewpoint they consider that some combination of dredging, stream clearing and replacement of the culverts at Bates Drive must be undertaken. This viewpoint is held because they consider that Council has undertaken channel works (stream clearing and dredging) in the past and Council is therefore obligated to continue with such measures. Particularly, since their properties are now encoded as flood liable on the S149 certificate and they were never advised of this flood liability when they purchased the land. They also consider that some enlargement of the waterway capacity at Bates Drive is required to further reduce flood levels.

The issue of liability following the encoding of S149 certificates is outside the scope of this study as is also, the perceived obligation by Council to continue undertaking channel works. We note that both these issues are commonly raised in such studies throughout NSW.

At the time of subdivision in the 1960's, very little was known about flooding. It is only in the last 25 years or so that Councils have developed a better understanding or detailed knowledge of flooding (and other hazards such as bushfire, earthquake, land slip). As appropriate information or knowledge becomes available Councils have started to advise owners of such hazards on the S149 certificate. This flood knowledge is continually being updated as the outcomes of more recent floods or studies are analysed. A notable example of this is the greater consideration given to blockage of culverts in design flood analyses. This need has arisen as a direct result of the post event evaluation of the August 1998 flooding which occurred in North Wollongong.

A world wide change in our perception and appreciation of the environment has meant that channel works (and many other activities in our life) which were regularly undertaken in the past are now effectively prevented if they "harm" the environment. Rigorous studies (EIS or REF) must be undertaken to justify such works and there are heavy penalties if environmental impacts created or laws are broken. This is one of the main reasons why dredging or many of the other flood modification measures are no longer considered to be as viable as they may have been in the past

5.2 Assessment of Floodplain Management Measures

The possible measures that would eliminate inundation to all buildings in the 1% AEP event include:

- house raising,
- flood proofing,
- levee,
- voluntary purchase.

None of the above (except possibly voluntary purchase under the right conditions) are supported by the local residents.

Voluntary purchase is too expensive and is unlikely to receive government funding. House raising and flood proofing are much less expensive but are probably not suited to the particular buildings affected. However some form of flood proofing (if it can be made to work) would be a very cost effective mitigation measure that has no significant dis-benefits.

A levee has been rejected by the residents and its construction would introduce additional (internal drainage) problems.

The residents generally favour undertaking flood modification measures to help reduce flood levels. In the 1% AEP event it was found that a maximum reduction in flood level of up to 200 mm immediately upstream of Bates Drive and up to 500 mm reduction near Box Road could be achieved with a combination of dredging and bridge works. However, the lowest building would still be inundated by approximately 400 mm in that event. The high cost, low benefit/cost ratio, inability to prevent inundation to all buildings and likely high environmental concerns means that all major flood modification measures are unlikely to receive funding.

Any measure that would reduce the likelihood of culvert blockage at Bates Drive would be supported by the residents and is recommended.

New or upgrading of existing response modification measures are generally not considered by the residents to be of significant benefit. Nevertheless these measures are cost effective and generally have high benefit/cost ratios.

The use of development control measures to limit future flood damages is supported. One such measure is the recent Flood Risk Management DCP prepared for Sutherland Shire. It is noted that as most of the houses are now 30 years or older there is an increasing trend to demolish and re-build rather than renovate the existing house. Implementation of an expensive flood mitigation measure may not be required if this trend continues in the short to medium term.

5.3 Conclusions

The relatively low number of buildings inundated in the 1% AEP event, 13 assuming 100% blockage, or only 7 if NO blockage is assumed, means that expensive management measures cannot be supported purely on economic grounds. The most cost effective measure is probably flood proofing (if it can be made to work). This measure has the advantage in that there would be no adverse environmental consequences and no impact on other residents. If it is offered, it can then either be taken up or rejected by the owners. It could also be offered as an incentive to renovate or re-build the house. Allowing or encouraging redevelopment with appropriate building and floor level controls to occur would also be a cost effective measure.

Nevertheless, the residents consider that some flood modification works should be undertaken even if not supported by benefit/cost analysis or normal Government funding requirements for floodplain management. At a minimum they would prefer:

- measures to reduce blockage of the Bates Drive culverts,
- stream clearing, if only for aesthetic and social reasons,
- dredging,
- construction of a slot in the base of the Bates Drive culverts,
- reactivation of the Management Plan for the creek. This plan supports implementation of water quality control devices.

6. ACKNOWLEDGEMENTS

This study was carried out by Webb, McKeown & Associates Pty Ltd and funded by Sutherland Shire Council, the Roads and Traffic Authority and the Department of Infrastructure, Planning and Natural Resources. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Sutherland Shire Council,
- Department of Infrastructure, Planning and Natural Resources,
- Residents of the Oyster Creek catchment.

7. REFERENCES

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FIGURE 1

OYSTER CREEK CATCHMENT

FIGURE 2
STUDY AREA

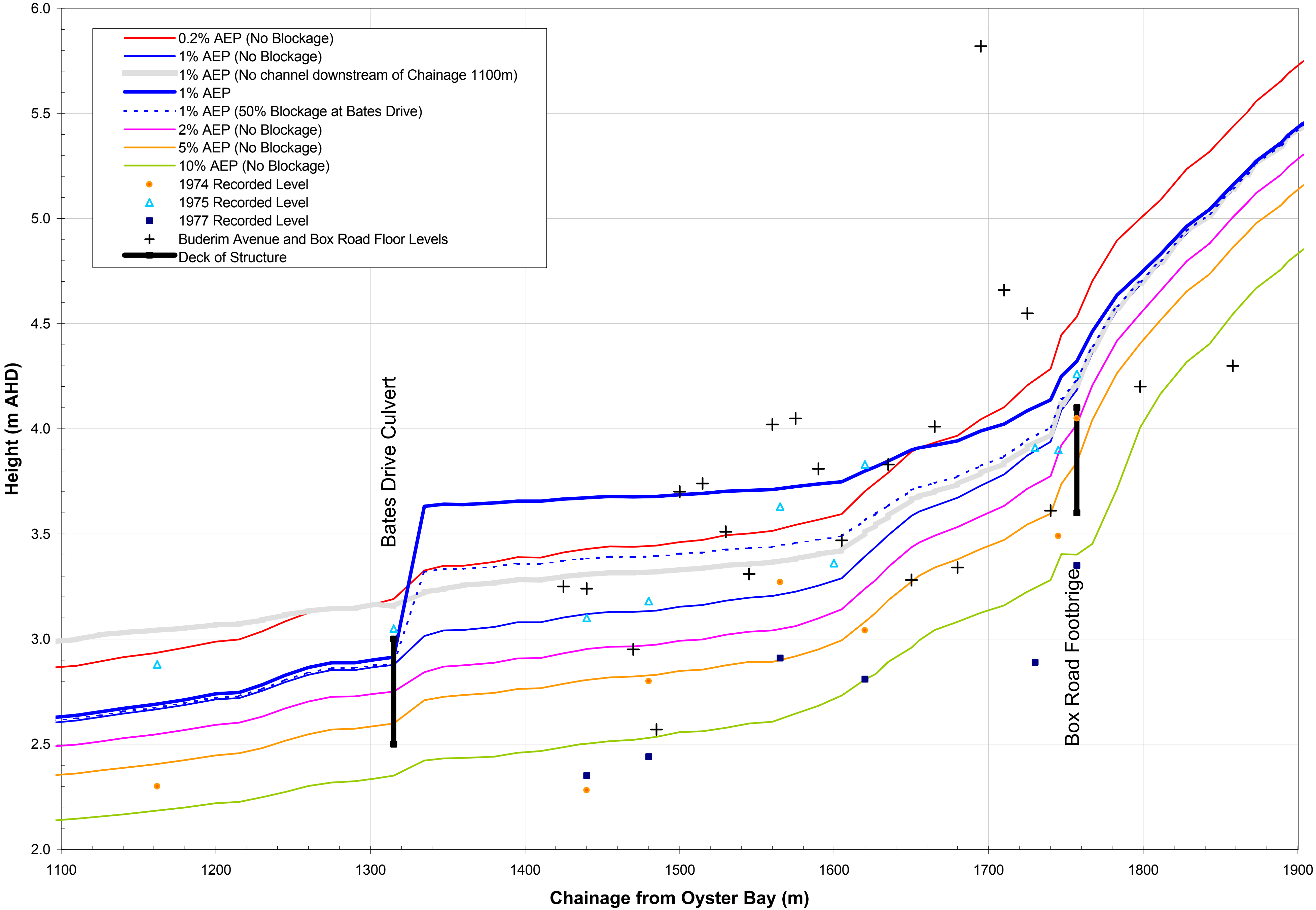


FIGURE 3
PEAK HEIGHT PROFILES
HISTORICAL FLOOD DATA

J:/JOBS/23078/Mike11/results.xls 15/04/04

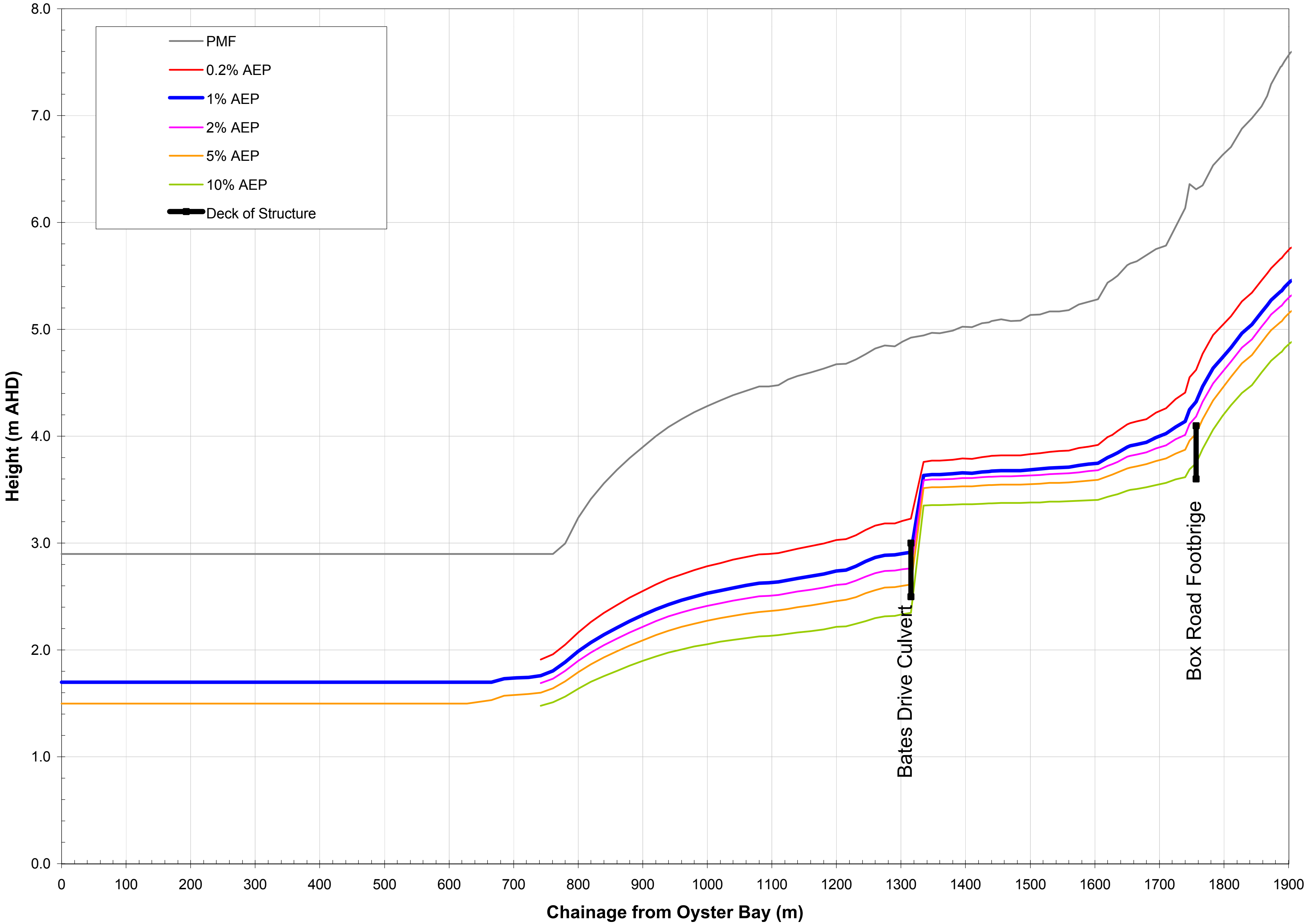
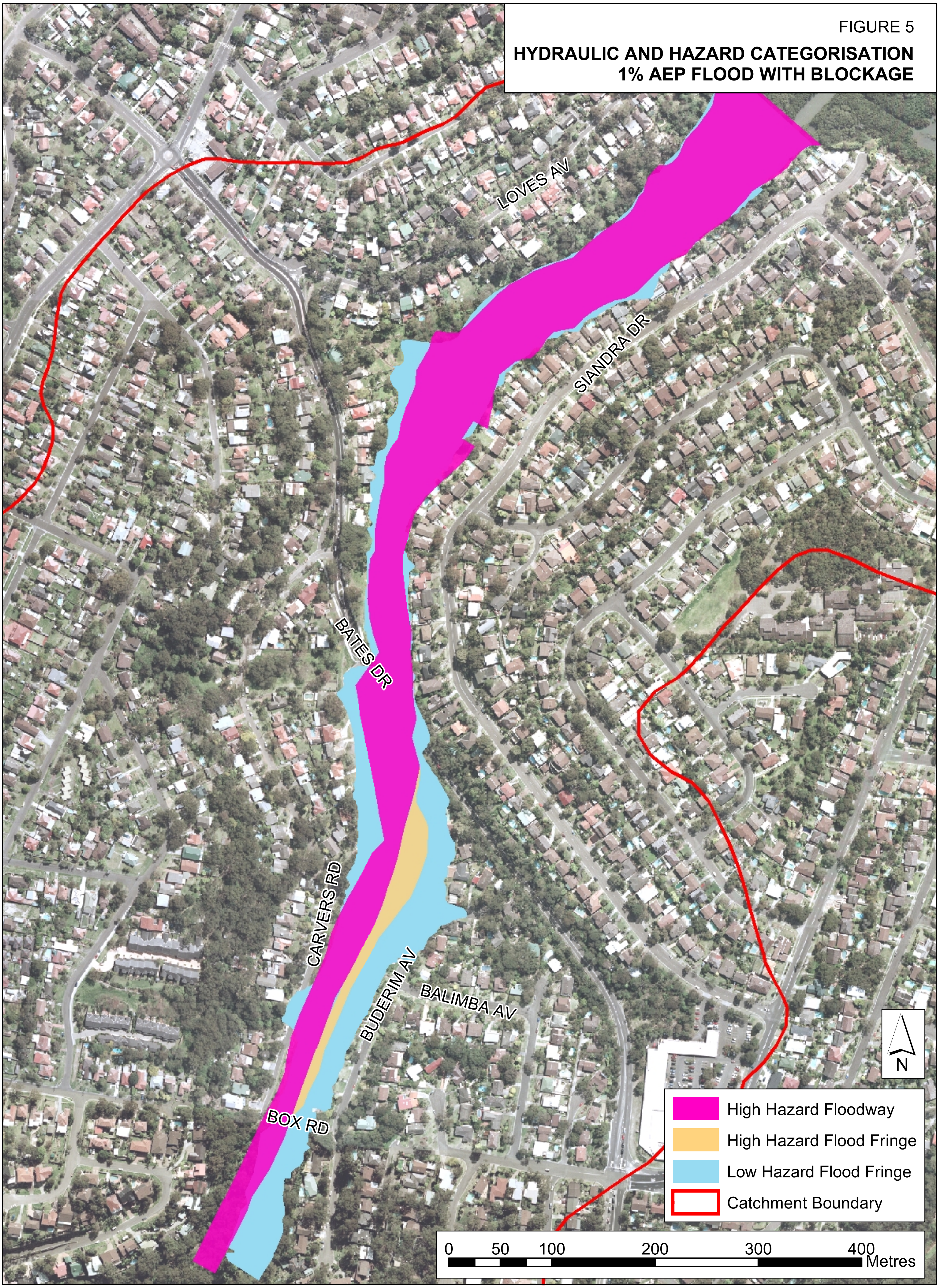


FIGURE 4
PEAK HEIGHT PROFILES
DESIGN FLOODS WITH 100% BLOCKAGE

FIGURE 5

HYDRAULIC AND HAZARD CATEGORISATION
1% AEP FLOOD WITH BLOCKAGE



Note: Extent of floodplain defined from available topographic contour information. Actual extent may vary with more detailed survey.

FIGURE 6

DESIGN FLOOD CONTOURS
1% AEP FLOOD WITH 100% BLOCKAGE

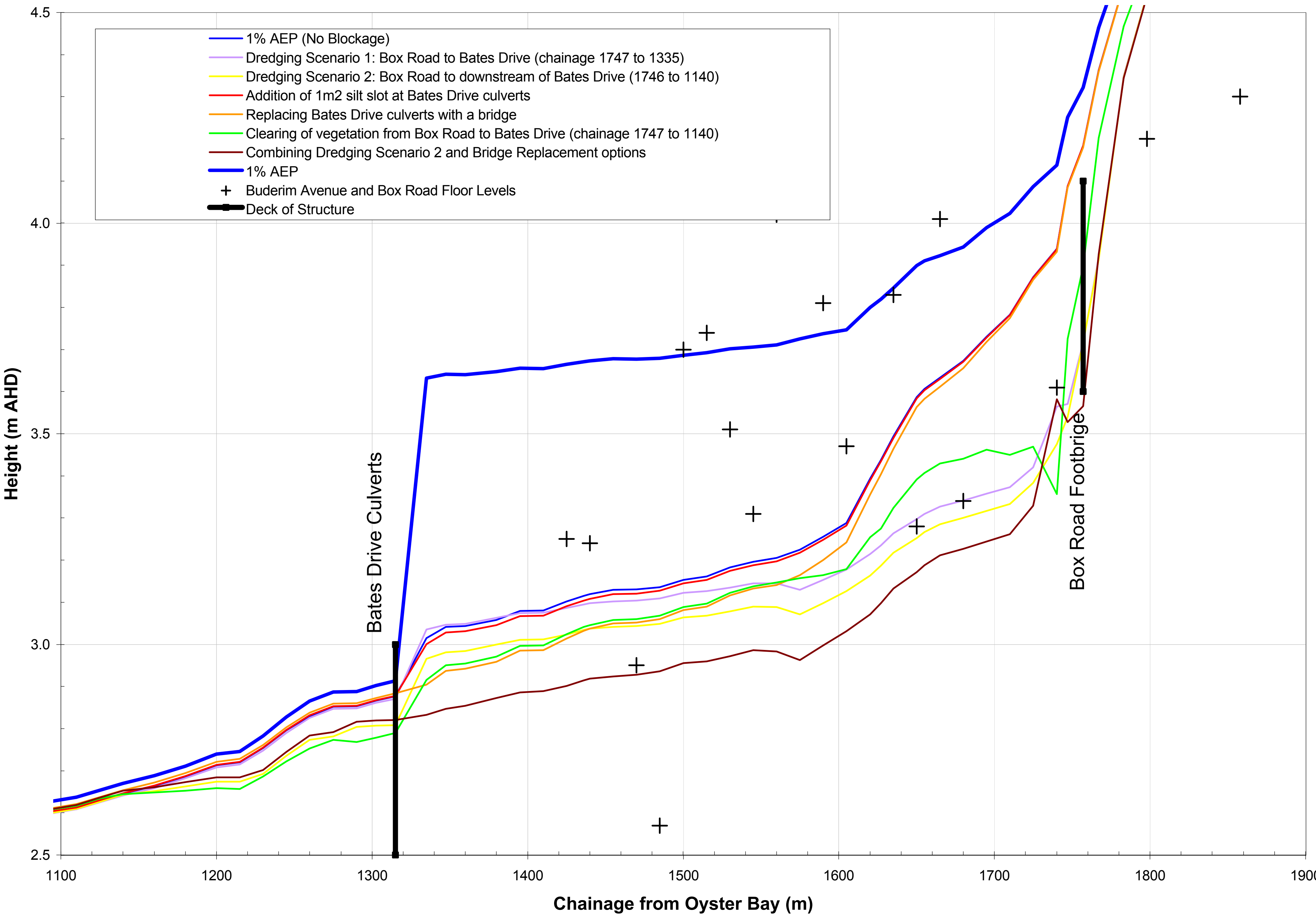


FIGURE 7
FLOOD MODIFICATION MEASURES
1% AEP FLOOD WITH NO BLOCKAGE

APPENDIX A: GLOSSARY OF TERMS

Taken from the Flood Management Manual (Jan 2001 edition)

acid sulfate soils
Are sediments which contain sulfide mineral pyrite. These sediments may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual prepared by the Acid Sulfate Soil Management Advisory Committee (ASSMAC).

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

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

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

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

caravan and moveable home parks
Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the Local Government Act, 1993.

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

consent authority
The council, government agency or person having the function to determine a development application for land use under the Environmental Planning and Assessment Act (EP&A Act). The consent authority is most often the council, however there are instances where legislation or an environmental planning instrument (EPI) specifies a Minister or public authority (other than a council), or the Director General of Planning NSW, as having the function to determine an application.

development Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).

infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.

new development: refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN) A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

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

ecologically sustainable development (ESD) Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual are related to ESD.

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

emergency management A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

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

flood Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood education, awareness and readiness	**flood education** seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness. **flood awareness** is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures. **flood readiness** is an ability to react within the effective warning time.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level, as indicated in the 1986 Floodplain Development Manual (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Floodplain Development Manual.
Flood Planning Levels (FPLs)	The combination of flood levels and freeboards selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans. The concept of flood planning levels supersedes the "standard flood event" of the first edition of this manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.

flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	A factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted flood planning level and the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as “greenhouse” and climate change. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Floodplain Management Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

local overland flooding Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

local drainage Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

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

major drainage Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:

- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or

- water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or

- major overland flow paths through developed areas outside of defined drainage reserves; and/or

- the potential to affect a number of buildings along the major flow path.

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

merit approach The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

minor, moderate and major flooding
Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures
Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 and further discussion is given in Appendix J of the Floodplain Management Manual.

peak discharge
The maximum discharge occurring during a flood event.

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

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

probability
A statistical measure of the expected chance of flooding (see annual exceedance probability).

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

runoff
The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.

stage
Equivalent to “water level”. Both are measured with reference to a specified datum.

stage hydrograph
A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.

survey plan
A plan prepared by a registered surveyor.

water surface profile
A graph showing the flood stage at any given location along a watercourse at a particular time.

wind fetch
The horizontal distance in the direction of wind over which wind waves are generated.