

Eastwood & Terrys Creek Floodplain Risk Management Study & Plan



Conditions in West Parade (and Eastwood Park in the background) during the November 1984 flood

Flood Study Report

November 2008

(Reprinted October 2009)

CITY OF RYDE

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Report of City of Ryde's
Eastwood & Terrys Creek Floodplain Management Committee, prepared by

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FOREWORD

The NSW Government's Flood Policy is directed at providing solutions to existing flooding problems in developed areas, and ensuring that new developments are compatible with the flood hazard and do not create additional flooding problems in other areas. Under the Policy, the management of flood prone land remains the responsibility of local government.

The policy provides for a floodplain management system comprising the following four sequential stages:

- | | |
|-------------------------------------|--|
| 1. Flood Study | Determines the nature and extent of the flood problem. |
| 2. Floodplain Risk Management Study | Evaluates management options for the floodplain with respect to both existing and future development. |
| 3. Floodplain Risk Management Plan | Involves formal adoption by Council of a plan of management for the floodplain. |
| 4. Implementation of the Plan | Involves construction of flood mitigation works, where viable, to protect existing development. Uses planning controls to ensure that future development is compatible with flood hazards. |

The Council of the City of Ryde is responsible for local planning and land management in its Local Government Area (LGA) including the management of flood prone areas in the Eastwood and Terrys Creek sub-catchment areas. Through its Floodplain Risk Management Committee, Council proposes to prepare a comprehensive Floodplain Risk Management Plan for the study area in accordance with the NSW Government's 2005 Floodplain Development Manual.

This report is part of the first stage of the management process and has been prepared for Council by Bewsher Consulting Pty Ltd. It documents the nature and extent of flooding throughout the study area and therefore is enabling Council to proceed to undertake a Floodplain Risk Management Study where detailed assessment of the flood mitigation options and floodplain management measures would be undertaken and to then develop a Floodplain Risk Management Plan.

The draft Floodplain Risk Management Study and Plan (including this Flood Study Report) was placed on exhibition between 4 February and 13 March 2009. A number of changes were subsequently made to the Floodplain Risk Management Study and Plan, including the assessment of some additional floodplain management options, further review of the draft flood risk precincts provided in this report, and sensitivity testing for the 1984 flood model calibration. The draft flood risk maps presented in this report have now been superseded by revised mapping presented in the Floodplain Management Study and Plan.

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EXECUTIVE SUMMARY

In accordance with NSW Government policy, the Council of the City of Ryde is committed to preparing a Floodplain Risk Management Plan for the Eastwood and Terrys Creek sub-catchment areas. This report documents the first stage of the process of preparing the Plan – that is, the preparation of a flood study report.

The study area consists of mostly urban development, totals almost 500 hectares and includes the suburbs of Eastwood and Marsfield. While the majority of the stormwater drainage infrastructure is owned by Council, the larger trunk drainage channels and conduits are mostly owned by Sydney Water Corporation.

The consultants drew on both previous flood study reports and additional community consultation to review historical records about flood problems that have been experienced in the catchment and this process confirmed that the worst known flood was in November 1984.

Through the development of computer-based (DRAINS) hydrologic models and a (TUFLOW) hydraulic model, the report assesses catchment-wide flows and catchment flood behaviour for both the November 1984 flood and a range of design flood events including the 100 year average recurrence interval (ARI) and probable maximum floods (PMF). Flood inundation and risk mapping has been undertaken.

The modelling confirms that there are substantial flood problems in the western portion of the Eastwood town centre which lies within the depression forming the Terrys Creek floodplain. There are also significant numbers of residential properties which are flooded either from Terrys Creek overbank flows or tributary flows making their way to the Terrys Creek channel.

The detailed DRAINS and TUFLOW models provide a sound platform for the flood modelling tasks that will be undertaken during preparation of the Floodplain Risk Management Study and Plan.

1. INTRODUCTION

Bewsher Consulting was commissioned by the City of Ryde in May 2006 to assist its Floodplain Risk Management Committee in preparing a Floodplain Risk Management Study and Plan for Eastwood and Terrys Creek.

The study area includes that portion of Terrys Creek within the City of Ryde from Terry Road to the creek's confluence with the Lane Cove River. In addition, as shown in **Figure 1**, it includes all significant tributaries of Terrys Creek.

There is a diverse range of authorities and community groups with an interest in Terrys Creek. For example, both Parramatta City Council and Hornsby Shire Council have part of their local government areas within the catchment. In addition, the channelised portion of Terrys Creek is under the control of Sydney Water.

Council's Floodplain Risk Management Committee has been charged with overseeing the preparation of the Study and Plan. The Committee is comprised of Councillors and officers from the City of Ryde in addition to representatives from Parramatta City Council, Hornsby Shire Council, Sydney Water, the State Rail Authority, the State Emergency Service, the Department of Environment and Climate Change and most importantly, a number of local community representatives.

This report provides a description of the establishment and calibration of a computer model of flood behaviour throughout the study area. This model will become the primary tool for assessing both the existing flood behaviour and the changes which may occur through the implementation of any flood mitigation options that may be proposed during the course of the study.

2. CATCHMENT DESCRIPTION AND PREVIOUS STUDIES

2.1 CATCHMENT OVERVIEW

2.1.1 Catchment Areas

For the purposes of Council's management of the stormwater systems within the City of Ryde, the Terrys Creek catchment has been traditionally divided into the Eastwood and Terrys Creek drainage subcatchments.

The Ryde component of the Eastwood subcatchment is about 169 hectares in area and extends from the intersection of Marsden Road and Terry Road to Blaxland Rd, Eastwood. The Terrys Creek subcatchment comprises an area of about 326 hectares and extends from the intersection of Blaxland Road and Kings Road to the Lane Cove River.

The upstream portion of Terrys Creek (within Parramatta City Council) has an estimated area of 160 hectares, while the remaining portion of the catchment (within Hornsby Shire Council) has an estimated area of 357 hectares. The estimated total area of Terrys Creek is therefore approximately 1012 hectares.

The Eastwood town centre is located within the Eastwood subcatchment, and straddles the Main Northern Railway Line (**Figures 1 and 2**). The railway embankment divides the Eastwood town centre into eastern and western halves.

2.1.2 Flood History

Flooding on the western side of the Eastwood town centre results from overland flows originating from the upstream areas of the main Terrys Creek catchment, within Parramatta City and from overland flows generated from within the Eastwood subcatchment itself. A lack of overland flowpaths creates a situation where major storm flows flood the western part of the Eastwood town centre.

On the eastern half of the Eastwood town centre, localised flooding results from under-capacity piped drainage systems combined with structural impediments to overland flow. The subcatchment draining through the eastern side of the town centre rises at the ridgeline bisecting The Ryde Hospital in Denistone.

The Eastwood town centre has a long history of flooding and the impacts and damage caused by even moderate flooding events is well documented. The catchment has experienced several significant storm events including the 1967, 1984 and 1989 storm events, with a large number of properties being inundated during these events. In the major November 1984 flood it is estimated that over 70 houses or commercial properties experienced above floor level flooding.

2.1.3 Watercourses

The major watercourse through the Terrys Creek catchment is an open channel commencing upstream of Mobbs Lane and Fred Spurway Reserves in Epping. The watercourse heads eastwards into the City of Ryde, passing under Terry Road near to Tarrants Avenue, and emerging in Braemar Park where it is then conveyed in a concrete trapezoidal channel. The channel approaches the Eastwood town centre at Shaftsbury Road and Glen Street, where it passes through Glen Reserve to Hillview Lane.

The channel runs parallel to Hillview Lane, before transitioning into underground conduits of covered channel and box culverts to pass beneath Lakeside Road, Progress Avenue, Hillview Road, Eastwood Park and West Parade. These discharge into a short open channel immediately to the east of West Parade, adjacent to the railway embankment. The trunk drainage system passes beneath the embankment, emerging on the eastern side of the town centre.

On the eastern side of the railway embankment, a subcatchment area drains from Fourth Avenue through to First Avenue to the embankment. Stormwater in this area is conveyed by a system of underground pipes and mostly obstructed overland flow paths to Railway Parade, where it discharges to Terrys Creek. Numerous smaller subcatchments drain via stormwater pipes to the major stormwater lines running through the town centre.

Beyond the Eastwood town centre, the concrete trapezoidal channel continues east of Blaxland Road to near Bertram Street. Terrys Creek then meanders in an open channel for approximately three kilometres in a north-easterly direction through the suburbs of Marsfield, Epping and North Epping, whereupon it flows into the Lane Cove River, and in turn into the Parramatta River at Woolwich.

2.2 EARLIER FLOOD STUDIES

2.2.1 1990 Ryde Stormwater Drainage Investigation

This 1990 study (**Reference 1**) examined stormwater drainage in four of Council's major urban catchments, being Eastwood (182 ha), Charity Creek (237 ha), Buffalo Creek (500ha) and Shrimptons Creek (547ha). It included field inspection, measurement plus hydrologic and hydraulic modelling of all storm water conduits equivalent to 600mm diameter or greater.

The Eastwood catchment runoff regime was modelled using RAFTS software with 25 sub-catchments defining the catchment-wide flows. Design events from 1 year ARI to 100 year ARI were modelled and typically it was found that the critical storm duration varied from 25 minutes at the top of the catchment to 120 minutes at and near the outlet.

Pipe hydraulic analysis was undertaken using RATHGL software (with the design flows generated by the software adjusted until they agreed with the corresponding sub-catchment flows from RAFTS). For the Eastwood catchment there were 82 sub-catchments with 115 pits and 39 nodes. Page 7 of the report describes the sources for pit inlet capacities, pit loss coefficients and invert levels, while pages 38 & 39 summarise the design event problems along the various modelled stormwater pipe systems.

2.2.2 1991 Terrys Creek Study

Under a commission from the then Sydney Water Board, Bewsher Consulting undertook a catchment management study of Terrys Creek in 1991 (**Reference 2**). The downstream limit of the study catchment was the end of the Board's lined channel near Somerville Park. A combination of hydrologic (RAFTS) and hydraulic (HEC-2) modelling was used to model the November 1984 flood and a range of design events up to and including the 100 year ARI event. Water quality modelling was also undertaken.

The report focussed on the performance of the Board's trunk drainage system between Terry Road and Somerville Park and found that the worst flood problems were associated with the western side of the Eastwood town centre.

2.2.3 2001-2002 Eastwood Tunnel Investigation

In two reports dated October 2001 and October 2002 (**References 3 and 4**), Robinson GRC Pty Ltd examined the potential to build a tunnel that would serve to significantly reduce the flood problems on the western side of the Eastwood town centre. The tunnel was intended to collect all the catchment runoff (up to and including the 100 year event) reaching D. Hamilton Reserve (adjacent to Terry Road) and convey that flow to lower Terrys Creek downstream of Blaxland Road.

The hydrologic modelling undertaken during the 2001 study tested two options for the tunnel:

- firstly, a 1200 metre long tunnel that discharged to the main channel near Somerville Park; and
- secondly, a 1600 metre long tunnel that discharged at Forrester Park (which meant that the tunnel's flows would be discharged downstream of flood vulnerable properties in Bertram Street and Cassia Place).

It was recommended that the longer tunnel being investigated further since:

- the modelling of both tunnel options showed that they would increase downstream peak flood flows and hence the properties at Bertram Street and Cassia Place would not be disadvantaged by implementation of the longer tunnel; and

- the longer tunnel would also intercept more catchment runoff upslope of the Eastwood town centre and hence achieve more flood mitigation benefits.

In the October 2002 report, Robinson GRC Pty Ltd used a hydraulic (HEC-RAS) model to quantify the changes in flood levels that would result from implementation of either tunnel option. The report also looked at two tributary catchments where surface flows would also result in significant retail/commercial area flood damages. Using hydrologic (DRAINS) model results, the report concluded that:

- a micro tunnel would substantially reduce flooding in Rowe Street East and Railway Parade, and
- the completion of Shaftsbury Road drainage augmentation works which had already been commenced by Council would significantly reduce retail property damages in Rowe Street West.

2.2.4 2005 Terrys Creek Study

Under a commission from Parramatta City Council, Cardno Willing prepared a Sub-catchment Management Plan (**Reference 5**) for the Parramatta and City of Ryde areas of the Terrys Creek catchment. They used a combination of:

- hydrologic (RAFTS) and hydraulic (MIKE-11) modelling to calculate flood levels between Mobbs Lane and Marook Street to Forrester Park; and
- water quality (MUSIC) modelling to assess catchment runoff water quality.

A range of flood mitigation/modification measures were examined including the upgrading of some trunk system culverts and some tributary pipe systems and the earlier Forrester Park tunnel option was also modelled further. The study also made recommendations regarding water quality management options.

3. ESTABLISHMENT OF COMPUTER MODELS

3.1 HYDROLOGIC MODEL

3.1.1 DRAINS Software

The DRAINS software has been used to model the hydrologic regime of the Terrys Creek catchment to its confluence with the Lane Cove River (see **Figure 2**).

DRAINS is a comprehensive hydrologic modelling program for designing and analysing various types of catchments and urban stormwater drainage systems. It also includes some hydraulic modelling capabilities for pipes and overland flowpaths. It was first released in January 1998 and is marketed by Watercom Pty Ltd. The software is widely used in Australia and Council itself has used DRAINS for many years.

3.1.2 Model Boundaries

The catchment runoff has been assessed by developing a model of the upper catchment (whose outlet is at Bertram Street) and a second model of the middle and lower portions.

The two models consist of the following elements:

- (a) pit-by-pit modelling of the 1,400 pits throughout the City of Ryde portion of the catchment;
- (b) replication of 'RAFTS' subcatchments that had been used to previously model the Parramatta Council portion of the catchment (as documented in the 2005 report, **Reference 5**); and
- (c) development of five 'RAFTS' subcatchments to define the flow contributions from the Hornsby Council portion of the catchment (utilising contour and other catchment information contained in a 2002 report (**Reference 6**)).

3.1.3 Principal Model Parameters

The DRAINS models of the City of Ryde Council area were developed using the following data to replicate the 2006 catchment conditions:

- (a) stormwater pit and pipe data sourced from Council's stormwater asset database which was updated and supplemented by:
 - (i) field work undertaken by both the consultant and Council; and

- (ii) approved adoption of averaged data as assessed by the consultant based on data contained in the Council database (e.g. 'missing' pit depths were derived from review and averaging of the database's depth information); copies of design plans for works recently built by Council in various locations (including substantial works in Shaftsbury Road, Rowe Street and the micro tunnel in Railway Parade); copy of design plans for the next stage of the micro tunnel works in Railway Parade/Rowe Street East (which were actually under construction during the study);

Figure 2 documents the range of stormwater pipe sizes throughout the study area.

- (b) Catchment soil data and rainfall losses as adopted in the 2005 study (**Reference 5**). That is:

TABLE 1: SOIL DATA AND RAINFALL LOSSES

Soil Type:	Type 3
Antecedent Moisture Content (AMC):	3
Initial Losses:	1mm for paved areas and 5mm for grassed areas.

- (c) sub-catchment boundaries which were derived using digital contour plans provided by Council;
- (d) impervious percentages assigned on the basis of values derived from a range of 'typical' land uses/neighbourhoods which were directly measured using digital aerial images (dated 2006) provided by Council;
- (e) representative pit loss coefficients (see below) and inspection of design plans and constructed pits;

TABLE 2: PIT LOSS COEFFICIENTS

PIT CONFIGURATION	LOSS COEFFICIENT
No angle change through pit	0.5
Angle change (less than 45°)	1.2
Angle change (more than 45°)	1.7
Multiple pipe junction pit	2.0
Inlet headwall	1.5
Most upstream pit	3.0

- (f) the 'Hornsby' pit inlet capacity relationships embedded in DRAINS together with the *AR&R* (**Reference 11**) recommendation of 20% blockage of on-grade inlets and 50% blockage of sag inlets;
- (g) a combination of *AR&R* (**Reference 11**) temporal patterns and Council's design rainfall data for 'LGA Zones 1 & 2' were utilised in the lower and upper models respectively.

Note that for modelling of the calibration event (i.e. 8 November 1984), temporal patterns from nearby rainfall recorder stations were used as detailed in **Section 4.1**.

3.2 HYDRAULIC MODEL

3.2.1 TUFLOW Software

Following various discussions with Council officers, the widely used and Australian developed TUFLOW model (**Reference 9**) was chosen as the principal hydraulic modelling tool for use in the study.

There were seen to be numerous advantages of using a sophisticated two-dimensional (2D) model such as TUFLOW for simulating flood conditions within Terrys Creek and its tributaries. These advantages included not only the model's ability to simulate flood flows along a complicated network of overland flowpaths such as occurs in the study area, but also the ability of the model to produce figures to aid community understanding and acceptance of the flood study results.

The technical description of the TUFLOW model and its specific application to Terrys Creek is provided in **Appendix B**.

The following sections of the report describe the establishment and operation of the TUFLOW model to simulate:

- (a) the November 1984 flood event in the Terrys Creek catchment using the known rainfall data. The simulated flood levels and extents for this event were then compared with the historical records; and
- (b) the design 5 year, 10 year, 50 year and 100 year average recurrence interval (ARI) and probable maximum flood (PMF) events.

3.2.2 Model Coverage and Structure

As commissioned, TUFLOW software has been used to define a combined picture of mainstream and overland flow flooding throughout the City of Ryde portion of the study catchment.

The upstream limit of the mainstream section is Terry Road which defines the LGA boundary between Parramatta and Ryde and its downstream limit is the confluence with

the Lane Cove River. The extent of tributary overland flow modelling corresponds to earlier broad-scale mapping undertaken by Council.

The TUFLOW model is made up of the following elements:

- (a) a two dimensional hydraulic grid with cell width of 3 metres (square) described in the previous paragraph (and as shown in **Figures 5 to 8** covering all as-commissioned areas);
- (b) a digital elevation model (DEM) which covers the entire hydraulic model area. The DEM has been prepared by the consultant using ALS data provided by Council and roughnesses (in the form of Mannings 'n' values) have been varied throughout the model footprint to reflect local landuses or vegetation types (refer Table B1 in **Appendix B**). Building footprints have been digitised and included in the model (and generically assigned a very high roughness coefficient to reflect the potential for floodwaters to inundate them) while the curtilage area coefficient includes allowance for potential impacts associated with a variety of property features including landscaping, fences, etc.;
- (c) the DRAINS network of pits and pipes exists as a one-dimensional (1D) layer lying under the DEM with inlet capacities derived on the basis of pit lintel and grate openings obtained from Council's database. Consistent with the DRAINS modelling, 20% blockage was adopted for on-grade inlets and 50% blockage for sag inlets;
- (d) details of the lined Sydney Water channel system plus associated road culvert and private bridge crossings are defined in a 1D layer within the DEM. Data for these elements were directly extracted from earlier survey-based hydraulic model files of the system (and as-necessary supplementary field measurement);
- (e) inflow hydrographs were directly imported from the DRAINS modelling. In the case of the City of Ryde pipe networks, the runoff hydrographs for all sub-catchments were imported to the corresponding pits in TUFLOW.

4. CALIBRATION AND OPERATION OF THE MODELS

4.1 CALIBRATION OF MODELS TO NOVEMBER 1984 FLOOD

4.1.1 1991 Sydney Water Board Study

The 1991 Sydney Water Board study (**Reference 2**) constituted the first comprehensive flood assessment of the Terrys Creek catchment (at least as far downstream as Somerville Park where the Board's lined channel ends).

It described in some detail the extent of flood problems that had been experienced throughout the study area. The description was heavily based on the data contained within responses to a questionnaire that had been delivered to all properties in the catchment, plus additional data provided by Sydney Water Board, Ryde and Parramatta Councils. The report documents how the November 1984 event was found to be the worst flood and a review of the 75 surveyed flood levels presented in the report's Appendix G shows that 32 (or 43%) relate to that event.

A collection of photographs taken during the November 1984 flood are reproduced in **Appendix A**.

The 1991 study found that there were no rainfall recorders within the catchment but examined the rainfalls recorded at the nearest recorders — at West Epping and Ryde Pumping Station — for the storm of 8 November 1984. There was found to be a marked variation in the storm temporal patterns for the two recorders and **Table 3** which is reproduced from a 1985 BOM report (**Reference 7**) also shows how the intensity of the storm bursts were considerably higher at Ryde.

TABLE 3: MAXIMUM RAINFALL INTENSITIES RECORDED DURING THE EARLY MORNING OF 8 NOVEMBER 1984 (mm/h)

LOCATION	DURATION (HOURS)										
	0.1	0.2	0.3	0.4	0.5	1	2	3	6	12	24
Ryde	155	150	118	110	99.0	64.5	41.0	29.0	15.0	9.3	5.0
Hornsby	140	130	115	104	94.0	59.5	39.8	27.8	14.6	8.9	5.5
Chatswood	125	123	98.3	78.8	68.0	51.0	38.0	27.0	14.0	7.7	6.9
West Epping	80.0	72.5	56.7	55.0	51.0	35.5	25.8	18.5	12.3	8.6	4.9

Despite the differences in storm patterns, both recorders had very similar 0900 to 0900 hour 24 hour total rainfalls as shown in **Table 4** (which is reproduced from the 1991 study report). The table also shows that the 24 hour total rainfall measured at Chester Street, Epping (which is located just on the northern edge of the catchment), is very similar to that recorded at the two rainfall recorder stations while that measured at Eastwood Bowling Club (which is located just on the south-eastern edge of the catchment) is higher than that recorded at the two rainfall recorder stations.

TABLE 4: NOVEMBER 1984 DAILY RAINFALL TOTALS (mm)

LOCATION	7 NOVEMBER	8 NOVEMBER	9 NOVEMBER
Met Bureau Stations			
Marsfield (066156)	51.4	172.0	10.0
Eastwood Bowling Club (066087)	59.0	142.4	11.4
Epping Chester Street (066020)	62.0	114.0	27.6
Sydney Water Board Stations			
West Epping (566040)	57.5	116.0	1.5
Ryde Pumping Station (566037)	51.0	117.0	8.5

In the 1991 study, the West Epping and Ryde storm patterns were separately imported into the RAFTS model of the study catchment and not surprisingly consistently larger peak flows were calculated using the Ryde data. Furthermore it was found that a good fit to historic flood levels was obtained when the Ryde-derived flows were imported into the study's hydraulic model. The study therefore concluded that it was more than likely that the typical storm pattern over the catchment was similar to that recorded at Ryde.

4.1.2 Simulation of 1984 Flood in DRAINS and TUFLOW

For this study, initially the West Epping rainfall pattern was applied to the upper catchment DRAINS model and the Ryde Pumping Station pattern was applied to the middle and lower catchment DRAINS model. However after the importation of these flows into the TUFLOW model, it was found that the calculated flood levels along the main channel were consistently lower than the recorded levels.

Next, the Ryde rainfall pattern was adopted throughout both DRAINS models and the resultant flows imported into the TUFLOW model. This generated a much-improved overall fit to the flood levels. Apart from several minor adjustments to floodplain roughness values which served to improve the 'fit', the initial model results were adopted, see **Figure 5** (Sheets 1 to 6).

Table 5 documents both:

- (a) the historic information that was compiled from Council's flood data base and the flood levels (in metres AHD) documented in Appendix G of the 1991 study, and
- (b) the corresponding depth and/or flood level computed by the TUFLOW model

for all of the flood level locations mapped in **Figure 5**.

It can be seen from the table, that in almost all cases a good fit (i.e. where the difference between observed and calculated values is less than 0.1m) to satisfactory fit (i.e. where the difference is more than 0.1m and typically less than 0.2m) has been obtained. While, as indicated in the 'Comments' column of the table, there were some observed flood levels/depths which could not be replicated in the model, a number of those locations related to depth of water in garages or other buildings and it is considered likely that those within building ponding depths could be very different to the adjacent surface flow depths.

The TUFLOW results were compared with the calibration modelling reported in the 2005 report (**Reference 5**).

Firstly, the DRAINS/TUFLOW peak flows are significantly larger than the 2005 MIKE-11 model flows principally due to this study's adoption of the Ryde rainfall pattern throughout the catchment. For example, at Auld Avenue the TUFLOW peak flow was 47 m³/s while the 2005 MIKE-11 peak flow was 22 m³/s; at Glen Reserve, the respective flows were 55 m³/s and 34 m³/s and at Sommerville Park they were 73 m³/s and 48 m³/s.

Secondly, of the seven mainstream historic levels downstream of Terry Road that were used in the 2005 study, it was found that TUFLOW produced a significantly better fit at four locations (at Auld Avenue, Shaftsbury Road, Hillview Road and downstream of Doomben Avenue), similar levels at two locations (at "Mr Craft" in Progress Avenue and Ball Avenue) and a worse fit at one location (just downstream of Blaxland Road). Additionally there is a series of three flood observations at Cassia Place (opposite Somerville Park) including one surveyed flood level which were also used during the TUFLOW calibration process. The TUFLOW model was able to replicate the surveyed flood level very well, whereas the MIKE-11 calculated level was found to be well below the historic level.

It was therefore concluded that the combination of DRAINS and TUFLOW modelling undertaken for this study had achieved a very satisfactory calibration result.

With regard to culvert blockage, the 1991 study reported that there was no clear record of blockage having been experienced during or after the 1984 flood. However the hydraulic modelling that was undertaken during that study found that a better fit was obtained to the historic flood levels between Progress Avenue and Hillview Road if a 20% blockage factor was applied to the twin culverts whose inlet headwall is at Progress Avenue.

TABLE 5: CALIBRATION TO NOVEMBER 1984 FLOOD

Property ID	Street No	Street Name	Record Description	Fig 1 Sheet No. Reference	Flood Level (mAHD)			Flood Depth (m)			Remarks
					Historical	Modelled	Diff(m)	Historical	Modelled	Diff(m)	
1	21	TERRY ROAD	BC-25, level in garage.	1	73.00	73.40	0.40	-	0.48	-	Historical level could not be replicated
2	28	AULD AVENUE	Depth in yard.	1	-	71.14	-	0.60	0.07	-0.53	Historical depth could not be replicated
3	26	AULD AVENUE	Depth in yard.	1	-	71.00	-	0.60	0.41	-0.19	Satisfactory fit
4	22	AULD AVENUE	BC-33, Level at channel wall and driveway.	1	70.20	70.23	0.03	-	0.52	-	Good fit
4A	22	AULD AVENUE	Depth in yard.	1	-	70.93	-	0.60	0.69	0.09	Good fit
4B	22	AULD AVENUE	Depth in yard.	1	-	70.42	-	0.60	0.58	-0.02	Good fit
5	200	SHAFTSBURY ROAD	Reported flooded in Nov 84.	1	-	69.79	-	-	0.86	-	
6	198	SHAFTSBURY ROAD	Reported flooded in Nov 84.	1	-	69.75	-	-	1.08	-	
7	11	AULD AVENUE	Reported flooded in Nov 84.	1	-	69.77	-	-	1.36	-	
8	9	AULD AVENUE	Reported flooded in Nov 84.	1	-	69.72	-	-	1.16	-	
9	7	AULD AVENUE	Reported flooded in Nov 84.	1	-	69.72	-	-	1.15	-	
10	5	AULD AVENUE	Reported flooded in Nov 84.	1	-	69.70	-	-	1.35	-	
11	190	SHAFTSBURY ROAD	BC-34, Level in house.	1	69.52	69.55	0.03	-	1.52	-	Good fit
12	1/3	DARVALL ROAD	BC-46, Level at front garden - redevelopment took place since 1984.	1	84.60	84.50	-0.10	-	0.13	-	Good fit
13	15	DARVALL ROAD	Depth in garage.	1	-	93.24	-	0.10	0.08	-0.02	Good fit
14	70	RUTLEDGE STREET	Reported flooded in Nov 84.	1	-	79.55	-	-	0.39	-	
15	68	RUTLEDGE STREET	BC-44, Level at side gate.	1	79.60	79.55	-0.05	-	0.16	-	Good fit
16	66	RUTLEDGE STREET	BC-43, Level in house.	1	79.30	79.21	-0.09	-	0.33	-	Good fit
17	64	RUTLEDGE STREET	Depth in yard.	1	-	78.96	-	0.30	0.27	-0.03	Good fit
18	62	RUTLEDGE STREET	Depth in yard.	1	-	78.67	-	0.30	0.21	-0.09	Good fit
19	N/A	RUTLEDGE ST	Depth over road intersection.	1	-	77.38	-	0.45	0.28	-0.17	Satisfactory fit
20	56A	TARRANTS AVENUE	BC-40, Depth in garage.	1	-	75.21	-	0.10	0.11	0.01	Good fit
21	58	TARRANTS AVENUE	Reported flooded in Nov 84.	1	-	74.76	-	-	0.13	-	
22	293	ROWE STREET	BC-45, Level at front verandah.	1	71.87	71.87	0.00	-	0.28	-	Good fit
23	4	RICHARDS AVENUE	BC-34, Level in house and depth over floor.	1	70.30	70.21	-0.09	0.15	0.66 *	0.51	Good fit to flood level.
24	2	RICHARDS AVENUE	BC-35, Level in house and depth over floor.	1	70.15	70.14	-0.01	0.25	0.65 *	0.40	Good fit to flood level.
25	213	ROWE STREET	Reported flooded in Nov 84.	1	-	69.21	-	-	0.18	-	
26	211	ROWE STREET	Reported flooded in Nov 84.	1	-	69.18	-	-	0.15	-	
27	201	ROWE STREET	Depth over floor.	1	-	69.28	-	0.30	0.08 *	-0.22	Satisfactory fit
28	1	LAKESIDE ROAD	Reported flooded in Nov 84.	1	-	67.11	-	0.05	0.17	0.12	Satisfactory fit
29	8	HILLVIEW LANE	BC-49, Fruit Attack, Reported flooded in Nov 84.	1	-	66.46	-	-	0.65	-	
30	6	PROGRESS AVENUE	Reported flooded in Nov 84.	1	-	66.31	-	-	0.37	-	
31	4	PROGRESS AVENUE	Post Office, Depth over floor.	1	-	66.07	-	0.15	0.39	0.24	Satisfactory fit
32	2	PROGRESS AVENUE	BC-48, Bing Lee, Depth over floor.	1	-	66.04	-	0.30	0.31	0.01	Good fit
33	10	HILLVIEW ROAD	BC-58, Just Rags	1	65.84	66.02	0.18	-	0.37	-	Satisfactory fit
34	8	HILLVIEW ROAD	Depth over floor.	1	-	65.77	-	0.40	0.40 *	0.00	Good fit
35	8A	HILLVIEW ROAD	Depth at road.	1	-	65.94	-	0.95	0.89	-0.06	Good fit
36	4	HILLVIEW ROAD	BC-54, Previously Beckers Hairdressers	1	65.58	65.68	0.10	-	0.27	-	Good fit
37	6	HILLVIEW ROAD	Depth over floor.	1	-	65.71	-	0.30	0.44 *	0.14	Satisfactory fit
38	6	HILLVIEW ROAD	BC-56, Previously Mr Craft	1	65.87	65.94	0.07	-	0.79	-	Good fit
38A	16	RAILWAY PARADE	BC-62, Previously Towntalk Butchery, Depth over floor.	1	68.37	68.22	-0.15	0.15	0.10 *	-0.05	Satisfactory fit
39	6	RAILWAY PARADE	Depth over floor.	1	-	68.22	-	0.60	0.22 *	-0.38	
40	17	RAILWAY PARADE	Reported flooded in Nov 84.	1, 2	-	68.22	-	-	0.08	-	
41	15	RAILWAY PARADE	Reported flooded in Nov 84.	1, 2	-	68.22	-	-	0.15	-	
42	13	RAILWAY PARADE	BC-63, Previously Commonwealth Bank, Depth over floor.	1, 2	68.21	68.22	0.01	0.10	0.21 *	0.11	Good fit to flood level
43	115	ROWE STREET	Depth over floor.	1, 2	-	69.22	-	0.05	0.04 *	-0.01	Good fit
44	112	ROWE STREET	Reported flooded in Nov 84.	2	-	69.83	-	-	0.10	-	
45	110	ROWE STREET	Reported flooded in Nov 84.	2	-	69.80	-	-	0.11	-	
46	106-108	ROWE STREET	Reported flooded in Nov 84.	2	-	69.81	-	-	0.15	-	
47	100	ROWE STREET	Reported flooded in Nov 84.	2	-	70.30	-	-	0.43	-	
48	100	ROWE STREET	Reported flooded in Nov 84.	2	-	70.24	-	-	0.10	-	
49	96	ROWE STREET	Reported flooded in Nov 84.	2	-	70.34	-	-	0.02	-	
50	94	ROWE STREET	Depth over floor.	2	-	NA	-	0.50	NA	-	Historical depth could not be replicated
51	92	ROWE STREET	Reported flooded in Nov 84.	2	-	NA	-	-	NA	-	Historical flooding could not be replicated
51A	263	RYEDALE ROAD	BC-64, Level and depth in garage.	2	79.28	79.37	0.09	0.25	0.35 *	0.10	Good fit to flood level
52	263	RYEDALE ROAD	Depth in yard.	2	-	79.41	-	0.75	0.55	-0.20	Satisfactory fit
53	31	DENISTONE ROAD	Depth in garage.	2	-	81.29	-	0.70	0.06	-0.64	Historical depth could not be replicated
54	23	DENISTONE ROAD	Depth in yard.	2	-	80.67	-	0.75	0.19	-0.56	Historical depth could not be replicated
55	21	DENISTONE ROAD	BC-65, Level and depth in garage.	2	81.56	81.37	-0.19	0.30	0.16 *	-0.14	Satisfactory fit
55A	21	DENISTONE ROAD	Depth in yard.	2	-	81.23	-	0.60	0.14	-0.46	Historical depth could not be replicated
56	46	FOURTH AVENUE	BC-66, Garage and Depth in garage.	2	85.20	85.18	-0.02	0.50	0.13	-0.37	Good fit
56A	46	FOURTH AVENUE	Depth in yard.	2	-	86.55	-	0.30	0.22	-0.08	Good fit
57	26	EDGAR STREET	Reported flooded in Nov 84.	2	-	74.75	-	-	0.16	-	
58	53	DOOMBEN AVENUE	Reported flooded in Nov 84.	2	-	60.95	-	-	0.06	-	
59	20	BALL AVENUE	BC-70, Level at corner of hall.	2	61.00	60.91	-0.09	-	0.49	-	Good fit
60	2	BALL AVENUE	BC-71, Level at garage.	3	59.90	59.87	-0.03	-	0.17	-	Good fit
61	13	BERTRAM STREET	BC-72, Level under house.	3	58.51	58.78	0.27	-	0.84 *	-	Satisfactory fit
62	3	CASSIA PLACE	Reported flooded in Nov 84.	3	-	NA	-	-	NA	-	
63	4	CASSIA PLACE	Reported flooded in Nov 84.	3	-	58.75	-	-	1.01	-	
64	5	CASSIA PLACE	BC-74, Level and depth in caravan port.	3	58.47	58.49	0.02	0.75	0.61	-0.14	Good fit
65	26B	VIMIERA ROAD	Depth in garage.	3	-	58.04	-	0.40	0.53	0.13	Satisfactory fit +
65A	26B	VIMIERA ROAD	Depth over floor. (+0.25m)	3	57.84	57.93	0.09	-	-	-	Good fit +
65B	28	VIMIERA ROAD	Depth in yard.	3	-	58.06	-	0.80	0.81	0.01	Assumed deepest corner of yard
66	10	JUPP STREET	Reported flooded in Nov 84.	3	-	61.16	-	-	0.43	-	
67	17	MILHAM AVENUE	Reported flooded in Nov 84.	3	-	67.31	-	-	0.06	-	
68	15	MILHAM AVENUE	Reported flooded in Nov 84.	3	-	67.31	-	-	0.47	-	
69	10	MILHAM AVENUE	Reported flooded in Nov 84.	3	-	68.92	-	-	0.72	-	
70	19	HUNTS AVENUE	Reported flooded in Nov 84.	3	-	73.63	-	-	0.03	-	
71	14	BELLAMY AVENUE	Reported flooded in Nov 84.	3	-	70.61	-	-	0.18	-	
72	7	ABUKLEA ROAD	Reported flooded in Nov 84.	4	-	67.39	-	-	0.25	-	
73	2	CULLODEN ROAD	Depth in garage	4	-	68.16	-	0.90	0.39 *	-0.51	Historical depth could not be replicated
74	21	ABUKLEA ROAD	Reported flooded in Nov 84.	3, 4	-	72.79	-	-	0.29	-	
75	134	BALACLAVA ROAD	Depth in house	4	-	81.59	-	0.15	0.14 *	-0.01	Good fit
76	4	BRUNTON PLACE	Reported flooded in Nov 84.	5	-	68.80	-	-	0.14	-	
77	2	BRUNTON PLACE	Reported flooded in Nov 84.	5	-	69.17	-	-	0.20	-	
78	1	EASTWOOD AVENUE	BC-67, Level in garage.	1	66.17	66.25	0.08	-	1.08	-	Good fit

* Depth relative to ground surface, not building floor level.
+ Location amended following resident's advice.

Max Error 0.40 m
Mean Error 0.02 m
Std Error 0.13 m

Total Points 23
Within 0.1m 18
Within 0.1m to 0.2m 3
Within 0.2m to 0.3m 1
Greater than 0.3m 1

In comparison the more sophisticated TUFLOW overland flow modelling showed that with a nil culvert blockage factor at Progress Avenue, the model was generating levels which were typically only marginally higher than the local historic flood levels (reference **Table 5** Flood Records 29 to 38). Also at the Auld Avenue and Shaftesbury Road culvert crossings (reference **Table 5** Flood Records 4 and 11 respectively) the ‘unblocked’ TUFLOW model had achieved a very good fit to the historic flood levels. Based on these findings, the TUFLOW calibration model reflects ‘unblocked’ conditions at all culvert crossing locations.

4.1.3 Public Review

The set of November 1984 flood maps shown in **Figure 5** were placed on public display in July and August 2007 and landowners in the study area were formally invited to review them. Feedback forms were available at the display so that participants could provide written comments. Twelve forms were received and of those twelve, nine provided comments about the displayed maps. In response to a question on “your overall assessment of the accuracy of the model”, four said they were “accurate”, three said “don’t know”, one said “poor match” and one did not answer. Each of the “don’t know” and “poor match” response forms included additional comments and a review of those comments found that the flood maps were generally successful in reproducing the local area flood regimes.

During the afternoon and evening of 9 August 2007, the display was manned by Council officers to provide the opportunity for the community to have the study explained to them and to receive answers to any questions that they had. As a result, two people made observations about the information provided in the 1984 flood maps. The first felt that the maps accurately represented the historic flood while the second, although questioning the accuracy of the modelling in relation to the flood regime experienced at their Rutledge Street residence, did not provide details of their experience.

These findings, and the absence of new details such as flood depths, led to the conclusion that there were no specific grounds for amending the displayed model.

4.2. VERIFICATION OF MODELS TO OTHER FLOOD EVENTS

The 1991 study documents how the questionnaire responses also identified floods occurring in late April 1988 and on 7 and 10 February 1990. Rainfall temporal patterns as recorded at West Epping and Ryde Pumping Station were imported into the study’s RAFTS hydrologic model and flows throughout the catchment were calculated for these storms. While some differences in individual storm rainfall patterns and totals were observed — and these generated differing peak flows (especially for the 8/11/84 and 10/02/90 events) — the report concluded that the April 1988 and February 1990 events were probably “slightly less than a 5 year flood event”, while the November 1984 event “was probably similar to a 20 year flood event”.

Unfortunately while a number of the 1991 questionnaire respondents provided data about flooding experienced in February 1990 many of them did not distinguish between the 7 and 10 February storms (and as a consequence, most of the February 1990 surveyed flood levels presented in the report's Appendix G do not include the actual day of the month).

As a result there is no clear picture of how the flooding which was associated with those two events differed from each other. While the result is a rather confusing picture, it is noted that the modelled 7 and 10 February 1990 flows presented in the report are in fact quite similar and therefore it would appear that the two events were very similar in magnitude. Hence perhaps it is not surprising that many of the respondents may have been unable to distinguish differences between their experiences of the two events.

While the City of Ryde flood data base distinguishes between the different storm dates in February 1990, the corresponding descriptions provide only general guidance on the extent of problems experienced and there is very little data about flood depths at specific locations.

Considering all of the above, there is only very limited data about flooding that occurred in either of the February 1990 storms. As a consequence there is insufficient data for model verification purposes.

Similarly there is only very limited flood level/depth data for the April 1988 storm event which made that event also not suitable for model verification purposes.

4.3. DESIGN FLOOD MODELLING

4.3.1 Model Operation and Mapping

Having achieved an overall satisfactory replication of flood depths and flood levels that were observed in the major flood of 8 November 1984, the calibrated TUFLOW model formed the platform for the subsequent modelling of the design 5 year, 10 year, 50 year and 100 year ARI and Probable Maximum Flood (PMF) events that were specified in Council's study brief.

The principal changes made to the calibration model consisted of:

- (a) insertion of the various stormwater upgrades (as provided by Council) which have been undertaken in the last twenty years including the 2007 stage of the micro tunnel in Rowe Street East and Railway Parade, and
- (b) inclusion of the Committee's adopted blockage policy, as follows:
 - a blockage factor of 25% applied to culverts whose diagonal dimension exceeds six metres;
 - a blockage factor of 35% applied to culverts whose diagonal dimension is between two metres and six metres;

- a blockage factor of 50% applied to culverts whose diagonal dimension is less than two metres; and
- a blockage factor of 35% applied to culvert fences that are perpendicular to the flow direction.

As noted earlier, the DRAINS design rainfall data was supplied by Council. Following modelling of a range of design storm durations within DRAINS, it was found that the critical storm duration throughout the hydraulic modelling area was 120 minutes for the 5 year to 100 year ARI events and 15 minutes for the PMF event. Hence the corresponding DRAINS output hydrographs were used for the TUFLOW modelling.

Table 6 lists the TUFLOW-derived peak conduit and overland flows for a range of locations which are shown in **Figure 3**.

Figure 4 is the key plan showing the location of the six component map sheets, while Sheets 1 to 6 of **Figures 6 to 8** define the 5 year ARI, 100 year ARI and PMF flood inundation and contour maps.

Blockage reduces culvert capacities and the corresponding increases in flood level mean that additional floodplain storage areas come into play upstream of each 'blocked' culvert. These changes — which may impact on downstream flood flows and levels — have been assessed using the TUFLOW model. By running the model for the case of 'nil' culvert blockage and comparing the results with the 'design' model run, it was found that some flood levels were higher for the 'nil' blockage case, but only in the area downstream of all culverts. Since the Blaxland Road culvert is the most downstream of these culverts, the flood level increases only occur downstream of that crossing (and in that area the increase was found to be between 0.2 and 0.3 metres in the 100 year event). The data presented in **Figures 6 to 8** are compilations of the higher flood levels generated by comparison of the "blocked" and "unblocked" TUFLOW model results.

4.3.2 Draft Flood Risk Precincts

To assist with land use planning in the study area, the floodplains have been mapped into various flood risk precincts.

Flood risk can be thought of mathematically as the probability of something happening, multiplied by its consequences. These consequences relate to property damage and personal safety. It is important not to confuse 'flood risk' with 'flood hazard' or 'provisional flood hazard' which generally relate to a source of potential harm or damage in a specific flood. (These terms are defined in the *Floodplain Development Manual*). For example, a site may experience high hazard conditions in a 100 year flood and low hazard conditions in a 5 year flood.

On the other hand, flood risks as used here to define land use planning precincts, do not relate to a single flood, but rather to the combined effect of all floods. Thus the risk precincts consider the probabilities and consequences of flooding over the full spectrum of flood frequencies that might occur at a site, not just those that occur during a single flood.

TABLE 6: TUFLOW MODEL PEAK FLOW SUMMARY (m3/s)

FLOOD EVENT (and culvert blockage conditions)	AULD_AV Total	RAILWAY Total	BLAXLAND RD Total	FORRESTER_PK Total
5 year ARI unblocked	35.4	42.2	49.2	64.5
5 year ARI blocked	33.8	39.2	43.7	57.0
10 year ARI unblocked	41.4	51.1	58.7	75.4
10 year ARI blocked	37.9	44.3	49.5	66.6
20 year ARI unblocked	47.8	58.3	66.4	89.1
20 year ARI blocked	41.9	47.3	53.9	75.0
50 year ARI unblocked	54.0	61.5	70.7	98.5
50 year ARI blocked	51.3	50.2	58.4	83.6
100 year ARI unblocked	61.9	64.2	74.5	106.5
100 year ARI blocked	58.5	52.4	62.4	91.3
PMF unblocked	226.7	93.3	109.3	211.3
PMF blocked	230.5	89.5	102.5	191.4

FLOOD EVENT (and culvert blockage conditions)	HARRISON_AV			WENTWORTH_RD/ RUTLEDGE_ST			RUTLEDGE_ST-RUTLEDGE_ST			FIRST_AV			WELBY_ST		
	Pipe	Overland	Total	Pipe	Overland	Total	Pipe	Overland	Total	Pipe	Overland	Total	Pipe	Overland	Total
5 year ARI unblocked	1.5	0.7	2.1	1.3	1.3	2.6	1.1	2.5	3.7	1.6	2.3	3.6	0.8	7.7	8.4
5 year ARI blocked	1.5	0.7	2.1	1.3	1.3	2.6	1.1	2.5	3.7	1.6	2.3	3.5	0.8	7.9	8.6
10 year ARI unblocked	1.5	1.1	2.5	1.3	1.6	3.0	1.1	3.1	4.2	1.6	3.1	4.1	0.9	9.2	9.9
10 year ARI blocked	1.5	1.1	2.5	1.3	1.7	3.0	1.1	3.1	4.2	1.6	3.1	4.1	0.9	9.2	9.9
20 year ARI unblocked	1.5	1.8	3.2	1.4	2.2	3.5	1.2	3.9	5.0	1.6	4.2	5.2	0.9	11.2	12.0
20 year ARI blocked	1.5	1.8	3.2	1.4	2.2	3.5	1.2	3.9	5.0	1.6	4.2	5.2	0.9	11.2	12.0
50 year ARI unblocked	1.5	2.3	3.7	1.4	2.6	3.9	1.2	4.6	5.8	1.6	5.1	6.1	0.9	13.2	14.1
50 year ARI blocked	1.5	2.3	3.7	1.4	2.6	3.9	1.2	4.6	5.7	1.6	5.1	6.1	0.9	13.2	14.1
100 year ARI unblocked	1.5	2.8	4.2	1.4	3.0	4.4	1.2	5.2	6.4	1.6	6.0	6.9	0.9	15.1	16.0
100 year ARI blocked	1.5	2.8	4.2	1.4	3.0	4.4	1.2	5.3	6.5	1.6	6.0	6.9	1.0	15.1	16.0
PMF unblocked	1.9	14.4	16.1	1.4	15.7	17.2	1.3	24.8	26.0	1.7	21.7	22.3	1.2	53.3	54.1
PMF blocked	1.9	14.3	16.1	1.4	16.0	17.4	1.3	24.6	25.9	1.7	21.8	22.4	1.2	53.3	54.1

Notes: Peak flow derived by summation conduit and overland flow hydrographs (where applicable)

FLOOD EVENT (and culvert blockage conditions)	LANSLOWNE_ST			BALACLAVA_RD			CULLODEN_RD			MAWARRA_CR		
	Pipe	Overland	Total	Pipe	Overland	Total	Pipe	Overland	Total	Pipe	Overland	Total
5 year ARI unblocked	1.2	1.3	2.5	14.1	1.4	15.5	3.1	2.8	5.9	1.3	0.7	2.0
5 year ARI blocked	1.2	1.4	2.5	12.8	2.6	15.3	3.1	2.8	5.9	1.3	0.7	2.0
10 year ARI unblocked	1.2	1.5	2.7	14.4	3.6	18.0	3.1	4.0	7.0	1.3	0.8	2.1
10 year ARI blocked	1.2	1.6	2.7	13.1	5.3	18.4	3.1	4.0	7.0	1.3	0.8	2.1
20 year ARI unblocked	1.2	2.1	3.3	14.4	8.3	22.3	3.1	5.4	8.4	1.3	1.0	2.4
20 year ARI blocked	1.2	2.1	3.3	13.3	10.0	22.7	3.1	5.4	8.4	1.3	1.0	2.4
50 year ARI unblocked	1.2	2.6	3.8	14.3	12.1	25.7	3.1	6.7	9.7	1.4	1.3	2.7
50 year ARI blocked	1.2	2.6	3.8	13.3	13.2	25.7	3.1	6.7	9.7	1.4	1.4	2.7
100 year ARI unblocked	1.2	3.1	4.3	14.3	16.1	29.3	3.1	8.1	11.1	1.4	1.7	3.1
100 year ARI blocked	1.2	3.1	4.3	13.3	17.0	29.2	3.1	8.1	11.1	1.4	1.6	3.0
PMF unblocked	1.5	15.8	17.2	14.1	82.9	92.2	3.5	37.7	40.7	1.8	9.7	11.4
PMF blocked	1.5	15.7	17.2	12.8	83.4	92.3	3.5	37.8	40.7	1.8	9.6	11.4

Notes: Peak flow derived by summation conduit and overland flow hydrographs (where applicable)

As the risk precincts are to be used for land use planning purposes, the risk classification system assumes typical residential landuses on all land and ignores the existing uses¹.

After considering the consequences of flooding during the frequent events such as the 5 year ARI, through to the very rare events such as the PMF, it was decided to classify the floodplains into three flood risk precincts: 'high', 'medium' and 'low'. Sheets 1 to 6 of **Figure 9** show the draft high, medium and low flood risk precincts.

Whilst the risk precincts were defined using the above procedure, it was necessary to determine a simplified method by which the precincts could be conveniently and consistently mapped². The following system was used for this mapping:

- ▶ **High flood risk precinct** was mapped as the area of the floodplain which would be provisionally high hazard in a 100 year flood (as according to Figure L2 of the *Floodplain Development Manual*). In addition to including 100 year provisionally high hazard areas in the high flood risk precinct, other parts of the floodplain were also considered where:
 - (a) in a 100 year event, significant evacuation difficulties exist (e.g. islands surrounded by provisionally high hazard conditions); or
 - (b) in floods rarer than a 100 year event, the potential for significant or extreme consequences exist which are not otherwise apparent from consideration of only the 100 year flood or more frequent flood events. For example, catchment diversions, areas subject to overtopping of levees and embankments, areas subject to severe bank or bed erosion, or other conditions that can lead to unusually high depths, velocities or otherwise produce very dangerous flood conditions. Whilst the probabilities of these events might be low, the consequences can in some cases be extreme and thus produce a high risk.
- ▶ **Medium flood risk precinct** was mapped as the remaining area inundated in a 100 year flood event and beyond the 'high' flood risk precinct. For reasons similar to

¹ This is because the precincts are to be used to determine the appropriateness of future development. Thus vacant and developed land in similar locations within a floodplain would be classified into the same risk precinct, despite the fact that the consequences of flooding on the developed land are likely to be much higher than on the vacant land.

² Such mapping is preferably undertaken in a geographic information system (GIS) and may need to be carried out by Council staff or other consultants at some time in the future. Further, whilst the present study has been completed with the best available hydraulic and topographic data, it is recognised that better data may become available in the future, e.g. during the preparation of individual DAs, and therefore some of the risk precinct mapping may need to be revised. Therefore it was necessary to provide a simplified numerical procedure to map the flood risk precincts and this was developed for Eastwood and Terrys Creek based largely on the depths and velocities in a 100 year flood. Nevertheless the analysis carried out indicates that this simplified system ensures that the resultant mapping will be consistent with the more complete definition of risk precincts involving consideration of all flood events. Note also that further checks would be required before this simplified procedure could be considered for risk precinct mapping in other catchments within the LGA.

those discussed above under (a) and (b), it is possible for some otherwise 'low' flood risk areas to be elevated to 'medium', when the flood conditions warrant it.

- ▶ **Low flood risk precinct** was then mapped as all remainder of the floodplain (defined as the limit of inundation in a PMF) but not identified as either a high flood risk or medium flood risk precinct.

The derivation and application of the draft risk precincts will be confirmed by the Committee as the management phase of the current study is completed.

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- › Department of Environment and Climate Change;
- › State Emergency Service;
- › RailCorp;
- › Sydney Water Corporation;
- › the Floodplain Risk Management Committee; and
- › the NSW State Government.

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7. GLOSSARY

Note that terms shown in bold are described elsewhere in this Glossary.

100 year flood	A flood that occurs on average once every 100 years. Also known as a 1% flood. See annual exceedence probability (AEP) and average recurrence interval (ARI) .
50 year flood	A flood that occurs on average once every 50 years. Also known as a 2% flood. See annual exceedence probability (AEP) and average recurrence interval (ARI) .
20 year flood	A flood that occurs on average once every 20 years. Also known as a 5% flood. See annual exceedence probability (AEP) and average recurrence interval (ARI) .
afflux	The increase in flood level upstream of a constriction of flood flows. A road culvert, a pipe or a narrowing of the stream channel could cause the constriction.
annual exceedence probability (AEP)	AEP (measured as a percentage) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 1% AEP flood is a flood that has a 1% chance of occurring, or being exceeded, in any one year. It is also referred to as the '100 year flood' or 1 in 100 year flood'. The terms 100 year flood , 50 year flood , 20 year flood etc, have been used in this study. See also average recurrence interval (ARI) .
Australian Height Datum (AHD)	A common national plane of level approximately equivalent to the height above sea level. All flood levels , floor levels and ground levels in this study have been provided in metres AHD.
average annual damage (AAD)	Average annual damage is the average flood damage per year that would occur in a nominated development situation over a long period of time.
average recurrence interval (ARI)	ARI (measured in years) is a term used to describe flood size. It is the long-term average number of years between floods of a certain magnitude. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years. The terms 100 year flood , 50 year flood , 20 year flood etc, have been used in this study. See also annual exceedence probability (AEP) .
catchment	The land draining through the main stream, as well as tributary streams.
Development Control Plan (DCP)	A DCP is a plan prepared in accordance with Section 72 of the <i>Environmental Planning and Assessment Act, 1979</i> that provides detailed guidelines for the assessment of development applications.
DECC	Department of Environment and Climate Change, formerly the Department of Natural Resources.

discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m³/s) . Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving.
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the <i>Local Government Act 1993</i> .
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
EP&A Act	<i>Environmental Planning and Assessment Act, 1979.</i>
extreme flood	An estimate of the probable maximum flood (PMF) , which is the largest flood likely to occur.
flood	A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunamis.
flood awareness	An appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood level	The height of the flood measured with reference to a specified datum such as Australian Height Datum (eg the flood level was 7.8m AHD). Terms also used include stage and water level .
flood liable land	Land susceptible to flooding up to the probable maximum flood (PMF) . Also called flood prone land . Note that the term 'flood liable land' now covers the whole of the floodplain , not just that part below the flood planning level (FPL) .
flood planning levels (FPLs)	The combinations of flood levels (derived from significant historical events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans . The concept of flood planning levels supersedes the 'designated flood' or the 'flood standard' used in earlier studies.
flood prone land	Land susceptible to flooding up to the probable maximum flood (PMF) . Also called flood liable land . Note that the term 'flood prone land' now covers the whole of the floodplain , not just that part below the flood planning level (FPL) .
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate damages during a flood .

flood study	A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood sizes.
floodplain	The area of land that is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land or flood liable land .
Floodplain Risk Management Plan	A management plan developed in accordance with the principles and guidelines in the <i>Floodplain Development Manual</i> (NSW Government, 2005). (Note that the term 'risk' is often dropped in common usage and 'Floodplain Risk Management Plans' are referred to as 'Floodplain Management Plans').
Floodplain Risk Management Study	A study carried out in accordance with the principles and guidelines in the <i>Floodplain Development Manual</i> (NSW Government, 2005) that assess options for minimising the danger to life and property during floods . These measures, referred to as 'floodplain management measures/options' aim to achieve an equitable balance between environmental, social, economic, financial and engineering considerations. (Note that the term 'risk' is often dropped in common usage and 'Floodplain Risk Management Studies' are referred to as 'Floodplain Management Studies').
floodway	Those areas of the floodplain where a significant discharge of water occurs during floods . Floodways 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 .
flow	See discharge
foreshore building line	A line fixed by resolution of Council in respect of land fronting any bay, river, creek, lagoon, harbour or ocean, which provides a setback distance where buildings or other structures would normally be prohibited.
freeboard	Provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the flood planning level (FPL) is actually provided. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain , such as wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as climate change. This factor of safety is typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this study the hazard is flooding which has the potential to cause damage to the community. See high hazard and low hazard .
high hazard	Possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity .
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak discharges , flow volumes and the derivation of hydrographs for a range of floods.
Local Environmental Plan (LEP)	A Local Environmental Plan is a plan prepared in accordance with the <i>Environmental Planning and Assessment Act</i> , 1979, that defines zones, permissible uses within those zones and specifies development standards and other special matters for consideration with regard to the use or development of land.
low hazard	Should it be necessary, truck could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.
m AHD	Metres Australian Height Datum (AHD) .
m/s	Metres per second. Unit used to describe the velocity of floodwaters.
m³/s	Cubic metres per second or 'cumecs'. A unit of measurement for creek or river flows or discharges . It the rate of flow of water measured in terms of volume per unit time.
merit approach	The principles of the merit approach are embodied in the <i>Floodplain Development Manual</i> (NSW Government, 2005) and weigh up social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains .
overland flowpath	The path that floodwaters can follow as they are conveyed towards the main flow channel or if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters leaving the confines of the main flow channel may or may not re-enter the main channel from which they left – they may be diverted to another watercourse.
peak discharge	The maximum flow or discharge during a flood.
present value	In relation to flood damage, is the sum of all future flood damages that can be expected over a fixed period (usually 20 years) expressed as a cost in today's value.
probable maximum flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land , that is, the floodplain .
reliable access	During a flood , reliable access means the ability for people to safely evacuate an area subject to imminent flooding within effective warning time , having regard to the depth and velocity of floodwaters, the suitability of the evacuation route, and other relevant factors.
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

runoff	The amount of rainfall that ends up as flow in a stream, also known as rainfall excess.
SES	State Emergency Service of New South Wales.
stage	Equivalent to water level (both measured with reference to a specified datum). See flood level .
stage–damage curve	A relationship between different water depths and the predicted flood damage at that depth.
velocity	The term used to describe the speed of floodwaters, usually in m/s .
water level	Equivalent to stage (both measured with reference to a specified datum). See flood level .
water surface profile	A graph showing the height of the flood (stage , water level or flood level) at any given location along a watercourse at a particular time.