SUTHERLAND SHIRE COUNCIL





JUNE 2005



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OYSTER CREEK FLOOD STUDY

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

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

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

- 1. Flood Study
 - determine the nature and extent of the flood problem.
- 2. Floodplain Risk Management
 - 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 Flood Study constitutes the first 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 that define flood behaviour for existing catchment conditions.



This report was prepared by Webb, McKeown & Associates on behalf of Sutherland Shire Council and details the hydrologic and hydraulic investigations carried out to determine the design flood levels, flows and velocities. It represents the first 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 km² to Oyster Bay on the Georges River and 2.4 km² to Bates Drive (1300 m upstream). The catchment is within Sutherland Shire Council's local government area and is within the suburbs of Sutherland, Kirrawee, Jannali, Kareela and Oyster Bay. Flooding of roads and residential properties has occurred in the past between Box Road and Bates Drive.

All relevant available rainfall, flood and topographic data were collected and analysed as part of the study. Whilst there is a reasonably good flood record in the mid 1970's (1974, 1975, 1977), there is no flood information since that time. The quantity and quality of the available historical flood data has therefore influenced the hydrologic and hydraulic modelling approach adopted for this 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 with the downstream limit of the model being Oyster Bay and the upstream limit approximately 170 m upstream of Box Road (1900 m upstream of Oyster Bay).

The hydrologic and hydraulic models were calibrated (as far as possible) making best use of available historical data to ensure that they reasonably simulated recorded floods. For both models, parameter values from established texts and those found to be applicable in previous studies were used in determining appropriate values for the present study.

Design rainfall data were determined from Australian Rainfall & Runoff (1987) and input to the hydrologic model to define design flow inputs to the hydraulic model. Design flood levels were obtained by inputting the design flows and boundary conditions to the hydraulic model. The lower parts of the creek are influenced by a combination of:

- flows entering from the Oyster Creek catchment,
- elevated water levels in the Georges River (obtained from the Georges River Flood Study).

An "envelope" approach was used to determine design flood levels in these lower areas.

At Bates Drive there are six (3000 mm by 1800 mm) box culverts beneath the road. There is anecdotal information that some blockage of two of the culverts occurred during the March 1974

flood. This information, together with results from a post flood review of culverts following the August 1998 floods in North Wollongong, indicates that best practice is to assume 100% blockage of the Bates Drive and Box Road waterway openings for all design events.

Thus the design flood profiles indicate a steep gradient across Bates Drive. There is a much lesser gradient at Box Road as the "blocked" waterway area represents only a small percentage of the total waterway area available.

The accuracy of the design flood levels at any one location is largely dependent on the availability of reliable historical flood data, the survey data, and the accuracy of the design rainfall intensities. The accuracy of the design flood levels from the Georges River Flood Study is considered to be of the order of ± 0.3 m. For Oyster Creek upstream of the influence from the Georges River the accuracy is more likely to be in the order of ± 0.5 m due to the paucity of data available for model calibration. Whilst reliable flood height data are available from the floods in the mid 1970's the annual exceedance probability of these events cannot be accurately determined.

A range of sensitivity analyses were undertaken to assess the hydraulic impacts of varying the adopted design parameters.

It is recommended that Council undertake a post flood data collection exercise immediately following each future event. The data collected can then be used to refine the model calibration, hence improving the accuracy of the design flood levels.

1. INTRODUCTION

Oyster Creek has a 3.5 km² 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 (Figure 2).

In July 2003 Webb McKeown 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, undertake community consultation, review environmental impacts, obtain approvals, and prepare detailed designs and contract documents for waterway improvement and flood mitigation works in Oyster Creek. 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) was completed in October 2003 and was based on a Flood Study undertaken by Sutherland Shire Council (Reference 2).

Reference 1 outlined the likely high cost of 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). This process involves the four sequential stages as outlined in the Foreword of this report. Completion of this process will ensure that a strategic approach to the management of the Oyster Creek floodplain is adopted.

The primary objectives of this Flood Study are:

- to define the flood behaviour of the Oyster Creek catchment by quantifying flood levels, velocities and flows for a range of design flood events under existing catchment and floodplain conditions,
- to assess the hydraulic categories and undertake provisional flood hazards mapping,
- to formulate a suitable hydraulic model that can be used in a subsequent Floodplain Risk Management Study to assess various floodplain management measures.

This report details the results and findings of the Flood Study investigations. The key elements are:

- a summary of available data,
- reasons for the choice of hydrologic and hydraulic models,
- definition of the design flood behaviour for existing conditions through the analysis and interpretation of model results.

The Flood Study does not consider flooding from local drainage which may result from inadequate urban drainage provisions such as may occur with runoff along Buderim Avenue. A glossary of flood related terms is provided in Appendix A.

2. BACKGROUND

2.1 Catchment Description

Oyster Creek (Figure 1) has a catchment area of some 2.4 km² upstream of Bates Drive and 3.5 km² 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 opens out to form a narrow flood plain (see Figure 1 and Photographs 1 & 2). This 450 m long section of the creek is the main area of interest. Downstream of Bates Drive the creek forms a mangrove lined estuary leading into Oyster Bay and the Georges River and is bounded by residential properties on either side (Oyster Bay and Kareela).

The study area for this investigation was taken as the 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 and where developments are largely outside the floodplain.

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 were constructed between 1963 and 1971 on fill placed on the floodplain adjoining and parallel to the creek (Photographs 3, 4 and 5). Reference 4 indicates that at the time the channel was excavated to a 20 m wide x 1.5 m deep channel.

In the early 1960's six (3000 mm x 1800 mm) box culverts were constructed across the creek at Bates Drive (road level of approximately 3.0 mAHD). The inverts of the culverts are at approximately 0.7 mAHD which means that they act as a weir across the creek. As a result, the creek upstream is a semi-tidal, predominantly freshwater environment (refer Photographs 2 and 6), whilst downstream it is an estuarine environment (Photograph 1).

In the 1970's a subdivision along Siandra Drive, Kareela occurred with further filling of the floodplain.

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. This has exacerbated local flooding problems along Buderim Avenue according to Reference 2.

Reference 2 suggests that constructing a slot through one of the culverts, dredging the creek bottom, building a levee wall and widening the creek would reduce flood levels and subsequent impacts to Buderim Avenue properties. The works represent a significant investment outlay for Council and the actual mitigation benefits (and disbenefits) of the works are not fully defined.

Reference 1 indicates that construction of a slot in the culvert would change the tidal regime and ecology of the reach from predominantly freshwater/brackish to marine. Dredging of the creek would change the appearance and amenity of the area and require the disposal of 1000 m³ of sediments (which may be contaminated). Reference 1 also indicates that the advantages and disadvantages of both these measures and disposal requirements for the sediments would need to be addressed with the community and relevant government authorities.

It is clear from historical photographs that the creek channel that exists today is significantly larger than what it was prior to 1960. Downstream of the Bates Drive culverts a 20 m wide (approximately) channel up to 2.0 m deep has been dredged on the eastern side of the floodplain. 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 less than 1 m deep. No accurate records of the extent of dredging are available.

2.2 Available Data

The following sources of information have been reviewed as part of this assessment:

- various field inspections,
- Flood Study, Sutherland Shire Council, May 2002 (Reference 2), and associated models (DRAINS, HEC-RAS) and results files,
- Oyster Creek Flood Investigations Project Report by M G Carleton, November 1977 (Reference 4). This study provides the only record of historical flood data for the creek (refer Photographs 7 to 12),
- survey data Sutherland Shire Consulting Services, December 2001 and January 2004 (Figures 3a and 3b),
- Concept Flood Mitigation Plan, Sutherland Shire Council.

Detailed site inspections were undertaken by Webb McKeown on several occasions to develop and refine our understanding of the catchment and conditions within the study area.

Apart from the references mentioned above there have been no other investigations into flooding along Oyster Creek.

2.3 Photographs



Photograph 1: View downstream of Bates Drive



Photograph 3: View upstream along Buderim Avenue



Photograph 5: No. 5 Buderim Avenue



Photograph 2: View upstream of Bates Drive



Photograph 4: View downstream along Buderim Avenue



Photograph 6: Carvers Road





Photograph 8: Looking to Bates Dr - March 1975



Photograph 7: No. 5 Buderim Ave - March 1975

Photograph 9: No. 5 Buderim Ave - March 1975



Photograph 10: Buderim Avenue - March 1975



Photograph 11: No. 7 Buderim Ave - March 1975



Photograph 12: Box Road - March 1975

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 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 floodwaters may be exacerbated by inadequate local drainage provisions and elevated water levels at the downstream outlet of the urban drainage (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 will occur several hours after the flood peak in Oyster Creek. This is because the peak levels in the Oyster Creek catchment are typically the result of short duration intense storms of up to two hours duration. In contrast, the peak levels in the Georges River result from longer duration storms of say 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 in the Georges River do not necessarily result from the same period of rainfall.

2.5 Preliminary Environmental Assessment

2.5.1 Water Quality

The tidal range in Oyster Creek downstream of the culverts is similar to that in the Georges River and along the open coast generally. Assuming the culvert inverts are at 0.7 mAHD and based on a long term analysis of water levels at Picnic Point, tidal overtopping and 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 levels. The volume of water upstream of the culverts at low tide is less than 400 m³ 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 flows 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 weir 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 catchment and sewage inflows, but resident times are likely to be short because of the high runoff levels and subsequent tidal flushing.

2.5.2 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 in the upper limits near Box Road cover the full creek width. 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 of the creek 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 Buderim Avenue side has a mix of gums, wattles and fruit trees.

2.5.3 Fauna

The predominant faunal feature of the existing creek environment upstream of Bates Drive is the flock of black ducks which feed and roost in the area. 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*.)

2.5.4 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, with 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 to the creek and the fact that they face away from the creek and often have high back fences. In the upper part of the reach exotic trees and creepers impact upon the view.

2.5.5 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.

2.6 Dredging

Reference 4 indicates that Sutherland Shire Council undertook channel deepening works twice within the period from 1971to 1975. Photographs of the March 1975 flood show the dredge in the creek (Photograph 9). Reference 4 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 indicated that boats had previously entered the inlet, suggesting a much greater depth than at present (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. DATA

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On a large river system there are generally stream height and historical records going back to the early 1900's, or in some cases even further. However in small urban catchments, such as Oyster Creek there are no stream gauges or official historical records. A picture of flooding must therefore be obtained from an examination of rainfall records and local knowledge. For this reason, a comprehensive data collection exercise was undertaken.

3.1 Rainfall

3.1.1 Overview

Rainfall is recorded either daily (24hr rainfall totals to 9:00am) or continuously (pluviometers measuring depths within small time periods of typically 2 to 5 minutes). Daily rainfall data have been recorded for over 100 years at many locations within the Sydney basin. In general pluviometers have only been installed since the 1960's (Table 1). Together these records provide a picture of when and how often large rainfall events have occurred in the past.

However, care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past events due to a combination of factors including local site conditions, human error or limitations inherent to the type of recording instrument used. Examples of limitations that may impact the quality of data used for the present study are highlighted in the following:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can
 occur for a range of reasons including operator error, instrument failure, overtopping and
 vandalism. In particular, many gauges fail during periods of heavy rainfall and records
 of large events are often lost.
- Daily read information is usually obtained at 9:00am. Thus if the storm encompasses this period it becomes "split" between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00am reading.
- The duration of intense rainfall required to produce flooding in the Oyster Creek catchment is typically less than three hours. This is termed the "critical storm duration". For a much larger catchment, such as the Georges River, the critical storm duration may be several days. For Oyster Creek a short intense rainfall can produce flooding but if the rain stops quickly (typical of a thunderstorm), the daily rainfall total may not necessarily reflect the magnitude of the intensity and subsequent flooding.

- Rainfall records frequently can have "gaps" ranging from a few days to several weeks or even years.
- Pluviometer records provide a much greater insight into the intensity (depth v time) of rainfall events and have the advantage that the data can generally be analysed electronically. These data have much fewer limitations than daily read data. The main drawback is that the relevant gauges have only recently been installed and many are now discontinued (refer Table 1). These gauges can also fail during storm events due to the extreme conditions.
 - Rainfall events which cause flooding in the Oyster Creek catchment are usually very localised and as such only accurately "registered" by a nearby gauge. Gauges sited only a few kilometres away can show very different intensities.

3.1.2 Pluviometers

Table 1 indicates the locations of the Sydney Water (SW) and Bureau of Meteorology (BOM) rainfall gauges close to the catchment. There may be other private gauges in the area (e.g. bowling clubs, golf clubs, schools) but these records cannot be readily located.

Table 1: Rainfall Stations within Approximately an 8km Radius of Oyster Creek

Station No	Agency	Station Name	Elevation	Distance (km)	Date Opened	Date Closed	Туре	Latitude	Longitude
			(mAHD)	from Oyster Bay					_
66058	BOM	Sans Souci (The Boulevarde)	9	5.1	01-11-1899		Daily	-34.00	151.13
66104	BOM	Lilli Pilli		7.9	01-05-02	31-12-41	Daily	-34.05	151.15
66001	BOM	Audley	23	6.3	1899	1979	Daily	-34.07	151.05
66103	BOM	Revesby Linden Pk		5.8	01-09-03	31-12-24	Daily	-33.97	151.05
66049	BOM	Penshurst	70	5.3	01-06-04	31-12-70	Daily	-33.97	151.08
566035	SW	Penshurst Tanks	60	4.9	01-06-04	10-12-71	Daily	-33.97	151.09
66177	BOM	Sutherland (Avondale)	91	4.1	1906	1911	Daily	-34.05	151.07
66040	BOM	Miranda	40	3.0	1906		Daily	-34.03	151.06
66132	BOM	Carlton	30.5	7.5	01-02-07	31-12-24	Daily	-33.97	151.13
66060	BOM	Sutherland Mwsdb	121	2.3	01-04-07	31-12-72	Daily	-34.03	151.07
566045	SW	Sutherland	100	2.3	01-04-07	01-10-72	Daily	-34.03	151.06
66029	BOM	Hurstville McLeod St	61	5.7	01-01-28	01-01-53	Daily	-33.97	151.10
66069	BOM	Waitara Parade	5	4.1	01-08-52	31-12-81	Daily	-33.98	151.10
66086	BOM	Cronulla Wwtp	10	8.3	01-08-58		Daily	-34.03	151.16
566018	SW	Cronulla STP	10	8.3	31-12-79		Continuous	-34.03	151.16
66090	BOM	Cambrai Ave	170	7.8	01-11-62	06-09-93	Daily	-34.06	151.01
66144	BOM	Peakhurst Forest Rd	48	5.4	01-05-64	31-12-69	Daily	-33.97	151.07
566061	SW	Caringbah (Davies Kent P/L)	25	4.3	05-04-66	19-12-73	Continuous	-34.03	151.12
66148	BOM	Peakhurst Golf Club	20	5.1	01-09-69		Daily	-33.97	151.06
566047	SW	Mortdale Bowling Club	40	4.4	12-12-77		Continuous	-33.98	151.08
566048	SW	Oyster Bay	8	0.0	1979	19-07-83	Continuous	-34.01	151.08
66176	BOM	Audley	120	6.0	1979		Daily	-34.07	151.06
66181	BOM	Oatley (Woronora Parade)	42	4.2	01-01-82		Daily	-33.98	151.08
566056	SW	Yarrawarrah	150	6.5	12-08-83	08-02-01	Continuous	-34.06	151.03
566078	SW	South Cronulla	20	9.2	09-02-90		Continuous	-34.07	151.15
566092	SW	Sutherland Bowling Club	115	2.3	06-07-91		Continuous	-34.03	151.07
566090	SW	Carss Park Bowling Club	8	5.0	19-09-91		Continuous	-33.99	151.12
566093	SW	Engadine Bowling Club	178	8.3	14-11-91	08-02-01	Continuous	-34.06	151.01
566098	SW	Caringbah Bowling Club	27	4.4	23-12-91		Continuous	-34.03	151.12
566103	SW	Peakhurst Bowling Club	32	6.1	26-05-92	08-02-01	Continuous	-33.96	151.07
566108	SW	Menai Police Stn	100	6.1	13-11-92	01-02-01	Continuous	-34.02	151.01
566109	SW	Illawong Reservoir	60	3.2	01-12-92	15-03-93	Continuous	-34.00	151.05
566111	SW	Menai High School	100	5.3	31-05-93	24-03-95	Continuous	-34.00	151.02
66204	BOM	Green Point	18	1.4	13-02-98		Daily	-34.00	151.07

Note: It is likely that there are also several "unofficial" gauges at Bowling or Golf Clubs.

BOM = Bureau of Meteorology

SW = Sydney Water

3.1.3 Design Data

Design rainfall data were calculated in accordance with Australian Rainfall and Runoff (Reference 5) and are listed in Table 2.

		Average Exceedance Probability									
Duration		20%	10%		5%	2%	6	1%	0.5%	0.2	%
30 minutes	intensity in mm/h	72	82		94	111		124	136	154	
	depth in mm	36		41	47		55	62	68		77
1 hour	intensity in mm/h	49.8	57		66	78		87	96	109	
	depth in mm	50		57	66		78	87	96		109
1.5 hours	intensity in mm/h	39.1	44.6		52	61		68	75	85	
	depth in mm	59) (67	77		92	102	113		128
2 hours	intensity in mm/h	32.8	37.4		43.3	51		57	63	71	
	depth in mm	66		75	87		102	114	126		143
3 hours	intensity in mm/h	25.6	29.1		33.7	39.8		44.4	49.1	56	
	depth in mm	77		37	101		119	133	147		167
4.5 hours	intensity in mm/h	19.9	22.6		26.2	30.9		34.5	38.1	43.1	
	depth in mm	90	1)2	118		139	155	172		194
6 hours	intensity in mm/h	16.7	18.9		21.9	25.8		28.8	31.9	36.0	
	depth in mm	100	1	14	131		155	173	191		216
9 hours	intensity in mm/h	13.0	14.7		17.0	20.1		22.4	24.7	27.9	
	depth in mm	117	1	33	153		181	202	223		251
12 hours	intensity in mm/h	10.9	12.3		14.3	16.8		18.7	20.7	23.3	
	depth in mm	130	14	48	171		202	225	248		280

Table 2: Design Rainfall Data

3.2 Historical Flood Information

3.2.1 Overview

A data search was carried out to identify the dates and magnitudes of historical floods. 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 for model calibration. The following sources of data were investigated:

- Sutherland Shire Council,
- previous reports,
- local residents,
- rainfall records.

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 likely dates of flooding to be established.

3.2.2 Flood History

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 4). 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 in at least four events (refer Table 3).

Event	No. of Buildings	House No's *	Approximate Peak	Number of	
	Inundated above	Inundated in	Level at Bates Drive	Recorded	
	floor	Buderim Avenue	(mAHD)	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,	3.0	11	
		27,31,33,39			
4 March 1977	nil	-	2.4	8	

 Table 3:
 Flood History from M G Carleton's Report

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

Since 1977 Sutherland Shire Council has no records of houses or yards being inundated. Council has a record of a flood mark for the 21st March 1983 event at 458 Box Road (approximately 80 mm below the floor level of 4.2 mAHD). However there are no other records for this event. A questionnaire survey undertaken as part of this study (refer Section 3.4) indicates that no overbank flooding and inundation of private property has occurred since 1977. Thus it would appear that the only documented period of flooding is from 1969 to 1977 and is contained in Reference 4.

3.2.3 Issues Identified in Reference 4

The following issues relating to flood levels were described in Reference 4:

- construction of a sewer crossing in the 1970's may have reduced the width of the creek (by 2 m) and the depth by 0.9 m,
- a log may have partially restricted two of the six cells under Bates Drive in the 1974 flood,
- another slightly smaller event than 26th March 1974 occurred on 21st April 1974 (peak level greater than 2.0 mAHD but probably less than 2.8 mAHD),
- three floods occurred in 1973 and one in 1972,
- the event of March 1975 caused widespread flooding throughout Sydney and the rainfall was documented in Reference 6. It was estimated that based on rainfall and flood records at Miranda 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,
- elevated tide levels may have increased historical flood levels in the lower reaches of Oyster Creek.

3.3 Survey

Survey data were provided by Sutherland Shire Council as indicated on Figures 3a and 3b.

3.4 Public Survey

As part of this study a public survey consisting of a newsletter and questionnaire was carried out in December 2003, followed by phone calls and interviews with selected respondents.

The questionnaire was sent to those residents who lived within close proximity of the creek (Figure 4). Follow up calls were made to respondents who advised that they would be able to identify flood levels on their property, or who had other relevant information. The results of the questionnaire are summarised in Table 4 and presented in Figures 4 and 5.

Table 4:Questionnaire Survey

Number sent out	158
Number returned	41 (26%)
Number flood affected properties:	8
Consisting of: Inundated Land	7
Inundated Houses	1
Source of Flood Damage:	
Failure of Stormwater Drainage System	3
From Oyster Creek	5
Dates of Key Flood Events Identified (see Figure 5)*:	
1970	1
1972	1
1975	2
1977	3
1979	2
Not Specified	1

* Some residents affected on more than one occasion

The last major flood event that is known to have inundated properties occurred in 1977. As indicated on Figure 5, 80% of the current residents moved in after this date which greatly limits their knowledge of flooding.

Other water related issues were raised by the respondents and these are summarised in Figure 5. Maintenance of the creek was noted several times and included concerns about pollution and overgrown vegetation. Some residents thought the drainage system was inadequate and this had led to problems on their property. Respondents also had strong opinions both for and against flood modification measures, especially dredging of the creek.

4. APPROACH ADOPTED

A diagrammatic representation of the Flood Study process is shown in Diagram 1. A hydrologic model (WBNM) was established for the entire catchment (Figure 6) and used to convert rainfall data into streamflow for input to a hydraulic (MIKE-11) model of Oyster Creek (Figure 7). To ensure confidence in the results, both models require calibration and verification against observed historical events. With the limited amount of rainfall and flood data available and given the lack of any stream gaugings, the model calibration process focussed on ensuring the design flood levels are compatible with the expected frequency of the known historical events. The calibrated MIKE-11 model was then used to quantify the design flood behaviour for a range of design storm events up to and including the Probable Maximum Flood (PMF).



Diagram 1: Flood Study Process

5. HYDROLOGIC MODELLING

5.1 General

Hydrologic models suitable for design flood estimation are described in AR&R 1987 (Reference 5). In current Australian engineering practice, examples of the more commonly used runoff routing models include RORB (Reference 7), RAFTS (Reference 8) and the Watershed Bounded Network Model (WBNM - Reference 9). These models allow the rainfall depth to vary both spatially and temporally over the catchment and readily lend themselves to calibration against recorded data. The WBNM model was chosen as it has been used widely by the consultants. However, either of the two other models would have been equally suitable.

The Oyster Creek catchment has been previously modelled in Reference 2 using DRAINS to provide design discharges at Bates Drive. However this model did not incorporate all the pipe drainage system and only very limited results are available.

5.2 Model Configuration

The WBNM model simulates a catchment and its tributaries as a series of sub-catchment areas based on watershed boundaries linked together to replicate the rainfall/runoff process through the natural stream network. The adopted sub-catchment division is shown on Figure 6. The model input data includes definition of physical characteristics such as:

- surface-area,
- proportion developed (imperviousness),
- stream shortening to represent the sealing of natural drainage paths.

The model established for this study comprises a total of 22 sub-areas and included all tributaries upstream of Oyster Bay. The layout of the sub-areas was defined to provide a reasonable level of spatial detail within the catchment and to provide flow hydrographs at specific locations. Catchment areas for each sub-area were determined from 2 m topographic contours provided by Council in GIS format. Impervious areas were defined in the WBNM model based on an analysis of existing development shown on Council's digital aerial photography.

5.3 Calibration and Verification

5.3.1 Key Model Parameters

In calibrating the WBNM model, several parameters can be varied to achieve a fit to observed data:

Rainfall losses

Two parameters, initial loss and continuing loss, modify the amount of rainfall excess to be routed through the model storages.

Lag parameter

The lag parameter affects the timing of the catchment response to the runoff process and is subject to catchment size, shape and slope.

5.3.2 WBNM Calibration

The WBNM model is calibrated by adjusting one or more of the model parameters in order to match observed streamflow hydrographs. However, as there were no observed flow data available within the Oyster Creek catchment this process was not possible. Rather, the parameters adopted for this study were based on values recommended in AR&R and our own experience elsewhere in Sydney. A lag parameter value of 1.29 (recommended parameter for uncalibrated catchments), an initial loss of 0 mm and continuing loss of 2.5 mm/h were adopted. AR&R suggests values for initial loss ranging from 0 mm to 35 mm for eastern NSW catchments. Although it is a conservative assumption, the use of zero initial loss for the present study was considered justified in that prior to the flood producing rains, the catchment is likely to be wet from preceding rain. The adopted value of 2.5 mm/h for continuing loss has been found to be applicable over a wide range of catchments in eastern Australia.

It was not possible to derive flow hydrographs for historical events (1975 and 1977) because there was no available nearby pluviometer or daily read gauge (Table 1).

6. HYDRAULIC MODELLING

6.1 General Approach

Given the objectives of the study, the available data and in view of the nature of the watercourse and potential flow paths within the study area, a one-dimensional (1D) flow representation provides the most efficient and effective assessment of flood behaviour. This is particularly so given that within the study area the floodplain is relatively confined. A fully two-dimensional (2D) model could not be justified for this study because of the additional expense and survey requirements. More importantly, in view of the limited quantity and quality of calibration data, a 2D model would offer no significant advantages over a corresponding 1D model.

Hence a 1D hydraulic model of the floodplain was established using the MIKE-11 software package (Reference 10). The MIKE-11 model is widely used in flood engineering both within Australia and internationally. It is a proven tool for the dynamic modelling of branched networks comprising complex cross-sections and hydraulic control structures.

The MIKE-11 model layout of Oyster Creek extends from 170 m upstream of Box Road down to the confluence with Oyster Creek (Figure 7). The model cross-sections were derived from the detailed survey information (Figures 3a and 3b) provided by Council in Reference 2 and additional survey provided in January 2004. Bates Drive was defined implicitly in the model as a composite control structure with capacity for both culvert throughflow in combination with road overtopping. At Box Road the nature of the footbridge is such that it is not expected to act as a significant hydraulic control. However the in-channel roughness at this location was increased to make an allowance for any localised hydraulic impacts when the deck becomes overtopped.

7. DESIGN FLOOD RESULTS

7.1 Overview

There are two basic approaches to determining design flood levels, namely:

- flood frequency analysis based upon a statistical analysis of the flood events, and
- *rainfall/runoff routing* design rainfalls are processed by a suite of computer models to produce estimates of design flood behaviour.

The approach adopted for this study reflects current engineering practice and is consistent with the quality and quantity of available data. The flood frequency approach requires a reasonably complete homogeneous record of flows over a number of decades to give satisfactory results. No such records were available within the catchment. Hence, a rainfall/runoff routing approach using the WBNM model was adopted to derive estimates of design inflow hydrographs. These estimates then defined boundary conditions to produce corresponding design flood levels using the MIKE-11 hydraulic model.

7.2 Hydrologic Modelling

Design rainfall intensities and temporal patterns were derived from AR&R (Reference 5) and used as input for the WBNM model. Uniform depths of rainfall with zero areal-reduction factor were applied across the entire catchment.

Design inflow hydrographs for a range of durations (ranging from 30 minutes to 9 hours) for the 1% AEP event were then input to the calibrated hydraulic model to determine the "critical storm duration" or the design burst that produces the highest peak flood levels along the creek. The 2 hour duration storm was found to be critical. This particular duration was then adopted for all other design event frequencies. In a similar manner, the 45 minute storm duration was found to be the critical duration for the PMF event. For all simulations, the key WBNM model parameters were unchanged from those previously indicated in Section 5.3.

For each event, the design flows from the WBNM model were used to define hydrograph inflows for the MIKE-11 model at corresponding locations throughout the catchment. The peak discharges from the MIKE-11 model at selected locations (assuming no blockage at Bates Drive or Box Road) are shown in Table 5.

Location	Peak Discharges in m³/s					
	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
Upstream limit of MIKE-11 model	36	49	57	65	84	251
Box Road	36	49	57	65	84	250
Bates Drive	40	53	62	70	92	281
550 m downstream of Bates Drive	43	56	66	75	98	304
Downstream limit of MIKE-11 model	46	60	71	81	105	326

Table 5: Peak Design Discharges (m³/s)

Note: Assumes no blockage at Bates Drive or Box Road.

7.3 Hydraulic Modelling

7.3.1 Tailwater Conditions

In addition to runoff from the catchment, the reach of Oyster Creek downstream of Bates Drive can also be influenced by backwater effects resulting from Georges River flooding. As noted previously, these two distinct flooding mechanisms may or may not result from the same storm. The Oyster Creek catchment is much smaller in size (3.5 km²) compared to the Georges River catchment (960 km²). Hence, for a given flood event, it is more likely that the Georges River level would peak after the corresponding flood peak occurs in Oyster Creek. It is acknowledged however that this may not necessarily be the case. Consideration must therefore be given to accounting for the joint probability of coincident flooding from both runoff from the Oyster Creek catchment and backwater effects from the Georges River.

A full joint probability analysis is beyond the scope of the present study. Traditionally, it is common practice to estimate design flood levels in these situations using a 'peak envelope' approach that adopts the highest of the predicted levels from the two mechanisms. For each design event on Oyster Creek, the relevant design flows are used in conjunction with a static water level of 1.2 mAHD in the Georges River. This simplified approach is considered appropriate given that 1.2 mAHD is approximately the level of the highest annual tide and Bates Drive is some 1300 m upstream.

A sensitivity analysis of the relative impacts of assuming different tailwater conditions is presented in Section 7.6.