GREAT LAKES COUNCIL

SMITHS LAKE FLOOD STUDY

SEPTEMBER 2008

WEBB, McKEOWN & ASSOCIATES PTY LTD

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FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any 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 four 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 Smiths Lake Flood Study constitutes the first stage of the management process for Smiths Lake and its catchment area. Webb, McKeown & Associates were commissioned by Great Lakes Council to prepare this Flood Study. Funding for this study was provided from the Department of Environment and Climate Change and Great Lakes Council. The following report documents the work undertaken and presents outcomes that define flood behaviour for existing catchment conditions.

SUMMARY

The NSW Government's Flood Policy provides for:

- a framework to ensure the sustainable use of floodplain environments,
- solutions to flooding problems,
- a means of ensuring new development is compatible with the flood hazard.

Implementation of the Policy requires a four stage approach, the first of which is preparation of a Flood Study to determine the nature and extent of the flood problem. The Smiths Lake Flood Study was initiated in order to obtain a better understanding of flooding in the catchment.

The specific aims of the Smiths Lakes Flood Study are to:

- determine design flood levels, flows and velocities for a range of flood frequencies,
- assess wind/wave climate and wave run-up at specific locations,
- undertake a flood damages assessment to assess the extent of the existing flooding problem and identify utilities and roads subject to flooding,
- assess the hydraulic categories and undertake provisional hazard mapping,
- assess the impact of a greenhouse induced sea level rise.

Description of Lake System: Smiths Lake has a catchment area of 34km^2 with a lake surface of 10km^2. Tributaries feeding to the lake are Wamwarra Creek, Tarbuck Creek and Bramble's Creek. Other inflows into the lake are largely overland flows or direct rain over the lake itself.

Smiths Lake is connected to the Pacific Ocean via an entrance which once opened naturally but since 1932 has been opened by mechanical means (digging of a narrow channel). In the past this may have been carried out by local residents but is now undertaken by Council.

The contributory catchment is largely undeveloped except for the small townships of Smiths Lake and Tarbuck on the northern shore and Bungwhal on the western shore of the lake. Northern sections of the catchment are mostly moist open forest, with some cleared and disturbed remnant vegetation.

South of the lake, the catchment generally consists of *a coastal Sclerophyll* complex in National Park areas with clear sections and disturbed remnant vegetation near the coast.

The following sub-headings provide a summary of the key elements of the study.

Review all available data, namely:

- reports, photographs, Council records,
- review of Council's database of flooding reports,
- review of rainfall data,
- review of water level data,

- a comprehensive field survey including floor levels, road levels and other utilities.

Determine Approach: A rainfall-runoff approach was adopted due to the absence of long term historical flood height data. This approach involved the setting up of two computer models - a hydrologic model to convert rainfall to runoff and a hydraulic model to convert the runoff to flows, flood levels and simulate the ocean entrance breakout.

Calibration to Historical Flood Levels: This was achieved by ensuring that the modelled rate of fall of the lake matched those actually recorded after the mechanical openings.

Determination of Design Flood Levels: Following establishment and calibration (where possible) of the models, design rainfall temporal patterns from Australian Rainfall and Runoff (1987) were obtained. These data were input to the hydrologic/hydraulic models to determine design flood behaviour including the calculation of design flood levels. Due to the limited quality and quantity of the calibration data available and in view of the sensitivity analyses, it is estimated that the order of accuracy is up to ±0.3. This order of accuracy is typical of such studies and can only be improved upon with additional observed flood data to refine the model calibration and particularly the entrance breakout.

Is also noted that the design flood approach assumes that Council continues with its informal entrance opening management policy. Should this change then this would affect the design flood levels. A review of this policy should be undertaken in the Floodplain Risk Management Study and a formal policy be adopted.

Wave Runup: The maximum wave runup based on an assessment of the various parameters (wind, fetch, foreshore) was determined for nine sites on the foreshore. The results indicate an average runup height of 0.4 m to 0.5 m and a maximum of 0.9 m in the 100y ARI event. This information should be incorporated in Council’s flood related development controls.

Flood Problem Areas: The study has indicated that floodwaters will inundate the low lying areas surrounding the lake including the two caravan parks and the Frothy Café but no residential building floors.

Outcomes: The main outcomes of this study are as follows:

- full documentation of the methodology and results,
- a modelling platform that will form the basis for a subsequent Floodplain Risk Management Study and Plan.

One recommendation of this study is to highlight the importance of collecting and maintaining a database of rainfall, flood height and entrance breakout data. Whilst the rainfall and flood height data are collected by gauges it is vital that data from any future ocean breakout is recorded as photographs (with the date/time recorded) and survey data. During the course of this study the mechanical opening of the entrance on 8th November 2006 was monitored and photographs/survey data obtained.

A second recommendation is that Council should adopt a formal entrance opening policy as part of the Floodplain Risk Management Study and Plan. This would involve:

- a review of the existing informal policy,
- consideration given to altering the existing let out level of 2.1 mAHD,
- review of the social and environmental factors which may be adversely affected by human intervention of the natural opening/closing regime of the lake,
- consideration given to maintaining a “maximum” berm level. So even if Council is unable to mechanically open the berm, the lake will open by itself at a nominated level,
- consideration given to the possible effects of the Greenhouse Effect on the opening policy.

1. INTRODUCTION

Smiths Lakes (Figure 1) is located approximately 25km south of Forster on the NSW lower-north coast between Wallis Lake and the Myall Lakes. The catchment is small (34km^2 including the lake) and relatively undeveloped with approximately one fifth within the boundaries of Myall Lakes National Park or the State Forest. The only significant development is around the immediate lake foreshores, namely the village of Smiths Lake which is located on the northern foreshore near the entrance, as well as small settlements at Tarbuck Bay and parts of Bungwhal (Figure 2). The catchment is drained by several small creeks including Wamwarra Creek, Bramble's Creek and Tarbuck Creek.

The lake itself has a surface area of 10km^2 and is over 3km wide in places. Within the lake there are three islands, Big Island, Little Island and Bull Island with a total area of approximately 0.4km^2. The ocean entrance is across a wide sandy beach called Sandbar Beach. This entrance is normally closed, but it is opened mechanically by Council to avoid flooding problems (usually when the lake level reaches around 2.1 mAHD). Lake openings occur on average about every 1¼ years.

The primary objectives of this Study are:

- to define the flood behaviour of the Smiths Lake 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 hazard mapping (in accordance with the NSW Floodplain Development Manual (2005)),
- to formulate suitable hydrologic and hydraulic models that can be used in a subsequent Floodplain Risk Management Study to assess various floodplain management measures, including the effects of future development.

The scope of this study is such that:

- the hydrologic model covers the entire catchment,
- the hydraulic model incorporates the entire extent of Smiths Lake.

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

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

A glossary of flood related terms is provided in Appendix A.

2. BACKGROUND

2.1 Catchment Description

The Smiths Lake catchment extends for approximately 8km in the north-south direction, and from 7km east-west (Figures 2 and 3). It is bounded on the south by the Myall Lakes catchment, and on the north by the Wallis Lake catchment. The estuary is a “barrier lagoon system” with a coastal sand dune barrier on the eastern foreshore impounding the lake waters within a drowned valley. The irregular outline of the drowned valley bedrock forms most of the remaining foreshores.

The lake itself has a relatively flat bed with a maximum depth of around 3.5 m below mean sea level (-3.5 mAHD). The foreshore areas generally rises quite steeply, at a grade of around 20% to the surrounding hills. The highest point in the catchment is 150 mAHD at Caves Hill, immediately west of the lake. The northern part of the catchment rises to about 100 mAHD.

There are several creeks, but no major rivers, draining into the lake. The largest of the creeks is Wamwarra Creek, which enters the lake from the north-west. There are small, low lying floodplain deltas where Wamwarra, Tarbuck and Bramble’s Creeks enter the lake. At the ocean entrance there is an extensive marine tidal delta which extends over most of the entrance area.

2.2 Previous Studies

A summary of previous relevant investigations are described in this section.

Smiths Lake Estuary Process Study (Reference 1 - 1998)
An Estuary Process Study was completed in 1998 and reported on various attributes of Smiths Lake including; catchment characteristics, lake hydrodynamics, sediment dynamics, water quality, flora/fauna and waterway usage.

Smiths Lake Estuary Management Study and Management Plan (Reference 2 - 2001)
The study reported on the environmental and socio-economic characteristics of the lake. Possible management options to address the various estuarine issues were proposed.

Smiths Lake Planning Study (Reference 3 - 2000)
The study aimed to identify the opportunities and constraints to development in the catchment with more detailed studies within the Smiths Lake village area. The study briefly mentioned flooding within Smiths Lake but focussed more on the impacts of future developments and a possible water sensitive design approach.

2.3 Causes of Flooding

Flooding within the Smiths Lake catchment may occur as a result of a combination of factors including:

- An elevated water level in Smiths Lake due to persistent rain over the entire catchment draining into the lake.
- Closed entrance conditions.
- Raised water levels in Smiths Lake due to a high tide and/or storm surge when the entrance is fully or partially open.
- Wind wave action along the foreshore (refer Appendix B).
- Local runoff over a small area accumulating (ponding) in low spots above the general water level of the lake. Generally this occurs in areas which are relatively flat with limited potential for drainage. This type of flooding may be exacerbated by inadequate or blocked local drainage provisions and restricted overland flow paths. This type of flooding is not considered within this Flood Study.

These factors may occur in isolation or in combination with each other.

2.4 Climate

The climate is influenced by topography, latitude, local differences in altitude, proximity to the ocean, and temperature/precipitation patterns determined by the Tasman Sea. The Smiths Lake catchment is relatively small, lying generally within the coastal strip and experiencing the warm, moist conditions of the coast. As a result the Smiths Lake catchment has a warm temperate climate, influenced by a sub-tropical maritime air mass, with high rainfall and humidity and no large seasonal or daily contrasts.

There are a number of Bureau of Meteorology (BoM) rainfall stations within and near the Smiths Lake catchment. The longest available record held by the BoM in close proximity to the lake is at Coolongalook State Forest. For the period 1938 to 1970 the average annual rainfall is 1205 mm and the annual median is 1091 mm. Monthly averages and medians are shown in Table 1, where it can be seen that the wettest month is March and the driest month is September.

Table 1: Rainfall Averages and Medians (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	122	159	174	100	86	121	60	78	55	81	73	95
Median	97	156	123	76	55	71	31	55	41	63	74	64

Temperature data are also available at Coolongalook State Forest. Mean daily maximum and minimum temperatures for the period 1887 to 2004 are shown in Table 2.

Table 2: Mean Monthly Temperatures (°C)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	27.7	27.6	26.7	23.7	20.5	18.1	17.7	19.1	21.8	23.8	26.4	27.8
Min	15.8	16.3	14.7	10.8	7.4	5.2	3.6	4.6	6.6	9.6	12.1	14.3

The prevailing winds during the summer are from the north-east. They bring warm moist air which creates sub-tropical weather. Winds are generally 10 to 20 km/hr but localised thunderstorms can create gusts over 100 km/hr.

During winter the prevailing winds are from the west and south-west. They bring cool dry air, although when westerly winds occur in summer they can be hot and dry. Winds are generally 10 to 20 km/hr, but can reach up to 50 km/hr.

Average evaporation data are available at Taree. For the period 1970 to 1997, the average annual evaporation is 1373 mm, and the average monthly evaporation data are as shown in Table 3.

Table 3: Evaporation (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evap	171	141	129	96	64	53	62	84	113	142	154	173

These evaporation rates are generally considered applicable for exposed locations away from significant water bodies. Local meteorological effects (mainly humidity) near coastal inlets can cause reductions of 5 to 10 percent. Evaporation is relevant for the Smiths Lake catchment due to the significant surface area of the lake and is the main mechanism (apart from an ocean breakout) for reducing lake levels.

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change (IPCC), evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing "greenhouse" gases. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase,
- the balance of evidence suggests human interference has resulted in climate change over the past century,
- global sea level has risen about 0.1 m to 0.25 m in the past century,
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

The current best estimate for projected sea level rise is of 0.18 m to 0.91 m by the year 2090.

On a regional basis the CSIRO Climate Change Group predicted increased air and water temperatures, and greater frequency and intensity of severe storms for the NSW coastline. According to some predictions, east coast lows, which are the main causes of storms and floods on the mid north coast, would be more intense, leading to increased occurrence of gale force winds and flooding. However, later research indicates that this may result in a possible reduction in storminess and rainfall.

Current estimates are that design rainfalls may increase by up to 30% in parts of NSW, however in this locality the best estimate is of up to 10%.

2.5 Catchment Description

The catchment land is largely undeveloped due to the presence of National Parks, State Forest and other conservation areas. Protected areas cover the majority of the southern side of the lake which is relatively flat. A large area of the protected land is moist low lying land covered in paperbarks. A significant proportion of the unprotected land is rural farming land generally used to farm livestock. This land is predominate to the west of the catchment and is the highest land within the area.

The soils of the lake's catchment are generally of low fertility having developed from the sedimentary rocks which in turn developed from "acidic" volcanic bedrock. The chief soils of the flat coastal lowlands are leached sands which have uniform profiles, and in swamp areas, organic acid peats. The soils are highly permeable and susceptible to wind erosion when exposed on dunes.

Land use in the Smiths Lake catchment reflects the topography and soils of the area. Most development is concentrated around the lake which is the central feature of the area. Figures 2 and 4 show the existing land use/vegetation pattern in the catchment.

The only area of significant historical land use change is the Smiths Lake village area. This is the main development area, consisting of a mix of permanent residences and holiday homes. There are also a number of other residences at Tarbuck Bay and Bungwahl, and several scattered around the lake. The Sandbar Caravan Park is located near Smiths Lake village on the north-east foreshore, with a golf course and two quarries nearby. These developments have occurred progressively since road improvements in the early 1970's.

Most of the northern catchment is native forest growing on rural land which is unused because it is too steep and infertile.

Most of the southern catchment is within the Myall Lakes National Park and includes the NSW University Research Station located near Horse Point.

2.6 Human Impacts

Major human impacts affecting the catchment are mechanically opening the entrance, existing and future development, and the “Greenhouse Effect”.

Undoubtedly the most significant human impact on flooding has been mechanical opening of the entrance at a lake level of 1.7 mAHD from 1932 (anecdotal information) to 1999 and the current level of opening at 2.1 mAHD. This opening level is significantly below the natural opening level of the lake (by around 1 m). As a result the volume of water which flows through the entrance at breakout is around half that which would be available for a natural breakout.

In terms of the lake hydrodynamics, this means that the lake is opened at least twice as often as it would naturally. As a result entrance openings are smaller and the lake probably remains tidal for shorter periods. The changes in entrance hydrodynamics have major implications for sediment dynamics, water quality, estuarine ecology and the flooding regime.

Another possible human impact on flooding is catchment clearing. Land clearing, and in particular urban development, can have a significant impact on the volume of runoff from a catchment. For an estuary like Smiths Lake which is usually closed, increased catchment runoff could reduce the time between openings if the change in runoff volume was significant. However, the overall level of catchment clearing and urbanisation in the Smiths Lake catchment is not significant at this point in time and as a result the increase in total catchment flows is likely to be less than 1%.

In local sub-catchments where development is concentrated, such as in Smiths Lake village, the impact of catchment development can be very significant causing increased erosion.

In relation to the Greenhouse Effect there is some consensus that a rise in global ocean water levels will occur, but it remains uncertain as to whether storm activity and rainfall levels will increase or decrease along the NSW coast.

Any increase in mean ocean tide level would be matched by coastal erosion and accretion in the entrance area. As a result there would be an increase in tide levels in the lake approximately equal to the changes in the ocean. Such an increase would raise the level of the lake at closure and so reduce the volume of runoff required to fill the lake to the 2.1 mAHD opening level. This would increase the number of entrance openings, reduce the size of the entrance channel, and probably increase the magnitude of the average annual water balance in terms of tidal flows.

If there is an increase in rainfall and hence flood frequency, this would also increase the occurrence of entrance breakout events and hence tidal flows throughout the estuary. However, if rainfall levels decrease there would be a corresponding decrease in the number of entrance openings and a smaller average annual water balance, which would counter the effects of ocean level increases.

2.7 Beach Berm Height

Smiths Lake is one of some 100 estuarine systems with intermittently open and closed entrances (sometimes known as ICOLLS - Intermittently Closed and Open Lake and Lagoon Systems) along the NSW coast. The morphology of the entrance is a product of the interaction between the fluvial, tidal and wave processes. A cyclical process occurs of entrance infill, berm building and the entrance scour and opening. The main factor determining the flood level from a given amount of rainfall is the initial water level in the lake, the level of the entrance berm and the mechanism for opening.

The berm is a depositional feature which results from an accumulation of sediment on the landward entrance of the limit of wave runup activity. Deposition of sediment occurs as the wave uprush velocity decreases due to gravity, friction and percolation into the sands. If conditions allowed, the berm could rise to the maximum height of the wave runup. The height of wave runup is a product of the incident wave conditions (height and period) and beach slope. Aeolian processes may also influence the berm development.

The berm is generally characterised by a steeply sloping seaward beach face and a more gently sloping landward face. It is possible that without human intervention the crest of the berm at Smiths Lake would exceed 3 mAHD. Thus flood levels would have to reach this level before overtopping, scouring and opening would occur.

Human intervention has meant that full development of the berm at Smiths Lake has never occurred since 1932.

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 dating back to the early 1900's, or in some cases even further. However, in catchments such as Smiths Lake there are generally limited historical records available. A picture of flooding must therefore be obtained from this data set and local knowledge. Whilst there are no long term records there is an automatic water level recorder and pluviometer which have over 10 years of data.

3.1 Rainfall

3.1.1 Overview

Rainfall data is recorded either daily as 24hr rainfall totals to 9:00am or continuously (pluviometer). Daily rainfall data has been recorded for over 100 years in the Smiths Lake catchment. 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 or misrepresented.
- Daily read information is usually obtained at 9:00am in the morning. 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.
- Rainfall records can frequently have “gaps” ranging from a few days to several weeks or even years.

3.1.2 Available Rainfall Data

Table 4 presents a summary of the BoM rainfall gauges located close to, or within the catchment. There may also be other private gauges in the catchment (bowling clubs, schools) but these data have not been collected as there is no public record of their existence.

Table 4: BoM Daily Read Rainfall Stations within a 15km radius of Smiths Lake

Station No.	Station Name	Elevation (mAHD)	Distance (km) from Smiths Lake	Date Opened	Date Closed
60144	Smiths Lake (Patsys Flat Road)	40	0	Apr 1980	Current
60088	Pacific Palms	42	4.5	Sep 1968	May 1983
60028	Seal Rocks Camping Reserve	4	7.4	Sep 1897	Current
60047	Bungwahl (Buttaba)	32	10	Sep 1961	May 1994
60032	Topi Topi	n/a	10.6	Jan 1936	May 1957
60095	Bungwahl	n/a	11.7	Mar 2002	Current

n/a = not available

Data was not collected for gauges outside the catchment as they are considered to be too far away to be relevant.

3.1.3 Analysis of Daily Read Data

An analysis of daily rainfall data was undertaken to identify and place past storm events in some context. All daily rainfall depths greater than 150 mm recorded at 60028 (109 years of record), 60047 (33 years of record), 60144 (26 years of record), 60032 (21 years of record) and 60088 (15 years of record) have been ranked and are shown in Table 5. The Manly Hydraulics Laboratory (MHL) pluviometer data at Tarbuck Bay (1996 to present) is also shown (refer Figure 5a). It should be noted that these are 24 hour totals recorded at 9:00am and thus do not necessarily compare with the peak 24 hour depths recorded by the pluviometer.

Table 5: Daily Rainfalls Greater than 150 mm

Rank	Date	Rainfall (mm)	Rank	Date	Rainfall (mm)
MHL - TARBUCK BAY:			**60088 - PACIFIC PALMS:**		
1	14/05/2003	197	1	13/03/1974	202
2	04/11/2006*	195	2	04/03/1977	168
60028 - SEAL ROCKS:			**60032 - TOPI TOPI:**		
1	13/03/1974	254	1	18/06/1949	220
2	12/03/1974	220	2	21/01/1938	172
3	17/01/1940	191	3	02/05/1953	166
4	13/01/1911	184	**60047 - BUNGWAHL (BUTTABA)**		
5	19/03/1940	184	1	13/05/1963	341
6	13/01/1968	176	2	13/03/1974	216
7	17/03/1907	165	3	04/03/1977	186
8	24/01/2001	163	4	21/01/1971	166
9	16/04/1927	160			
10	20/03/1959	151			

Note: 60095 (Bungwahl) and 60144 (Smiths Lake) did not have any recorded daily rainfall above 150 mm.
* November 2006 record only included for Tarbuck Bay

3.1.4 Analysis of Pluviometer Data

Since 1996 Manly Hydraulics Laboratory (MHL) has been operating a pluviometer at Tarbuck Bay on Smiths Lake. The data from May 1996 to December 2006 was analysed. From the 15 minute interval data over this period the maximum rainfall for given durations were calculated and are shown in Table 6.

Table 6: Maximum Depths - Tarbuck Bay Pluviometer

Duration	Rainfall in Period (mm)
15 min	30
1 hr	103
2 hr	124
4 hr	139
6 hr	160
12 hr	184
24 hr	199

The two periods of significant rainfall producing the maximum depths occurred on 6th to 7th January 2006 and 3rd to 5th November 2006. Up to the 4 hour durations were from the January 2006 event and the longer durations from the November 2006 event. Cumulative mass curves for these two periods are provided on Figure 5b. The 6th to 7th January event is significant as it exceeded the 1h and 2h 500y ARI design rainfall depths. The 3rd to 5th November event exceeded the 6h 200y and 12h 100y design rainfall depths.

It would appear that these events were fairly localised as the rise in the lake water level was only approximately 0.2 m in January 2006 and 0.3 m in November 2006.

3.1.5 Design Data

Design rainfall data obtained from Australian Rainfall & Runoff (Reference 4) are given in Table 7.

Table 7: Design Rainfall Data

Duration	Rainfall (1)	Average Recurrence Interval (y)									
		1	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**PMF**
1h	Intensity (mm/hr)	31	40	51	57	65	75	83	91	101	320
	Depth (mm)	31	40	51	57	65	75	83	91	101	320
2h	Intensity (mm/hr)	20	25	32	36	41	47	51	56	62	235
	Depth (mm)	40	51	64	71	81	93	103	112	125	470
6h	Intensity (mm/hr)	10	13	15	17	19	22	24	26	28	380
	Depth (mm)	60	75	92	101	114	130	142	153	169	760
9h	Intensity (mm/hr)	7.7	9.7	12	13	14	16	18	19	21	NOT CALCULATED
	Depth (mm)	69	87	105	115	129	146	159	172	190	
12h	Intensity (mm/hr)	6.4	8.0	9.6	11	12	13	15	16	17	
	Depth (mm)	76	96	116	126	141	160	174	187	206	
18h	Intensity (mm/hr)	5.0	6.3	7.6	8.3	9.3	11	12	13	14	
	Depth (mm)	89	112	136	149	167	190	207	224	247	
24h	Intensity (mm/hr)	4.2	5.2	6.4	7.0	7.9	9.0	10	11	12	
	Depth (mm)	100	126	153	168	188	215	234	254	280	
30h	Intensity (mm/hr)	3.6	4.6	5.6	6.1	6.9	7.9	8.6	9.3	10	
	Depth (mm)	108	136	167	183	206	236	257	279	308	
36h	Intensity (mm/hr)	3.2	4.0	5.0	5.5	6.2	7.0	7.7	8.4	9.2	
	Depth (mm)	115	146	178	197	222	253	277	301	333	
48h	Intensity (mm/hr)	2.6	3.3	4.1	4.5	5.1	5.9	6.5	7.0	7.8	
	Depth (mm)	126	160	198	218	246	283	310	337	373	
72h	Intensity (mm/hr)	2.0	2.5	3.1	3.5	3.9	4.5	4.9	5.4	6.0	
	Depth (mm)	142	180	224	248	281	324	356	388	431	

(1) Intensity refers to the average hourly depth of rainfall for the storm period.
Depth refers to the total depth of rainfall falling in the storm period.

3.2 Tarbuck Bay Water Level Data

The Department of Public Works and Services - MHL operates a network of continuous water level recorders along the NSW coast, one of which is located in Smiths Lake at Tarbuck Bay (Figure 2). Water level data at Tarbuck Bay (Figure 6) is available from May 1996 to November 2006. Hourly readings were obtained for this period with the highest water level recorded of 2.25 mAHD on 29th May 2005. The long term average water level based upon the nine years of Tarbuck Bay data available is approximately 1.0 mAHD.

The historical maximum rates of rise of the lake level were calculated based on hourly data for various time periods (Table 8). By comparison the estimated rates of rise for the 5y and 100y ARI design events are also shown.

Table 8: Maximum Rate of Water Level Rise (1996 to 2006)

Time (hours)	Recorded #			Design *			
	Rise (m/period)	Rate of Rise (m/hr)	Date	5y ARI Rise (m/period)	100y ARI Rise (m/period)	500y ARI Rise (m/period)	PMF Rise (m/period)
1	0.12	0.12	14/07/1999	0.17	0.28	0.35	1.12
2	0.14	0.07	14/07/1999	0.21	0.34	0.42	1.63
6	0.17	0.03	14/11/2006	0.27	0.45	0.54	2.62
12	0.24	0.02	31/10/2004	0.30	0.51	0.62	n/c
24	0.38	0.02	14/05/2003	0.33	0.61	0.77	n/c
36	0.45	0.01	13/05/2003	0.31	0.66	0.85	n/c

Notes: * The design events assume 0 mm initial loss and 2.5 mm/h continuing loss over the catchment and that the entire rainfall enters the lake within the specified time period. This latter assumption is largely correct for the 12 hour and longer durations but will not be correct for the shorter durations, particularly for the 1 and 2 hour durations where runoff will enter the lake over several hours. Thus for the shorter design durations the rise per hour is exaggerated.
Rises below 1.1 mAHD (i.e due to tidal affectation) were not considered.
N/C Not calculated.

3.3 Entrance Openings

3.3.1 Background

The ocean entrance has been opened mechanically since 1932. Initially the entrance was opened by fishers, usually to encourage the running of prawns. Since the 1960's the entrance has been opened by Council, usually to prevent flooding of low lying developments, but also occasionally for water quality or construction purposes.

Until 1999 a lake level of around 1.7 mAHD triggered an entrance opening to prevent flooding. However after 1999 the trigger level was increased to 2.1 mAHD in order to reduce the number of openings and so more closely replicate the natural opening regime. At this level there are a number of developments potentially subject to inundation, including the Frothy Coffee boat shed, the foreshore camping areas at Sandbar and several septic tanks, notably at the UNSW research station. In 1996/1997 the majority of septic tanks in the area were replaced with a mains sewage system.

A survey of the entrance berm across Sandbar Beach was carried out in November 1995 by the Department of Natural Resources (under its prior name) which showed the lowest section of the berm to be at 2.6 mAHD. This level is above the present 2.1 mAHD trigger level for mechanical opening.

A second management change after 1999 was the relocation of the mechanical opening to be a minimum distance of 150 m from the southern dune. This was undertaken to minimise erosion of the southern dune. All subsequent openings have conformed with this condition.

3.3.2 Historic Entrance Openings

Since 1996 Great Lakes Council has kept records of mechanical openings of the entrance and MHL has recorded the lake level at Tarbuck Bay (Figure 6). The greatest rises in a 24 hour period are shown on Figure 7.

There have been nine openings since 1996 with eight of these recorded by the Tarbuck Bay gauge. These eight openings have been graphed together with the rainfall data in Figures C1-8 in Appendix C. The details of the entrance openings are summarised in Table 9 and described below.

Table 9: Historical Entrance Openings Since 1996

Date Opened	Time of Opening	Water Level at Opening (mAHD)	Hrs to Open(1)	Closing Date(2)	Days to Close	Opening Notes	Maximum Water Level Recession (m)			Rain Influence
							1hr	2hr	6hr	
10/01/1996	*	1.87	*	*	*	South corner, severe erosion	*	*	*	No
10/04/1997	16:00	1.55	28	09/05/1997	29	30 m from south corner	0.08	0.15	0.42	No
18/06/1998	13:00	1.84	25	01/07/1998	13	40 m from south corner	0.13	0.26	0.67	No
03/05/1999	20:00	1.90	26	13/05/1999	10	Some erosion on south dune	0.23	0.45	0.98	No
MANAGEMENT CHANGES OCCURRED										
11/05/2001	15:00	2.14	31	20/05/2001	10	200 m from southern dune	0.20	0.39	0.84	No
04/06/2002	12:00	2.03	41	29/06/2002	25	160 m from southern dune	0.15	0.29	0.74	No
15/05/2003	11:00	2.10	32	28/05/2003	13	150 m from southern dune	0.21	0.40	0.86	Yes
29/03/2005	12:00	2.25	34	08/04/2005	10	150 m from southern dune	0.28	0.52	1.07	No
08/11/2006	12:00	2.22	18.5	?	?	See Figure 8b	0.32	0.59	1.21	No

Notes:

(1) Time to open is taken as the time from the initial fall in water level to the time the tide becomes an influence.

(2) The date of closing is subjective and is based upon the combined effect of the cessation of tidal influence in the lake and where lake levels begin a long term trend of rising.

* Tarbuck Bay water level data is not available for the 1996 event.

January 1996: From May 1995 to late November 1995 the lake water level slowly built up from 1.0 mAHD to 1.7 mAHD. The level remained constant at 1.7 mAHD over December 1995. On 4th January 1996 the level rose to 1.75 mAHD. On 10th January the level started to rise again, reaching 1.85 mAHD by midday on 11th January. The entrance was opened mechanically early in the morning of 12th January. The entrance remained open for approximately three months until mid April 1996 when it closed to tidal flows with the lake level at approximately 0.5 mAHD.

April 1997: This was a non-typical event. The lake level at the time of opening was only 1.55 mAHD and an opening was made to assist in the laying of sewer pipes. This allowed pipe trenches to be excavated without the need for dewatering.

June 1998: From April 1998 the lake level gradually built up to 1.84 mAHD on the 18th June 1998 when it was opened. Upon opening the level fell rapidly at a rate of 0.13 m per hour. It took 9 hours for the entrance to develop. The entrance stayed opened for 13 days.

May 1999: In the preceding months to May 1999 the water level gradually built up until a peak level of 1.9 mAHD was reached on 3rd May and the entrance was mechanically opened. The rate of recession of waters was a maximum of 0.23 m per hour which reflected the high starting water level. Erosion of the southern dune was reported as a result of this event.

May 2001: Over the preceding 5 months to the May 2001 event the water level rose gradually. Over the immediate preceding days high rainfall lead to the fairly rapid increase in lake levels resulting in an increase of 0.4 m over the final two days prior to opening at 2.14 mAHD on 10th May.

June 2002: In June 2002 the entrance was opened at a level of 2.03 mAHD which followed a gradual rise from 1.65 mAHD over a period of approximately 10 days.

May 2003: The May 2003 entrance opening is different to the other openings due to the large volume of rain falling both in the lead up to and after the opening. The rate of rise of the lake prior to the opening was much faster than recorded in other events with a rise of 0.48 m to reach 2.1 mAHD in the preceding 24 hours.

March 2005: The level at the opening on 29th March was the highest recorded (2.25 mAHD). The initial fall in the water level was very rapid.

November 2006: This opening was monitored by an engineer from Webb McKeown and a large number of photographs (Figure 8b) and dimensions recorded (Table 10). The water level rose gradually (1 m to 1.75 mAHD) from June to September 2006 followed by a rapid 0.2 m rise. The water level then slowly fell until a 0.3 m rise on 5th November precipitated the opening on 8th November.

Table 10: November 2006 Opening

Time	Length	Width (m)	Depth (mm)	Cross-Sectional Area (m^2)	Comments
12:00 pm	80	5	300	15	width 5 m bed scouring at ocean
12:30 pm	80	6	300	18	width still only 6 m scour working upstream
1:00 pm	80	8	300	24	standing waves - excavated sand restricting width and upstream movement of erosion scour
1:30 pm	80	10	300	30	300 mm deep over 10 m width but deeper where restricted
1:45 pm	80	10	500	50	width 15 m at ocean, 10 m half-way up and 10 m upstream
2:00 pm	80	12	500	60	500 mm depth at 12 m width, “U” channel 10 m upstream 15 m at ocean
2:30 pm	85	15	500	75	18 m at ocean, “U” channel upstream
2:45 pm	90	20	700	140	at 2:50 pm upstream shoal gone, flow increases
2:45 pm	100	28	900	250	one big standing wave
3:10 pm		33	1500	500	big standing waves moving upstream rapid erosion
3:15 pm		40	2000	800	big standing waves moving upstream rapid erosion
3:30 pm		47	2000	940	big standing waves moving upstream rapid erosion

Time	Length	Width (m)	Depth (mm)	Cross-Sectional Area (m^2)	Comments
3:45 pm		56			big standing waves moving upstream rapid erosion
4:00 pm		59			flows change to sub-critical, no standing waves - bank erosion slows
4:15 pm		70?			
5:00 pm		85?			
8:00 pm		100+			

Note: All dimensions are estimates.

3.4 Wind Action across the Lake

Wind blowing across an open water body creates surface currents as a result of wind friction on the water. These currents flow in the predominant wind direction. When approaching land, the wind generated currents pile up creating a slight increase in water level on the down wind shoreline. This is called wind setup.

There are no data on wind generated currents or wind setup in Smiths Lake. Based on comparisons with other wide shallow estuaries in NSW it is reasonable to assume that currents up to 0.5 m/s (or approximately 3% of average wind speed) could be generated during prolonged storm conditions, resulting in a setup of up to 0.1 m.

Wind blowing across Smiths Lake also creates waves. The height and period of the waves is determined by the fetch length, water depth, wind velocity and wind duration. As waves break they runup the foreshore. This is called wave runup and has been examined in Appendix B.

3.5 Tidal Hydrodynamics

Ocean water levels have an important impact on the hydrodynamics of the lake when the lake entrance is open.

Ocean levels near the lake entrance are determined by the normal astronomic tide plus the effects of winds, waves, currents, barometric pressure, etc. As is the case for all the NSW coast, there are two astronomic tides each day, with a mean tidal range of around 1.0 m, a mean neap range of 0.7 m, and a mean spring range of around 1.4 m. The maximum tidal range is generally less than 2.0 m, with peak water levels around 1.1 mAHD. However, for an open coast beach entrance such as Smiths Lake, ocean levels during storms can exceed 2.0 mAHD due to storm surge and wave setup effects. Several flood studies on the mid-north coast have assumed a 100y ARI ocean level of 2.6 mAHD (Reference 10). Wave runup on the foreshore might reach 5 mAHD on a suitably graded foreshore. The effect of ocean levels is discussed further in Section 7.4.

When the lake entrance is open, levels within the estuary are predominantly determined by the ocean tide and bathymetric effects in the entrance channel. Larger ocean tides result in larger variations in the lake, but the size (width, depth and length) of the entrance channel has a far greater effect. Tidal influence in the lake is generally greatest immediately after breakout when the channel is at its largest. Immediately after breakout is completed, sediments from the beach system begin to infill the entrance and restrict flows.

Infilling is usually quickest after breakout, but is dependent on the amount of sand being moved into the entrance by ocean waves and currents, by the size of the tides, and the volume of catchment runoff. On average it takes about 2 months before the entrance is completely blocked to tidal flows, although wave overtopping of the low entrance dune can continue for some time after closure.

3.6 Historical Flood Information

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. Reliance must therefore be made on the following:

? Great Lakes Council,
? previous reports,
? local residents
? Bureau of Meteorology rainfall records,
? MHL water level and pluviometer data at Tarbuck Bay.

3.7 Other Data

3.7.1 Lake Hydrosurvey

The hydrosurvey (Figure 9a) shows the lake is separated into three basins of similar surface area. The middle basin between Big Island and Simons Point is the largest and deepest with an area of around 3.6km^2 and a maximum depth to minus 3.5 mAHD. The western basin has an area of 3.2km^2 and a depth to minus 2.5 mAHD, while the eastern basin or entrance area has an area of around 3.0km^2 but a depth over much of the area of less than minus 1 mAHD except in the northern Symes Bay portion where depths exceed minus 3.5 mAHD.

The entrance bathymetry has a major impact on lake hydrodynamics, with the barrier deposits preventing (entrance closed) or severely restricting (entrance open) tidal flows. The overall shallow depth of the lake (<4 m below mean sea level) also means that wind (and tide) generated currents are significant.

3.7.2 Entrance Openings

Because the lake is normally closed at the ocean entrance and hence not influenced directly by tides, the recurrence period and length of time the entrance remains open are of major significance to the hydrodynamics of the estuary. When the entrance is open the hydrodynamics of the lake are determined by the size of the entrance channel.

Previous reports indicate that the lake is opened on average every eighteen months and that the entrance then remains open for varying periods, usually for around two months. Periods of over 12 months have been reported. A concerted effort was made to confirm these entrance opening/closing periods, which appear to be based on anecdotal evidence. However, there is only very limited recorded data on entrance openings prior to 1996. What little information is available does not contradict the above findings.

Figure 6 shows the eight openings recorded by the Tarbuck Bay water level recorder.

3.8 Survey

Bathymetry of the lake was available from Reference 1 (DECC formerly DNR funded survey) and is reproduced on Figure 9a.

Detailed survey information was undertaken as part of this study by Mark Searles Surveyors. The data included:

? building floor levels below 4 mAHD,

? road levels of low-lying (below 4 mAHD) public roads around the foreshore of Smiths Lake.

This information is provided on Figure 9b.

3.9 Community and Local Resident Survey

Each resident, of surveyed properties (building floors below 4 mAHD) was asked if they could show any historical flood mark on their property and if so these were photographed, levelled and described.

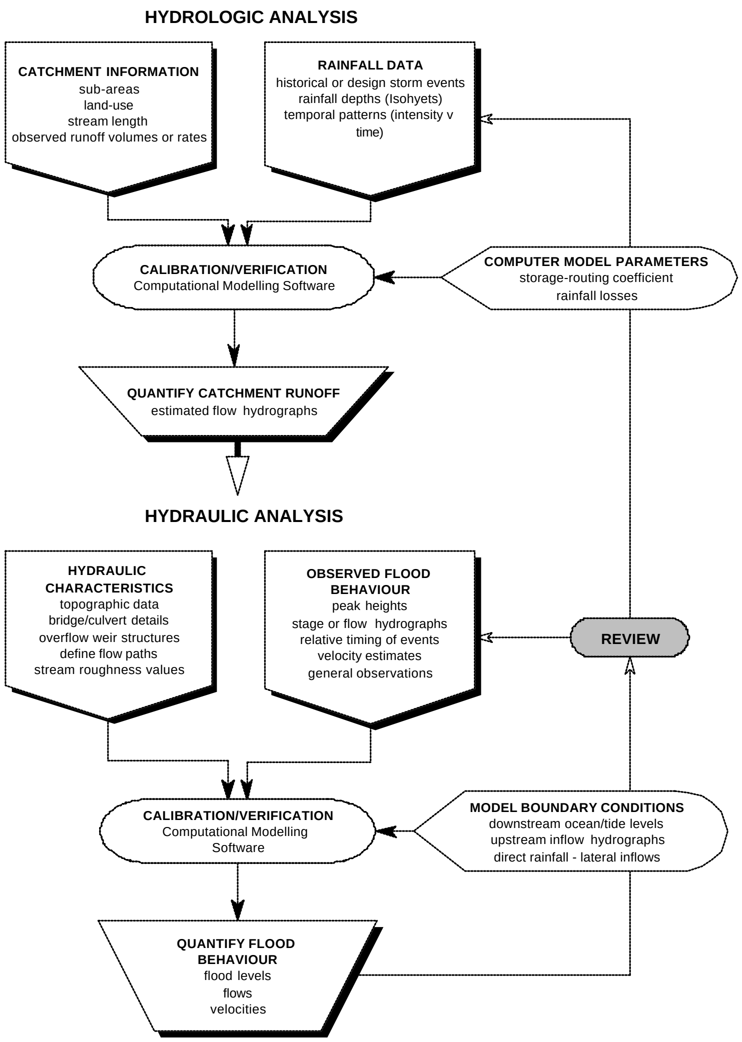
3.10 Photographic Record

Council and Webb McKeown (opening of November 2006) have a collection of photographs depicting flooding along the foreshore and various entrance openings. A selection of this information is provided as Figures 8a and 8b.

4. FLOOD STUDY PROCESS

A diagrammatic representation of the Flood Study process is shown in Diagram 1. The WBNM hydrologic model (Reference 5) was established for the entire catchment (Figure 3) and used to convert rainfall data into streamflow for input to a hydraulic (RUBICON - Reference 6) model. To ensure confidence in the results, both models require calibration and verification against observed historical events. As there are no flow gaugings on the tributaries entering Smiths Lake it was not possible to calibrate the hydrologic model to peak flows. Recommended model parameters were therefore adopted. Calibration of the hydraulic model (RUBICON) was possible and focussed on replicating the average fall in water level in the lake following an opening. The calibrated RUBICON 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 4). In current Australian engineering practice, examples of the more commonly used runoff routing models include RAFTS (Reference 7), the Watershed Bounded Network Model (WBNM - Reference 5) and RORB (Reference 8). These models allow the rainfall depth to vary both spatially and temporally over the catchment and readily lend themselves to calibration against recorded flow data (if available).

For the present study the WBNM hydrologic model has been used, largely because it has been widely used on surrounding catchments.

5.2 WBNM Modelling

5.2.1 Model Configuration

The WBNM model simulates a catchment and its tributaries as a series of sub-areas based on watershed boundaries linked together to replicate the rainfall/runoff process through the natural stream network. The adopted subdivision is shown on Figure 3. The model input data includes definition of physical characteristics such as:

? surface-area,
? proportion developed (generally only for urbanised catchments),
? stream shortening (where man-made alterations have occurred).

The model established for this study comprised a total of 14 sub-areas (including the lake itself). 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 for inclusion into the hydraulic model. Catchment areas were determined from topographic contours provided by Council in GIS format.

Given the low density of development in the urban areas it was assumed that there were no impervious areas of sufficient magnitude to be included in the hydrologic model.

5.2.2 Key Model Parameters

In calibrating the WBNM model, two main parameters can be varied to achieve a fit to observed data (peak flow and volume):

? *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.

5.2.3 Calibration

Calibration of a hydrologic model is only possible if there are flow data (obtained from streamflow gaugings) available. As there are no such data for the tributaries entering Smiths Lake calibration was not possible.

A limited volumetric calibration is possible by calculating the volume change in the lake and comparing this to the volume of runoff based on the rainfall data. The main limitation of this form of calibration is that it is highly dependant on the assumed loss rate and rainfall distribution. Table 8 provides some indication of the maximum recorded rate of rise and when compared to the design rises (assuming 0 mm initial loss and 2.5 mm/h continuing loss) indicates an ARI of around the 5y ARI except for the 24 and 36 hour durations where the recorded rise exceeds the 5y ARI. The design values assume a constant rainfall over the entire catchment which will rarely occur. Figure 5b indicates that the 6th to 7th January 2006 and 3rd to 5th November 2006 rainfall were very localised given the relatively small increases in lake level.

In the absence of available calibration data the following parameters were adopted for design:

Storage routing parameter ‘C’	=	1.29
Initial Loss	=	0 mm
Continuing Loss (this was applied uniformly across the catchment and no account was taken of the different losses for rain falling on land as opposed to water)	=	2.5 mm/h

6. HYDRAULIC MODELLING

6.1 Approach

The RUBICON hydrodynamic model software was used to quantify the hydraulic aspects of flood behaviour (e.g. flood levels and velocities). RUBICON is a fully dynamic computer based 1D model (quasi 2D) and uses different elements to simulate complex flow over floodplains and through channel systems. The model is capable of accurately simulating tidal hydrodynamics and is able to simulate entrance opening dynamics.

The lake system is modelled in RUBICON with the hydrographs included from the WBNM model.

6.2 Rate of Rise of Lake

Generally in flood studies the hydraulic model is used to replicate the recorded peak height profile along a creek for several historical events. Inflows to the hydraulic model are obtained using the historical rainfall depths and temporal patterns from pluviometers.

This approach was initially investigated with a view to using RUBICON to replicate the rise in water level. This can be achieved through adjustment of rainfall losses and assumptions on the rainfall distribution over the catchment. However this is a relatively arbitrary approach and provides little confidence in the use of results for design. For example, it is obvious that in both the 2006 rainfall events (January and November) there was either significant initial losses or the period of intense rainfall was very localised over the catchment.

6.3 Rate of Fall of Lake

The RUBICON model can be used to replicate the opening of the beach berm to the ocean.

As noted in Table 9 nine openings have been recorded since 1996 and eight of these have been recorded by the Tarbuck Bay water level recorder. These events together with the hourly rainfalls are provided on Figures C1 to C8.

With the exception of May 2003 all the openings occurred when the rain had ceased. Whilst there may have been some residual runoff still entering the lake for the remaining events, the amount is considered to be insignificant.

The rate of fall of the lake for all eight events together with the average is shown on Figure 10. Most notably all the events since the change in the opening level in 1999 show similar rates of fall. Calculated discharges through the entrance are provided on Figure 11.

6.4 Calibration - Entrance Opening

The physical processes involved in entrance breakouts from coastal lagoons are extremely complex and cannot be readily modelled. A physical model is deficient because scale factors mean that grain size, water depth, turbulence and other features cannot be accurately represented. Numerical modelling is difficult because of the rapid changes in flow state and sediment movement characteristics.

However, when examining lagoon estuaries it is necessary to be able to accurately simulate the entrance opening process. Webb, McKeown & Associates have written a sediment movement, process based, entrance breakout routine. The routine was developed specifically to allow the RUBICON hydrodynamic model to simulate the breakout of coastal lagoons. This procedure has previously been used at Terrigal, Wamberal, Avoca and Cochrone Lagoons at Gosford and at the mouth of the Shoalhaven River at Shoalhaven Heads.

The RUBICON model simulates flow over the entrance berm during breakout using the broad-crested weir formula. The routine provides for both free overflow and submerged flow. Scour from the berm during breakout is calculated using the Ackers and White total sediment load equation.

The Ackers and White equation calculates total sediment load as a function of:

? grain size,
? specific gravity,
? velocity,
? hydraulic gradient,
? hydraulic radius,
? depth.

The entrance berm is defined as a low, flat, trapezoidal prism perpendicular to the flow path. Breakout an occur as a result of overtopping or mechanical opening. The breakout channel can be defined to suit the constraints of the site.

The beach berm is described in the model by the following parameters:

? its length (parallel to the ocean),
? its width (perpendicular to the ocean),
? its depth (thickness of sand from crest level to the lowest level it erodes),
? grain size (the D35 value is used in the Ackers and White formula).

A width to depth ratio and a side batter slope were provided in order to define a trapezoidal channel. Scouring (removal of sediment) occurs from the side and the base in order to maintain the trapezoidal channel dimensions.

At each timestep the program calculates the total sediment load at the entrance using the Ackers and White formula. It is assumed that this load is obtained from scouring of the beach berm. The dimensions of the berm are thus reduced according to the pre-selected criteria to account for the scouring of the trapezoidal channel. No infilling of the berm is permitted.

The results for the following adopted parameters are provided on Figure 12:

? initial water level: 2.2 mAHD (this level was taken rather than 2.1 mAHD as in November 2006 and March 2005 the lake was at this level before it was opened),

? four constant ocean levels of 0 m, 0.5 m, 1.0 m and 1.5 mAHD and using the recorded tides (Port Stephens gauge),

? D35: 0.25,

? maximum width: 60 m,

? inflow: nil,

? maximum depth to which erosion can occur: -1 mAHD,

? depth of cut by excavator: 0.4 m (i.e. to an invert of 1.8 mAHD, a 1:20 depth to width ratio is assumed).

A summary of the key points from Figure 12 are:

? The rate of fall of the lake for the five events (May 2001, June 2002, May 2003, March 2005 and November 2006) are shown as solid lines. Data for the previous openings (January 1996, April 1997, June 1998, May 1999) are not shown as these events were opening at a lake water level less than 2 mAHD. Each of the five events were opened at slightly different levels which makes a comparison of the rate of fall of the lake difficult. It is noted that the 2001 and 2003 events were opened at approximately the same level and produced very similar rates of fall. The 2002 event matched the 2001/2003 profiles after approximately 6 hours. The 2005 and 2006 profiles were very different, even though they started at approximately the same level. There is no apparent explanation for this other than it is assumed that the initial cut in the dune and amount of sand to be removed differed. We note for example that in November 2006 some excavation occurred inland of the berm within the sand delta. Possibly this did not occur in March 2005.

? Whilst it is possible to alter the parameters within the hydraulic model to reflect different extents of excavation, there is no record of these extents for the actual extents, except for November 2006. The model has therefore been set up to provide the “best fit” to the range of data.

? The model was run for four different fixed tides (0 m, 0.5 m, 1 m, 1.5 mAHD). The results indicate that the 1.5 mAHD tide affects the rate of fall after 2 hours. For the three other fixed levels the rate of fall diverges after say 4 hours but by this time the lake has fallen by 0.3 m and flooding within the lake is not affecting properties.

? The tides for the five “opening” events were obtained from the Port Stephens gauge and the model run for each of these tidal conditions. The results show that it is only after 6 hours that the different tidal conditions have any affect on the rate of fall. It is noted that the November 2006 “tide” produced the most rapid rate of fall which may partially explain why the November 2006 rate of fall was the most rapid of all the “opening” events.

In conclusion the “normal” tide range of up to 1 mAHD has no significant impact upon the rate of fall of the lake in the first few hours, by this time the lake has fallen by some 0.3 m. The key determinant of the rate of fall is the size of the cut and nature of the erosion procedure. Further collection from future lake openings is required to develop a greater understanding of the mechanisms controlling the rate of erosion.

Further discussion of the impacts of ocean level are provided in Section 7.

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 *flood frequency* approach requires a reasonably complete homogeneous record of flood levels/flows over a number of decades to give satisfactory results. No such records were available within the catchment. For this reason *rainfall/runoff routing* approach using the WBNM model results was adopted for this study. These hydrographs define boundary conditions to the RUBICON hydraulic model. This approach reflects current engineering practice and is consistent with the quality and quantity of available data.

7.2 Hydrologic Modelling

Design temporal patterns were derived from AR&R (Reference 4) and used as input for the WBNM model. Uniform depths of rainfall assuming zero initial loss and 2.5 mm/h continuing loss with zero areal-reduction factor were applied across the entire catchment.

Design inflow hydrographs for a range of durations (ranging from 1 hour to 36 hours) were derived for design events from the 2y ARI to the 500y ARI and PMF.

7.3 Hydraulic Modelling

Preliminary hydraulic modelling has indicated that the peak water level in the lake is determined by:

? the initial water level in the lake prior to the design rainfall,

? the depth of rainfall over the catchment and the consequent amount of runoff. The temporal pattern of the rainfall is largely irrelevant as it is the volume of runoff rather than the peak flow entering the lake that is critical,

? the height of the entrance berm. If the entrance is open then the lake can easily contain the 100y ARI design runoff (refer Table 8). As indicated previously the height of the berm has been “regulated” since 1932 by man-made openings. Currently the”trigger level” is 2.1 mAHD, although it reached 2.2 mAHD in November 2006. This is the most critical factor determining design flood levels,

? whether a man-made opening in the entrance berm can be undertaken. In the eight previous openings the opening has been undertaken following the peak rainfall and generally under fair weather conditions. Under adverse weather conditions it is possible that a man-made opening could not be undertaken. The lake level would then rise (assuming there is sufficient inflow) to the height of the entrance berm. Once the water level reaches the height of the beach berm and overtopping occurs then the lake level will cease to rise and will fall as floodwaters from the lake scour out the entrance,

? Table 8 indicates that only in events larger than the 500y ARI will the volume of runoff produce a rise greater than 0.85 m.

7.4 Tailwater Ocean Conditions

7.4.1 Design Data

Tidal data are available from the Forster gauge as well as from Port Stephens. The Forster gauge, though the closest to Smiths Lake, is located within the entrance heads and for this reason does not accurately record the ocean tide levels. Port Stephens is the next closest tidal gauge and historical records for this gauge were obtained. The highest level recorded since 1986 at the Forster gauge is 1.0 mAHD in June 2005 and at Port Stephens is 1.34 mAHD in June 1999.

The design ocean levels at Fort Denison based on 80+ years of record (as reported in the Forster South Breakwater Physical Model - July 2004) are:

? 100y ARI 1.50 mAHD,
? 50y ARI 1.47 mAHD,
? 20y ARI 1.43 mAHD,
? 10y ARI 1.39 mAHD,
? 1y ARI 1.28 mAHD.

These estimates include a storm surge component but not wave setup (Fort Denison is not affected by wave setup).

Accurate estimates of stillwater (i.e. not wave set up) ocean levels greater than the 100y ARI are not possible but an indicative Extreme level is 1.78 mAHD (reported in Reference 11).

It should be noted that the highest astronomic tide in a year reaches approximately 1.1 mAHD.

7.4.2 Wave Setup

The above design ocean levels are applicable along the NSW coast where there is no wave setup component. However at Smiths Lake some wave setup component is expected.

Wave setup occurs in the surf zone where the shoreward kinetic energy of the breaking and broken waves is converted to gravitational potential energy in the form of increased water levels. Wave setup is largely confined to the nearshore area and is highly dependent on factors such as the wave height, wave length, water depth and embayment slope.

Along exposed NSW beaches wave setup can be of the order of 1.7 m during very large energy wave climate conditions, but this setup is only maintained if the wave energy remains high for a sustained period of around an hour. Wave setup can be relieved by a lull in wave energy, by alongshore rips and currents and at estuary entrances. The extent of the relief is highly dependent on the specific site conditions.

The estimated 100y ARI ocean level at Wallis Lake is 1.85 mAHD (assuming no climate change). However this is a deep entrance with a relatively small wave setup component.

At Smiths Lake no detailed ocean water level studies have been undertaken. The Forster/Tuncurry Flood Study (September 1989 - Reference 10) indicated a peak wave setup of

100y ARI	1.6 m
50y ARI	1.45 m
20y ARI	1.3 m

for shallow unprotected estuary or river entrances.

Thus a peak level of 3.1 mAHD (1.5 mAHD ocean level plus 1.6 m wave setup) could be reached. However this assumes coincidence of the two peaks. Reference 10 (and compatible with Reference 12) indicated peak design ocean levels including wave runup of:

100y ARI	2.6 mAHD
50y ARI	2.4 mAHD
20y ARI	2.2 mAHD

No ocean estimates are available for events greater than the 100y ARI.

7.4.3 Coincidence of Elevated Ocean Level and Design Rainfalls

Investigation of the coincidence of the elevated ocean with the peak lake level requires a joint probability analysis. However there is insufficient historical data to undertake such an analysis.

If the entrance is open and a 100y ARI ocean event occurs the resulting peak flood level will reach of the order of 2.6 mAHD (assuming peak ocean levels taken from Reference 10), 2.4 mAHD in the 50y ARI and 2.2 mAHD in the 20y ARI.

This design scenario is likely to have a frequency of occurrence less than a 100y ARI as for the majority of the time the entrance is closed. The influence of ocean levels on a closed entrance depends on the height of the beach berm, the amount of overtopping and the preceding lake level. “Pumping” of the lake water level will certainly occur as waves break over the berm but the storm would have to continue for a long time to significantly increase water levels over a 10km^2 lake.

7.4.4 Conclusions on Effect of Elevated Ocean Conditions

For events up to the 100y ARI ocean conditions only becomes a significant contributing factor if the ocean levels exceed say 1.5 mAHD. The effect will depend upon the peak height and duration of the ocean event and the nature of the beach berm during the event.

7.5 Rainfall Induced Design Event with Ocean Levels below 1.5 mAHD

Design flood (lake) levels cannot be determined for Smiths Lake using a traditional rainfall-runoff approach due to the influence of Council's entrance opening policy. If the policy is enforced then the peak lake levels will not exceed the level at which the lake is opened. In theory all design events will therefore reach approximately the same peak level.

The only possible scenario (for a low ocean level condition) that could produce a higher level than 2.1 mAHD (assumed nominal opening level) is if the lake rose to near 2.1 mAHD, Council had not opened the lake and the design rainfall event occurred. The lake will rise to whatever is the beach berm level, overtop and gradually the lake level will fall as scouring of the entrance berm occurs. For this scenario the peak lake level would depend on the height of the beach, the volume of runoff entering the lake and whether Council is able to make an opening in the berm. Once even a small opening is made, or the berm is overtopped, the outflow from the lake will erode the beach berm and the lake level will fall.

The probability of the above scenario occurring is likely to be rarer than the probability of the design rainfall event under consideration as the design rainfall could equally occur when the lake is open or half full. If either of these two latter scenarios occurred then a lake level above 2.1 mAHD would not occur.

After consideration of the above factors the adopted design approach was determined as follows:

? the starting water level in the lake is 2.2 mAHD (refer Section 6.4),

? Council is able to cut a small opening in the beach berm (0.4 m deep) with an upstream invert at 1.8 mAHD. The remainder of the berm is at 3.5 mAHD and is not overtopped but is eroded as the opening becomes enlarged. All parameters are identical to those used for the calibration events (refer Section 6.4),

? the design rainfall commences immediately prior to any outflow from the lake,

? the rate of outflow from the lake and erosion of the beach berm is defined by the calibrated RUBICON breakout procedure as shown on Figure 12,

? a constant ocean level of 0.5 mAHD was assumed. As shown by the sensitivity analysis on Figure 12, a constant or varying ocean level between 1 mAHD has no significant impact on the peak lake level but does affect the rate of fall of the lake.

The results for the above analysis indicate that for all design events (up to the 500y ARI event) the maximum increase in water level above the starting level of 2.2 mAHD is 0.1 m (i.e. to 2.3 mAHD).

Thus the rate of outflow quickly exceeds the rate of inflow due to scouring of the entrance. Therefore it is assumed that for all events up to the 500y ARI the peak water level could reach 2.3 mAHD assuming Council's current entrance opening procedure.

For the PMF the rate of inflow is significantly greater than the rate of outflow during the initial few hours of the lagoon opening. This is due to a combination of the much greater rainfall intensities and the different rainfall temporal patterns which are used for the PMF compared to those in Australian Rainfall and Runoff (Reference 4) which are used for all other design events. As a result, hydraulic modelling indicates that the PMF may reach 3.5 mAHD. This scenario assumes that the only exit for the floodwaters is via the man-made opening (i.e. no overtopping of the remainder of the beach berm).

The rate of rise of the lake during the design events is provided in Table 8. Up to the 500y ARI event the rate of rise is a maximum of 0.35 m/hour. However for the PMF the maximum rate is 1.1 m/hour.

7.6 Design Flood Levels

The peak design flood levels based on the above analysis are:

PMF	3.5 mAHD (rainfall induced)
100y ARI	2.6 mAHD (ocean induced)
50y ARI	2.4 mAHD (ocean induced)
20y ARI	2.3 mAHD (rainfall induced)

For the 200y and 500y ARI the dominant mechanism will be ocean inundation. However no estimates of ocean level are available for these events.

7.7 Hydraulic Classification

The Floodplain Development Manual defines three hydraulic categories which can be applied to areas of the floodplain.

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

"*Flood storage* areas are 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."

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

All land below 1.3 mAHD is considered to be Floodway with land above this Flood Fringe.

7.7.1 Flood Hazard Classification

Provisional (hydraulic) hazard categorisation are based on the depth and velocity of floodways. As the velocity of flow is negligible, except near the opening, depth has been the sole criteria adopted for determining the provisional hazard. Assuming a 100y ARI flood level of 2.3 mAHD and a depth of 1 m signifying high hazard, all land below 1.3 mAHD is High Hazard and all land above is Low Hazard.

True *Flood Hazard* is a measure of the overall adverse effects of flooding. It incorporates threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. These factors are not included in the provisional (hydraulic) hazard assessment.

For the true hazard, land is classified as either *low* or *high* hazard for a range of flood events. The classification is a qualitative assessment based on a number of factors as listed in Table 11.

Table 11: Hazard Classification

Criteria	Weight [(1)]	Comment
Rate of Rise of Floodwaters	Low	Rises slowly.
Duration of Flooding	Low	Goes quickly (if berm is opened).
Effective Flood Access	Low	Easy access to high ground.
Size of the Flood	Low	All floods reach same level.
Effective Warning and Evacuation Times	Low	Residents aware of flooding due to rainfall.
Additional Concerns such as Bank Erosion, Debris, Wind Wave Action	Medium	Wind waves may introduce problem along the foreshore. Ocean waves will enter if the entrance is open and may impact on the eastern foreshore of the Smiths Lake township. Fortunately the buildings in this area are elevated and the heavy vegetation will dissipate the wave energy.
Evacuation Difficulties	Low	Relatively easy access to high ground.
Flood Awareness of the Community	Medium	All residents are aware that lake will rise with rainfall but probably not if due to ocean inundation.
Depth and Velocity of Floodwaters	Low	Up to 1 m depth but nil velocity.
Ocean Effects	High	Will have a significant impact if the entrance is open.

Note: (1) Relative weighting in assessing the hazard.

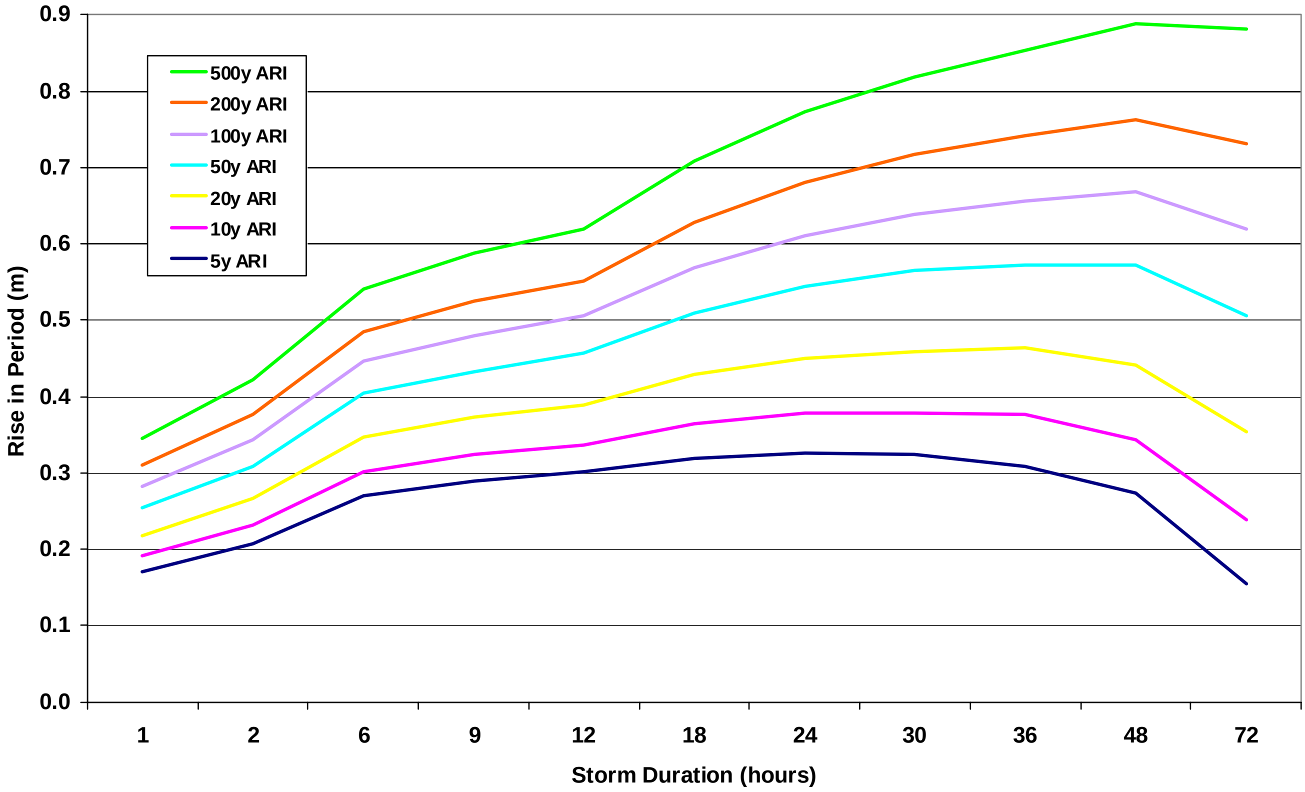
Based upon the above assessment the preliminary hydraulic hazard classification should change when taking account of all other hazard factors particularly the effect of ocean inundation. There is no recognised qualitative procedure for taking the above factors into account but a qualitative procedure suggests a more appropriate boundary between Low and High hazard is 2 mAHD.

7.8 Sensitivity Analysis

7.8.1 Entrance Opening

The only factors having a significant impact on the preceding design flood estimation approach are related to the entrance opening. For example raising the entrance opening level by 0.1 m would produce a similar 0.1 m rise in the rainfall induced design flood level. If Council could not undertake an opening at the agreed level the lake would rise to the height of the berm.

Detailed sensitivity analysis of changing the entrance opening procedure was not undertaken, however a review of the design data shown in Table 8 provides a general assessment of the likely implications of a large rainfall event occurring and Council being unable to open the entrance. The maximum rise for various design events and durations is shown in the graph below.



Thus given the following assumptions:

- a starting lake level of 2.2 mAHD (Section 7.5),
- a 100y ARI lake level of 2.6 mAHD (ocean induced - refer Section 7.6),
- Council is unable to open the entrance,
- rainfall losses of 2.5 mm/hour,
- the beach berm is of infinite height,

the lake would not reach the 100y ARI lake level (0.4m rise) in a 10y ARI and smaller event. For larger events the 100y ARI level of 2.6 mAHD would be reached in 2 hours in a 500y ARI event and approximately 4 hours in a 100y ARI event. The graph also illustrates that for the longer duration events there is a point where the peak rise decreases as the total losses (continuing loss of 2.5 mm/h) reduce the total rainfall excess (rainfall minus losses).

The effect of changing the adopted downstream ocean level was simulated for rainfall induced events with the results shown on Figure 12. These indicate no change to the peak lake level but a significant impact on the rate of fall of the lake.

7.8.2 Ocean Effects

For ocean induced events the most significant factor is the estimated peak ocean level and in particular the estimate of wave setup. Any change to these levels will have a direct affect on the design flood levels.

8. THE COST OF FLOODING

The cost of flood damages and the extent of the disruption to the community depends upon many factors including:

- 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, sedimentation.

Flood damages can be defined as being "tangible" or "intangible". Tangible damages are those for which a monetary value can be assigned, in contrast to intangible damages, which cannot easily be attributed a monetary value (stress, injury, loss to life, etc.).

8.1 Tangible Flood Damages

While the total likely damages in a given flood is useful to get a "feel" for the magnitude of the flood problem, it is of little value for absolute economic evaluation. When considering the economic effectiveness of a proposed mitigation option, the key question is what are the total damages prevented over the life of the option? This is a function not only of the high damages which occur in large floods but also of the lesser but more frequent damages which occur in small floods.

The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by taking into account the probability of a flood occurrence. By this means the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

A flood damages assessment was undertaken for existing development in the Smiths Lake community and is summarised below.

8.1.1 Building Floors

A detailed survey of all building floor levels less than 4 mAHD was undertaken by a Registered Surveyor in October 2006. The results indicate the following:

- lowest residential floor level = 3 mAHD,
- number of residential floors below 3.5 mAHD = 7,
- number of residential floors below 4.0 mAHD = 17,
- lowest non-residential floor level = 2.2 mAHD (Frothy Coffee Café),
- 2nd lowest non-residential floor level = 2.4 mAHD (Fishing boatshed),

- 3rd, 4th lowest non-residential floor level = 3 mAHD (Machinery Shed, University Zoology Room),
- number of non-residential floors below 4 mAHD = 33.

Based on the above data the only building likely to experience flood damages as a result of flooding (assuming flooding does not reach 3 mAHD) is the Frothy Coffee Café.

The café is a commercial enterprise which experiences minimal damage to the building or contents (as they can easily be raised) but significant damage due to loss of trade (café and boat hire business).

The magnitude of the flood damages is impossible to accurately estimate as it will depend upon many factors, including:

- duration of flooding, a key factor is how long the lake remains near the opening level (2.1 mAHD). It is likely that customers will not frequent the café if they see the lake water level close to the floor level,
- the time of year (holiday period, long weekend),
- the weather conditions (in severe weather conditions that cause flooding, few will wish to hire boats or frequent cafes).

For the above reasons no quantification of the tangible damages at the Frothy Coffee Café has been attempted.

8.1.2 Road Levels

The detailed survey also included all roads with levels below 4 mAHD. A summary of this information is provided on Figure 13. This shows that the lowest road levels from Tarbuck to Smiths Lake along The Lakes Way is 2.5 to 3 mAHD with the majority greater than 3 mAHD.

8.1.3 Other Affected Land Users on the Floodplain

The significant other affected land users in the floodplain are:

- the Sandbar and Bushland Caravan Parks near Cellito Beach,
- the university research station on the southern shore,
- the golf course near Cellito Beach.

The degree of affectation caused by flooding of these sites will depend upon a number of factors (similar to those for the Frothy Coffee Café). Probably the most significant of users are the two caravan/camping parks. As shown on Figure 8b the lower sites were inundated in the November 2006 event. However as far as we are aware no vans or other residences were inundated above floor level. It should be noted that this situation may be different if a similar event occurred during the holiday season. Although, given that there is a few hours of warning and residents will note the lake level rising, it should be possible to safely move vans and tents to high ground.

8.2 Intangible Flood Damages

The intangible damages associated with flooding are inherently more difficult to estimate. In addition to property damage (internal, external and structural) additional costs/damages are incurred by residents affected by flooding, such as stress, risk/loss to life, injury etc.

In many flood liable communities the magnitude of intangible flood may exceed the tangible damages. At Smiths Lake this is unlikely to be the case due to the relatively slow rate of rise of the lake and the acceptance by the community that lake levels will rise until the entrance is opened to release the floodwaters.

9. ACKNOWLEDGMENTS

This study was carried out by Webb, McKeown & Associates Pty Ltd and funded by Great Lakes Council and the Department of Environment and Climate Change. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Great Lakes Council,
- Department of Environment and Climate Change,
- Floodplain Management Committee,
- Residents of the Smiths Lake catchment.

10. REFERENCES

1. Great Lakes Council
Smiths Lake Estuary Processes Study
Webb, McKeown & Associates, April 1998.

2. Great Lakes Council
Smiths Lake Estuary Management Study and Management Plan
Webb, McKeown & Associates, May 2001.

3. Great Lakes Council
Smiths Lakes Planning Study
WBM Oceanics, 2000.

4. Pilgrim, D H (Editor in Chief)
Australian Rainfall and Runoff - A Guide to Flood Estimation
Institution of Engineers, Australia, 1987.

5. Boyd, M J, Pilgrim, D H and Cordery, I
A Watershed Bounded Network Model for Flood Estimation - Computer Programmes and User Code
Report No. 154, Water Research Laboratory, University of New South Wales, 1979.

6. Haskoning/Delft Engineering Software
RUBICON System Documentation
November 1986.

7. Goyen, A G and Aitken, A P
A Regional Stormwater Drainage Model
Hydrology Symposium, 1976.

8. Laurenson, E M and Mein, R G
RORB Version 4, Runoff Routing Program, User Manual
Monash University, May 1988.

9. Great Lakes Council
Wallis Lake Floodplain Risk Management Study
Webb, McKeown & Associates, Draft Report, 2007.

10. Public Works
Forster/Tuncurry Flood Study
Public Works, September 1989.

11. Gosford City Council
Broken Bay Beaches - Coastal Processes Study
Patterson Britton & Partners, May 1998

12. Department of Infrastructure Planning and Natural Resources
Draft Guideline No 5 - Ocean Boundary Conditions
March 2004