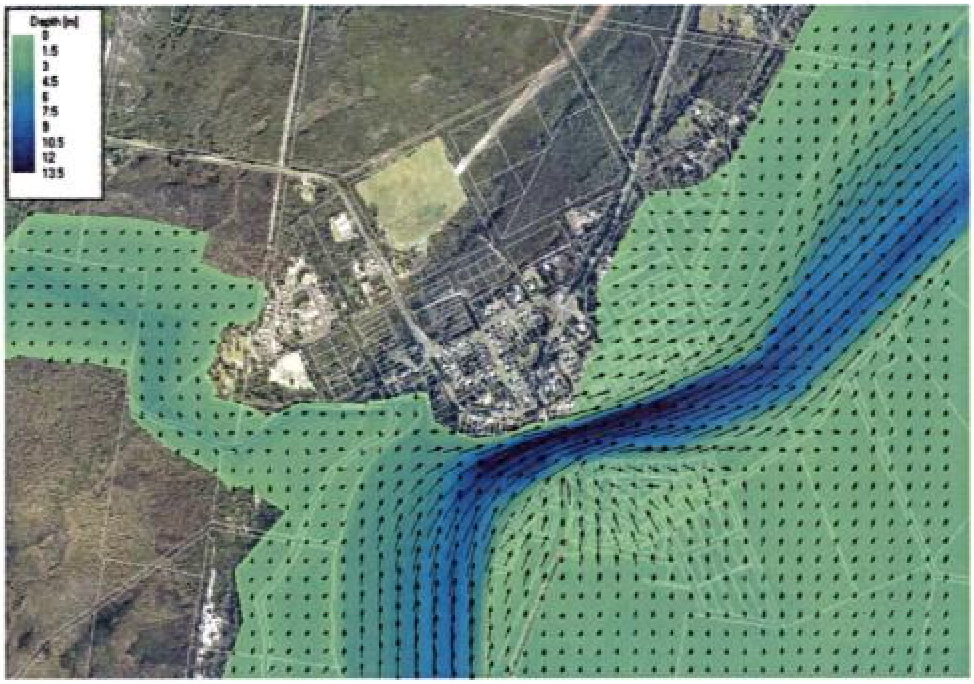
BALLINA SHIRE COUNCIL

WARDELL & CABBAGE TREE ISLAND FLOOD STUDY



Issue No. 3
OCTOBER 2004

Patterson Britton
& Partners Pty Ltd
consulting engineers

BALLINA SHIRE COUNCIL

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1 INTRODUCTION

Wardell is a small town on the North Coast of New South Wales that is located on the banks of the Richmond River about 15 kilometres upstream from Ballina (*refer* **Figure 1**). The town has a population of about 500 and includes a mixture of commercial, industrial and residential precincts. Development has occurred along both sides of the river, although the extent of development along the southern bank is more recent and less extensive.

As shown in **Figure 2**, Wardell is located on the northern bank of the river north from Bingal Creek. The smaller urban area on the south-eastern bank of the Richmond River is known as East Wardell. East Wardell and Wardell are connected by the Pacific Highway bridge crossing of the Richmond River. Due to their proximity to the river, parts of both Wardell and East Wardell are susceptible to flooding.

Cabbage Tree Island is located further upstream along the Richmond River, approximately midway between Wardell and the village of Broadwater (*refer* **Figure 2**). The Island has been inhabited by the Jali Aboriginal community for many years and contains a number of residential properties, an historic primary school, a workshop and a range of buildings that are used for recreation, administration and health services. The current population of the Island is about 170.

The *'Ballina Floodplain Management Study'* (*1997*) considered flooding along the lower reaches of the Richmond River below Broadwater. Investigations undertaken for the study determined that floodwater depths of up to 2 metres and flow velocities of 0.8 m/s would occur across Cabbage Tree Island in floods of the magnitude of the 100 year recurrence event. As a comparison, the largest recorded flood occurred in February 1954 and is considered to be of a similar magnitude to the design 80 year recurrence event.

The 1997 report concluded that Cabbage Tree Island would be designated as a high hazard floodway during a 100 year recurrence flood.

However, the *Ballina Floodplain Management Study* (*BFMS*) primarily focuses on areas downstream of Pimlico Island (*refer* **Figure 2**). Only "broad scale" flood characteristics are defined in the report for areas around Wardell and Cabbage Tree Island.

In recent years, applications for development at Wardell and Cabbage Tree Island have been assessed on an individual basis with reference to Council's *Flood Policy*. Council's *Flood Policy* requires, among other things, that:

§ minimum fill levels be based on the design 100 year recurrence flood level; and,

§ that minimum floor levels be based on the minimum fill level plus a freeboard of 300 mm in low hazard areas and 500 mm in high hazard areas.

As a result, development within the floodplain requires the site on which development is proposed to be filled to specified elevations. However, Council believes that a more strategic approach could be developed and implemented.

Accordingly, Council decided to proceed with the development of Floodplain Risk Management Plans for both Cabbage Tree Island and the village of Wardell.

In accordance with procedures outlined in the NSW Government's *'Floodplain Management Manual'* (*2001*), Council commissioned Patterson Britton & Partners to undertake a Floodplain Management Study for the region, with a view to developing separate Floodplain Risk Management Plans for each urban area.

As outlined above, a number of flood studies have previously been undertaken for the Lower Richmond River. However, the information presented in these previous flood studies only provides "broad scale" flood data. A detailed analysis of flood behaviour through the village of Wardell or across Cabbage Tree Island was not undertaken.

Therefore, the first step toward developing the Floodplain Risk Management Plans involved the preparation of a Local Flood Study. The primary objective of the Local Flood Study is to define flood behaviour and to produce information on flood flows, velocities, levels and flood extents, for a range of flood events, under existing floodplain and catchment conditions. This will provide Council with definitive information on the characteristics of flooding along the Richmond River between Broadwater and Wardell. This information will then allow Council to undertake more informed decision-making and emergency response planning.

This Local Flood Study Report documents the findings of investigations undertaken to better define flood behaviour across Cabbage Tree Island and in the vicinity of Wardell. It is a more detailed Flood Study for these areas and will serve as the basis for assessing flood damage reduction measures and making planning decisions. The assessment of flood damage reduction measures and the consideration of flood management options for the area will be considered separately through the development of a Floodplain Risk Management Plan for each area.

2 FLOODING ISSUES

2.1 STUDY AREA

The Richmond River is a relatively large coastal river that drains a catchment of about 6900 km^2 in northern New South Wales. It rises in the McPherson Ranges near the Queensland-NSW border, and flows in a southerly direction to Casino. Below Casino, the river flows in a south-easterly direction to its confluence with the Wilson River near Coraki (*refer* **Figure 1**). Downstream of Coraki, the river is joined by Bungawalbyn Creek and continues in a south-easterly direction to Woodburn.

At Woodburn, the Richmond River changes course and flows in a north-easterly direction toward Ballina where it discharges to the ocean. Between Woodburn and Ballina, the river follows an alignment parallel to the coastline (*refer* **Figure 1**).

In its lower reaches, the Richmond River passes the villages of Woodburn, Broadwater and Wardell. A number of islands are also located within this section of the river, including Cabbage Tree Island, which is located midway between Broadwater and Wardell (*refer* **Figure 2**).

The area of interest for this Flood Study is highlighted in **Figure 2**. It extends from the small village of Broadwater to downstream of Pimlico Island, which is near the confluence of the Richmond River and Empire Vale Creek. The floodplain in this area is generally flat with ground levels typically varying between 2 and 8 metres above mean sea level (*MSL*).

Notwithstanding, the topography gradually rises to the west and to the north of Wardell. East Wardell is located on a low lying section of the floodplain with typical ground elevations that are about 2 metres above sea level.

2.2 ISSUES

2.2.1 Cabbage Tree Island

Cabbage Tree Island is susceptible to flooding from the Richmond River during relatively frequent floods. The February 1954 flood is the highest flood recorded at the Island. It reached a peak elevation of 3.1 mAHD and resulted in floodwater depths in the village area of up to 1.5 metres.

Previous studies determined that sections of Cabbage Tree Island would be inundated during floods rarer than the 10 year recurrence event. Modelling undertaken for the *'Ballina Floodplain Management Study'* (*1997*) determined that a 10 year recurrence flood in the Richmond River would reach a peak elevation of 2.1 mAHD at Cabbage Tree Island.

Council has undertaken floor level surveys for dwellings and buildings located on the Island. A total of 32 properties were surveyed and all are predicted to be inundated to above their ground floor level in events rarer than the 10 year recurrence flood (*BFMS, 1997*).

However, it should be mentioned that most buildings are two-storey and have their primary living areas raised to above the 100 year recurrence flood level.

The 1997 Study determined that in the context of the NSW Government's *Flood Prone Lands Policy*, the Island should be categorised as a high hazard floodway. The NSW Government's *Floodplain Management Manual* (*2001*) recommends against development within areas defined as high hazard floodways.

Council understands that, as it is the consent authority for the determination of development applications relating to the Island, it may only receive an indemnification against loss or damage resulting from flooding if it has acted in a manner consistent with the provisions of the *Floodplain Management Manual*. Accordingly, Council is proceeding with the development of a Floodplain Risk Management Plan for the Island.

Notwithstanding, there continues to be State Government pressure for further development on Cabbage Tree Island. There have been at least two new dwellings constructed in the village area of the island since publication of the 1997 Report (***pers. comm., Mr Peter*** *O'Keefe, 2004*). Continued development has occurred because the Jali Aboriginal community who reside there, maintain a cultural link to the Island. This cultural link is extremely important to them and the option of relocation of the community due to the flood risk is not well regarded.

Hence, the major issue confronting the community, Council and the State Government, is one of determining an acceptable mechanism for managing the flood risk to which residents of the Island may be exposed. In this regard, it is possible for residents to continue to live on the Island, but this should not be accepted as a fait–a-complie, and other options should be seriously considered. If retention of the village is adopted, it will be necessary to develop and implement a robust flood emergency response strategy for the community.

In recognition of this, the only access to Cabbage Tree Island is via a bridge on the western side of the Island. The bridge connects the Island to Back Channel Road, which runs parallel to the western bank of the Richmond River and effectively links the Island to Wardell (*refer* **Figure 2**). The deck of the bridge has a typical elevation of 3.1 mAHD and Back Channel Road varies in elevation between 1.3 and 2.4 mAHD.

As outlined above, the predicted peak level of the 10 year recurrence flood in the vicinity of the Island is about 2.1 mAHD. Therefore, it is likely that Back Channel Road will be cut by floodwaters once flood levels in the Richmond River reach predicted peak levels for events of the magnitude of the 10 year recurrence flood.

Accordingly, Council is concerned that as floodwaters rise and begin to inundate the Island, there will be no flood free vehicular route available for evacuation.

2.2.2 Wardell and East Wardell

Most of the village of Wardell is located on relatively high ground and is not typically affected by floods. The 1997 Report determined the 100 year recurrence flood level at Wardell (*downstream of the Pacific Highway Bridge*) to be 3.0 mAHD. The 10 year recurrence flood level was estimated to be 1.8 mAHD. Most of the village is above the 4 metre contour and therefore does not experience flooding.

However, the area downstream of Wardell Bridge and east of the Pacific Highway does experience flooding (*refer* **Figure 2**), even in moderate events. Properties that front the river along Richmond Street, as well as those along Fitzroy, Sinclair, Swamp and Wilson Streets, can be inundated when floodwaters either overtop the banks of the river or "back-up" along stormwater pipes.

East Wardell is also susceptible to flooding. It is located on the eastern floodplain of the Richmond River opposite Wardell on land that is typically below the 3 metre contour. The majority of the urban areas of East Wardell would be inundated in events of the magnitude of the 10 year recurrence flood. All areas except a short section of the Pacific Highway are predicted to be inundated in the 100 year recurrence flood.

Fifty dwellings are located at East Wardell. Of these about 13 are susceptible to inundation in floods of the magnitude of the design 100 year recurrence flood (*i.e., peak level of about 3.0 mAHD*).

Increasing demand for development in the village and at East Wardell has led Council to be concerned about urban expansion and the applicability of its existing *Flood Policy*. The existing policy in flood prone areas is defined in *Policy Statement No.11 – Flood Levels* of Council's Development Control Plan No.1 – Urban Land. This addresses *the filling of sites in flood prone areas* and states the following:

- minimum fill levels for areas within the study area covered by the *Ballina Floodplain Management Study* (*1997*) (*BFMS*) are to be based on the design 100 year recurrence flood level;
- minimum floor levels are to be based on the minimum fill level plus a freeboard of 300 mm in flood prone areas within the study area of the BMFS (*1997*).
- minimum fill levels are to be 300 mm above the highest recorded flood level for flood prone areas outside of the study area covered by the BFMS (*1997*); and,
- minimum floor levels are to be 600 mm above the highest recorded flood level for flood prone areas outside of the study area of the BFMS (*1997*).

Council now wishes to determine whether there are options available to allow the development of land that is currently zoned residential, commercial or industrial, but which is below the minimum fill level.

3 REVIEW OF AVAILABLE INFORMATION

3.1 PREVIOUS STUDIES

3.1.1 Ballina Floodplain Management Study (1997)

Synopsis

The *'Ballina Floodplain Management Study'* (*1997*) addresses flooding issues upstream along the Richmond River to Broadwater (*refer* **Figure 1**). The study aimed to define existing flood behaviour, establish baseline floodplain management information and document the findings of investigations into the impact on flooding of proposals for development in the vicinity of Ballina.

As part of the study, a tidal hydraulic model was set up for the tidal reaches of the Richmond River and its tributaries. The model was developed using the ESTRY software and was based on a range of survey data, including:

- bed profiles obtained from ADCP measurements undertaken by Manly Hydraulics Laboratory in November 1994;
- cross-sections of the Richmond River obtained by the NSW Public Works Department in 1980; and,
- cross-sections of Fishery Creek and North Creek Canal, which were gathered by Ballina Shire Council specifically for the study.

The tidal model was calibrated to water levels and discharges collected over a tidal cycle in November 1994 (*Manly Hydraulics Laboratory, 1995*). Data recorded at 17 water level sites and 8 discharge sites was used to calibrate the tidal hydraulic model. Calibration was achieved by adopting a Manning's *n* roughness value of 0.022 for all sections of the channel.

The tidal model established the in-bank hydraulic capacity of the tidal rivers and creeks, providing a base from which to develop a flood model.

The flood model was developed to cover the channel and floodplain of the lower Richmond River upstream to Broadwater. It was calibrated to measurements recorded during major flooding that occurred in March 1974 and February 1976. Flood level boundary conditions were input to the upstream end of the model in the Richmond River at Broadwater and in Tuckean Broadwater at Bagotville Barrage.

Although peak water level data was recorded for the 1954 flood (*largest flood on record*), no detailed rainfall or time varying water level data was available for use as model boundary conditions. Hence, calibration of the ESTRY flood model to the February 1954 flood was not undertaken.

Bagotville Barrage, which was constructed in 1966, has little influence on Richmond River flows during significant flood events. The structure was designed as a tidal barrage and therefore only controls tidal propagation and minor flood flows (*BFMS, 1997*).

Manning's *n* values for floodplain regions varied depending on the vegetation type. The values listed in **Table 1** were adopted.

Table 1 MANNING'S 'n' VALUES ADOPTED IN ESTRY MODEL

VEGETATION TYPE	MANNING'S 'n' VALUE
Township Areas	0.04
Lightly vegetated fields	0.06
Mature Sugar Cane	0.15
Dense Swamp Vegetation	0.20

Flooding of the lower Richmond River region was determined to originate from three major sources:

- Richmond River flood: overtopping of the Richmond River caused by rainfall over the Richmond River catchment.
- Local catchment flood: localised rainfall swelling local creeks and floodplains such as Maguires, Emigrant and North Creeks, which are located north and west of Ballina.
- Ocean storm tide: elevated ocean levels caused by low depressions (*barometric setup*), strong onshore winds (*wind setup*) and storm wave conditions (*wave setup*). The peak ocean elevated levels were determined to be 1.7 , 1.8 and 2.0 for the 10, 20 and 100 year recurrence events, respectively (*BFMS, 1997*). Anticipated sea level rise due to the Greenhouse Effect was not considered (*except in sensitivity analyses*).

In reality, flooding could occur from any combination of these sources. However, a manageable combination of events was assumed for the purposes of the study.

If each flood source (*determined independently*) has a 100 year recurrence interval (*for example*), the probability of all three of these flood sources occurring simultaneously is significantly lower. However, it would be expected that each flood source would not occur in isolation.

Hence, for each design flood, one of the three flood sources above was assumed to dominate with the two non-dominant sources modelled with a lower 10 year annual recurrence interval. This was repeated such that each source was in turn dominant and the other two sources non-dominant. The design flood was taken as the maximum of the three simulated single source dominated floods and the values derived are shown in **Table 2**.

For example, the 100 year flood that is used to set habitable floor levels in the region, was assumed to be the maximum of:

- a 100 year Richmond River flood, combined with a 100 year 72 hour local catchment flood occurring coincident with a 10 year recurrence ocean storm tide;
- a 10 year Richmond River flood, combined with a 100 year 12 hour local catchment flood (*critical duration, yielding the highest flood levels*) occurring coincident with a 10 year recurrence ocean storm tide; or,
- a 10 year Richmond River flood, combined with a 10 year 12 hour local catchment flood occurring coincident with a 100 year recurrence ocean storm tide.

It is also highly unlikely that all three sources would peak together. The timing of the flood peak at Broadwater was assumed to be 3 days after peak elevated ocean conditions are predicted to occur. The local rainfall peak was assumed to coincide with the peak elevated ocean conditions.

Design flood levels at Broadwater were determined based on flood frequency analysis of peak recorded levels at Broadwater Sugar Mill, for which records have been kept since 1917. For Bagotville Barrage, design flood levels were simply assumed to be an addition to the Broadwater flood level. This addition varied linearly from zero below a level of 2.0 mAHD, up to 0.4 metres for the 100 year recurrence event.

For the extreme event, a peak discharge of 8000m^3/s was assumed in the Richmond River downstream of Broadwater. About 5000 m^3/s of this flow was assumed to originate from the Richmond River itself, with the residual 3000m^3/s emanating from Tuckean Swamp.

Local catchment flooding was determined using hydrologic (*catchment runoff*) models for the catchments of Maguires Creek (*above Teven*), Emigrant Creek (*above Tintenbar*), North Creek (*several kilometres above Martins Lane*), and other minor creeks (*including Duck and Chilcotts Creek*). The RAFTS-XP software was used to develop the models.

Streamflow data for calibration of the hydrologic models was only available at one location along Maguires Creek (*near Teven*). The available data extended from 1973 to 1993 but was considered to be based on a rating curve of questionable accuracy. Based on a (*conservative*) calibration of the Maguires Creek catchment, similar catchment coefficients were applied to the other catchments in the study area.

Conclusions of Relevance to this Study

The peak flood levels listed in **Table 2** were determined from the investigations and one-dimensional hydraulic modelling undertaken for the 1997 Report.

It should be noted that the recorded peak flood level at Broadwater in the 1974 flood was 3.25 mAHD, whereas in 1976 the recorded peak flood level was only 1.7 mAHD. At Bagotville Barrage, the peak flood level during the 1974 flood was 3.63 mAHD.
The approximate extent of areas of high hazard was also determined as part of investigations undertaken for the 1997 Report. Cabbage Tree Island and sections of Wardell were determined to be areas of high provisional flood hazard.

Table 2 EXISTING DESIGN FLOOD LEVELS

LOCATION	DESIGN FLOOD LEVEL (m AHD)			
	10 year	20 year	100 year	Extreme
Downstream of Pimlico Island	1.57	1.77	2.48	4.13
Downstream of Wardell Bridge	1.80	2.12	3.00	4.87
Upstream of Wardell Bridge	1.90	2.27	3.24	5.25
Cabbage Tree Island (bridge)	2.06	2.46	3.44	5.47
Broadwater	2.28	2.76	3.84	6.12
Bagotville Barrage	2.38	2.96	4.24	6.46

As discussed in **Section 2**, the report recommended that Ballina Shire Council adopt the 100 year design flood as the flood selected for planning and floodplain management activities. This recommendation was based on consideration of social, economic and ecological issues, as well as the flooding characteristics determined as part of the investigation.

It was therefore recommended that Council's *Flood Policy* be revised to specify that:

- minimum fill levels are to be based on the 100 year design flood level;
- minimum floor levels are to be based on the minimum fill level plus a freeboard of 300 mm in low hazard areas and 500 mm in high hazard areas;
- major developments (*such as residential subdivisions*) in low hazard areas require a separate and specific flood investigation as per the requirements of the then *Floodplain Development Manual* (*1986*);
- all developments in high hazard areas be avoided except in special circumstances, in which case a flood investigation is required.

The Wardell region is predicted to have about two (*2*) days warning time before being inundated by floodwaters. Flood warnings in the area are typically issued by the Bureau of Meteorology and generally broadcast by the State Emergency Service. The 1997 Report considered this to be ample time to warn and evacuate communities in the lower Richmond River.

3.1.2 Mid Richmond Flood Study (1999)

Synopsis

The *'Mid Richmond Flood Study'* was published in 1999 for a range of local government agencies. The Study generally focussed on detailing flood behaviour along the Richmond River upstream of Wardell to Coraki. The term "Mid Richmond" describes the extensive floodplain basin that extends from a natural constriction in the river and floodplain at Broadwater, upstream as far as Coraki.

A hydrologic model was developed as part of the study to simulate catchment rainfall-runoff processes. The hydrologic model was used to generate river flows for use in a hydraulic model. The hydraulic model was developed using the MIKE-11 software and extends from the ocean at Ballina to upstream of Casino.

Both the hydrologic model and the hydraulic model were calibrated to the historical floods of March 1974 and April 1988, and were verified to the floods of February 1954 and March 1987. A Manning's *n* value of 0.022 was adopted for most of the length of the channel downstream of Bungawalbyn Creek. Manning's *n* values for floodplain regions varied depending on the vegetation type similar, but the finally adopted values were similar to those used in the modelling undertaken for the 1997 Report. An *n* value of 0.05 was used for open fields, 0.10 to 0.12 for bushland areas and 0.15 for areas of mature sugar cane.

Conclusions of Relevance to this Study

Flooding in the Mid-Richmond is dominated by flows carried by the three major tributaries which are the Richmond and Wilsons Rivers, and Bungawalbyn Creek. Design flood levels determined for lower reaches of the study area near Wardell and Cabbage Tree Island are listed in **Table 3**.

Table 3 DESIGN FLOOD LEVELS FROM MID RICHMOND FLOOD STUDY

LOCATION	DESIGN FLOOD LEVEL (mAHD)			
	10 year	20 year	100 year	Extreme
Wardell (river)	1.85	2.19	3.10	6.12
Broadwater (floodplain)	2.35	2.48	3.77	7.03
Broadwater (river)	2.39	2.84	3.80	7.04
Bagotville Barrage (floodplain)	2.49	3.17	4.21	7.54

It should be noted that estimates of peak flood level for the extreme event are significantly higher than those presented in **Table 2** for the 1997 Report. For example, at Wardell, the estimated extreme flood level is about 1.1 metres higher.

3.1.3 Review of Ballina Flooding Assessments

In 1999, Lawson and Treloar Pty Ltd reviewed four flood assessments undertaken by WBM Oceanics in the Ballina Shire LGA. These had been undertaken after completion of the *Ballina Floodplain Management Study* in 1997. The proposed development sites were located in Ballina and in floodplain areas to the north and west.

Each of the assessments was used to assist in rezoning submissions, for which filling was proposed according to (*and in some cases beyond*) Scenario 3E of the *'Ballina Floodplain Management Study'* (*1997*). A number of objections to the floodplain filling were received by Ballina Shire Council from concerned residents.

A fifth flood assessment was also reviewed. This was undertaken by WBM for Connell Wagner as part of the finalisation of the preferred bypass route around Ballina for the Pacific Highway. All assessments assumed that local catchment flooding was dominant.

All flooding assessments utilised the ESTRY model which was refined as necessary in each case. The ESTRY model is a one dimensional model with the floodplain represented as a series of interconnected storage nodes and storage versus height relationships defined from limited topographic information. Storage nodes are interconnected by flow path channels represented by a single typical cross section.

Lawson and Treloar Pty Ltd (*1999*) noted the reliance of the ESTRY model on the assumed flow paths that were interconnected to approximate two dimensional flow. They concluded that two dimensional modelling using boundary conditions derived from the existing ESTRY model, would be required for more detailed assessments of flood impacts associated with development proposals.
Lawson and Treloar Pty Ltd (*1999*) also reviewed the *'Ballina Floodplain Management Study'* (*1997*). They noted that only modest topographic coverage of the floodplain was used in some sections of the ESTRY model and recommended that more detailed topographic data be obtained for future flood modelling in the area.

On this basis, it can be concluded that the independent investigations undertaken by Lawson & Treloar Pty Ltd, determined that more detailed topographic data should be obtained (*e.g., from photogrammetric low level surveys*) and two-dimensional modelling should be undertaken, especially when considering localised flooding issues.

3.2 AVAILABLE TOPOGRAPHIC AND HYDROGRAPHIC DATA

All available survey data along the lower Richmond River was compiled as part of the data collection and review phase for this project. This involved the review of a database of topographic and hydrographic surveys of NSW coastal streams held by the Department of Commerce (*formerly the Department of Public Works and Services*).

A range of relevant surveys was viewed at the Sydney offices of the Department of Commerce and hard copies of those plans considered to provide useful data for the study were obtained. These plans include river cross-sections, channel shoaling soundings and some floodplain cross-sections.

Unfortunately, the extent of reliable existing survey data was generally limited to the cross-sections of the river which were gathered as part of a hydrosurvey undertaken by PWD in 1980. The alignment of those river cross-sections that were surveyed as part of the hydrosurvey are shown in **Figure 3**. Plots of the cross-section profiles are included in **Appendix A**.

In addition to this data, there is 1:25000 series topographic mapping showing contours of the natural surface of the floodplain of the lower Richmond River. Plans covering the study area include:

- Empire Vale 9640-3-S;
- Wardell 9540-2-S; and,
- Woodburn 9539-1-N.

However, these plans only show contours of natural surface at 10 metre intervals. As determined from previous investigations, flooding in the study area is likely to result in peak flood levels that are lower than 10 metres above Australian Height Datum (*ie., 10 metres above mean sea level*). For example, the predicted peak level of the Probable Maximum Flood is about 7 mAHD.

Therefore, the 1:25,000 series topographic mapping of the floodplain is of limited value. It only defines the likely lateral extent of the floodplain and does not provide any insight into local topographic features below the 10 metre contour. Based on the PMF level of 7 mAHD, topographic features between the 2 and 6 metre contour are most likely to influence or control flooding patterns downstream from Broadwater.

3.3 PROPERTY SURVEYS

Ballina Shire Council has undertaken a survey of potentially flood liable properties at both Wardell and Cabbage Tree Island. The information collected includes location co-ordinates, floor and ground levels for each building, and a comprehensive description of the property.

A summary of the property survey data available for Wardell and Cabbage Tree Island is included in **Appendix B**.

3.4 HISTORICAL FLOOD DATA

Flood level data for the February 1954 flood was provided on plans supplied by Ballina Shire Council (*1983*). The location of flood marks recorded for this event and the corresponding peak flood level are presented in **Figure 4**.

Details of historical flood marks and associated peak levels were also extracted from reports documenting previous investigations, including the 1997 and 1999 Reports.

Unfortunately, this only uncovered a limited number of historical flood marks within the study area for the March 1974 and 1976 floods. These flood marks relate to gauge records at the Broadwater Sugar Mill and at the downstream side of the Pacific Highway crossing of the Richmond River at Wardell. The locations of each of the flood marks are shown in **Figure 4**.

4 STUDY METHODOLOGY

4.1 PURPOSE OF INVESTIGATIONS UNDERTAKEN FOR THIS REPORT

One of the conclusions drawn from reviews of the previous investigations undertaken into flooding in the lower Richmond River (*refer* **Section 3.1.3**) was that the modelling completed for the previous investigations was based on only "modest topographic coverage of the floodplain". It was recommended that detailed information defining the topography of the floodplain be obtained, especially when considering localised flooding issues.

This infers that the existing ESTRY and MIKE-11 models of the lower Richmond River are at best broad scale models and are not suitable in their current form, for the assessment of localised and detailed flooding problems.

The issues confronting the management of flooding and development at both Wardell and Cabbage Tree Island, are intrinsically "localised flooding problems". Accordingly, and following on from the recommendations arising from the review of the 1997 and 1999 Reports, investigations into the impact of flooding on communities at these locations need to be based on more detailed topographic data and flood analysis.

In recognition of this, a methodology was developed to firstly obtain additional and more detailed survey data, and secondly to use this data to more reliably model flood behaviour in the vicinity of both Wardell and Cabbage Tree Island. A brief overview of that methodology is outlined in the following sections.

4.2 METHODOLOGY

4.2.1 Additional Data Collection

As inferred above and detailed in **Section 3.2**, the existing data defining the bathymetry of the lower Richmond River and topography of the adjoining floodplain is of limited value to a detailed investigation of flood behaviour. Existing 1:25,000 topographic mapping identifies the 10 mAHD contour as the minimum contoured level across the study area. This study is interested in levels below the 8 metre contour.

Therefore, in consultation with the Technical Sub-Committee, it was determined that extensive additional topographic data needed to be obtained to ensure that modelling for the project could meet the study objectives.

A brief was prepared outlining the requirements for the definition of ground level data from photogrammetry. Subsequently, Southern Aerial Surveys Pty Ltd (*now AAM Hatch*) was engaged to fly the area and develop contour mapping and a digital terrain model.

Additional hydrosurvey of the Richmond River was also undertaken to complement the cross-sections available from the survey carried out by PWD in 1980.

The additional survey data was obtained during 2002/03 and was subsequently processed to develop a detailed digital terrain model of the floodplain between Broadwater and Pimilico Island. The additional hydrosurvey was also gathered during this period and processed separately for use in the flood investigation.

The additional data was combined with that which existed prior to commencement of the project. A summary of the full data-set is shown in **Figure 5**. Detailed contour mapping of the Study Area developed from the digital elevation model (*DEM*) generated from the full data-set, is shown in **Figure 6**.

4.2.2 Computer Modelling

The methodology employed to use the additional data to better define flood behaviour between Broadwater and Wardell, was based on the development of a two-dimensional computer model of the river and its floodplain. All previous investigations, including those undertaken for the 1997 and 1999 Reports, were based on one-dimensional modelling of the river. Overbank flows were simulated as a series of branches within the one-dimensional model.

The two-dimensional model was developed using the RMA-2 software package. RMA-2 is a fully two dimensional finite element model developed by Resource Management Associates (*RMA*) of the USA and Prof. Ian King of the University of NSW. It uses finite element methods to solve 2D depth averaged equations for turbulent energy losses, friction losses and horizontal momentum transfer, and offers significant benefits over the more traditional finite difference techniques such as MIKE-21 and *TuFlows*.

The primary benefit of RMA-2 is that it can be applied with a variable grid geometry employing elements with irregular and curved boundaries which can be modified as required without the need for regeneration of the entire grid. This capability allows any shaped boundary to be modelled exactly.

RMA-2 has the capacity for the degree of discretisation of the model network to be varied across the model domain. As a result, detailed features such as levees or irregular stream boundaries can be matched in the model network as required.

Accordingly, a more detailed definition of the floodplain can be incorporated than is the case with 1D models. Finite element nodes can be placed at any location and spacing, and thereby can match locally important features. This flexibility is particularly advantageous in defining flow paths in irregular floodplain areas such as encountered across Cabbage Tree Island and around Wardell.

In addition, RMA-2 is particularly adaptable to the simulation of wetting and drying of swamp and mudflat areas, as occurs in estuaries during tidal cycles, and across floodplains when floodwaters overtop river banks. This capacity ensures that the interaction between mainstream and overbank flows is reliably modelled and that changes in flow paths arising from modifications to floodplain features or structures can be identified.

The topographic data obtained for the project was used to develop an RMA-2 model of the lower Richmond River and its floodplain. The area covered by the model is identified in **Figure 2**.

Upstream and downstream boundary conditions were developed from the results derived by the ESTRY modelling that had been undertaken for the 1997 Report. The upstream boundary conditions comprised discharge hydrographs taken from the ESTRY model output at a point near Broadwater. The downstream boundary condition comprised time-varying water levels for each flood frequency, taken at a point near Pimilico Island.

In effect, the RMA-2 model was "nested" within the existing ESTRY model of the lower Richmond River.

The RMA-2 model was initially calibrated to the water surface profile generated from the ESTRY modelling undertaken for the 1997 Report. However, further calibration was required to be undertaken to match recorded flood levels at Broadwater and Wardell.

The calibrated RMA-2 model was then used to simulate flow behaviour during flooding of the lower Richmond River and its floodplain, and thereby produce flood levels and flow velocities at selected points of interest.

5 HYDRODYNAMIC MODEL DEVELOPMENT

5.1 MODEL DEVELOPMENT

As outlined in **Section 4**, the RMA-2 software was used to develop a two-dimensional model of the lower Richmond River and its floodplain between Broadwater and Pimlico Island. RMA-2 is a fully two dimensional finite element model developed by Resource Management Associates of the USA and Prof. Ian King of the University of NSW.

RMA-2 was chosen for this investigation because it has the following attributes:

- it allows for the lateral distribution of flow as it moves downstream along a river system, and thereby ensures reliable distribution of flow to floodplain areas;
- it uses finite element methods to solve 2D depth averaged equations for turbulent energy losses, friction losses and horizontal momentum transfer, and therefore offers significant benefits over the more traditional finite difference modelling techniques;
- it can be applied using a variable grid geometry employing elements with irregular and curved boundaries which can be modified as required without the need for regeneration of the entire grid; and,
- it permits the simulation of systems that flood and dry during the analysis period.

5.1.1 Network Development

The RMA-2 model was developed with reference to aerial photography of the study area and the digital elevation model (*DEM*) created from the additional survey data. The river cross-sections gathered by hydrosurvey were also used to “build” the network.

The adopted model network is shown in **Figure** 7 and extends along the Richmond River from Broadwater to Empire Vale Creek. The 10 metre contour approximately defines the lateral extent of the model network. The model network also extends along Tuckean Broadwater upstream to Bagotville Barrage.

River and creek channels were simulated in the model using a minimum of 4 rectangular finite elements. That is, two elements placed side by side were assumed to represent the bed of the stream, with the other two elements adjacent to these representing the banks. Cross-sections from the hydrosurvey were used to define the elevations adopted at the corner nodes of each of the river channel elements. The finite element network was aligned with the surveyed cross-sections of the Richmond River to enable flood heights and velocities to be easily related back to the location of these cross-sections.

The size and location of elements for floodplain areas was based on the degree of variation of topography and the level of detail likely to be required to achieve the study objectives. For example, greater numbers of elements were used to define the topography of Cabbage Tree Island and Wardell Village than were used to represent the eastern floodplain of the Richmond River adjacent to the coastline (*refer density of elements in* **Figure 7**).

The Pacific Highway was also incorporated within the model network by placing levee elements along its alignment. This ensures that the interaction between the river and the eastern floodplain is reliably modelled. The use of levee elements also allows the frequency of highway overtopping to be investigated and the significance of road upgrades on flood behaviour to be determined.

5.1.2 Channel and Floodplain Roughness

Main channel and overbank roughness values were determined for the study area by inspection of aerial and cross-section photographs and from field observations of the channel and floodplain vegetation density. The initial roughness values that were adopted were determined by comparing vegetation density observed in the field with standard photographic records of stream and floodplain condition for which Manning's 'n' values are documented in the literature.

The roughness parameters that were initially adopted for use in the RMA-2 model are listed in **Table 4**.

Table 4 INITIAL VALUES OF ROUGHNESS PARAMETERS USED IN RMA-2 MODEL

ELEMENT MATERIAL TYPE	EQUIVALENT MANNING'S 'n' ROUGHNESS VALUE
River of Creek Channel	0.02
Vegetated river banks	0.08
Floodplain Areas after harvesting of sugar cane	0.06
Floodplain Areas with mature sugar cane	0.14
Roadway	0.016
Urban Area with Standard Residential Dwellings on quarter acre blocks	0.02

5.1.3 Boundary Conditions

The determination of boundary conditions is an important aspect of the work due to the "nested" nature of the RMA-2 model within the more extensive ESTRY model of the lower Richmond River.

Boundary conditions are required for the RMA-2 model at the upstream ends near Broadwater on the Richmond River, and at Bagotville Barrage within Tuckean Broadwater. Boundary conditions are also required at the downstream end of the model near Pimlico Island.

In all cases, the initial boundary condition data was obtained from the results of the one-dimensional modelling of the lower Richmond River that was undertaken for the *'Ballina Floodplain Management Study'* (*1997*). The boundary condition data was extracted directly from ESTRY model results files supplied by WBM Oceanics, who authored the 1997 Report.

Downstream Boundary Conditions

A time varying stage-hydrograph was adopted as the downstream boundary condition for all simulations (*ie., calibration and design*). The stage-hydrograph was based on values of water level versus time extracted from the ESTRY modelling results for ESTRY model node 15. Node 15 corresponds to the downstream side of Pimlico Island, which is the downstream extent of the RMA-2 model.

Stage-hydrographs were extracted for each of the following:

- the March 1974 flood;
- the February 1976 flood;
- the design 5, 10, 20 and 100 year recurrence events; and,
- the Probable Maximum Flood (*PMF*).

Values for peak stage generated by the ESTRY model at Node 15, are included within **Appendix C** for each of the listed events.

As discussed in **Section 3.1**, there was not sufficient recorded data for the February 1954 flood to allow satisfactory calibration of the ESTRY model to this event *BFMS, 1997*). Therefore, without boundary condition data from the ESTRY model, it was not possible to calibrate the RMA-2 model developed for this investigation to the 1954 flood.

Upstream Boundary Conditions

Initially, the upstream extent of the RMA-2 model was chosen to coincide with the apparent narrowing in the floodplain immediately north of Broadwater and just downstream of the confluence of the Richmond River with Tuckean Broadwater. The location was chosen due to the natural constriction in the topography of the floodplain, which provides a good location for a flow boundary condition. This area of apparent narrowing of the floodplain corresponded to the location of ESTRY model Node 29.

Accordingly, flow data was extracted from the ESTRY model results files for Node 29 for the range of events listed above. This data was initially used to define boundary conditions for the upstream end of the model.

5.2 RMA-2 MODEL CALIBRATION

5.2.1 Calibration Process

The RMA-2 model that was initially developed only extended upstream to the “necking” in the floodplain near the confluence of the Richmond River with Tuckean Broadwater. This model extent was in accordance with the Study Brief and was determined based on providing a model that extended a sufficient distance upstream from the area of interest; i.e., Cabbage Tree Island.

However, attempts to calibrate the initial RMA-2 model to the flood profile generated by the ESTRY model proved unsatisfactory.

The calibration scenario profile generated by the RMA-2 model showed a steep rise in the water surface upstream of Goat Island and plateauing of the profile at the very upstream extent of the model. It was initially thought that this afflux was due to the two-dimensional model more reliably simulating flood behaviour in the vicinity of the two islands. However, Council requested that the issue be further investigated.

These investigations determined that the differences were also due to the raising of the Pacific Highway between Broadwater and Wardell that has occurred since 1995. Investigations showed that only a few small culverts had been incorporated within the road upgrading works and that the road raising had effectively "leveed" the right bank of the river in minor floods. That is, floodwaters carried by the channel can no longer be distributed to the right bank floodplain in the manner they had prior to upgrading of the Highway.

As a result, the RMA-2 model, which was based on data reflecting the raised Highway, determined higher flood levels along the Richmond River between Broadwater and Wardell for floods up to about a 10 year event.

Investigations were undertaken to determine the amount of flow that would be carried from the river to the right overbank floodplain via those culverts that had been installed as part of the road upgrade. It was determined that the total flow discharged via the culverts was less than 3% of the total river flow in a 100 year recurrence event, and less than 4% of the total river flow in a 10 year recurrence event.

On this basis, the original RMA-2 model correctly simulates contemporary flood behaviour. However, this clearly results in increased peak flood levels for some events, relative to the projections made by the ESTRY model. The ESTRY model was based on limited hydrographic and topographic survey data that pre-dates the Pacific Highway road upgrading works.

Due to the increase in peak flood levels, DIPNR and Council were of the view that a version of the RMA-2 model should be developed to reflect conditions that existed prior to the road raising. It was considered that this version of the RMA-2 model should be calibrated to recorded floodmarks obtained for floods that occurred in February of 1976 and March of 1974.

RMA-2 Model Calibration Scenario

The original RMA-2 model was modified by lowering of model node elevations along the alignment of the Pacific Highway to create a calibration scenario version of the model. The calibration scenario version of the model was based on the original model extent, which only extended upstream to Tuckean Broadwater.

Model parameters (*Manning's "n"*) were adjusted to obtain a "best fit" to match recorded flood levels and ESTRY model profiles for the 1976 and 1974 events. The "best-fit" was initially prepared to match the recorded flood levels and ESTRY model profile data for the 1974 flood. A good fit was able to be achieved, but the corresponding comparison with recorded and ESTRY model data for the 1976 flood was not as good.

The water surface profile generated for the 1976 event using the RMA-2 model was higher than the corresponding ESTRY model profile. In addition, the upstream projection of the profile recorded at the upstream end of the model suggested that the model would have generated a flood level at Broadwater that was substantially higher than a recorded flood mark for the 1976 flood.

In other words, the adjusted original RMA-2 model appeared to overestimate flood levels for the smaller floods such as the 1976 flood.

Despite many attempts, including adjustments to the model network and sensitivity testing of the model roughness coefficients, it was not possible to match the historic floodmarks using the discharge hydrographs extracted from the ESTRY model. The water surface profile for the 1976 event remained high.

In trying to lower the profile for the 1976 flood, the 1974 event would also be lowered, to the point where the quality of calibration for this event would suffer significantly. As a result, a more detailed investigation into the flow data used for model calibration was undertaken. A discussion of this investigation is provided in the following sections.

Comparison of RMA-2 Model Results with WBM ESTRY Model Results

The ESTRY model produced flood levels close to the recorded historic floodmarks for both calibration events. The ESTRY model has boundary conditions specified in the form of upstream and downstream flood levels for the Richmond River near Wardell, such as the floodmark data for the calibration events.

Accordingly, the modelled flood levels are naturally expected to fit very closely with the floodmark data. Flood discharge data created by the model is a result of model adjustment to fit the floodmarks.

The RMA-2 model uses this discharge data for input as an upstream boundary condition. The results from both models should coincide due to this common data, but the increased physical detail of the RMA-2 model network as compared with that of the ESTRY model may be the reason for the observed difference.

The calibration scenario profile generated by the RMA-2 model showed a steep rise in the water surface and plateauing of the profile at the very upstream extent of the model. The reason for this ‘lump’ in the profile was not clear.

It is also possible that the “blockage” to flow caused by Goat Island may adversely impact on the simulation of flood behaviour at the upstream end of the model, due primarily to the afflux caused by the island being in close proximity to the upstream end of the model.

Whether the profile would continue to plateau or rise again is not clear, and thus the calibration flood levels at the Broadwater Mill could not be properly estimated by simply projecting the water surface profiles from their former upstream extent. Accordingly, it was decided that the RMA-2 model should be extended upstream to allow calibration to the recorded flood marks at the Broadwater Sugar Mill.

5.2.2 RMA-2 Model Extension

Upstream Extension of Model

The location of the upstream extent of the original RMA-2 model was chosen due to the natural constriction in the topography of the floodplain to the north of Broadwater. This provides a good location for a flow boundary condition. However, as discussed above, it was necessary to extend the RMA-2 model upstream to the Broadwater Sugar Mill so that better calibration could be achieved to the 1974 and 1976 floods.

As shown in **Figure 6**, the floodplain and channel of the Richmond River are well defined by available survey extending about 2 kilometres upstream of the Broadwater Sugar Mill. Sufficient data was also compiled for the channel and floodplain of Tuckean Broadwater extending upstream to Bagotville Barrage.

This data was used to extend the model upstream and led to the generation of the model layout shown in **Figure 7**.

Revised Upstream Boundary Conditions

As discussed above, the upstream limit of the initial RMA-2 model approximately corresponded to Node 29 within the ESTRY model. Accordingly, flow data was extracted from the ESTRY model results files and was adopted to define the new upstream boundary conditions.

The upstream limit of the extended RMA-2 model corresponds approximately to Node 31 within the ESTRY model. However, discharge data was not available from WBM Oceanics for Node 31.

In order to expedite the investigation, a representative upstream boundary condition was adopted from the available data. The inflow hydrograph for the extended RMA-2 model was calculated as the discharge at ESTRY node 29 (*ie., the flow downstream of the confluence of Richmond River with Tuckean Broadwater*) minus the flow at ESTRY node 37 (*ie., the discharge flowing from the Tuckean Broadwater*).

Results of Calibration for Revised RMA-2 Model

The results of the calibration using the extended RMA-2 model are shown in **Figure 8**. Floodmarks for the 1954, 1976 and 1974 floods are included for comparison. A profile of the water surface for the February 1954 flood was drawn by linking the recorded floodmarks.

As shown in **Figure 8**, better calibration of the 1976 event was achieved using the revised model, albeit that the modelled water surface is still about 200 mm above the recorded flood level at the Broadwater Sugar Mill.

This discrepancy was further investigated by sensitivity checks based on variations in the roughness coefficients adopted within the model. The results of this analysis indicated that any adjustment of the values (*within acceptable limits*) would not cause a significant or beneficial improvement in the model calibration for the 1976 flood.

The apparently high modelled 1976 flood level at Broadwater Mill led us to query the upstream boundary condition for the extended RMA-2 model. Further inspection of the ESTRY model results revealed that the flow data varies inconsistently between the calibration events for particular ESTRY model nodes.

For example, the peak flow at ESTRY model node 37 (*the inflow from Tuckean Broadwater to Richmond River*) is about 160 m^3/s in the 1976 event, and about 1080 m^3/s in the 1974 event; ie., about 6 or 7 times greater (*refer* **Table 5**).

In contrast, the peak flow during the 1974 flood at a number of locations elsewhere along the main channel of the Richmond River is only double the corresponding flow for the 1976 event (*refer* **Table 5**).

Table 5 COMPARISON OF ESTRY DISCHARGE DATA FOR CALIBRATION EVENTS

LOCATION	ESTRY MODEL NODE	PEAK DISCHARGE *(m^3/s)*		RATIO OF 1974 DISCHARGE TO 1976 DISCHARGE
		Mar-1974	Feb-1976	
Bagotville Barrage	39	1190	155	7.7
Tuckean Inflow	37	1080	160	6.8
Downstream from Confluence	29	3195	1600	2.0
Confluence of Tuckean Broadwater and Richmond River	30	2065	1435	1.4
Upstream from Confluence (RMA inflow)	31 (calculated)	2150	1440	1.5

Baggotville Barrage was constructed in 1971 and was therefore operational in both the 1974 and 1976 floods.

It would appear that the data supplied by WBM Oceanics for the 1976 event, underestimates the flow entering the Richmond River via Tuckean Swamp. If this were the case, the methodology described above to determine representative inflow hydrographs for Tuckean Broadwater and the main channel of the Richmond River, may not be appropriate. It may be that the inflow to the model from Tuckean Swamp should be higher, which in turn would indicate that the flow entering the model along the main channel of the Richmond River should be lower. If so, the model generated flood level at Broadwater Mill in the 1976 flood, may be closer to the recorded level shown in **Figure 8**.

5.2.3 Investigation of Other Sources for RMA-2 Model Boundary Condition Data

In order to address the potential issue associated with the ESTRY model discharge data for Tuckean Broadwater, further investigations were undertaken to find suitable flow data for the Richmond River at the Broadwater Sugar Mill. This included inspection of the discharge hydrographs generated by a RAFTS model that was developed for the Mid Richmond Flood Study (*1999*).

Unfortunately, there were no calibration event results available on the Model Results CD for the Mid Richmond Flood Study project. However, data for the 100 year recurrence flood was available and was compared to the design 100 year recurrence flood discharge data provided by WBM Oceanics from the ESTRY model. The results of the comparison are shown in **Table 6**.

Table 6 COMPARISON OF ESTRY AND RAFTS PEAK DISCHARGE DATA FOR THE 100 YEAR FLOOD

LOCATION	ESTRY MODEL NODE	ESTRY MODEL DISCHARGE (*m³/s*)	RAFTS MODEL NODE	RAFTS MODEL DISCHARGE (*m³/s*)	DIFFERENCE (*RAFTS- ESTRY*) (*m³/s*)
Bagotville Barrage	39	1520	174	1047	-473
Tuckean Inflow	37	1330	173	1105	-225
Downstream from Confluence	29	3850	178	11690	7840
Confluence of Tuckean and Richmond	30	2470	172	11630	9160
Broadwater Mill	31 (calculated)	2580	171	11310	8730

The differences between the data-sets are quite significant. For locations along the Richmond River, the RAFTS model produced discharges up to 9000 m^3/s greater than those listed in the ESTRY model data. In contrast, the RAFTS model produced discharges significantly lower than the ESTRY model for nodes located along Tuckean Broadwater.

However, it should be noted that two different techniques were applied to arrive at the peak discharges established by each study. Hence, it was decided that discharges determined by the RAFTS model for the Mid Richmond Flood Study would not be suitable for RMA-2 model calibration or design simulations.

Accordingly, it will be necessary to obtain additional discharge data from WBM Oceanics for ESTRY model node 31, if better calibration of the 1976 flood is to be achieved.

Notwithstanding, based on the investigations completed for this report, the available data (*as described above*) suggests that the acquisition and application of this data may not substantially improve the calibration.

5.2.4 Conclusions in Relation to RMA-2 Model Calibration

The floods used to calibrate the RMA-2 model are the March 1974 and July 1976 events. Since these events, the Pacific Highway has been raised approximately 400 mm between Broadwater and Wardell Bridge as part of road upgrade works. Accordingly, the calibration flood events were modelled with a reduced levee elevation compared with the 'present-day' levee. It should be noted that the modelling of the design events was based on existing levels for the Pacific Highway.

The results of RMA-2 model calibration are presented as flood profiles for the March 1974 and February 1976 floods in **Figure 8**. A summary of the RMA-2 calibration results and their comparison to historic floodmarks and calibration flood levels obtained from the ESTRY model developed by WBM are listed in **Table 7**.

Table 7 MODEL CALIBRATION COMPARISONS

LOCATION	CALIBRATION FLOOD LEVEL (m AHD)					
	March 1974 Flood of Record			February 1976 Flood of Record		
	RMA-2	ESTRY	Flood Mark	RMA-2	ESTRY	Flood Mark
Downstream of Pimlico Island	1.98	1.98	-	1.15	1.15	-
Downstream of Wardell Bridge	2.42	2.47	2.49	1.29	1.31	-
Upstream of Wardell Bridge	2.64	2.68	-	1.37	1.37	-
Cabbage Tree Island	2.92	2.94	-	1.60	1.49	-
Broadwater (*sugar mill*)	3.22	3.25	3.25	1.92	1.70	1.70

The results show that a reasonable match was obtained between the ESTRY and RMA models for most of the length of the river. The only area where some departure exists is the upstream end of the models near Broadwater, where the RMA-2 model appears to overestimate the recorded flood level at Broadwater Sugar Mill for the 1976 flood.

Other points about calibration water surface profiles, and their comparison to ESTRY results and floodmarks:

§ The afflux modelled at Wardell Bridge using the RMA-2 model is comparable to the afflux determined using the ESTRY model (*refer* **Figure 8**). The afflux was also verified by completion of manual calculations using Bradley's method (*refer* **Appendix D**).

§ Goat Island and Cabbage Tree Islands appear to cause an afflux or "build-up" in the water surface profile in the area immediately upstream of each island.

§ The flood levels provided in **Table 7** show that there is some disagreement between the ESTRY model and the RMA-2 model results for the 1976 event toward the upstream limit of the model. The ESTRY model naturally fits the floodmark at Broadwater because the ESTRY model specified the water level as a stage boundary condition.

§ Ideally, the RMA-2 model should still match the recorded flood level. However, the discrepancy may be due to the adoption of an upstream flow boundary condition (*extracted from the ESTRY model*) that was unrealistically generated by the ESTRY model because of the stage boundary condition being forced to match the recorded flood level at Broadwater Mill.

6 DESIGN FLOOD SIMULATIONS

6.1 DESCRIPTION OF FLOOD BEHAVIOUR

Floods in the study area are typically caused by large flows through Broadwater in combination with elevated tailwater levels caused by ocean storm conditions. Floodplain elevations are typically low in the study area, particularly on the eastern side of the Richmond River where inundation can occur in relatively moderate floods or as a result of abnormally high tides.

In larger floods the natural and artificial features of the floodplain act as hydraulic controls and can constrict the flow between Broadwater and Wardell. In this area, the Pacific Highway has been elevated above the surrounding floodplain and effectively acts as a levee. The approach abutments to the Pacific Highway bridge crossing at Wardell also constrict the flow, resulting in significant energy or “head” losses.

The “head loss” through the bridge opening is associated with an increase in water levels upstream of the bridge. Floodwaters ‘build-up’ upstream of the bridge until they overtop the southern approaches to the bridge and inundate East Wardell and the eastern section of the floodplain.

During most floods the eastern floodplain provides a large storage area for excess floodwaters. Floodwaters also have a tendency to ‘back-up’ along Reedy Creek (*refer* **Figure 2**) which provides additional flood storage area in the eastern floodplain.

The relatively flat bed slope of the Richmond River in this area and the large storage afforded by the floodplain, results in a “flat” hydraulic gradient between Wardell and Empire Vale Creek. Typically, there is only about 300 mm fall between Wardell Bridge and Empire Vale Creek during moderate to large floods.

6.1.1 Flooding in the Vicinity of Cabbage Tree Island

The majority of residential dwellings on Cabbage Tree Island are built on poles to raise their floor levels above the level of common floods. Historic floods have led to inundation of almost the entire surface area of Cabbage Tree Island, which typically has land surface elevations lower than the 2 metre contour.

Due to its position in the centre of a major coastal river, the Island is highly susceptible to inundation when the Richmond River floods. Floodwaters typically overtop the banks of the river and inundate the Island, with flow velocities increasing significantly as the severity of the flood increases.

6.1.2 Flooding in the Vicinity of Wardell

Flooding in the vicinity of Wardell is influenced by the Pacific Highway bridge crossing of the Richmond River. During small to medium sized floods, no overtopping of the western banks of the Richmond River occurs upstream of the bridge.

Floodwaters overtop the western banks of the Richmond River downstream of the bridge crossing, inundating low lying areas of Wardell Township. These areas are generally restricted to those areas of the village east of the Pacific Highway.

In general, floodwaters are forced through the bridge opening resulting in an afflux that effectively increases upstream water levels by between 150 and 300 mm.

During large events, floodwaters typically inundate the majority of East Wardell. Properties that front Byron Street and Raglan Street are typically inundated, as are properties located west of the Pacific Highway along River Street and Hunter Street.

Hydrographic survey data for the Richmond River in the vicinity of the Pacific Highway bridge crossing indicates that the bed of the river in the vicinity of the bridge is about 5 metres lower than encountered upstream and downstream. This bed scour indicates that high velocities occur in the vicinity of the bridge crossing during floods, and attests to the "head" or energy loss through the bridge waterway during a major flood.

6.2 DESIGN FLOOD DISCHARGES

Design flood discharges have been determined by WBM for use in the ESTRY model that was developed for the 1997 Report. Following development and calibration of the RMA-2 hydrodynamic model, flood simulations were undertaken for the 5, 10, 20, 50 and 100 year recurrence floods, and the Probable Maximum Flood (*PMF*), using boundary conditions extracted from the ESTRY model prepared by WBM Oceanics. A summary of the peak discharges for each event is provided in **Table 8**.

Table 8 DESIGN PEAK FLOOD DISCHARGES

DESCRIPTION OF LOCATION	PEAK DISCHARGE (m^3/s)					
	5 Year	10 Year	20 Year	50 Year	100 Year	PMF
Broadwater (*Richmond River*)	1558	1756	1981	2398	2580	5097
Bagotville Barrage (*Tuckean Broadwater*)	182	409	696	1112	1521	2997

6.3 DESIGN FLOOD CHARACTERISTICS

6.3.1 Design Flood Levels

Design flood levels were extracted from the RMA-2 model results. Predicted peak flood levels for the 10, 20, 50 and 100 year recurrence events, and the PMF, are presented in **Table 9** for locations that correspond to the position of surveyed cross-sections along Richmond River (*refer* **Figure 5**).

Water surface profiles for these floods along the Richmond River channel are presented in **Figure 9**. A comparison between design flood levels determined for the '*Ballina Floodplain Management Study*' and design flood levels determined by the RMA-2 hydrodynamic model are provided in **Table 10**.

Table 9 PREDICTED PEAK FLOOD LEVELS ALONG RICHMOND RIVER

DESCRIPTION OF LOCATION	SURVEYED CROSS-SECTION (*refer* Figure 5)	PEAK FLOOD LEVEL (*mAHD*)					
		5 Year	10 Year	20 Year	50 Year	100 Year	PMF
Downstream of Pimlico Island	1	1.37	1.58	1.80	2.17	2.51	4.15
Pimlico Island	2	1.39	1.64	1.90	2.28	2.60	4.22
Pimlico Island	3	1.39	1.63	1.89	2.27	2.59	4.21
Upstream of Pimlico Island	4	1.42	1.72	1.99	2.38	2.69	4.28
Downstream of Little Pimlico Island	5	1.42	1.72	2.00	2.38	2.69	4.29
Little Pimlico Island (down*stream ana branch*)	6	1.44	1.74	2.03	2.42	2.73	4.34
Little Pimlico Island (down*stream main channel*)	7	1.45	1.76	2.05	2.45	2.76	4.37
Little Pimlico Island (up*stream ana branch*)	8	1.48	1.80	2.10	2.51	2.83	4.43
Little Pimlico Island (up*stream main channel*)	9	1.48	1.79	2.10	2.51	2.82	4.43
Upstream of Little Pimlico Island	10	1.48	1.79	2.10	2.51	2.82	4.43
Between Wardell and Little Pimlico Island	11	1.48	1.80	2.11	2.52	2.83	4.46
Between Wardell and Little Pimlico Island	12	1.50	1.82	2.14	2.56	2.88	4.51
Downstrean of Wardell Bridge crossing	13	1.51	1.83	2.15	2.56	2.88	4.56
Wardell Bridge crossing	14	1.49	1.81	2.13	2.56	2.89	4.58
Upstrean of Wardell Bridge crossing	15	1.59	1.96	2.33	2.79	3.13	4.71
Between Wardell and Cabbage Tree Island	16	1.59	1.97	2.33	2.80	3.14	4.71
Between Wardell and Cabbage Tree Island	17	1.63	2.01	2.38	2.84	3.18	4.74
Between Wardell and Cabbage Tree Island	18	1.61	1.99	2.37	2.84	3.18	4.74
Cabbage Tree Island (*downstream ana branch)*	19	1.70	2.10	2.48	2.95	3.28	4.81
Cabbage Tree Island (*downstream main channel)*	20	1.76	2.17	2.55	3.02	3.35	4.85
Cabbage Tree Island Bridge	21	1.86	2.28	2.65	3.11	3.42	4.91
Cabbage Tree Island (*main channel)*	22	1.86	2.28	2.65	3.12	3.44	4.91
Cabbage Tree Island (up*stream ana branch)*	23	1.93	2.34	2.71	3.15	3.46	4.94
Cabbage Tree Island (*upstream)* / Goat Island (downstream)	24	1.94	2.36	2.73	3.17	3.48	4.96
Goat Island (*upstream*)	25	1.95	2.36	2.72	3.16	3.47	4.94
Goat Island (*upstream*)	26	1.98	2.40	2.76	3.19	3.51	5.01
Upstream of Goat Island	27	1.98	2.39	2.75	3.18	3.49	4.98
Upstream of Goat Island	28	2.00	2.41	2.79	3.22	3.50	4.98
Confluence with Tuckean Broadwater	29	2.10	2.54	2.87	3.35	3.66	5.30
Upstream of Confluence with Tuckean Broadwater	30	2.10	2.54	2.89	3.38	3.68	5.33
Broadwater	31	2.17	2.60	2.94	3.41	3.72	5.37
Broadwater	32	2.21	2.65	2.98	3.47	3.78	5.51

Table 10 COMPARISON OF MODEL RESULTS

LOCATION	DESIGN FLOOD LEVEL (m AHD)							
	10 year		20 year		100 year		Extreme / PMF	
	Existing	PBP	Existing	PBP	Existing	PBP	Existing	PBP
Downstream of Pimlico Island	1.57	1.58	1.77	1.80	2.48	2.51	4.13	4.15
Downstream of Wardell Bridge	1.80	1.81	2.12	2.13	3.00	2.89	4.87	4.58
Upstream of Wardell Bridge	1.90	1.96	2.27	2.33	3.24	3.13	5.29	4.71
Cabbage Tree Island (bridge)	2.06	2.28	2.46	2.65	3.44	3.42	5.47	4.91
Broadwater	2.28	2.60	2.76	2.94	3.84	3.72	6.12	5.37

The results of the RMA-2 modelling were used to develop flood extent mapping for the study area. Flood extent mapping for the 100 year recurrence flood is presented in **Figures 10** and **11**. **Figure 12** shows the variation in depth of inundation and the variation in flow velocity across the floodplain and along the river channel.

The predicted flood extent for the 100, 10 and 5 year recurrence floods at Cabbage Tree Island is presented in **Figure 10**. As shown, the Island is predicted to be completely inundated during the 100 year recurrence flood. Furthermore, flooding of the village area is expected during floods of the magnitude of the 10 year recurrence event.

However, it should be noted that the dwellings have typically been constructed as on elevated structures with floor levels located a considerable height above the ground surface. **Figure 13** shows the predicted variation in floodwater depth and velocity across the island in the 100 year recurrence event.

Figure 11 shows the predicted flood extents for Wardell during the 100, 50 and 10 year recurrence floods. The figure shows that most of East Wardell is inundated during the 100 and 50 year recurrence events. Flooding in this area is not as extensive during the 10 year recurrence flood.

The section of Wardell that lies to the west of the Pacific Highway (*on the northern side of the Wardell Bridge*) is situated on raised ground and is therefore elevated above the floodplain. Accordingly, **Figure 11** shows that this area remains largely unaffected by flooding during events up to and including the 100 year recurrence flood.

However, the area of the village of Wardell east of the Pacific Highway is considerably lower. Therefore, during larger events such as the 100 and 50 year recurrence floods, floodwaters "back-up" into the village to a limit that corresponds approximately to the alignment of the Pacific Highway (*refer* **Figure 11**). The extent of inundation in this area is not as widespread for the 10 year recurrence flood.

The variation in floodwater depth and velocity at Wardell in the 100 year recurrence event is shown in **Figure 14**.

6.3.2 Design Flow Velocities

Peak in-channel flow velocities for a range of design events were extracted from the RMA-2 model results at the locations of the channel cross-sections shown in **Figure 5**. A summary of the results is provided in **Table 11**.

The following points are made in relation to the model results:

- The largest velocity for each design event is predicted to occur at the Pacific Highway bridge crossing at Wardell (*as to be expected*). This peak velocity at this location in the 100 year recurrence event is predicted to be 2.30 m/s.
- Flow velocities are also observed to increase upstream of Goat Island, coinciding with a slight trough in the water surface profiles shown in **Figure 9**.
- Along the stretch of river around Wardell (*i.e., between channel cross-sections 10 and 15*), the flow velocity is consistently 1 m/s or higher for all design floods.
- Elsewhere, the flow velocity was determined to range between 0.6 to 1.0 m/s.

It should also be noted that the flow velocity increases towards the upstream limit of the RMA-2 model at Broadwater, which is likely to be due to the upstream boundary condition. Therefore, the application of model results in the vicinity of Broadwater should be undertaken with caution.

Table 11 PREDICTED PEAK FLOW VELOCITIES ALONG RICHMOND RIVER

DESCRIPTION OF LOCATION	SURVEYED CROSS-SECTION (*refer* Figure 5)	PEAK INCHANNEL FLOW VELOCITY (*m/s*)					
		5 Year	10 Year	20 Year	50 Year	100 Year	PMF
Downstream of Pimlico Island	1	0.98	1.02	1.02	0.89	0.89	0.91
Pimlico Island	2	0.94	0.99	1.03	1.03	1.04	1.13
Pimlico Island	3	0.77	0.80	0.83	0.81	0.81	0.86
Upstream of Pimlico Island	4	0.75	0.83	0.92	1.01	1.03	1.24
Downstream of Little Pimlico Island	5	0.64	0.71	0.78	0.85	0.85	1.09
Little Pimlico Island (down*stream ana branch*)	6	0.42	0.54	0.70	0.88	0.95	1.28
Little Pimlico Island (down*stream main channel*)	7	1.15	1.26	1.34	1.41	1.42	1.58
Little Pimlico Island (up*stream ana branch*)	8	0.37	0.43	0.49	0.58	0.62	0.91
Little Pimlico Island (up*stream main channel*)	9	0.80	0.88	0.96	1.04	1.07	1.35
Upstream of Little Pimlico Island	10	1.03	1.10	1.17	1.24	1.25	1.50
Between Wardell and Little Pimlico Island	11	0.98	1.09	1.18	1.28	1.30	1.46
Between Wardell and Little Pimlico Island	12	1.19	1.30	1.34	1.37	1.39	1.58
Downstream of Wardell Bridge crossing	13	1.18	1.34	1.42	1.53	1.55	1.66
Wardell Bridge crossing	14	1.88	2.14	2.17	2.27	2.30	2.37
Upstream of Wardell Bridge crossing	15	1.01	1.09	1.07	1.06	1.07	1.10
Between Wardell and Cabbage Tree Island	16	0.58	0.65	0.66	0.69	0.70	0.73
Between Wardell and Cabbage Tree Island	17	0.83	0.91	0.90	0.91	0.93	1.02
Between Wardell and Cabbage Tree Island	18	1.10	1.16	1.13	1.12	1.12	1.28
Cabbage Tree Island (*downstream ana branch)*	19	1.01	1.08	1.06	1.04	1.04	1.10
Cabbage Tree Island (*downstream main channel)*	20	0.78	0.80	0.78	0.77	0.76	1.13
Cabbage Tree Island Bridge	21	0.84	0.95	0.92	0.92	0.90	0.89
Cabbage Tree Island (*main channel)*	22	0.79	0.80	0.77	0.90	0.90	1.04
Cabbage Tree Island (up*stream ana branch)*	23	0.89	0.94	0.94	0.93	0.93	1.06
Cabbage Tree Island (*upstream*)	24	0.63	0.66	0.68	0.74	0.74	1.20
Goat Island (*upstream*)	25	0.82	0.86	0.91	0.99	1.03	1.41
Goat Island (*upstream*)	26	0.31	0.32	0.35	0.53	0.57	0.79
Upstream of Goat Island	27	0.62	0.67	0.78	0.99	1.08	1.45
Upstream of Goat Island	28	1.11	1.21	1.26	1.50	1.60	2.11
Confluence with Tuckean Broadwater	29	0.80	0.82	0.84	0.96	0.99	1.20
Upstream of Confluence with Tuckean Broadwater	30	1.36	1.32	1.32	1.28	1.27	1.32
Broadwater	31	1.26	1.24	1.23	1.30	1.29	1.49
Broadwater	32	1.45	1.43	1.41	1.37	1.32	1.42

7 FLOOD HAZARD

7.1 FLOOD HAZARD

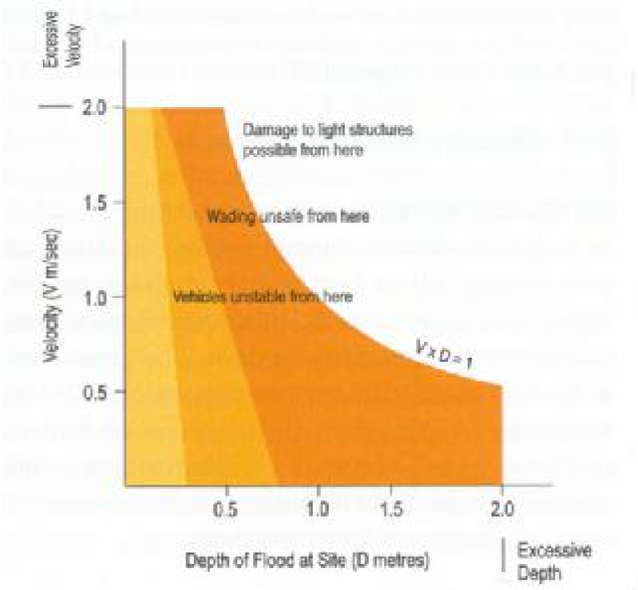
The personal danger and physical property damage caused by a flood varies both in time and place across the floodplain. Accordingly, the variability of flood patterns across the floodplain over the full range of floods, needs to be understood by flood prone landholders and by floodplain managers.

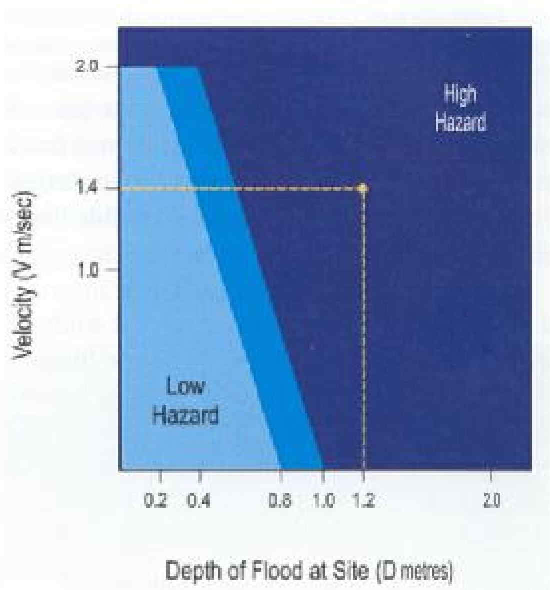
Representation of the variability of flood hazard across the floodplain provides floodplain managers with a tool to assess the existing flood risk and to determine the suitability of land use and future development. The hazard associated with a flood is represented by the static and dynamic energy of the flow, which is in essence, the depth and velocity of the floodwaters. Therefore, the flood hazard at a particular location within the floodplain, is a function of the velocity and depth of the floodwaters at that location.

The NSW Government's *'Floodplain Management Manual'* (*2001*), characterises hazards associated with flooding into a combination of three hydraulic categories and two hazard categories. Hazard categories are broken down into high and low hazard for each hydraulic category as follows:

- Low Hazard – Flood Fringe
- Low Hazard – Flood Storage
- Low Hazard – Floodway
- High Hazard – Flood Fringe
- High Hazard – Flood Storage
- High Hazard – Floodway

As a result, the manual effectively divides hazard into two categories, namely, high and low. An interpretation of the hazard at a particular site can be established from the following graphs, which have been taken directly from the manual.





The first of these shows approximate relationships between the depth and velocity of floodwaters and resulting hazard. This relationship has been used to define the provisional low and high hazard categories represented in the second of these plots.

7.2 ADOPTED HAZARD CATEGORISATION

As shown above, flood hazard is a measure of the degree of difficulty that pedestrians, cars and other vehicles will have in egressing flooded areas, and the likely damage to property and infrastructure. At low hazard, passenger cars and pedestrians (***adults***) are able to move out of a flooded area. At high hazard, wading becomes unsafe, cars are immobilised and damage to light timber-framed houses would occur.

Flood hazard is categorised according to a combination of the flow velocity and the depth of floodwater. The categories are defined by lower and upper bound values for the product of flow velocity and floodwater depth.

Spatial and temporal distributions of flow, velocity and water level determined from the RMA-2 computer modelling undertaken as part of this study, were used to determine the flood hazard in the vicinity of Cabbage Tree Island and through the township of Wardell.

Interpretation of this data indicates that for large events like the 100 year recurrence flood, most areas of flooded land on Cabbage Tree Island and within Wardell would fall within the high hazard category defined in the *'Floodplain Management Manual'* (*2001*).

Hence, for the purpose of understanding how the flood hazard affects existing development and areas of potential future development, it is useful to further subdivide areas falling within the high hazard category, into High Hazard, Very High Hazard and Extreme Hazard. Similarly, the low hazard category defined in the manual has been subdivided to create a Low Hazard and a Medium Hazard category.

Each of these categories and their relationship between depth of inundation and water velocity is shown in **Figure 15**. A summary of the criteria adopted for each hazard category is listed in **Table 12**.

Table 12 ADOPTED HAZARD CRITERIA

HAZARD CATEGORY	CRITERIA
Low	Depth (d) < 0.4 m & velocity (v) < 0.5 m/s
Medium	exceeding Low criteria, and $d \leq 0.8$ m, $v \leq 2.0$ m/s, and $v \times d \leq 0.5$
High	exceeding Medium criteria, and $d \leq 1.8$ m, $v \leq 3.0$ m/s, and $v \times d \leq 1.5$
Very High	exceeding High criteria, and with $d > 1.8$m, 0.5 m/s < velocity < 4 m/s & $v \times d \leq 2.5$
Extreme	exceeding Very High criteria and $v > 0.5$ m/s

7.3 PROVISIONAL FLOOD HAZARD

The criteria presented in **Table 12** was used to determine the provisional flood hazard at Cabbage Tree Island and Wardell. Results from the computer modelling completed for this study were combined with this hazard category criteria to generate provisional flood hazard mapping for the design 100 year recurrence flood. Mapping showing the variability in flood hazard for this event is presented in **Figures 16** and **17**. The limit of the low hazard area effectively defines the flood extent for each of these floods.

Flood hazard mapping contained in **Figure 16** shows that the flooded area on Cabbage Tree Island (*ie., the entire island surface*) may be subject to flood hazard that ranges between *high* to *very high* during the 100 year recurrence flood. **Figure 17** shows that most inundated area in East Wardell is predicted to be subject to a provisional flood hazard category that ranges between *medium* to *very high*. A majority of the flooded area within Wardell (*ie., downstream of the Wardell Bridge*) has a provisional flood hazard that ranges between *low* to *high*, although a small number of land parcels at the southern end of Wilson Road may be subject to *very high* flood hazard (*refer* **Figure 17**).

The hazard represented in this mapping is provisional only. This is because it is based only on an interpretation of the flood hydraulics and does not reflect the effects of other factors that influence hazard. For example, the impacts associated with areas of very high hazard may be reduced if an effective local flood plan is developed, implemented and maintained under the guidance of the State Emergency Services.

Accordingly, modification of the hazard mapping presented in **Figures 16** and **17**, may occur during the investigations required to develop a Floodplain Management Plan for Wardell and Cabbage Tree Island.

8 POTENTIAL FLOOD DAMAGE REDUCTION MEASURES

The assessment of measures to mitigate against the impact of flooding fall within the scope of a Floodplain Management Study. However, it is prudent to make some initial observations regarding potential flood mitigation measures that could be investigated during further work.

The particular focus areas for this study are the township of Wardell and settlement of Cabbage Tree Island. The RMA modelling indicates that Cabbage Tree Island, East Wardell and sections of Wardell are all likely to be prone to inundation by floodwaters in relatively minor flood events. There are a number of measures that could be investigated to help alleviate flood risk in these areas, including:

- Upgrading of the low level levee located along the western bank of the Richmond River to improve the level of protection afforded to low lying areas of Wardell;
- Modification to the abutments of the Wardell Bridge to improve the conveyance capacity and thereby reduce the potential for backwater flooding in upstream areas;
- Construction of a “deflector levee” at the upstream end of Cabbage Tree Island to reduce the hydraulic hazard that residents of the island could be exposed to during minor to moderate floods.

From a conceptual perspective, these measures have the potential to reduce flood damages in the areas of Wardell and Cabbage Tree Island. However, prior to a complete feasibility assessment, it would be important to re-model the hydraulic effects of these scenarios using amended versions of the RMA model.

9 CONCLUSIONS

Wardell and Cabbage Tree Island have experienced significant flooding due to the overtopping of the banks of the Richmond River. This flooding has resulted in damage to both public and private property, and has increased the risk of loss of life among those who reside on Cabbage Tree Island and those who live or work in low lying areas of Wardell and East Wardell. The most significant recent floods occurred in March 1974 and February 1976. The largest recorded flood occurred in February 1954 and is regarded as being equivalent to the 80 year recurrence event.

The key findings established by this study are:

(1) The majority of Cabbage Tree Island will be inundated once flood levels in the Richmond River reach an elevation corresponding to the 5 year recurrence flood (*refer* **Figure 10**). It was previously understood that inundation of the Island did not occur fully until levels reached the elevation of the 10 year recurrence flood. This is partly attributed to the impact of the raising of the Pacific Highway between Broadwater and Wardell. It is also a result of the two-dimensional modelling that has been undertaken for this study, which more realistically accounts for head losses created by the in-channel islands located along the Richmond River.

(2) Flood free access from Cabbage Tree Island is not possible during events larger than and including the 5 year recurrence event. Road access to the bridge linking the Island to the Back Channel Road is inundated in an event of this magnitude and the road would be impassable to vehicular traffic.

(3) The 100 year recurrence flood level in the Richmond River at Cabbage Tree Island is predicted to be about 3.35 mAHD. This corresponds to floodwater depths of up to 1.8 metres in the vicinity of areas of the Island that have been developed for housing. Most of the dwellings on the Island are constructed on stilts and their floor levels are typically above the 100 year recurrence flood level.

(4) The 100 year recurrence flood level at Wardell is predicted to be 2.89 mAHD immediately downstream from the Pacific Highway bridge crossing, and 3.13 mAHD upstream of the bridge.

(5) The area of Wardell township that is located to the east of the Pacific Highway is expected to be almost completely inundated during the 100 and 50 year recurrence floods. At least three existing dwellings are predicted to be inundated during the 10 year recurrence event.

(6) East Wardell is completely inundated during the 100 year recurrence flood and a significant portion is inundated during the 10 year recurrence flood.

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