Palerang Council

BRAIDWOOD CREEKS FLOOD STUDY

FINAL REPORT

April 2005

Project No. W4292

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Cover: Monkittee Creek bridge at Wallace Street (Kings Highway), Braidwood.

FOREWORD

This study has been prepared under the direction of the Braidwood Floodplain Management Committee in order to manage the flood risk associated with development on the floodplains of the Braidwood Creeks. The study has been undertaken in accordance with the NSW Government's *Flood Policy*.

The 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 Flood Policy, the management of flood prone land remains the responsibility of local government. To facilitate this the Government provides funding in support of floodplain management programs.

The policy provides for a floodplain risk 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.

Palerang Council is responsible for local planning and land management in the study catchments including the management of the floodplain and of the drainage system. The Council proposes to prepare a comprehensive floodplain risk management plan for the catchment in accordance with the NSW Government's *Floodplain Management Manual*.

This Flood Study is the first stage in the formulation of a comprehensive floodplain risk management plan for the Braidwood Creeks catchment. It is expected that this study will serve as a sound and comprehensive basis for the subsequent assessment of floodplain risk management actions and measures leading to the preparation and adoption of a plan.

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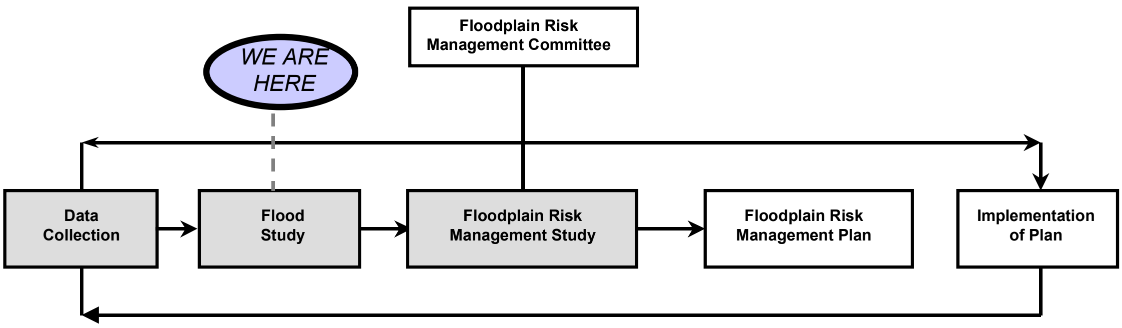
EXECUTIVE SUMMARY

Palerang Council, through the Braidwood Floodplain Management Committee, is in the process of developing a floodplain risk management strategy and plan for Braidwood.

The Need for the Study

The NSW Government's *Floodplain Management Manual* (NSW Government, 2001) provides guidance for Councils on developing solutions to existing flooding problems and ensuring new developments are compatible with the flood hazard and do not create additional flooding problems in other areas. The Manual sets out a process (shown below) for investigating, developing and implementing a Floodplain Risk Management Plan for flood-liable areas.



While Braidwood has not experienced any major floods in recent times, there is the potential for a major flood to occur at any time.

The former Tallaganda Shire Council with the assistance of the Department of Infrastructure Planning and Natural Resources (DIPNR) (formerly the Department of Land and Water Conservation), originally commissioned the preparation of this Flood Study as the first stage in a process that aims to ensure that:

- information on the nature of possible future flooding is available to the public;
- the use of flood liable land is planned and managed in a manner compatible with the risks associated with the assessed frequency and severity of flooding;
- new development on floodplains does not cause an increase in flood hazard and damage potential; and
- appropriate and effective flood warning systems exist, and emergency services are available for future flooding.

Study Objectives

The primary objective of the Braidwood Creeks Flood Study is to determine the flood behaviour along Gillamatong, Monkittee, Flood and Recreation Ground Creeks within the township of Braidwood and for a distance of 1 kilometre from the Braidwood town boundary. The floodplain that this study covers extends to the estimated limit of the Probable Maximum Precipitation (PMP) flood.

Study Area

The hydraulic study area is the Braidwood Township and areas up to one kilometre upstream and downstream along the creeks. It is defined generally by the 2(v) Zone of the Tallaganda Local Environmental Plan.

The town and study area is located within in the upper reaches of the Shoalhaven River catchment. The catchments of Gillamatong Creek, Monkittee Creek, Flood Creek and Recreation Ground Creek at Braidwood have a total area of 77 km^2.

What is in this Study

The flood study uses computer modelling techniques to predict the magnitude and extent of flooding at Braidwood for a range of event ARIs (Average Recurrence Interval). The results were compared with the limited available information on historical floods in Braidwood.

Hydrological modelling was used to predict flood flows for a range of events up to and including the Probable Maximum Flood (PMF). In turn the estimated historical and “design” flood flows have been converted into flood levels within the hydraulic study area through hydraulic (flood level) modelling. These results are then used to assess hydraulic categories and hazards.

The results of this study are presented in the form of flood levels, profiles and approximate flood extents. Average flow velocities and discharge proportions for main channels and overbank areas are also tabulated for the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI design storms and the Probable Maximum Precipitation (PMP) event. A map of hydraulic categories and Hazard zones is also presented.

Future Stages

This Flood Study forms the stage in the process of floodplain risk management at Braidwood. It provides information to Council and the community on the existing flood situation. Subject to the availability of funding it will be followed by a Floodplain Risk Management Study which will examine the possible non-structural measures and structural works to manage the flood risks at the town.

INTRODUCTION

BACKGROUND

Palerang Council, through the Braidwood Floodplain Management Committee, is in the process of developing a floodplain management strategy and plan for Braidwood.

The primary objective of the Braidwood Creeks Flood Study is to determine the flood behaviour along Gillamatong, Monkittee, Flood and Recreation Ground Creeks within the township of Braidwood and for a distance of 1 kilometre from the Braidwood town boundary. The floodplain that this study covers extends to the estimated limit of the Probable Maximum Precipitation (PMP) flood.

THE NEED FOR THE STUDY

While Braidwood has not experienced any major floods in recent times, there is the potential for a major flood to occur at any time.

The NSW Government's *Floodplain Management Manual* (NSW Government, 2001) provides guidance for Councils on developing solutions to existing flooding problems and ensuring new developments are compatible with the flood hazard and do not create additional flooding problems in other areas.

The Braidwood Floodplain Management Committee, with the assistance of the Department of Infrastructure Planning and Natural Resources (DIPNR) commissioned the preparation of this Flood Study as the first stage in a process that aims to ensure that:

- information on the nature of possible future flooding is available to the public;
- the use of flood liable land is planned and managed in a manner compatible with the assessed frequency and severity of flooding;
- new development on floodplains does not cause an increase in flood hazard and damage potential; and
- appropriate and effective flood warning systems exist, and emergency services are available for future flooding.

OBJECTIVES

As stated in Council's Brief, the primary objective of the study was to determine the flood behaviour along Gillamatong, Monkittee, Flood and Recreation Ground Creeks within the township of Braidwood and up to a distance of 1 kilometre from the Braidwood Town boundary.

The study was to produce information on flood levels, velocities and flows for a full range of flood events under existing catchment and floodplain conditions. The floods that have been investigated are the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI floods and the Probable Maximum Flood (PMF).

This study provides the information on flood behaviour to support a subsequent Floodplain Risk Management Study where a detailed assessment of flood mitigation options and floodplain risk management actions and measures will be undertaken.

WHAT IS IN THE STUDY

Drawing on the available limited information on historical floods in Braidwood, hydrological modelling of the catchment was carried out. Estimates of the flood flows generated by storms that have occurred previously and may occur in the future in the Gillamatong, Monkittee, Flood and Recreation Ground Creek catchments are described.

In turn estimated historical and “design” flood flows have been converted into flood levels within the hydraulic study area through hydraulic (flood level) modelling. These results are then used to assess hydraulic categories and hazards.

The results of this study are presented in the form of flood profiles and flood level contours. Average flow velocities and discharge proportions for main channels and overbank areas are also tabulated for the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI design storms and the Probable Maximum Precipitation (PMP) event. A map of hydraulic categories and Hazard zones is also presented.

> **Note:** This study was originally commissioned by the former Tallaganda Shire Council. Tallaganda Shire has since been absorbed into the Palerang Council area. For a period of 2004 the Council was known as Eastern Capital City Regional Council.

BACKGROUND

HOW THIS STUDY WAS UNDERTAKEN

This Study was carried out in accordance with the NSW Government's *Floodplain Management Manual* (NSW Government, 2001).

The Braidwood Floodplain Management Committee (FPMC) is managing the floodplain risk management process in accordance with flowchart given in **Figure 1**. This has included the commissioning and reviewing the progress of the preparation of this study by Cardno Willing (NSW) Pty Ltd.

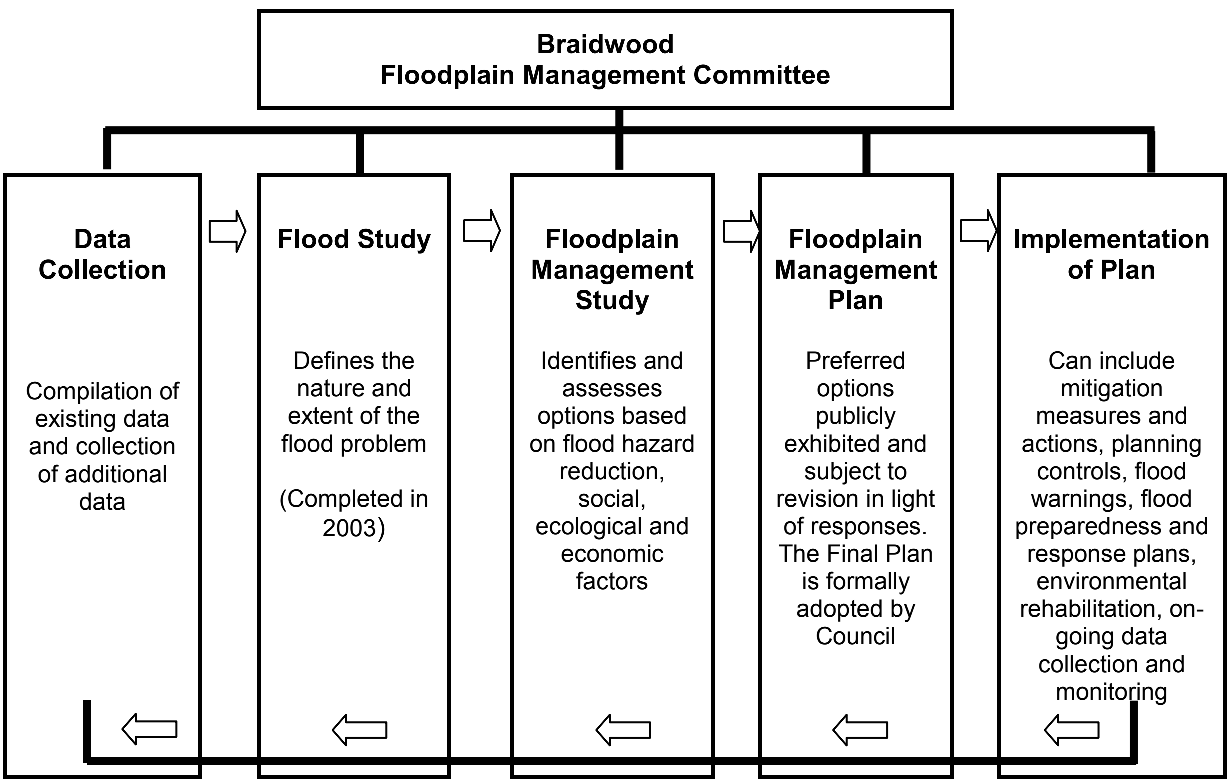


Figure 1
Floodplain Management Process
(adapted from NSW Government, 2001)

The flood study was divided into a series of sequential tasks that are summarised as follows:

Task 1 - *Compilation and Review of Available Information* to collect all available data of relevance to the study and to assess the magnitude and nature of the flooding problem.

Task 2 - *Topographical Survey* to gather cross section information for the purposes of hydraulic modelling and hydraulic and hazard categorisation.

Task 3 - *Acquisition of Additional Information* if required.

Task 4 - *Establish a Hydrological (flood flow) Model* to estimate catchment runoff during selected historical flood events as well as design floods together with the PMP flood.

Task 5 - *Hydraulic Modelling* of the creeks and their floodplains within the town area.

Task 6 – *Calibration, Verification and Sensitivity of Models* to adjust the model parameters to best match one or more historical floods including sensitivity analyses of the importance of model parameters.

Task 7 - *Modelling Design Floods* using the calibrated models to estimate the flood profiles, flood depths, flood velocities, and flow distribution across the floodplains for existing conditions.

Task 8 - *Hydraulic and Hazard Categorisation* to produce provisional flood inundation maps to delineate areas of different hydraulic and hazard categories.

Task 9 - *Preparation of Draft Flood Study Report* on the overall findings of the study.

Task 10 – *Final Report and Handover of Models* to handover all data files and results to Council.

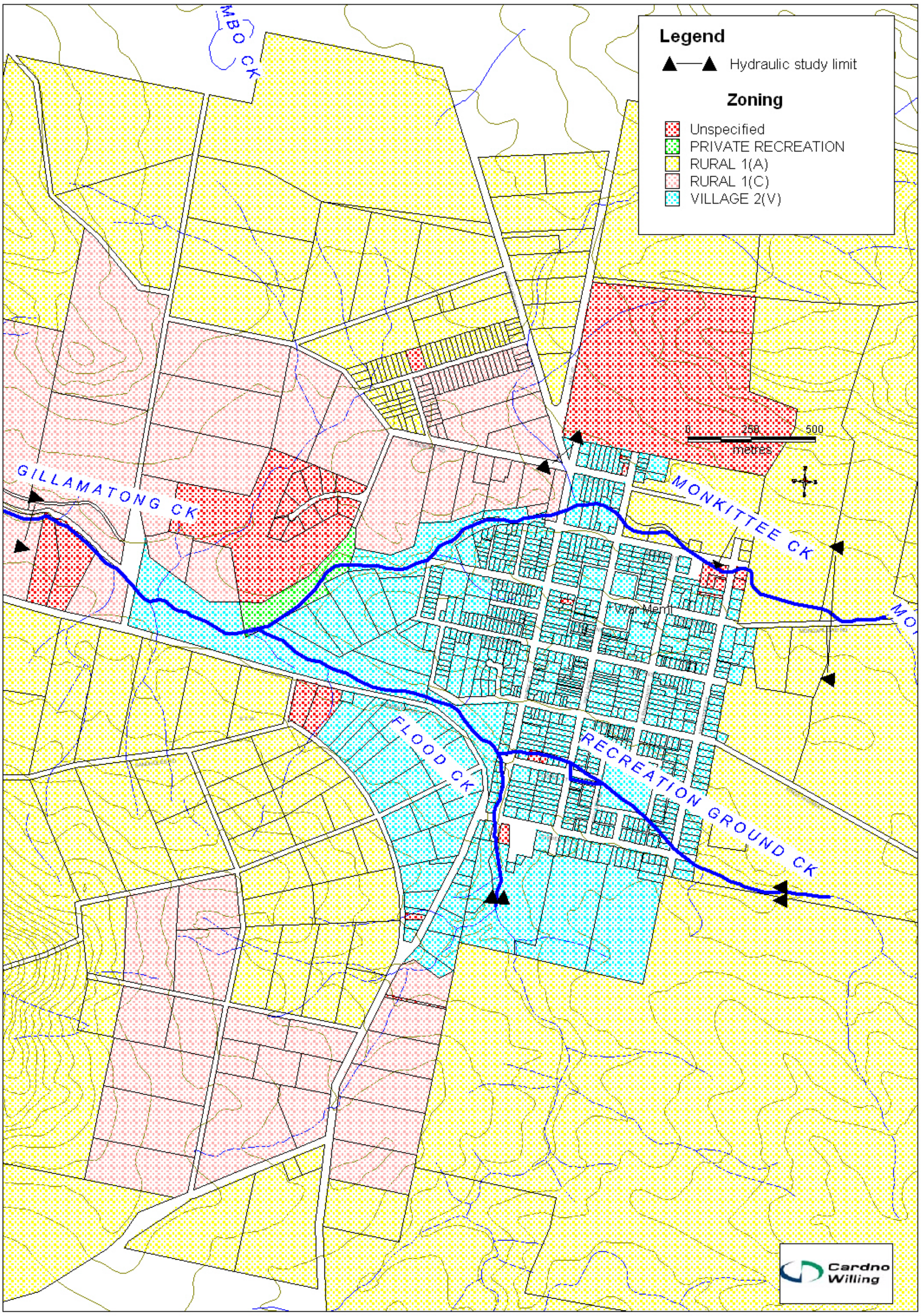
THE STUDY AREA

The study area lies within the overall catchment of the Shoalhaven River. The town of Braidwood (which has a population of around 1,100) is located in the upper reaches of the Shoalhaven River catchment.

The catchments of Gillamatong Creek, Monkittee Creek, Flood Creek, Recreation Ground Creek and their tributaries have a total catchment area of 77 km^2 at Braidwood. The major land uses in the catchment area include beef cattle and wool production.

The hydraulic study area is the Braidwood Township and areas up to one kilometre upstream and downstream along the creeks. It is defined generally by the 2(v) Village zone of the Tallaganda Local Environmental Plan 1991.

Figure 2 is a plan of the study area showing existing land zoning and the limits of the hydraulic study.



BRAIDWOOD FLOOD STUDY
VILLAGE AREA AND ZONING

FIGURE 2

FLOOD HISTORY

As stated by Council in its Brief, there has been very little previous work done on investigations into the nature, level and effect of flooding within Braidwood or the surrounding areas.

The basic information currently used by Council in relation to flooding is a plan prepared from the actual maximum flood levels recorded during the 1978 event.

For this study interviews were conducted by the consultants with some long-term residents of Braidwood. Limited data was obtained, more particularly for the 1978 flood. The historical flood data collected is provided in Appendix A.

DATA

All available maps and plans of relevance were obtained and reviewed during this study. Likewise gauged rainfall and streamflow data, observed flood level information, photographs of historical floods and other sundry information was collected and reviewed.

Appendix A lists the plans, surveys and other sources of information used for this study.

PREVIOUS STUDIES AND REPORTS

There are no known previous studies or reports directly dealing with flooding at Braidwood.

No stream gauges are operated in the local vicinity of Braidwood. The closest gauge to the study area is located on the Shoalhaven River at Warri Bridge, however this gauge is downstream of the creeks being considered in this report.

The *Shoalhaven Valley Flood Plain Management Study* (SK&P, 1981) included a general review of flooding in Braidwood, which is within the Shoalhaven River catchment. No detailed analyses were undertaken. It was reported that in 1978 Gillamatong Creek flooded the main street (Wallace Street) for the first time in the memory of local residents, and that *"During that flood event, six houses were inundated"*. The report then went on recommend that the flood liable areas be delineated and rezoned to prevent future development.

EXISTING FLOOD MANAGEMENT POLICY

The Tallaganda Local Environmental Plan 1991 contains the following reference to controls on land liable to flooding:

Flood liable land

29. (1) *A person shall not erect a building or carry out a work for any purpose on flood liable land except with the consent of the Council*

(2) *The Council may consent to an application for the erection of a dwelling-house on a site which includes flood liable land or land that, in the opinion of the Council, is liable to flooding, providing any floor of any building to be erected on that site in accordance with that consent will not be less than 0.6 metres above the level which, at the time of granting development consent, is the highest known flood level in relation to that site.*

(3) *The Council* may *consent to an application for the erection of a building or the carrying out of work on flood liable land or land that in the opinion of the Council is liable to flooding provided:*

(a) the Council is satisfied that:

(i) the development would not unduly restrict the flow of floodwaters;
(ii) the development would not unduly increase the level of flooding on other land in the vicinity; and
(iii) the structural characteristics of any building or works the subject of the application are capable of withstanding flooding;

(b) satisfactory arrangements are made for access to the building or work during the flood.

HYDROLOGY

Hydrologic modelling was undertaken to estimate stream discharges from rainfall. Complete flow hydrographs were prepared as input for hydraulic models that were used to estimate flood behaviour.

Full details of the hydrologic modelling are presented in **Appendix B**.

AIMS

The aims of the hydrological analyses were to:

(i) review available estimates of peak flows in the Braidwood Creeks catchment and/or in nearby catchments as a guide to design flood flows in the Braidwood Creeks; and

(ii) using available information estimate the flood hydrographs at key locations within the Braidwood Creeks catchments for one or more historical floods and for the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI design storms and the Probable Maximum Precipitation events. These hydrographs were in turn input into the hydraulic model of the Braidwood Creeks' floodplains to provide estimates of historical and design flood levels.

RAINFALL/RUNOFF MODEL

The model selected was the rainfall-runoff flood routing model, XP-RAFTS. This model was chosen because it is a well proven model and is recommended by *Australian Rainfall & Runoff* (AR&R) (IEAust., 1999). The catchment plan is presented in Figure 4. The model setup, sub-catchment layout and hydrologic data are described in Appendix B.

No historical streamflow data was available for the May 1925 and March 1978 flood events with which to calibrate the XP-RAFTS model. Instead an indirect calibration was undertaken by comparing the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI peak design storm flows with estimates given by the Probabilistic Rational Method that is detailed in AR&R, 1999.

The "calibrated" hydrological model was used to derive the design flood hydrographs required for hydraulic modelling.

HISTORICAL FLOODS

The only rainfall records for the historical floods of May 1925 and March 1978 that were investigated during this study were daily records. The 1925 rainfall event occurred over a three day period from 9am on 26^{th} May - 29^{th} May 1925 during which a total of 356.4mm of rain fell. The daily rainfall record for 1925 is shown in Figure B.2 in **Appendix B**.

The 1978 flood also occurred over a three day period from the 19th - 22nd March 1978 during which 294.6 mm of rain fell. The daily rainfall record for 1978 is shown in Figure B.3.

Rainfall Analysis

A comparison was made between the historical rainfall bursts and the Bureau of Meteorology's rainfall IFD (intensity-frequency-duration) data calculated for Braidwood. As the recorded rainfall was taken over a 24 hour period, the peak 24, 48 and 72 hour bursts in the record were compared to the rainfall depths calculated from the IFD data. The result of this analysis is shown in **Figure B.5**.

The peak 24 hour rainfall depth for the March 1978 flood event was very similar to the depth calculated for the 20 year ARI. For periods of 48 and 72 hours the rainfall depth increased to an amount between the 50 year ARI and 100 year ARI IFD curves.

The peak 24 hour depth for the 1925 event was placed between the 50 year ARI and 100 year ARI IFD curves before rising to a depth between the 100 year ARI and 500 year ARI IFD curves for the 48 and 72 hour durations.

These results suggest that both the 1925 and 1978 rainfall events were in the range of 50 year to 100 year ARI.

Flood Discharge Estimates

In the absence of pluviograph records, both the 1925 and 1978 storms were fitted to adjusted 72 hour AR&R storm temporal patterns matched to the daily rainfall depths which fell during the events. Details of this procedure are given in **Appendix B**.

The recorded rainfall and adjusted storm temporal patterns were used to provide estimates of the historical flood hydrographs at key locations within the Gillamatong, Flood and Recreation Ground Creek catchments. **Table 1** below summarises the peak flow estimates from XP-RAFTS at selected locations for the 1925 and 1978 floods (refer Figure 4).

Table 1 Estimated Peak Flows for Historical Floods

Location (see Figure 4)	XP-RAFTS Node	Estimated Peak Flows (m^3/s)	
		May 1925	March 1978
Recreation Ground Creek			
Ryrie St	RG4.0	14.6	12.1
Flood Creek			
	FL5.0	133.7	113.2
	FL7.0	152.7	129.4
Monkittee Ck – Gillamatong Creek			
	MA3.0	84.6	84.6
	GI5.0	221.8	188.2
	GI11.0	433.2	370.6

DESIGN FLOODS

Analyses were undertaken for design flood events with a range of rainfall durations. Design rainfall IFD curves for Braidwood and the upper catchment were derived from AR&R-1999 for events up to and including 100 year ARI. For the PMF, estimates of the Probable Maximum Precipitation (PMP) were derived using the Bureau of Meteorology's *Bulletin 53*. Details are given in Appendix B.

The critical durations for the catchments at Braidwood were found to be 48 hours for all the return periods analysed up to the 100 year ARI event. The long duration of the design storms is consistent with the 72 hour duration of the storms that produced the two historical floods in 1925 and 1978. The PMP event was found to have a critical duration of 2 hours within the catchment.

Table 2 summarises the estimated peak design flows at selected locations within the Braidwood Creeks' catchment for the 5 year ARI, 20 year ARI, 50 year ARI and 100 yr ARI and PMF design floods. Tables B.5 and B.6 in Appendix B give the estimated design flows over a range of storm durations for the return periods analysed.

Table 2 Summary of Estimated Design Flood Flows (m^3/s)

XP-RAFTS Node	5 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI	PMF
Recreation Ground Ck					
RG4.0	9.8	13.8	15.6	17.8	161.2
Flood Ck					
FL5.0	81.2	116.8	133.0	157.3	740.4
FL7.0	90.7	131.2	150.8	178.9	832.1
Monkittee Ck – Gillamatong Creek					
MA3.0	51.3	75.5	86.6	98.8	472.3
GI5.0	137.2	200.1	229.1	258.8	1275.9
GI11.0	262.9	379.8	435.2	518.4	2396.2

HYDRAULICS

Hydraulic modelling was undertaken to estimate flood levels and velocities from stream discharges.

Full details of the hydraulic modelling are presented in **Appendix C**.

AIMS

The aims of the hydraulic analyses were to:

(i) to assemble a hydraulic model of the Gillamatong, Monkittee, Flood and Recreation Ground Creek's floodplains and any major overland flow paths associated with breakouts from the creeks and within the limits of the available information calibrate the model using available historical flood levels;

(ii) run the "calibrated" hydraulic model to estimate flood discharges, flow velocities and flood profiles for the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI design storms and the Probable Maximum Precipitation (PMP) event;

(iii) use the model to identify the hydraulic hazard and hydraulic categories on the floodplain; and

(iv) provide a hydraulic model of the floodplain to facilitate the assessment of structural floodplain management options in a future Floodplain Risk Management Study

HYDRAULIC MODEL

The model selected was the XP-SWMM flood routing package. The model is widely used and recognised by engineering authorities in Australia. It is a state-of-the-art hydraulic model that is viewed as the equal of any comparable model used in Australia.

Within the XP-SWMM model suite the EXTRAN layer allows an unsteady flow one-dimensional node-link model for simulating branched and looped pipe/channel networks and complex floodplains to be assembled. It is capable of analysing combined major and minor drainage systems consisting of irregular open channels linked with pipe networks and may include pumps, orifices, loops, multiple outlets, tidal controls and detention basins.

Hydrographs may also be directly imported from XP-RAFTS as input into the detailed hydraulic model at boundaries of the model.

A hydraulic model of the existing floodplains of the various creeks was assembled and was run to estimate historical and design flood levels and flood velocities. Details of the model setup, node layout and modelling parameters are given in Appendix C.

The downstream boundary of the hydraulic model was located 1.8 km downstream of the confluence of Monkittee Creek and Flood Creek that forms Gillamatong Creek. This location was selected in order to ensure that the effects of any uncertainty in the downstream boundary conditions did not influence the flood level calculation within the town. It is considered that the model boundary is above the likely influence of any backwater flooding from the Shoalhaven River, and therefore a free outfall condition was assumed for all floods.

The upstream model boundaries were located upstream of the Braidwood town boundary on Flood, Recreation Ground and Monkittee Creeks. The layout of the hydraulic model is shown in Appendix C, Figure C.1.

HISTORICAL FLOODS

The hydraulic model was calibrated to flood heights observed during both the May 1925 and the March 1978 floods.

The steps involved in the calibration and verification process of the Braidwood Creeks floodplain model were as follows:

- estimation of Manning roughness values for the creeks and floodplains from field inspections and aerial photographs;
- adjustment of model parameters so that the combination of hydrologic and hydraulic models gave a good representation of flood levels for the May 1925 and March 1978 floods; and
- adoption of one set of model parameters to be used for design flood estimation;

The estimated flood levels for historical floods are compared with observed flood levels in **Table 3**.

Table 3
Comparison of Observed with Modelled Flood Levels for Historical Floods (m AHD)

Location	May 1925		March 1978		5 yr ARI	100 yr ARI
	Observed	Modelled	Observed	Modelled		
Pig & Whistle Pottery Shop (above floor level) (Node M10)	≈646.68	646.16	-	-	646.03	646.36
Archer Bridge (Node FL5.0)	-	-	640.1	640.04	640.14	640.58
On the floodplain in the vicinity of Torpey's Restaurant (Node M10)	-	-	≈ 646.0	646.00	646.03	646.36

In considering these results, allowance must be made for uncertainties in the 'observed' historical flood levels. It was concluded that as far as it is possible to determine, the predicted flood levels are in reasonably good agreement with observed flood levels and their likely corresponding frequencies.

DESIGN FLOODS

The predicted 5, 20, 50 and 100 year ARI flood levels and the PMF levels at selected locations are listed in Table 4 and shown on a map in Figure 5.

Table 4
Predicted Design Flood Levels at Selected Locations (m AHD)

Location	Node	5 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI	PMF
Monkittee & Gillamatong Creek						
Upstream Study Limit	GI5.0	648.52	648.82	649.06	649.09	652.58
d/s of Monkittee Street	M14	647.01	647.59	647.88	648.16	652.06
u/s of Wallace Street	GI6.0	646.11	646.99	647.38	647.73	651.77
d/s of Wallace Street	M10	645.60	646.05	646.24	646.43	649.69
Junction with Flood Creek	GI9.0	634.76	635.37	635.63	635.87	639.60
Downstream Study Limit	GI11.0	631.67	632.31	632.57	632.82	636.01
Flood Creek						
Upstream Study Limit	FL4.0	641.67	642.15	642.35	642.61	645.90
u/s of Cowper Street	F9	640.16	640.61	640.82	641.06	643.94
d/s of Cowper Street	F8	640.03	640.58	640.81	641.06	643.94
u/s of Archers Bridge	FL5.0	639.45	640.05	640.29	640.53	642.98
d/s of Archers Bridge	F7	639.13	639.59	639.77	640.01	642.87
Junction with Recreation Ground Creek	FL6.0	638.69	639.16	639.35	639.58	642.79
Recreation Ground Creek						
Upstream Study Limit	RG1.0	652.24	652.27	652.29	652.30	652.91
u/s of Monkittee Street	RG2.0	649.04	649.08	649.09	649.11	649.78
d/s of Monkittee Street	R6	648.40	648.49	648.53	648.57	649.63
u/s of Araluen Street	RG3.0	646.01	646.11	646.12	646.13	647.03
d/s of Araluen Street	R4	645.99	646.09	646.11	646.11	647.00
u/s of Wallace Street	R3.2	644.65	644.87	645.14	645.25	646.60
d/s of Wallace Street	R3	644.63	644.85	645.12	645.22	646.16
u/s of Ryrie Street	R2-drop	638.97	639.20	639.38	639.60	642.83
d/s of Ryrie Street	RG4.0	638.89	639.21	639.40	639.63	642.79

The full set of results for the design floods are given in Table C.5 in Appendix C. The design flood profiles for the Braidwood Creeks are given in Figures C.2 to C.4 in Appendix C.

FLOOD EXTENT

The estimated extent of the 100 year ARI flood is plotted in **Figure 6**. This flood extent is plotted against the available survey data which is rather limited; therefore it is most accurate at locations where there are cross-sections or detailed ground survey. Elsewhere, the plotted flood extent is less reliable. The precise flood extent on individual properties can be determined by detailed ground survey to relate ground levels to the calculated flood levels.

FLOOD DEPTHS AND VELOCITIES

The depth and velocity of flooding provides an indication of the likely hazard to people, buildings and other structures, and of the difficulty of rescuing people caught in floodwaters.

Velocities at the peak of the flood are estimated using computer models. Velocities and flood levels calculated by hydraulic analysis for the 5, 20, 50 and 100 year ARI and PMF events under existing conditions are given in **Appendix C**. The reported velocities are averages across the flow path, either the main channel or left and right overbank.

FLOOD HAZARD

Experience from studies of floods throughout NSW and elsewhere has allowed authorities to develop methods of assessing the hazard to life and property on floodplains. These guidelines are shown schematically in **Figure 3**.

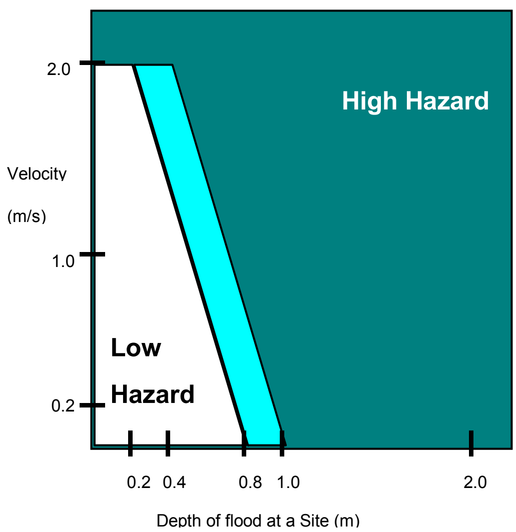


Figure 3
Provisional Hazard Categories (after NSW Government, 2001)

To use the diagram, it is necessary to know the average depth and velocity of floodwaters at a given location. If the product of depth and velocity exceeds a critical amount (as shown on **Figure 3**), the flood flow will create a High Hazard to life and property. There will probably be danger to persons caught in the floodwaters, and possible structural damage. Evacuation of persons would be difficult.

By contrast, in low hazard areas people and their possessions can be evacuated safely by trucks. Between the two categories a transition zone is defined in which the degree of hazard is dependent on site conditions and the nature of the proposed development.

This calculation leads to a provisional hazard rating. The provisional hazard rating may be modified by consideration of effective flood warning times, the rate of rise of floodwaters, duration of flooding and ease or otherwise of evacuation in times of flood.

HYDRAULIC CATEGORIES

The land which is affected by floodwaters can be divided into different categories based on its role in carrying floodwaters. **Floodways** are those areas where a significant volume of water flows. Blockage of floodways would alter the flow of water and could seriously increase the risk of flooding elsewhere. River and creek channels will always be floodways, and there may be other significant floodways carrying overbank flow as well as the main channel. However no such separate floodways were identified at Braidwood.

Flood storage areas are land that is important for the temporary storage of floodwaters during the passage of a flood. Substantial reduction of the capacity of a flood storage area would cause increased downstream flooding. The Recreation Ground at Araluen St and Keder St has been mapped as flood storage. Areas within the flood extent that are not shown as floodways or flood storage, are classified as flood fringe.

The identified floodways and flood storage areas based on a combination of the modelling results and field inspection. There is insufficient survey data to allow the accurate delineation of floodway widths along the creeks, instead they have been approximated by the extent of the 20 year ARI flood. The provisional hydraulic categories and hazard ratings for Braidwood are shown in **Figure 8**.

GREENHOUSE EFFECT

In recent years the likely impact of a change in climate resulting from the increase of Greenhouse gas emissions to the atmosphere (Greenhouse Effect) has been widely accepted. The scope of changes likely to occur and the timescale for such changes are not well defined and could encompass both general change in weather patterns (storminess) and a change in mean sea level.

At present, there is insufficient data available to allow predictions to be made of the effect with any degree of confidence. Estimates of the impact from global warming on storm intensity have been reduced during the past decade as observations have not supported original estimates.

Recent advice from the Bureau of Meteorology indicates that there is no intention at this time to revise design rainfalls to take into account the Greenhouse Effect because the possible mechanisms are unclear and there is no indication that any changes would increase design rainfalls for major events. The consequences of future climatic change for floodplain management at Braidwood are to introduce additional uncertainties into the flood level estimates.

ACCURACY OF RESULTS

It is important to recognise that any modelling studies provide only an estimate of the predicted flood levels. Although these estimates are based on the best data available at the time of writing, new data obtained in the future may lead to a revision of the estimates. Adoption of a suitable freeboard allowance is the most appropriate response to these uncertainties.

It is expected that further testing of sensitivity, particularly sensitivity to vegetation and hydraulic roughness, will form part of the future Floodplain Risk Management Study.

REFERENCES

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ABBREVIATIONS AND GLOSSARY

ABBREVIATIONS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff (1999 edition)
BoM	Bureau of Meteorology
DIPNR	Department of Infrastructure, Planning and Natural Resources
FPMC	Floodplain Management Committee
FRMS	Floodplain Risk Management Study
FRMP	Floodplain Risk Management Plan
GSDM	Global Short Duration Method
IFD	Intensity- Frequency-Duration
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
XP-SWMM	Unsteady flood routing program
XP-RAFTS	Rainfall/runoff program

GLOSSARY

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

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

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

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

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

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

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

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

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

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

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

flood — relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage (refer Section 1.9) before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood education, awareness and readiness

flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood readiness is an ability to react within the effective warning time.

flood fringe areas

the remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land

is synonymous with flood prone land (ie) land susceptible to flooding by the probable maximum flood (PMF) event. Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level, as indicated in the 1986 Floodplain Development Manual (see flood planning area).

flood mitigation standard

the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain

area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.

floodplain risk management options

the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.

floodplain risk management plan

a management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.

flood planning area

the area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “flood liable land” concept in the 1986 Floodplain Development Manual.

flood planning levels (FPL) are the combinations of flood levels and freeboards selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans. The concept of flood planning levels supersedes the "standard flood event" of the first edition of this manual.

flood prone land is land susceptible to flooding by the probable maximum flood (PMF) event. Flood prone land is synonymous with flood liable land.

flood risk potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.

existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.

future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

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

freeboard a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted flood planning level and the flood used to

	determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such and wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as “greenhouse” and climate change. Freeboard is included in the flood planning level.
hazard	a source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in Appendix G.
hydraulics	term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of this manual major drainage involves: ❑ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or ❑ water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger

to personal safety and property damage to both premises and vehicles; and/or

- major overland flowpaths through developed areas outside of defined drainage reserves; and/or
- the potential to affect a number of buildings along the major flow path.

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

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

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

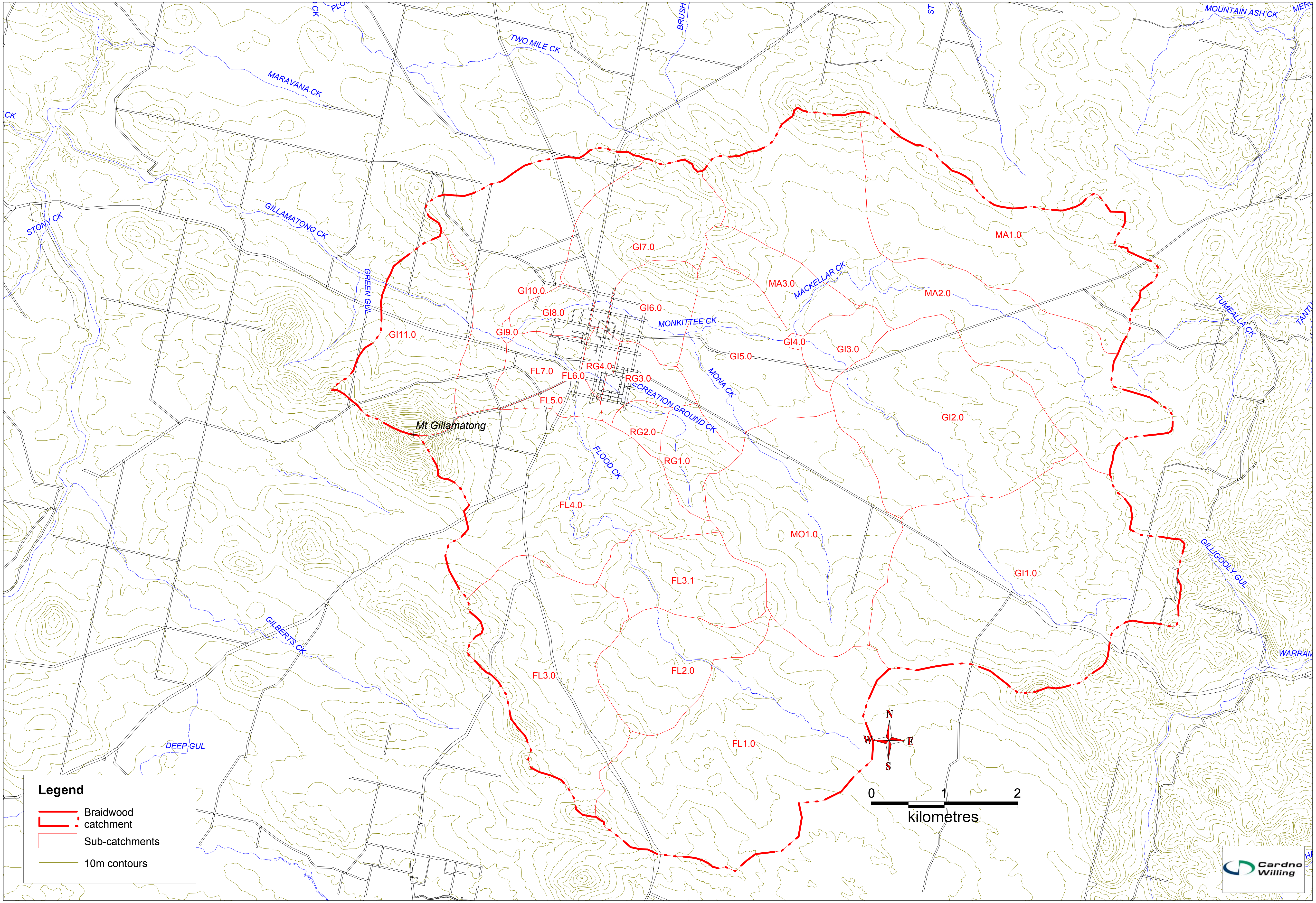
minor, moderate and major flooding both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

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

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

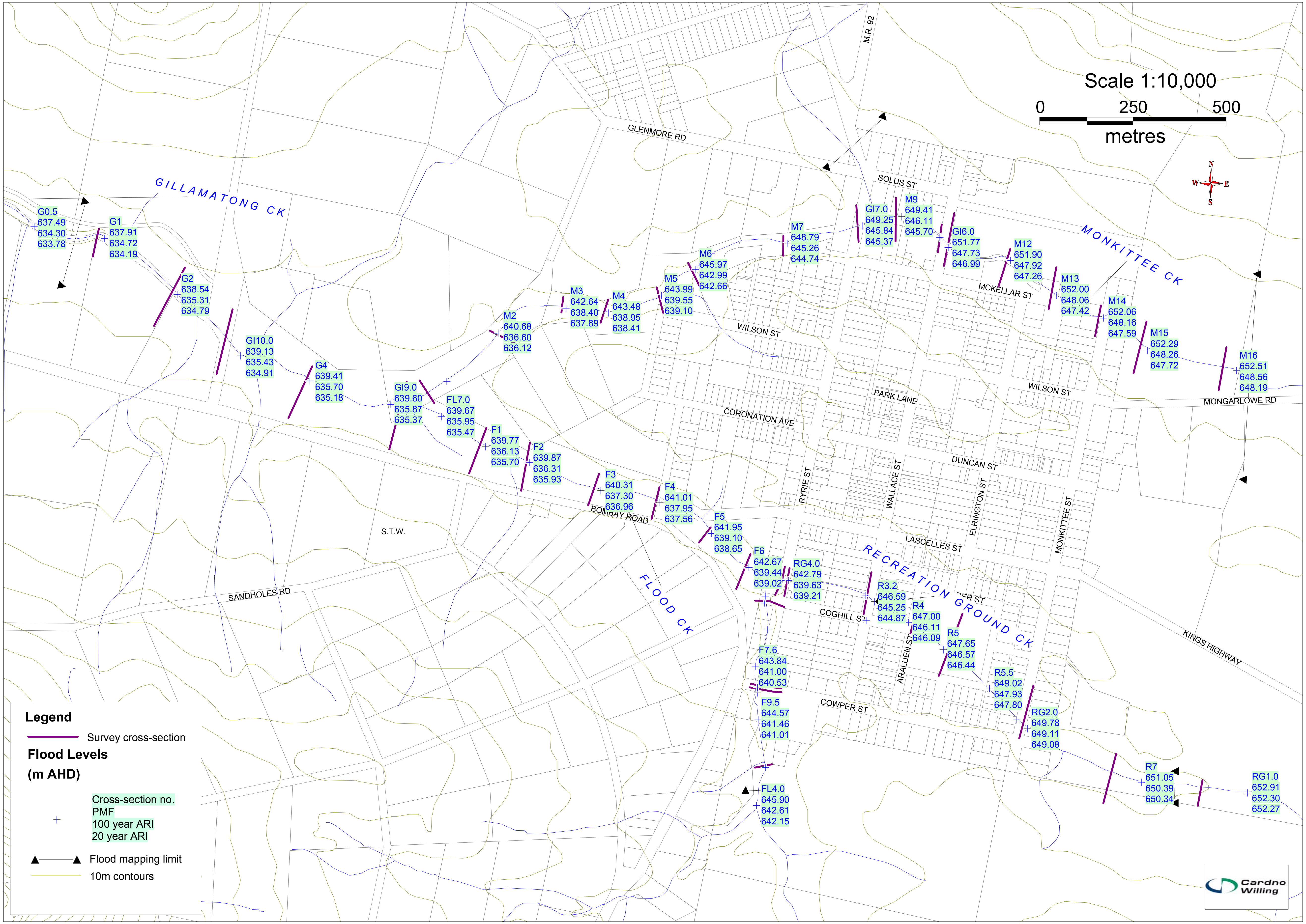
major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

peak discharge	the maximum discharge occurring during a flood event.
probable maximum flood (PMF)	the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event should be addressed in a floodplain risk management study.
probable maximum precipitation (PMP)	the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to the estimation of the probable maximum flood.
probability	a statistical measure of the expected chance of flooding (see annual exceedance probability).
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	equivalent to “water level”. Both are measured with reference to a specified datum.
stage hydrograph	a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	a plan prepared by a registered surveyor.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.



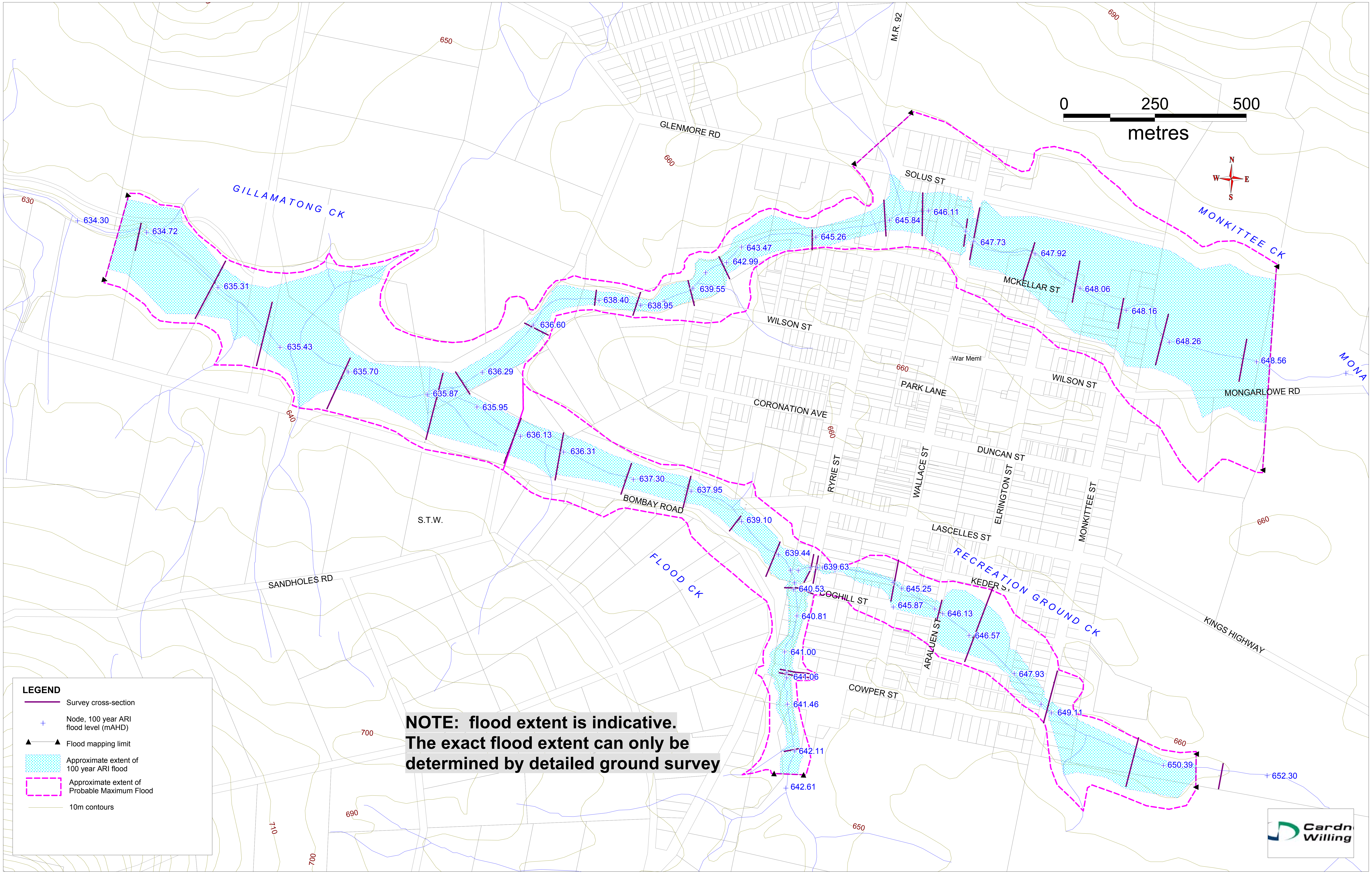
BRAIDWOOD FLOOD STUDY
CATCHMENT AREA

FIGURE 4



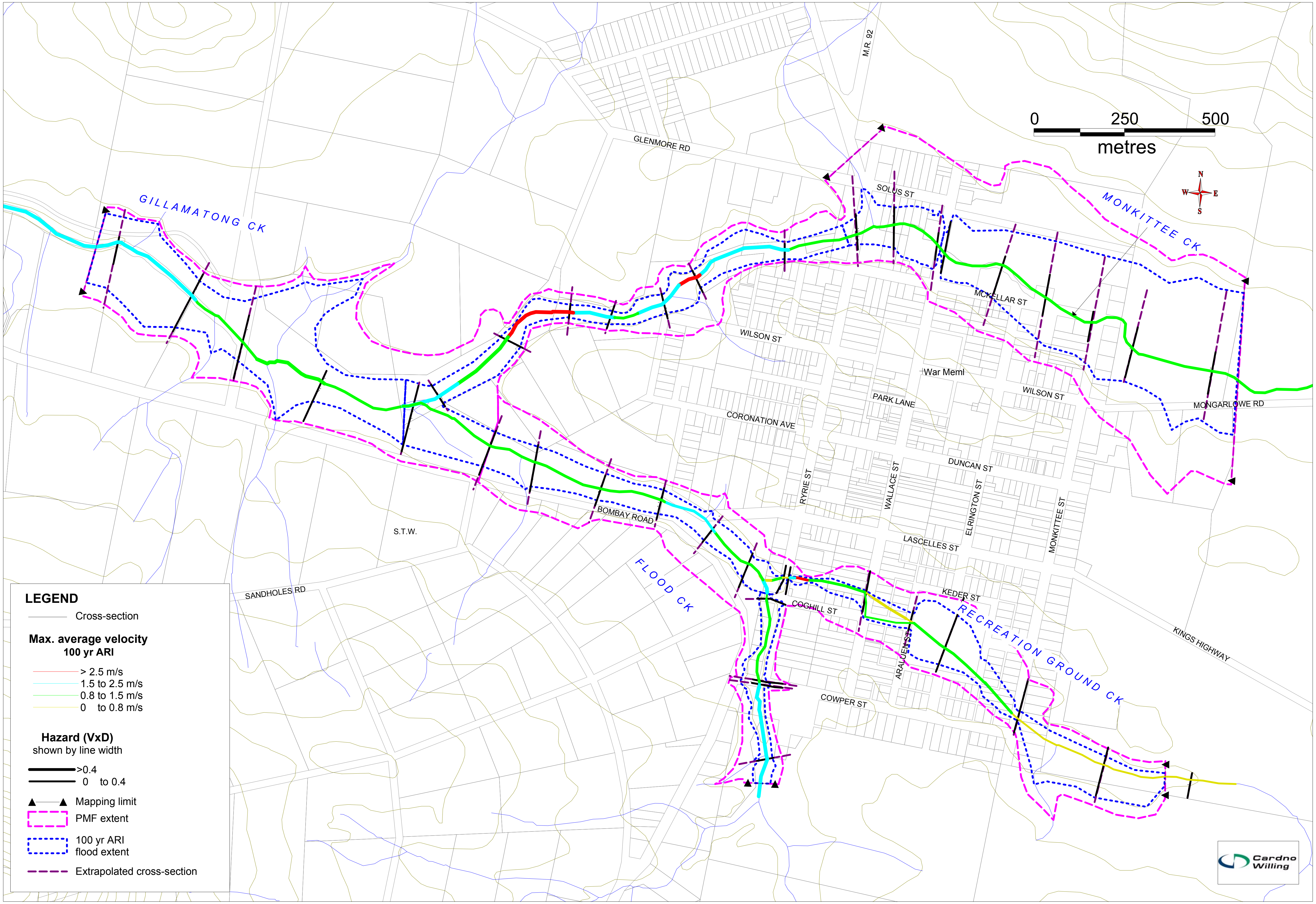
BRAIDWOOD FLOOD STUDY
DESIGN FLOOD LEVELS

FIGURE 5



BRAIDWOOD FLOOD STUDY
INDICATIVE 100 YEAR ARI FLOOD AND PMF EXTENT

FIGURE 6



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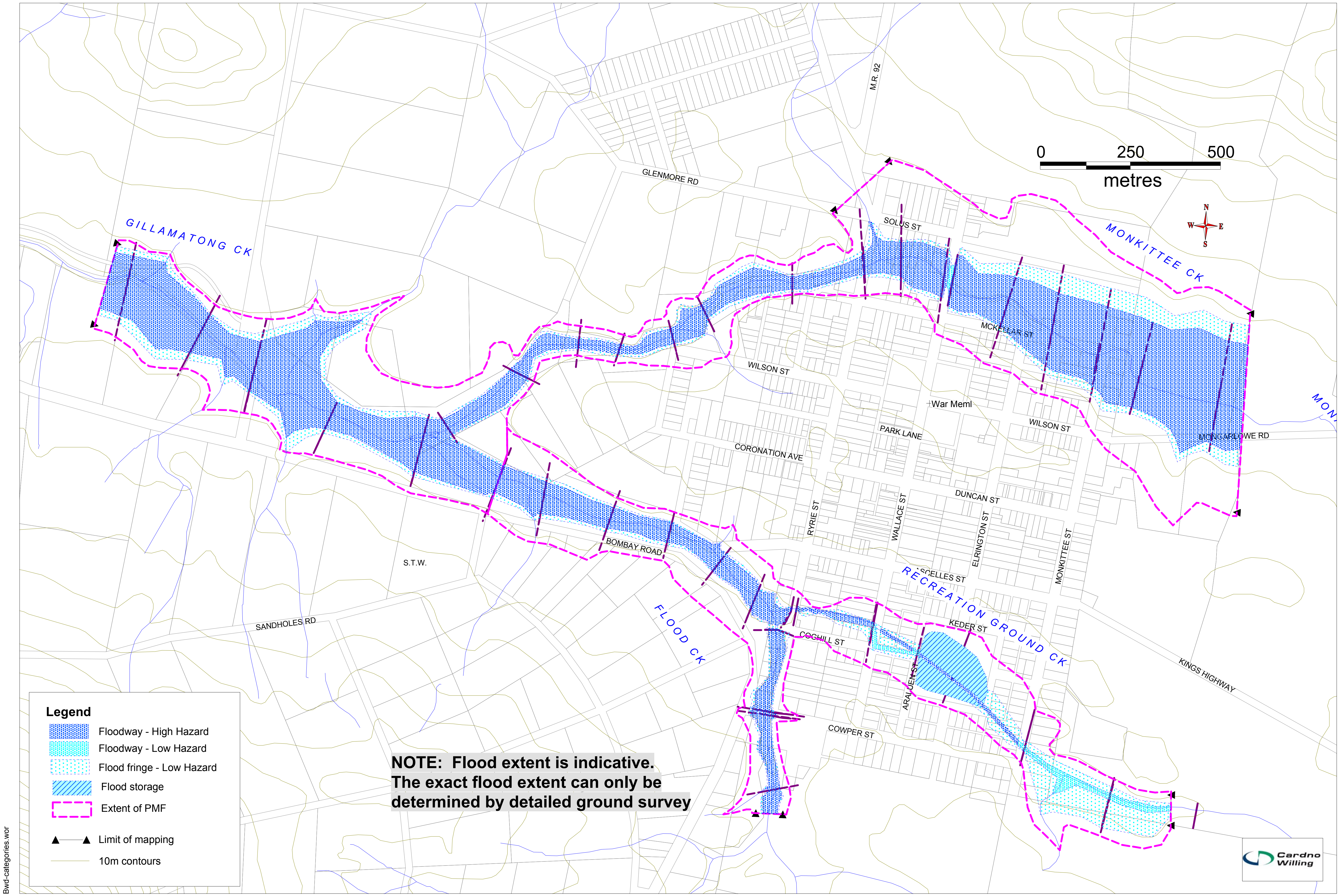
BRAIDWOOD FLOOD STUDY
100 YEAR ARI MAXIMUM AVERAGE VELOCITIES

FIGURE 7



BRAIDWOOD FLOOD STUDY
HYDRAULIC AND HAZARD CATEGORIES

FIGURE 8

APPENDIX A AVAILABLE DATA

SURVEY DATUM

Within the hydraulic study zone, topographic mapping was supplemented by surveyed cross-sections, at culverts and other selected locations as shown in **Figure A.1.** The survey was undertaken by Barry J Roberts & Associates of Braidwood. In some areas the survey did not extend to the limits of flooding and in these cases the cross-sections were extrapolated using 1:2000 scale orthophotomaps. Extrapolated cross-sections are shown by dashed lines on Figure A.1.

All levels in this report are expressed in metric units to the Australian Height Datum (AHD). All plans and models are referenced to the MGA grid, Zone 55.

RAINFALL AND STREAMFLOW DATA

Historical Rainfall

There are no continuous recording rainfall stations (pluviometers) in the study area catchments. There is a daily rainfall station operated by the Bureau of Meteorology (Station Number 069010) located on Wallace Street in Braidwood. Daily Rainfall records were obtained from the Bureau of Meteorology for the years 1925 and 1978 when significant flooding events are known to have occurred in the township of Braidwood.

Design Rainfall

For modelling a uniform distribution of design rainfall over the whole catchment was adopted.

Rainfall intensities and temporal patterns for the synthetic design storms were derived from Volume 2 of *Australian Rainfall and Runoff* (IEAust., 1999). A Rainfall Intensity-Frequency-Duration (IFD) table was generated for Braidwood and is given in **Table A.1.** The input parameters were as follows:

${}^{1}I_{2}$	=	29.0 mm/hr	${}^{1}I_{50}$	=	56.3 mm/hr
${}^{12}I_{2}$	=	6.0 mm/hr	${}^{12}I_{50}$	=	12.0 mm/hr
${}^{72}I_{2}$	=	1.8 mm/hr	${}^{72}I_{50}$	=	3.9 mm/hr
F_{2}	=	4.26	F_{50}	=	15.68

Skewness = 0.14

An areal reduction factor of 0.97 was applied to design rainfalls over the 77 km^2 catchment area in accordance with the formula in AR&R. The rainfall intensities in Table A.1 **include** the areal reduction factor.

Table A.1
Intensity-Frequency-Duration Table for Braidwood Catchment including Areal Reduction Factor (0.97)

	Rainfall Intensity (mm/hr)							
Duration	**1 yr ARI**	**2**	**5**	**10**	**20**	**50**	**100**	**500**
5 mins	69.65	90.49	118.15	135.14	157.63	188.02	211.86	271.01
6	65.27	84.79	110.63	126.49	147.50	175.87	198.12	253.32
7	61.61	80.03	104.35	119.28	139.05	165.75	186.69	238.58
8	58.50	75.97	99.01	113.13	131.85	157.13	176.94	226.04
9	55.79	72.44	94.36	107.80	125.61	149.64	168.48	215.16
10	53.42	69.34	90.28	103.10	120.12	143.07	161.05	205.60
11	51.29	66.57	86.64	98.93	115.23	137.22	154.44	197.10
12	49.38	64.09	83.37	95.18	110.84	131.97	148.52	189.49
13	47.67	61.84	80.42	91.79	106.88	127.23	143.15	182.60
14	46.09	59.79	77.74	88.71	103.28	122.91	138.28	176.35
15	44.65	57.92	75.27	85.88	99.97	118.96	133.82	170.61
16	43.33	56.19	73.01	83.28	96.93	115.32	129.72	165.35
17	42.11	54.60	70.92	80.88	94.13	111.97	125.94	160.48
18	40.96	53.12	68.98	78.66	91.52	108.85	122.41	155.98
20	38.92	50.45	65.48	74.64	86.83	103.25	116.09	147.86
25	34.78	45.08	58.43	66.57	77.41	91.99	103.38	131.56
30	31.64	40.98	53.07	60.43	70.23	83.41	93.72	119.17
35	29.14	37.72	48.81	55.56	64.54	76.62	86.07	109.38
40	27.09	35.07	45.34	51.58	59.90	71.08	79.82	101.38
45	25.38	32.84	42.43	48.26	56.03	66.46	74.61	94.72
50	23.92	30.94	39.95	45.43	52.73	62.54	70.19	89.07
55	22.66	29.31	37.82	42.99	49.89	59.14	66.37	84.19
60	21.55	27.88	35.96	40.87	47.40	56.18	63.04	79.93
75	18.79	24.31	31.39	35.70	41.43	49.13	55.14	69.98
90	16.77	21.70	28.05	31.90	37.04	43.95	49.35	62.66
2.0 hrs	13.98	18.10	23.43	26.68	30.99	36.79	41.33	52.54
3	10.79	13.98	18.13	20.66	24.03	28.56	32.11	40.87
4	8.96	11.63	15.10	17.23	20.04	23.84	26.81	34.16
5	7.77	10.08	13.10	14.96	17.41	20.72	23.32	29.74
6	6.91	8.97	11.67	13.33	15.52	18.49	20.81	26.55
8	5.75	7.47	9.73	11.12	12.96	15.44	17.38	22.21
9	5.36	6.96	9.07	10.36	12.08	14.40	16.22	20.73
10	4.99	6.48	8.45	9.66	11.26	13.43	15.13	19.35
12	4.43	5.76	7.53	8.61	10.05	11.99	13.51	17.29
14	4.03	5.23	6.85	7.85	9.17	10.95	12.36	15.84
16	3.70	4.81	6.31	7.24	8.47	10.13	11.43	14.68
18	3.42	4.46	5.87	6.74	7.89	9.45	10.67	13.73
20	3.20	4.17	5.50	6.32	7.40	8.88	10.03	12.92
22	3.01	3.93	5.18	5.97	6.99	8.38	9.49	12.23
24	2.84	3.72	4.91	5.66	6.63	7.96	9.01	11.63
36	2.17	2.84	3.78	4.37	5.15	6.21	7.04	9.15
48	1.78	2.33	3.12	3.62	4.27	5.16	5.87	7.64
60	1.51	1.99	2.67	3.10	3.67	4.44	5.06	6.62
72	1.31	1.73	2.34	2.72	3.22	3.91	4.45	5.84

Probable Maximum Precipitation

Estimates of the Probable Maximum Precipitation (PMP) for the study catchments for up to 6 hours duration were prepared using the procedure given in the Bureau of Meteorology's (BoM) Bulletin 53 entitled "*The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"* (GSDM).

The GSDM is based on using the sample outliers of a large population to estimate the rainfall from the optimum storm mechanism. Maximisation factors are used to adjust the storm rainfall to account for potential extreme moisture inflow. To estimate the optimum storm mechanism, the GSDM includes adjustments for moisture availability and differing topographic effects on rainfall depth.

Adjustment Factors

Terrain Roughness Adjustment - Rough Terrain is classified as "that in which elevation changes of 50m or more within horizontal distances of 400m are common". Based on this definition and an available interpretation of available topographic mapping the study catchment was considered to be 95% smooth and 5% rough.

Catchment Elevation Adjustment - The total catchment area is at an elevation below 1500m above sea level and therefore no adjustment for catchment elevation is applicable.

Moisture Adjustment Factor - The PMP rainfall depth duration curves in Bulletin 53 have been standardised to a moisture index equivalent to a surface dew-point temperature of 28°C. The moisture adjustment for the study catchments is 0.625

Spatial Distribution

The spatial distribution of the PMP across the study catchments was based on orientating the GSDM spatial pattern given in Bulletin 53 to maximise the rainfall depth across the catchments. The study catchments lies within four (4) rainfall zones corresponding to Ellipses A to D in Bulletin 53 (see Appendix B). The same spatial distribution was adopted for all storm durations. Use of the GSDM spatial pattern eliminates the need for the areal reduction factor which is used for design storms up to 100 year ARI.

Temporal Distribution

Bulletin 53 gives a single PMP temporal pattern for all PMP storms up to 6 hours.

PMP Rainfall Depths and Intensities

The estimated rainfall depths for each duration and for each of the four rainfall zones (Ellipses A to D) are summarised in **Table A.2**.

Table A.2
Adopted PMP Rainfall Depths and Intensities

Duration (hours)	Rainfall Depth (mm), (Rainfall Intensity (mm/h))			
	Ellipse A	Ellipse B	Ellipse C	Ellipse D
0.5	210 (420)	184 (368)	156 (312)	148 (296)
0.75	266 (355)	234 (311)	200 (267)	182 (243)
1	308 (308)	275 (275)	244 (244)	204 (204)
1.5	354 (236)	316 (211)	279 (186)	256 (171)
2	396 (198)	356 (178)	316 (158)	285 (143)
2.5	423 (169)	380 (152)	339 (136)	308 (123)
3	447 (149)	399 (133)	357 (119)	335 (112)
4	490 (123)	444 (111)	399 (100)	368 (92)
5	529 (106)	478 (96)	432 (86)	406 (81)
6	559 (93)	507 (85)	458 (76)	429 (72)

Streamflows

There are no existing or previous stream gauging stations located within the study catchments.

PREVIOUS STUDIES

The only known previous flood studies or reports covering the Braidwood creeks was a generalised Floodplain Management Study of the Shoalhaven River system carried out in 1981 (SKP, 1981).

OBSERVED FLOOD LEVELS

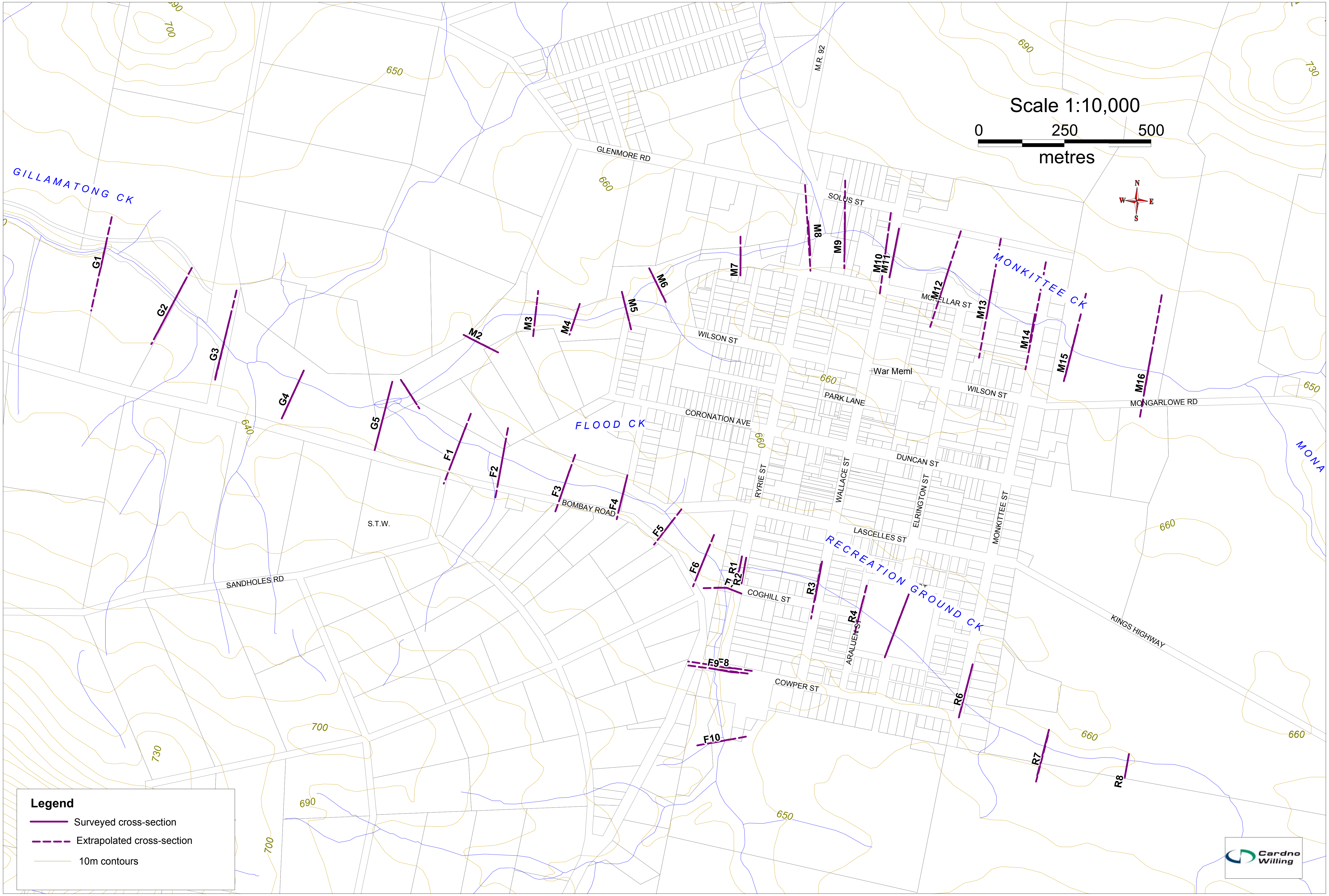
Interviews were conducted by the consultants with some long-term residents of Braidwood. Limited data was obtained, more particularly for the 1978 flood.

May 1925

The 1925 flood was remembered to have risen over the floor level of the building that is now called the Pig and Whistle Pottery Shop. This building is located at No. 4 Wallace Street, downstream of what was then Jew's Bridge.

March 1978

During the March 1978 flood, observations of flood levels were made at several locations within Braidwood. Archer Bridge was damaged during this flood to such an extent that it was subsequently replaced. Flood waters were observed to rise to a level equal to or just below the road deck level on Archers Bridge (640.2 m AHD). Flood levels were also observed to have washed out caravans located near Torpey's Restaurant and to have reached the edge of the side fence at Torpey's Restaurant.



BRAIDWOOD FLOOD STUDY
LOCATION OF SURVEYED CROSS-SECTIONS

FIGURE A.1

APPENDIX B HYDROLOGY

AIMS

The aims of the hydrological analyses were to:

(i) review available estimates of peak flows in the Braidwood Creeks catchment and/or in nearby catchments as a guide to design flood flows in the Braidwood Creeks; and

(ii) using available information estimate the flood hydrographs at key locations within the Braidwood Creeks catchments for one or more historical floods and for the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI design storms and the PMP (Probable Maximum Precipitation) events. These hydrographs were in turn input into the hydraulic model of the Braidwood Creek's floodplains to provide estimates of historical and design flood levels.

RAINFALL/RUNOFF MODELLING

Estimates of runoff from study catchments for the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI and Probable Maximum Precipitation events were obtained using the XP-RAFTS rainfall/runoff model.

The XP-RAFTS Model

The features offered by XP-RAFTS which were particularly suited to the study include:

(i) a link-node approach based on subcatchments (each comprising 10 sub-areas) joined by flood routing "links";
(ii) the option to calibrate each subcatchment separately within a watershed if required;
(iii) global or catchment dependent input of rainfall;
(iv) specific features for the modelling of urbanising and urban catchments including:
- direct inclusion of the "degree of urbanisation", U, in the storage-delay equation for subcatchment flow routing,
- optional separate routing of runoff from pervious and impervious surfaces for improved modelling of runoff from urban catchments,
- optional modification of the storage-delay equation to represent additional subcatchment storage in older urban areas with limited provision for overland flows

(iv) subcatchment roughness factor to characterise the full range of catchment conditions including forested catchments;
(vi) a range of rainfall loss models including:
- initial and continuing rainfall losses,
- proportional rainfall losses,
- full ARBM soil water balance model.

(vii) separate routing of flows using either a time lag or routing of flows using a Muskingum-Cunge flood routing procedure with cross sectional data;
(viii) direct import of gauged rainfall and/or gauged flow data from hydrometric data archiving systems including HYDSYS and PROPHET;
(ix) direct export of hydrographs to the XP-EXTRAN and MIKE-11 flood routing models;
(x) a graphical user interface with an embedded decision support system.

Model Description

Based upon the existing creeks and streams and the natural topography, an XP-RAFTS rainfall/runoff model was established for the Gillamatong Creek, Monkittee Creek, Flood Creek and Recreation Ground Creek catchments.

The catchment was subdivided based on catchment land use, topography and the location of significant hydraulic features eg. at the confluence of streams. The $77km^2$ catchment was discretised into 27 subcatchments. **Figure B.1** shows the sub-catchment boundaries and the XP-RAFTS network used for the analyses. The node locations are summarised in **Table B.1**.

Model Parameters

The approach which was adopted to the estimation of rainfall excess and its runoff was to subdivide each subcatchment into estimated pervious and impervious areas and to estimate the rainfall excess for both surfaces and to separately route the runoff from each surface to the subcatchment outlet ie. a "split" subcatchment modelling approach.

Imperviousness
The percentage of impervious area was based on a typical developed street block and took into account roofs, paved areas and the street network. The impervious area adopted for each sub-catchment varied from 0% impervious in the rural areas to 30% in the fully developed urban districts.

Vector Average Slope
The vector average slope for each subcatchment was determined from the available topographical plans.

Subcatchment Roughness
For each subcatchment, a surface roughness was entered for each surface type. The adopted surface roughness values were 0.025 for impervious surfaces 0.05 for pervious vegetated surfaces.

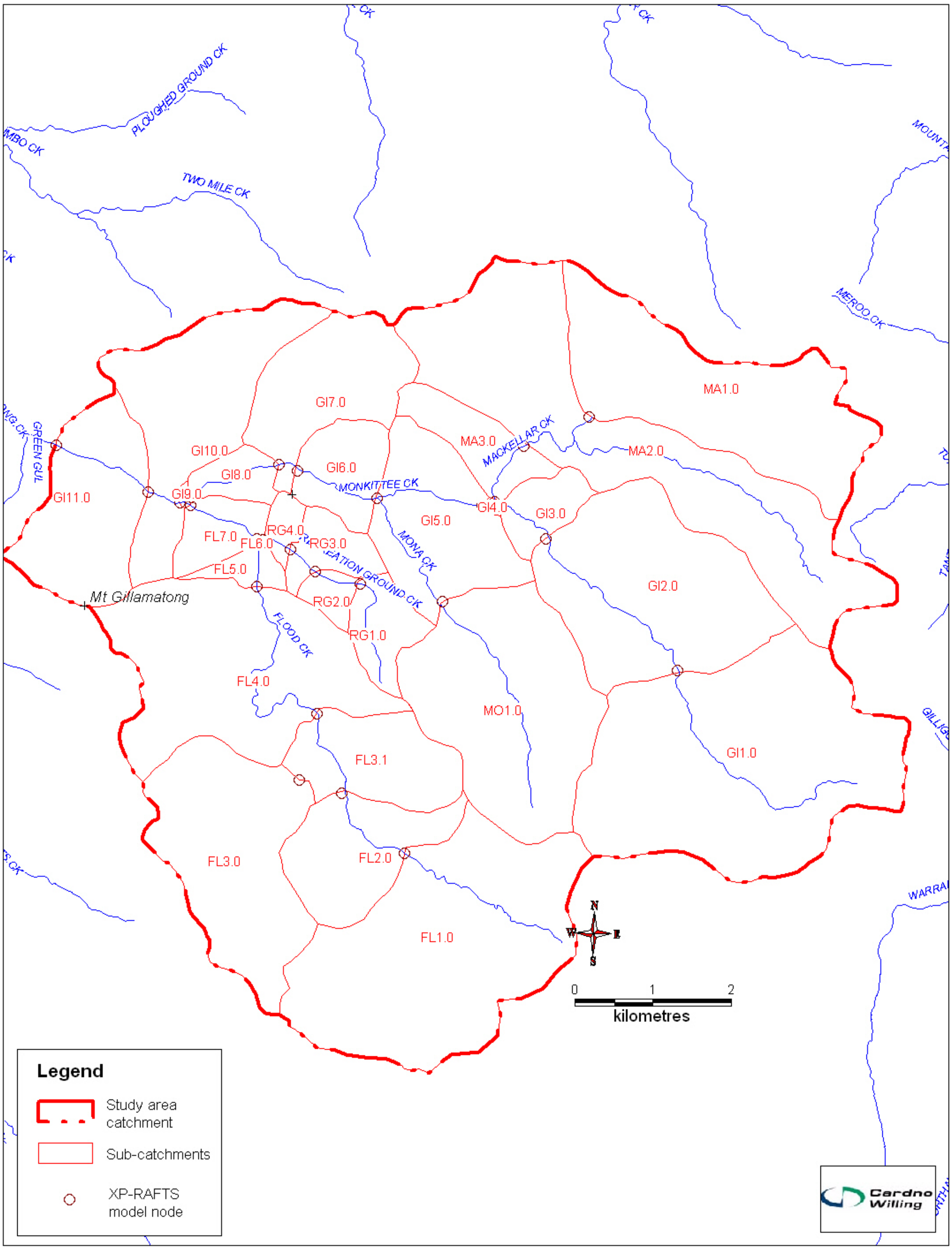
Hydrograph Routing
The routing of hydrographs from one subcatchment outlet (node) to the next downstream subcatchment outlet (node) was undertaken using simple lagging. The time of travel (or lag) for each reach (link) was calculated as the length of the reach divided by an average flow velocity.

Table B.1 Summary of XP-RAFTS Node Locations

XP-RAFTS Node	Description
GI1.0	Gillamatong Creek
GI2.0	Locked Gate Mongarlowe Rd
GI3.0	U/S of confluence (node GI4.0)
GI4.0	Confluence between Gillamatong & Mackellar Creeks
MA1.0	Mackellar Creek
MA2.0	Mackellar Creek
MA3.0	U/S of confluence (node GI4.0)
GI5.0	North of Hospital (where Gillamatong Ck enters Township)
GI6.0	U/S of culvert Wallace St
GI7.0	Track between Solus & Ryrie St
GI8.0	U/S of confluence (node GI9.0)
GI9.0	Confluence between Gillamatong & Flood Creeks
FL1.0	Flood Creek
FL2.0	D/S of dirt track
FL3.1	Flood Creek
FL4.0	Approx. 300m U/S of Cowper Street
FL5.0	U/S of Archer Bridge
FL6.0	Confluence between Flood and Recreation Ground Creeks
FL7.0	U/S of confluence (node GI9.0)
MO1.0	Mona Creek
RG1.0	Recreation Ground Creek upstream of town boundary
RG2.0	U/S of culvert at Monkittee St
RG3.0	U/S of culvert at Araluen St
RG4.0	D/s of culvert at Ryrie St near Coghill St
GI10.0	Dirt track near "Woolden Park"
GI11.0	2km D/S of Confluence between Gillamatong and Flood Creeks

ARBM Parameters

The ARBM rainfall loss model was adopted instead of an initial loss-continuing loss model based on its ability to better represent changes in rainfall infiltration during long duration storms. The parameter values used for the Braidwood Creeks XP-RAFTS model were based on values calibrated during a previous study of the Macquarie River catchment upstream of Bathurst by Willing and Partners. The Bathurst study was chosen due to the similarities to the geological and climatic conditions in the Braidwood Creeks catchment. The ARBM loss model values used for this study are given in **Table B.2**.



BRAIDWOOD FLOOD STUDY
XP-RAFTS MODEL

FIGURE B.1

Table B.2 ARBM Loss Model Values

Loss Model Variable	Adopted Values	
	Capacity	Initial Value
Impervious storage capacity (mm)	0.0	0.0
Interception storage capacity (mm)	1.0	0.0
Depression storage capacity (mm)	1.0	0.5
Upper soil storage capacity (mm)	12.5	5.0
Lower soil storage capacity (mm)	75.0	32
	Adopted Value	
Maximum evapotranspiration from upper soil zone (mm)	10	
Maximum evapotranspiration from lower soil zone (mm)	10	
Proportion of evapotranspiration from upper soil zone	0.7	
Variable rate groundwater recession factor	1	
Constant rate groundwater recession factor	0.94	
Upper soil sorptivity (mm/min$^{0.5}$)	5	
Saturated hydraulic conductivity (mm/min)	0.05	
Lower soil drainage factor	0.05	
Proportion of rainfall intercepted by vegetation	0.7	
Routing time step (mins)	1	

HISTORICAL FLOODS

Rainfall Analysis

The only source of rainfall data for the May 1925 and March 1978 floods within the township of Braidwood was daily rainfall data. In order to estimate the flood flows during these events it was necessary to derive a synthetic temporal pattern for the daily 9am rainfall depths recorded during each event. Inspections of the annual rainfall records for 1925 (see **Figure B.2**) revealed that the most significant event during the year occurred over three days from 9am on the 26th May 1925 to 9am on the 29th May 1925 during which a total of 356.4mm of rain fell. The 1978 flood also occurred over a three day period from 9 am on the 19th March 1978 to 9am on the 22nd March 1978 during which there was 294.6mm rain fell (see **Figure B.3**).

As these depths were recorded over a 72 hour duration it was decided to apply the AR&R 72 hour design storm temporal pattern to provide a synthetic storm for input to the XP-RAFTS model. The unadjusted AR&R 72 hour design pattern did not match the recorded daily rainfall depths so the 4 hour intervals within the AR&R temporal pattern were re-arranged to provide a better fit for the daily rainfalls totals. This procedure preserves the magnitudes of the peak rainfall intensities as discussed in AR&R, Section 3.6.2.

Table B.3 displays the recorded daily rainfall depths in comparison to the AR&R and adjusted AR&R Temporal Patterns. The synthetic temporal patterns for both the 1925 and 1978 events are shown in **Figure B.4**.

Table B.3
Comparison of Recorded Daily Rainfall Depths and 72 hour AR&R Temporal Patterns

Event	May 1925			March 1978		
	Recorded Daily Rainfall Depths (mm)	AR&R 72 hour design temporal pattern (mm)	Adjusted AR&R 72 hour design temporal pattern (mm)	Recorded Daily Rainfall Depths (mm)	AR&R 72 hour design temporal pattern (mm)	Adjusted AR&R 72 hour design temporal pattern (mm)
Day 1	54.9	172.85	54.5	36.8	142.88	36.53
Day 2	199.9	105.14	199.9	97.4	86.91	97.51
Day 3	101.6	78.41	101.9	160.4	64.81	160.56
Total	356.4	356.4	356.4	294.6	294.6	294.6

A comparison was made between the historical rainfall bursts and the IFD data calculated for Braidwood. As the recorded rainfall was taken over a 24 hour period, the peak 24, 48 and 72 hour bursts in the record were compared to the rainfall depths calculated using the IFD method. The result of this analysis is shown in **Figure B.5**.

The peak 24 hour burst for the March 1978 flood event was very similar to the depth calculated for the 20 yr ARI. As the extra rainfall periods were added on the rainfall depth increased to an amount between the 50 yr ARI and 100 yr ARI IFD curves.

The peak 24 hour burst for the March 1978 event was placed between the 50 year ARI and 100 year ARI IFD curves before rising to a depth between the 100 yr ARI and 500 yr ARI IFD curves for the 48 and 72 hour durations. These results suggest that both the 1925 and 1978 rainfall events were between 50 year and 100 year ARI.

Historical floods

The historical rainfalls were used as input to the XP-RAFTS hydrologic model in order to derive calculated hydrographs for the two historical floods. The ARBM loss model values were adjusted for the May 1925 flood as there was significant falls of rain in the week preceding the flood event. The moisture stores for the loss model were adjusted to reflect the antecedent rainfall.

Estimated peak flows from the XP-RAFTS model for the historical events are given below at selected locations in **Table B.4**. The figures are unrouted flows, ie before input to the hydraulic routing model.

Table B.4
Estimated Peak Flows for Historical Floods

Location (see Figure 3)	XP-RAFTS Node	Estimated Peak Flows (m^3/s)	
		May 1925	March 1978
Recreation Ground Creek			
Ryrie St	RG4.0	14.6	12.1
Flood Creek			
	FL5.0	133.7	113.2
	FL7.0	152.7	129.4
Monkittee Ck – Gillamatong Creek			
	MA3.0	84.6	84.6
	GI5.0	221.8	188.2
	GI11.0	433.2	370.6

DESIGN FLOODS

Design Storms up to 100 year ARI

For events up to the 100 year ARI event, a uniform distribution of design rainfall over the whole catchment was adopted. Rainfall intensifies and temporal patterns for the synthetic design storms were derived from Volume 2 of "*Australian Rainfall and Runoff*" (IEAust., 1987). The Rainfall Intensity – Frequency - Duration (IFD) table for Braidwood is given in **Table A.1**.

The 5 year, 20 year, 50 year and 100 year ARI design storms of 6, 9, 12, 18, 24, 36, 48 and 72 hours duration were modelled. The 48 hour design storm duration gave the greatest peak flows in the town area for the design storms run. The results of the analysis are summarised in **Table B.5**. As before these are the unrouted flows, before input to the hydraulic routing model.

Table B.5
Peak Flows for Design Floods (m^3/s)

XP-RAFTS Node	5 Year ARI							
	6 hr	9 hr	12 hr	18 hr	24 hr	36 hr	48 hr	72 hr
RG4.0	3.2	5.8	6.4	6.0	5.8	7.6	**9.8**	4.7
FL5.0	25.5	44.0	50.4	51.4	45.8	68.6	**81.2**	39.4
FL7.0	28.9	49.8	56.9	58.2	51.9	77.6	**90.7**	45.1
GI5.0	39.1	67.9	81.7	82.5	68.7	114.9	**137.2**	63.4
GI11.0	78.9	136.4	161.3	163.4	140.3	224.0	**262.9**	128.9
MA3.0	14.4	25.0	30.5	30.8	26.2	43.1	**51.3**	23.7

Table B.5 (continued)
Peak Flows for Design Floods (m^3/s)

XP-RAFTS Node	20 Year ARI							
	6 hr	**9 hr**	**12 hr**	**18 hr**	**24 hr**	**36 hr**	**48 hr**	**72 hr**
RG4.0	6.9	10.4	10.9	8.8	11.0	12.3	**13.8**	8.6
FL5.0	60.9	86.4	88.9	79.1	94.3	108.3	**116.8**	71.3
FL7.0	69.3	97.9	100.9	90.4	105.9	123.0	**131.2**	80.9
GI5.0	97.7	135.7	146.1	132.3	147.8	180.4	**200.1**	115.2
GI11.0	193.1	267.0	286.6	256.2	288.2	354.5	**379.8**	230.1
MA3.0	36.9	50.5	55.3	50.4	55.1	67.9	**75.5**	43.3
XP-RAFTS Node	**50 Year ARI**							
	6 hr	**9 hr**	**12 hr**	**18 hr**	**24 hr**	**36 hr**	**48 hr**	**72 hr**
RG4.0	9.7	14.3	14.0	11.0	14.4	14.6	**15.6**	11.1
FL5.0	86.7	120.8	116.1	101.4	125.5	129.4	**133.0**	95.3
FL7.0	98.1	136.9	131.3	115.6	142.1	146.8	**150.8**	108.8
GI5.0	140.6	193.4	191.2	169.5	201.6	214.7	**229.1**	157.0
GI11.0	276.0	377.0	375.2	329.0	387.8	423.3	**435.2**	312.8
MA3.0	52.1	72.0	72.2	64.6	76.8	80.7	**86.6**	59.0
XP-RAFTS Node	**100 Year ARI**							
	6 hr	**9 hr**	**12 hr**	**18 hr**	**24 hr**	**36 hr**	**48 hr**	**72 hr**
RG4.0	11.2	16.5	15.8	12.6	16.5	16.8	**17.8**	12.9
FL5.0	99.2	140.5	131.1	114.3	144.3	147.9	**157.3**	107.8
FL7.0	112.2	159.0	148.2	130.3	164.5	167.7	**178.9**	121.8
GI5.0	162.0	224.3	215.9	191.5	232.6	246.6	**258.8**	185.5
GI11.0	316.8	437.5	423.9	371.5	446.7	485.3	**518.4**	350.0
MA3.0	60.1	84.0	81.8	73.2	89.0	92.8	**98.8**	69.9

Probable Maximum Precipitation

As described in **Section A.3,** estimates of the Probable Maximum Precipitation were prepared for the study catchments for the 1, 2, 3, 4, 5 and 6 hour duration storms. These rainfall intensifies are given in **Table A.2**.

The spatial distribution of the PMP across the study catchment is presented in **Figure B.6**. The same spatial distribution was adopted for all storm durations. The PMP temporal pattern for all storms up to 6 hours given in Bulletin 53 was adopted.

The 1, 2, 3, 4, 5 and 6 hour duration PMP storms were modelled. A summary of the estimated unrouted peak flows for the PMP durations are in **Table B.6**.

Table B.6
Estimated Peak Flows for the PMP Event

XP-RAFTS Node	Estimated PMP Peak Flows (m^3/s)					
	1 hr	**2 hr**	**3 hr**	**4 hr**	**5 hr**	**6 hr**
RG4.0	**161**	139	117	102	90	81
FL5.0	604	**740**	709	668	614	566
FL7.0	668	**832**	810	773	712	658
GI5.0	1025	**1276**	1214	1117	1026	943
GI11.0	1948	**2396**	2330	2203	2035	1879
MA3.0	375	**472**	449	411	378	347

The table shows that a 2 hour duration is critical for the PMP in the Braidwood Creeks catchment, except on Recreation Ground Creek where the critical duration is estimated to be 1 hour.

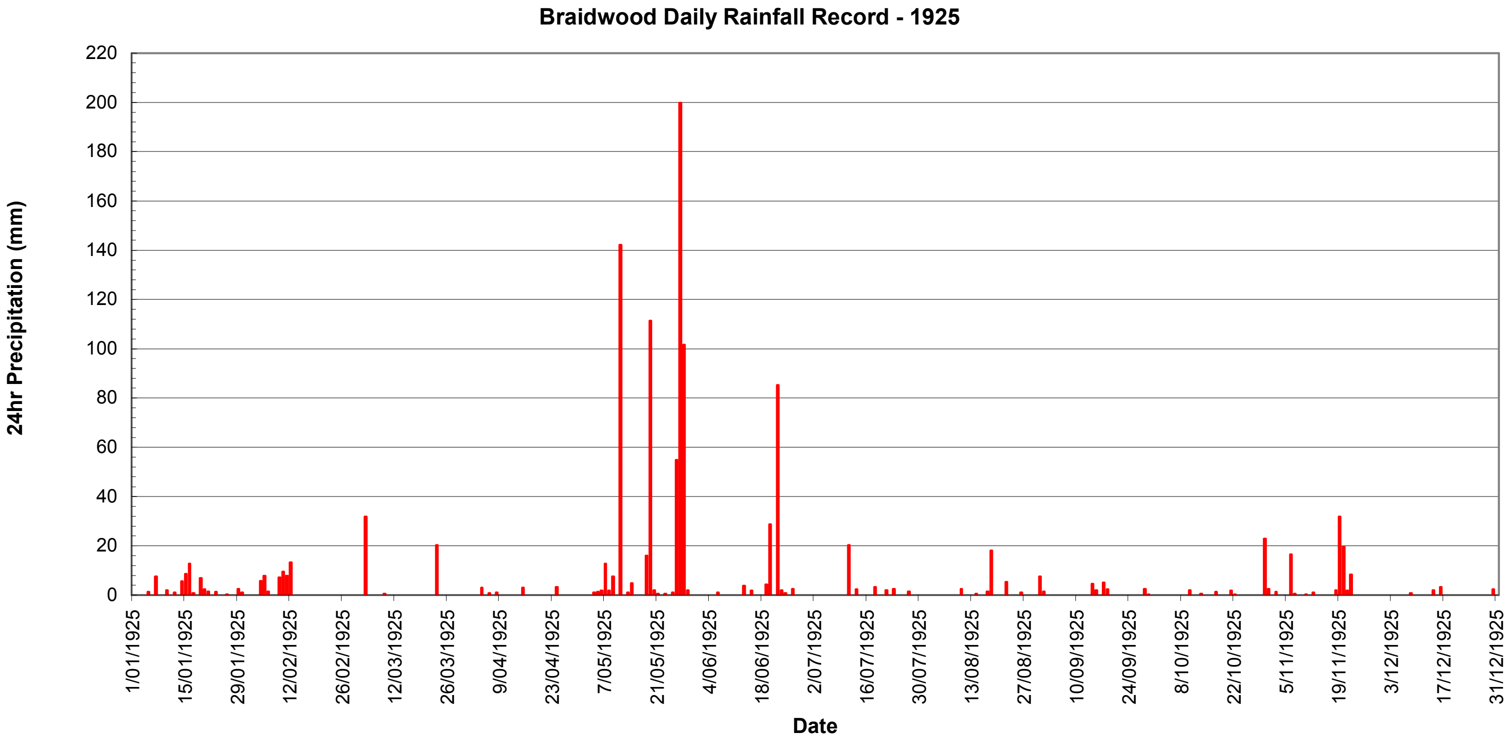


Figure B.2
Daily Rainfall for Braidwood, May 1925 event

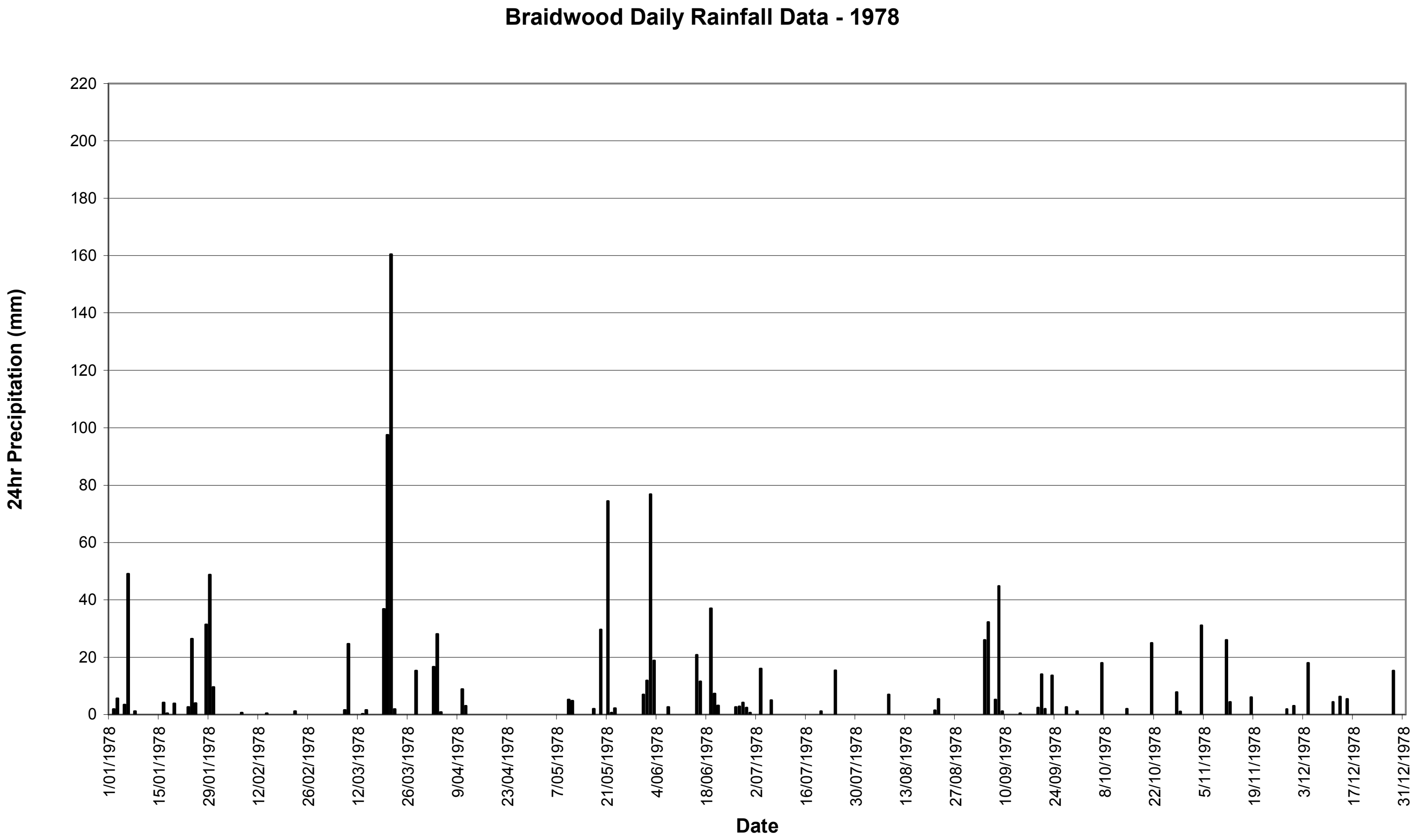


Figure B.3
Daily Rainfall for Braidwood, March 1978 event

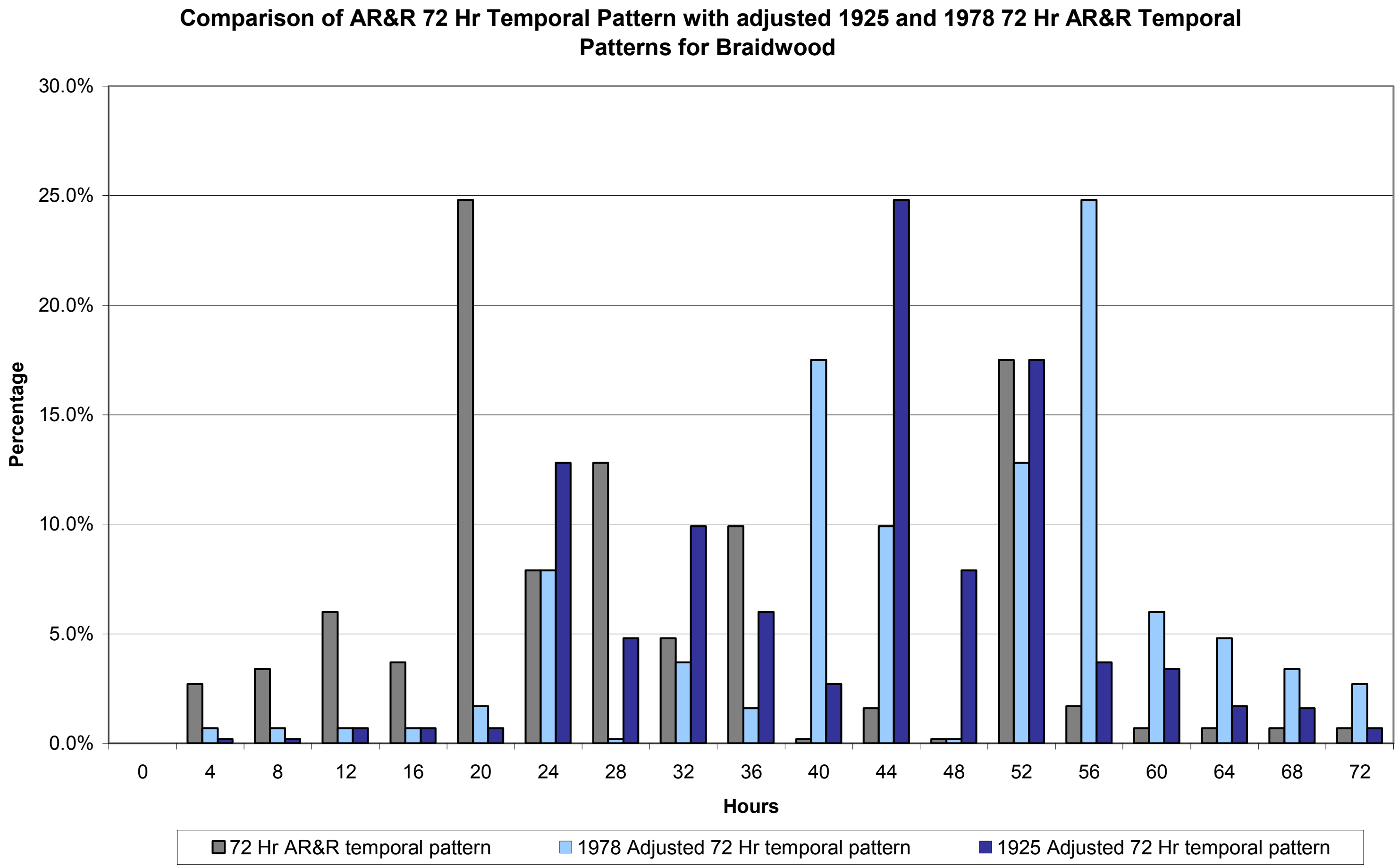


Figure B.4
Adjusted Temporal Patterns for Historical Flood Events

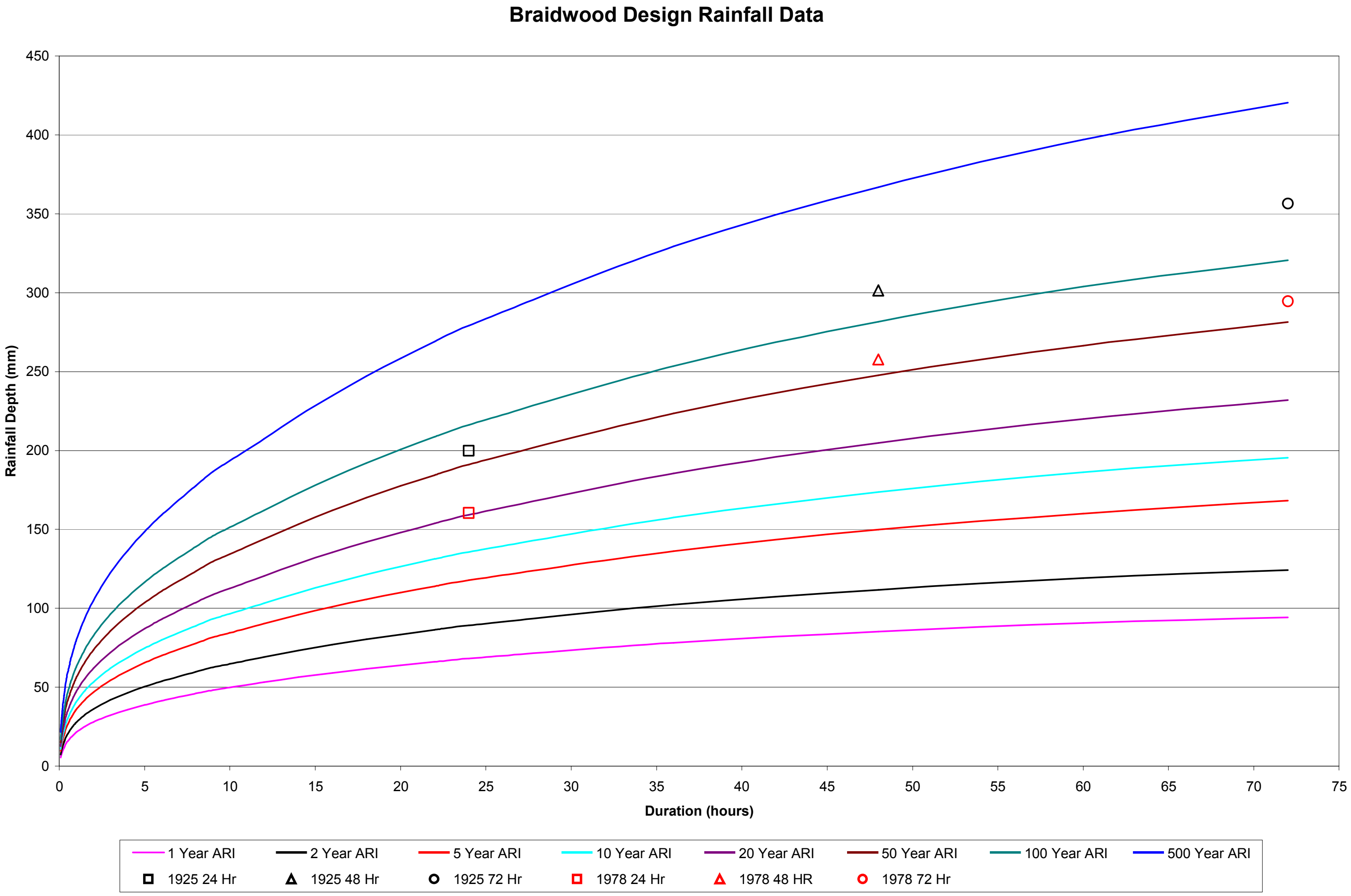
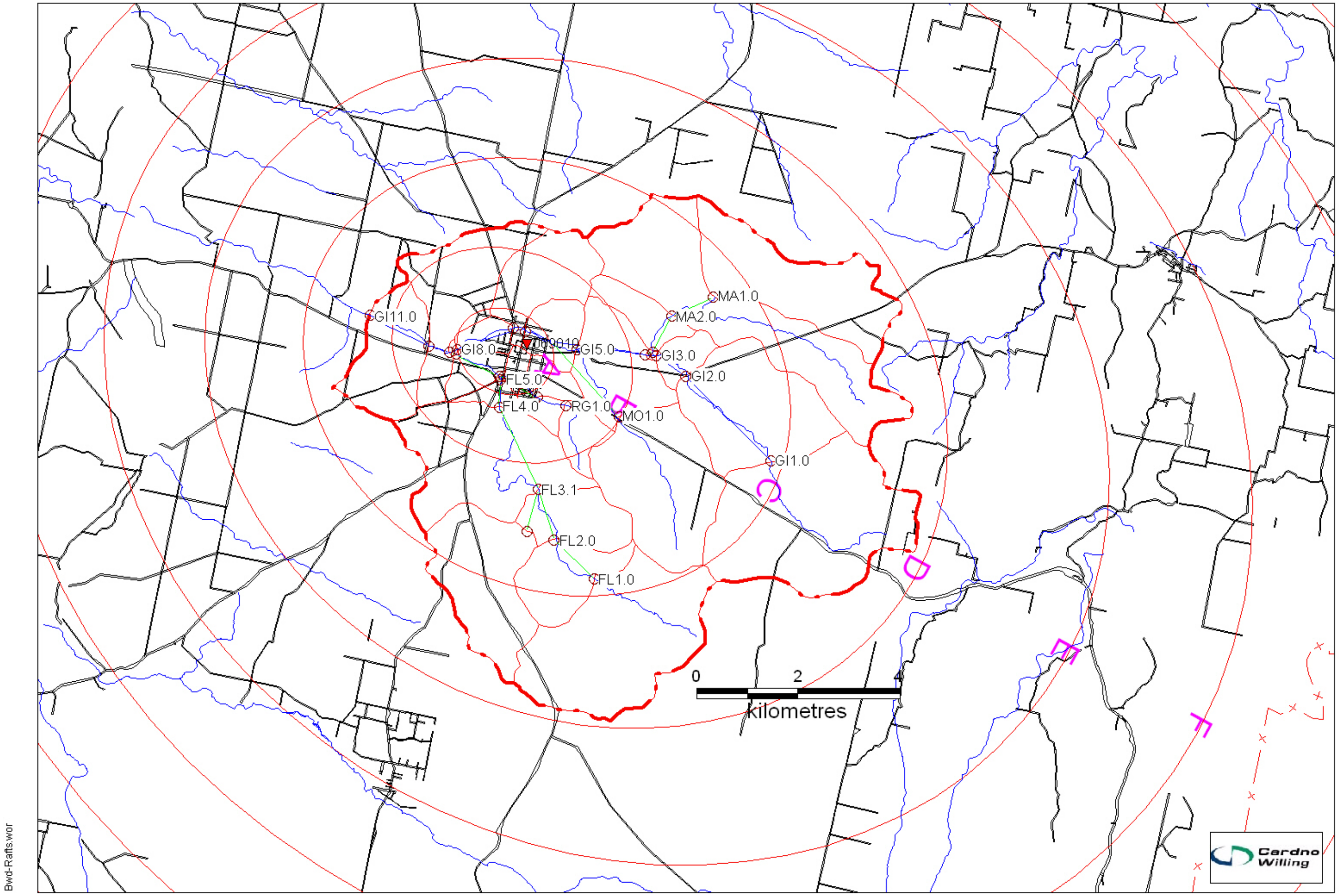


Figure B.5
Comparison of Historical Rainfall Bursts against IFD Curves



BRAIDWOOD FLOOD STUDY
SPATIAL DISTRIBUTION OF PMP

FIGURE B.6

APPENDIX C HYDRAULICS

AIMS

The aims of the hydraulic analyses were to:

(i) to assemble a hydraulic model of the Gillamatong, Monkittee, Flood and Recreation Ground Creek’s floodplains and any major overland flow paths associated with breakouts from the creeks and within the limits of the available information calibrate the model using available historical flood levels; and

(ii) run the "calibrated" hydraulic model to estimate flood discharges, flow velocities and flood profiles for the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI design storms and the Probable Maximum Precipitation (PMP) event.

(iii) provide a hydraulic model of the floodplain to facilitate the assessment of structural floodplain management options in the next stage of the Floodplain Risk Management process, namely the Floodplain Risk Management Study

HYDRAULIC MODELLING

The model selected was the XP-SWMM flood routing package.

The XP-SWMM Model

Within the XP-SWMM model suite the EXTRAN layer allows an unsteady flow one-dimensional node-link model for simulating branched and looped pipe/channel networks and complex floodplains to be assembled. It is capable of analysing combined major and minor drainage systems consisting of irregular open channels linked with pipe networks and may include pumps, orifices, loops, multiple outlets, tidal controls and detention basins.

Hydrographs may also be directly imported from XP-RAFTS as input into the detailed hydraulic model at any node in the model.

Model Description

A detailed model of Braidwood Creek’s floodplains was assembled. A total of 60 nodes were located at key locations based on the available and collected survey information including at stream confluences, and upstream and downstream of road crossings. The nodes were connected by links. The links represented the channel and floodplain of the Braidwood Creeks. **Figure C.1** shows the layout of the hydraulic model that was assembled for floodplains of the Braidwood Creeks.

Model Parameters

Cross Sections
Cross section data on the creeks and floodplains was obtained from survey conducted early in the study. In some areas the survey did not extend to the limits of flooding and in these cases the cross-sections were extrapolated using 1:2000 scale orthophotomaps.

Roughness Coefficients
Channel and floodplain roughness values were initially based on field assessments of the condition of the Braidwood Creek's channels, the amount and density of riparian vegetation and the condition of the floodplains.

Within the study area for the hydraulic investigation the floodplains are used for both urban and rural land uses.

Sections of Flood Creek (in particular) and the other creeks have high hydraulic roughness due to dense growth of willows and other riparian vegetation on the banks of the watercourses. This zone of high hydraulic roughness is typically confined to a narrow strip of floodplain adjacent to the banks of the watercourses and within the channels of the creeks.

The initial roughness values were adjusted during the "calibration" of the hydraulic model to observed flood levels during the March 1978 flood and tested against the May 1925 flood. This led to the adoption of higher roughness values in some sections of the Braidwood Creeks to improve the agreement between predicted and observed flood levels.

The final adopted channel and overbank roughness values are given in **Table C.1**.

It should be also noted that the hydraulic roughness of each cross section can be described by up to three different roughness values. Consequently in some locations the roughness value for a sub-section is a weighted roughness that reflects the proportion of high roughness and lower roughness zones across the sub-section.

HISTORICAL FLOODS

As discussed in **Appendix B,** Braidwood is known to have experienced significant floods in May 1925 and March 1978. In view of the greater amount of information available for the March 1978 flood, this flood was used to calibrate the hydraulic model while the May 1925 flood was used to verify the model.

May 1925 and March 1978 Floods

Cross Sections
Cross section data on the Braidwood Creek's floodplains was surveyed early in the study. On the basis of no other available information on historical cross sections, it was assumed that the surveyed cross sections and channel roughness values were representative of the channel and floodplain levels at the time of the historical floods.

Table C.1
Summary of Adopted Manning Roughness Values

(Link) Cross Section	Adopted Manning n Value Left Bank	Main Channel	Right Bank	(Link) Cross Section	Adopted Manning n Value Left Bank	Main Channel	Right Bank
Monkittee/Gillamatong Creeks				**Flood Creek**			
LG15	0.04	0.055	0.04	L28	0.05	0.065	0.05
LM16	0.04	0.055	0.04	LF10	0.05	0.065	0.05
LM15	0.05	0.065	0.05	LF9.5	0.05	0.065	0.05
LM14	0.05	0.065	0.05	LF8	0.05	0.065	0.05
LM13	0.05	0.065	0.05	LF7.6	0.05	0.065	0.05
LM12	0.05	0.065	0.05	LF7.3	0.05	0.06	0.05
LM10	0.05	0.065	0.05	LF7	0.05	0.06	0.05
LM9	0.05	0.065	0.05	LFL6.0	0.05	0.065	0.05
LG17.0	0.05	0.065	0.05	LF6	0.05	0.065	0.05
LM7	0.05	0.065	0.05	LF5	0.05	0.065	0.05
LM6.5	0.05	0.065	0.05	LF4	0.05	0.065	0.05
LM6	0.05	0.065	0.05	LF3	0.05	0.065	0.05
LM5.5	0.05	0.065	0.05	LF2	0.05	0.065	0.05
LM5	0.05	0.065	0.05	LF1	0.05	0.065	0.05
LM4.5	0.05	0.065	0.05	LFL7	0.05	0.065	0.055
LM4	0.045	0.06	0.045				
LM3	0.045	0.06	0.045	**Recreation Ground Creek**			
LM2	0.045	0.06	0.045				
LGI8	0.045	0.055	0.045	LRG1.0	0.045	0.06	0.045
LG5	0.05	0.045	0.05	LR7	0.045	0.06	0.045
LG4	0.05	0.045	0.05	LR6	0.06	0.05	0.06
LGI10	0.05	0.045	0.05	LR5.5	0.04	0.055	0.04
LG2	0.05	0.045	0.05	LR5	0.04	0.055	0.04
LG1	0.05	0.045	0.05	LR4	0.05	0.065	0.05
LG0.5	0.05	0.045	0.05	LR3	0.05	0.065	0.05
LG0.2	0.05	0.045	0.05	LR0.5	0.05	0.05	0.05
				L28	0.05	0.065	0.05

Note: A single Main Channel roughness value indicates that a uniform roughness was adopted across the whole cross section

Hydrographs

Inflow hydrographs for the March 1976 and March 1978 floods were estimated in the manner described in **Appendix B.4** and were directly input into the hydraulic model via an interface file. Total flow hydrographs were input at the upstream boundaries of the hydraulic model (Nodes MA1.0, GI1.0, MO1.0, RG1.0 and FL1.0) while local hydrographs were input at intermediate nodes as appropriate.

Downstream Boundary Condition
The adopted downstream boundary condition used on Gillamatong Creek was an approximation of normal depth calculated in XP-SWMM. This was determined to be the most appropriate boundary condition because the creek continues at a uniform grade for several kilometres before its confluence with the Shoalhaven River.

Results

The calibration and checking of the hydraulic model was undertaken iteratively to achieve the best possible agreement between the observed and predicted flood levels. The calibration was undertaken by adjusting the Manning roughness values in the channel and on the floodplain. A comparison of the observed and predicted peak flood levels in the March 1978 flood is given in **Table C.2** while the predicted flood levels for the May 1925 floods are summarised in **Table C.3.** The full results are given in **Table C.4**.

Table C.2
Comparison of Observed and Modelled Flood Levels - 1978 Flood

XP-SWMM Node	Location	Observed Flood Level (m AHD)	Modelled Flood Level (m AHD)
FL5.0	Archer Bridge	≈ 640.1	640.04
M10	On the floodplain within the vicinity of Torpey's Restaurant	≈646.0	646.0

Table C.3
Comparison of Observed and Modelled Flood Levels - 1925 Flood

XP-SWMM Node	Location	Observed Flood Level (m AHD)	Modelled Flood Level (m AHD)
M10	Above floor level of Pig and Whistle Pottery Shop	≈ 646.68	646.16

The flood levels calculated by XP-SWMM for the 1978 flood were in the vicinity of the observations available for that flood. When the XP-SWMM model was run for the 1925 flood, the calculated flood level was significantly below the observation of water rising above the floor of the Pig and Whistle Pottery Shop. Reasons for this difference could be that the Jews Bridge was smaller than the existing bridge, constricting flow more in the local area and forcing flood levels to rise. Hydraulic roughness values could have changed significantly within the creek over the latter half of the 20th century due to changes in vegetation in both the channel and on the floodplain. A further possibility is that blockages occurred during the historical flood.

Table C.4
Modelled 1978 and 1925 Flood Levels for Braidwood Creeks (m AHD)

Location	Node	May 1925 Flood	March 1978 Flood
Monkittee & Gillamatong Creek	Gl5.0	649.03	648.86
	M16	648.56	648.24
	M15	648.29	647.79
d/s of Monkittee Street	M14	648.13	647.59
	M13	647.76	647.31
	M12	647.56	647.14
u/s of Wallace Street	Gl6.0	647.21	646.84
d/s of Wallace Street	M10	646.16	645.99
	M9	645.82	645.63
	Gl7.0	645.52	645.29
	M7	644.87	644.65
	M6.5	643.19	643.04
	M6.5	643.19	643.04
	M5.5-drop	639.61	639.42
	M5	639.23	639.03
	M4.5-drop	638.64	638.37
	M4	638.59	638.31
	M3	638.09	637.80
	M2	636.29	636.04
	Gl8.0	636.00	635.74
Junction with Flood Creek	Gl9.0	635.62	635.28
	G4	635.46	635.08
	Gl10.0	635.25	634.81
	G2	635.15	634.69
	G1	634.73	634.03
	G0.5	634.12	633.54
	G0.2	633.20	632.80
	Gl11.0	630.71	630.52
Flood Creek	FL4.0	642.35	642.11
	F10	641.86	641.62
	F9.5	641.24	641.00
u/s of Cowper Street	F9	640.87	640.63
d/s of Cowper Street	F8	640.83	640.55
	F7.6	640.77	640.50
	F7.3	640.60	640.31
u/s of Archers Bridge	FL5.0	640.34	640.04
d/s of Archers Bridge	F7	639.78	639.55
Junction with Recreation Ground Creek	FL6.0	639.37	639.13
	F6	639.22	638.98

Location	Node	May 1925 Flood	March 1978 Flood
Flood Creek	F5	638.86	638.61
	F4	637.73	637.53
	F3	637.11	636.94
	F2	636.09	635.89
	F1	635.89	635.65
	FL7.0	635.70	635.39
Recreation Ground Creek	RG1.0	652.35	652.33
	R7	650.36	650.33
u/s of Monkittee Street	RG2.0	649.10	649.08
d/s of Monkittee Street	R6	648.52	648.47
	R5.5	647.91	647.83
	R5	646.64	646.59
u/s of Araluen Street	RG3.0	646.35	646.29
d/s of Araluen Street	R4	646.33	646.28
u/s of Wallace Street	R3.2	645.03	644.90
d/s of Wallace Street	R3	644.90	644.79
	R2.2	641.63	641.57
u/s of Ryrie Street	R2-drop	639.52	639.33
d/s of Ryrie Street	RG4.0	639.48	639.26
	R1	639.38	639.15
	R0.5	639.37	639.14

DESIGN FLOODS

The "calibrated" hydraulic model was then run to estimate flood discharges, flow velocities and flood profiles for the 5 yr ARI, 20 yr ARI, 50 yr ARI and 100 yr ARI design storms and the critical Probable Maximum Precipitation event.

Design flood levels were estimated by directly inputting the inflow hydrographs that were generated in the manner described in **Appendix B** into the "calibrated" floodplain model via an interface file and running the model.

The same downstream boundary condition that was adopted for the March 1978 and May 1925 floods was used for all design flood runs ie. normal depth conditions at the downstream boundary of the hydraulic model.

Design Flood Levels

The predicted flood levels at XP-SWMM node locations within the study area for the 5 year ARI, 20 year ARI, 50 year ARI and 100 year ARI design storms and the Probable Maximum Flood under existing conditions are summarised in **Table C.5**. Velocities in the design floods are given in **Table C.6**. The design flood profiles for Gillamatong/Monkittee Creek, Flood Creek and Recreation Ground Creek are given in **Figures C.2, C.3** and **C.4** respectively.

Table C.5
Design Flood Levels (m AHD)

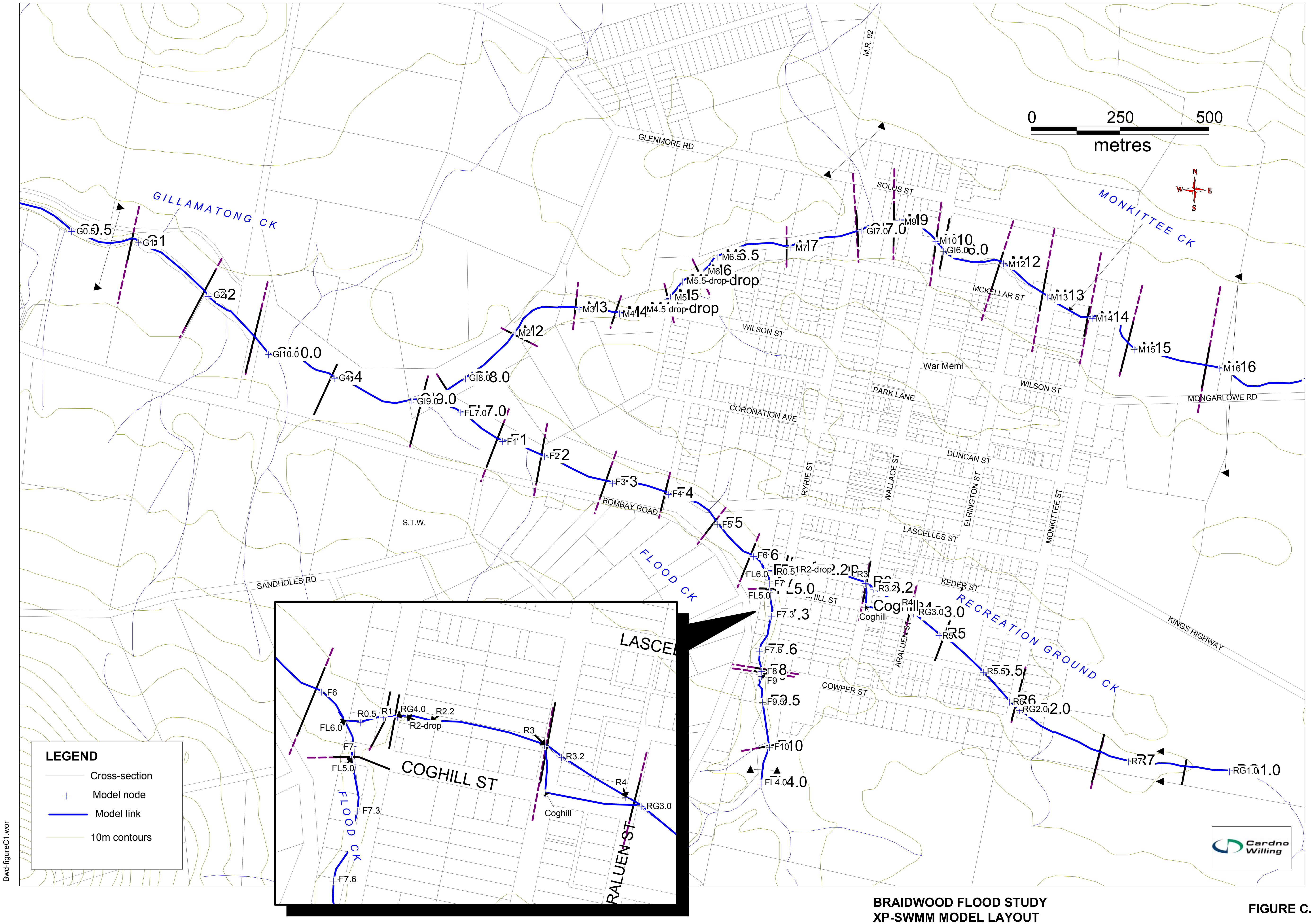
Location	Node Name	5 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI	PMF
Monkittee & Gillamatong Creek	GI5.0	648.52	648.82	648.95	649.09	652.58
	M16	647.87	648.19	648.37	648.56	652.51
	M15	647.18	647.72	647.99	648.26	652.29
d/s of Monkittee Street	M14	647.01	647.59	647.88	648.16	652.06
	M13	646.74	647.42	647.75	648.06	652.00
	M12	646.50	647.26	647.60	647.92	651.90
u/s of Wallace Street	GI6.0	646.11	646.99	647.38	647.73	651.77
d/s of Wallace Street	M10	645.60	646.05	646.24	646.43	649.69
	M9	645.24	645.70	645.90	646.11	649.41
	GI7.0	644.85	645.37	645.60	645.84	649.25
	M7	644.19	644.74	645.00	645.26	648.79
	M6.5	642.68	643.10	643.29	643.47	646.58
	M6	642.28	642.66	642.83	642.99	645.97
	M5.5-drop	639.04	639.50	639.71	639.92	644.20
	M5	638.63	639.10	639.32	639.55	643.99
	M4.5-drop	637.80	638.46	638.74	639.01	643.66
	M4	637.75	638.41	638.68	638.95	643.48
	M3	637.27	637.89	638.15	638.40	642.64
	M2	635.55	636.12	636.37	636.60	640.68
	GI8.0	635.28	635.82	636.06	636.29	640.13
Flood Creek	FL4.0	641.67	642.15	642.35	642.61	645.90
	F10	641.17	641.65	641.85	642.11	645.36
	F9.5	640.55	641.01	641.21	641.46	644.57
u/s of Cowper St	F9	640.16	640.61	640.82	641.06	643.94
d/s of Cowper St	F8	640.03	640.58	640.81	641.06	643.94
	F7.6	639.97	640.53	640.75	641.00	643.84
	F7.3	639.78	640.34	640.56	640.81	643.58
u/s of Archers Bridge	FL5.0	639.45	640.05	640.29	640.53	642.98
d/s of Archers Bridge	F7	639.13	639.59	639.77	640.01	642.87
Recreation Ground Creek	RG1.0	652.24	652.27	652.29	652.30	652.91
	R7	650.29	650.34	650.36	650.39	651.05
u/s of Monkittee St	RG2.0	649.04	649.08	649.09	649.11	649.78
d/s of Monkittee St	R6	648.40	648.49	648.53	648.57	649.63
	R5.5	647.66	647.80	647.86	647.93	649.02
	R5	646.27	646.44	646.50	646.57	647.65
u/s of Araluen St	RG3.0	646.01	646.11	646.12	646.13	647.03
d/s of Araluen St	R4	645.99	646.09	646.11	646.11	647.00
u/s of Wallace St	R3.2	644.65	644.87	645.14	645.25	646.59
	Coghill	645.79	645.86	645.87	645.87	646.54
d/s of Wallace St	R3	644.63	644.85	645.12	645.22	646.16
	R2.2	641.49	641.60	641.64	641.70	643.27
u/s of Ryrie St	R2-drop	638.97	639.20	639.38	639.60	642.83
d/s of Ryrie St	RG4.0	638.89	639.21	639.40	639.63	642.79
	R1	638.71	639.17	639.37	639.59	642.79
	R0.5	638.70	639.17	639.36	639.59	642.79

Location	Node Name	5 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI	PMF
Flood Creek	FL6.0	638.69	639.16	639.35	639.58	642.79
F6	F6	638.54	639.02	639.21	639.44	642.67
F5	F5	638.16	638.65	638.85	639.10	641.95
F4	F4	637.14	637.56	637.73	637.95	641.01
F3	F3	636.63	636.96	637.11	637.30	640.31
F2	F2	635.56	635.93	636.11	636.31	639.87
F1	F1	635.28	635.70	635.91	636.13	639.77
Junction with Gillamatong Creek	FL7.0	634.90	635.47	635.72	635.95	639.67
Gillamatong Creek	GI9.0	634.76	635.37	635.63	635.87	639.60
	G4	634.53	635.18	635.45	635.70	639.41
	GI10.0	634.24	634.91	635.18	635.43	639.13
	G2	634.12	634.79	635.06	635.31	638.54
	G1	633.52	634.19	634.47	634.72	637.91
	G0.5	633.12	633.78	634.05	634.30	637.49
	G0.2	632.49	633.13	633.39	633.64	636.83
limit of Study	GI11.0	631.67	632.31	632.57	632.82	636.01

Table C.6
Summary of Maximum Average Velocities across Floodplain (m/s) at Node Locations

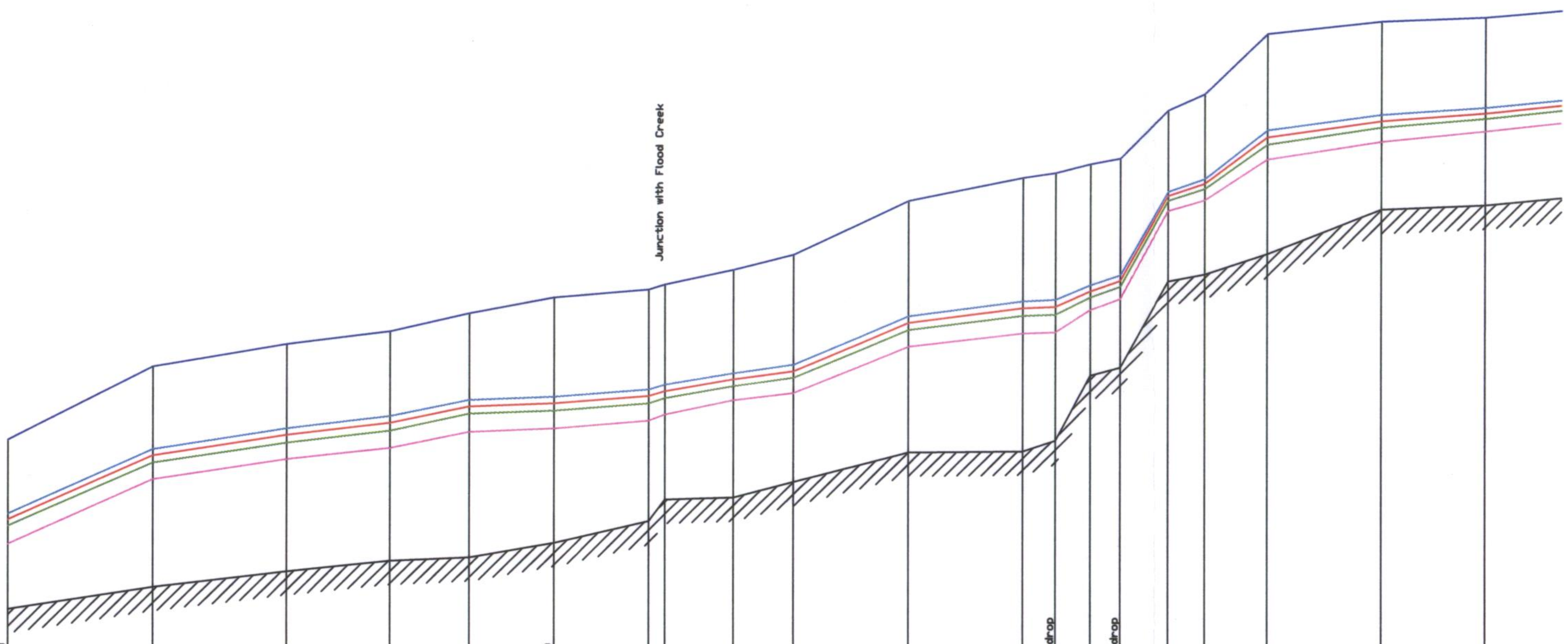
Location	U/s Node	Maximum	Average	Velocity	(m/s)	
	(see Fig. C1)	5 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI	PMF
Monkittee & Gillamatong Creeks	GI5.0	0.97	1.05	1.07	1.08	1.42
	M16	1.15	1.15	1.15	1.15	2.31
	M15	0.78	0.82	0.82	0.82	1.48
d/s of Monkittee St	M14	0.82	0.83	0.83	0.82	1.06
	M13	0.77	0.80	0.80	0.80	1.80
	M12	0.96	0.97	0.97	0.97	1.02
Wallace St - bridge	GI6.0	2.49	3.32	3.67	3.91	4.94
Wallace St – over road	GI6.0	0.00	0.16	0.54	0.85	3.95
	M10	1.01	1.09	1.12	1.15	1.50
	M9	1.01	1.04	1.05	1.05	1.28
	GI7.0	1.21	1.30	1.32	1.34	1.55
	M7	1.94	2.19	2.27	2.34	3.16
	M6.5	1.75	2.01	2.12	2.22	3.12
	M6	2.28	2.60	2.73	2.85	3.91
	M5.5-drop	1.83	2.03	2.10	2.17	2.53
	M5	1.98	2.08	2.12	2.15	2.51
	M4.5-drop	0.86	0.99	1.04	1.09	2.03
	M4	1.82	2.05	2.14	2.22	3.18
	M3	2.37	2.63	2.73	2.83	3.20
	M2	1.16	1.33	1.40	1.47	2.38
	GI8.0	1.45	1.56	1.62	1.68	2.69
Flood Creek	FL4.0	1.48	1.64	1.69	1.77	2.03
	F10	1.48	1.65	1.71	1.78	2.08
	F9.5	1.51	1.69	1.74	1.82	2.30
Cowper St - culvert	F9	3.10	3.06	3.10	3.10	3.47
Cowper St – over road	F9	2.14	2.14	2.14	2.14	2.30
	F8	0.75	0.81	0.83	0.88	1.30
	F7.6	0.95	1.01	1.03	1.06	1.57
	F7.3	1.26	1.32	1.34	1.40	2.24
Coghill St - bridge	FL5.0	2.11	2.49	2.67	2.90	3.06
Coghill St – over road	FL5.0	0.00	0.00	0.37	1.08	3.60
	F7	1.80	1.90	1.93	1.96	2.00
Recreation Ground Creek	RG1.0	0.39	0.44	0.45	0.47	0.98
	R7	0.11	0.14	0.15	0.21	0.61
Monkittee St – culvert	RG2.0	3.19	3.22	3.22	3.22	3.29
Monkittee St – over road	RG2.0	0.47	0.58	0.63	0.69	2.03
	R6	0.71	0.81	0.83	0.84	1.29
	R5.5	1.09	1.22	1.27	1.32	1.51
	R5	0.76	0.92	1.01	1.08	1.25
Araluen St – Coghill St overland flow	RG3.0	0.65	0.77	0.79	0.80	1.80
Araluen St - culvert	RG3.0	0.57	0.57	0.58	0.65	0.87
Araluen St – over road	RG3.0	0.37	0.40	0.53	0.61	1.30
	R4	0.76	0.76	0.76	0.76	0.90

Location	U/s Node	Maximum Average Velocity (m/s)				
	(see Fig. C1)	5 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI	PMF
Wallace St - culvert	R3.2	0.48	0.58	0.66	0.71	2.94
Wallace St – over road	R3.2	0.00	0.00	0.00	0.00	1.59
Coghill St – Wallace St overland flow	Coghill	0.87	1.02	1.04	1.05	2.11
	R3	1.20	1.36	1.36	1.36	1.36
	R2.2	2.04	2.30	2.39	2.51	4.79
	R2-drop	2.04	2.04	2.02	2.04	3.72
Ryrie St – culvert	RG4.0	2.99	3.40	3.47	3.50	10.04
Ryrie St – over road	RG4.0	0.00	0.00	0.00	0.00	2.13
	R1	0.97	0.97	0.97	0.97	2.27
	R0.5	0.67	0.75	0.69	0.71	1.48
Flood Creek	FL6.0	1.53	1.14	1.17	1.22	1.65
	F6	1.06	1.13	1.16	1.20	2.04
	F5	1.53	1.65	1.69	1.73	2.29
	F4	1.13	1.30	1.37	1.44	2.13
	F3	1.21	1.34	1.38	1.44	1.94
	F2	0.82	0.88	0.90	0.93	1.40
	F1	0.89	0.89	0.89	0.92	1.43
	FL7.0	0.82	0.82	0.82	0.83	1.41
Gillamatong Creek	GI9.0	1.07	1.11	1.14	1.17	1.92
	G4	1.34	1.42	1.45	1.49	2.20
	GI10.0	0.90	0.98	1.01	1.06	2.32
	G2	1.50	1.56	1.56	1.58	2.26
	G1	1.54	1.61	1.61	1.61	2.15
	G0.5	1.87	1.61	1.62	1.63	2.08
	G0.2	1.54	1.60	1.62	1.64	2.12
Limit of study	GI11.0	-	-	-	-	-



BRAIDWOOD FLOOD STUDY
XP-SWMM MODEL LAYOUT

FIGURE C.1

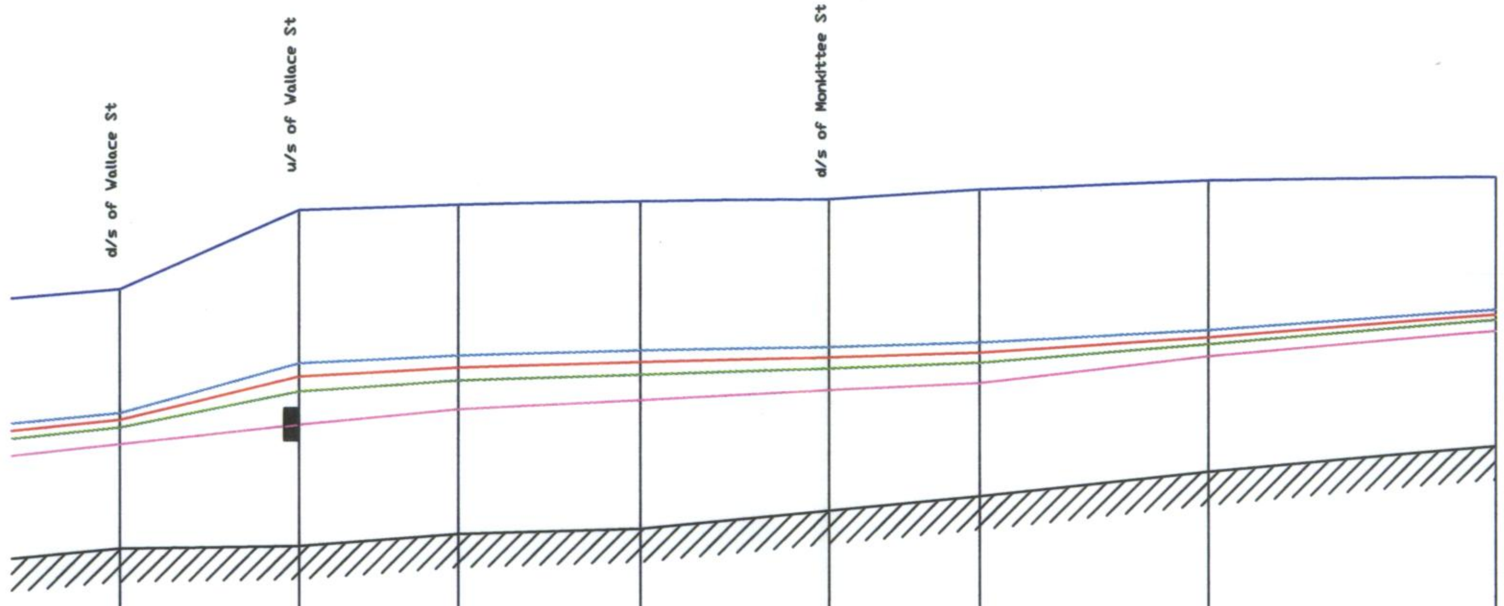


R.L. 625.000

CHAINAGE	XP-SWMM NODE	PMF FLOOD LEVEL	100 YR FLOOD LEVEL	50 YR FLOOD LEVEL	20 YR FLOOD LEVEL	5 YR FLOOD LEVEL	CREEK BED LEVEL
0	GI11.0	633.77	631.03	630.81	630.58	629.91	627.5
265	G0.2	636.48	633.43	633.19	632.93	632.31	628.32
510	G0.5	637.32	634.21	633.96	633.67	633.06	628.92
700	G1	637.80	634.67	634.42	634.13	633.49	629.32
845	G2	638.48	635.28	635.04	634.77	634.10	629.46
1000	GI10.0	639.07	635.41	635.16	634.89	634.23	630
1175	G4	639.37	635.68	635.43	635.16	634.52	630.8
1205	GI9.0	639.56	635.86	635.61	635.36	634.75	631.6
1331	GI8.0	640.10	636.28	636.05	635.81	635.28	631.68
1441	M2	640.66	636.60	636.36	636.12	635.55	632.27
1651	M3	642.64	638.40	638.15	637.89	637.27	633.37
1861	M4	643.48	638.95	638.69	638.41	637.76	633.4
1921	M4.5-drop	643.66	639.01	638.74	638.46	637.80	633.8
1985	M5	643.99	639.55	639.32	639.10	638.63	636.21
2040	M5.5-drop	644.20	639.92	639.71	639.50	639.04	636.51
2128	M6	645.97	642.99	642.83	642.66	642.28	639.69
2195	M6.5	646.58	643.47	643.29	643.10	642.68	639.95
2310	M7	648.79	645.26	645.00	644.74	644.19	640.72
2520	GI7.0	649.25	645.84	645.60	645.37	644.85	642.37
2710	M9	649.41	646.11	645.90	645.70	645.24	642.53

Horizontal Scale 1:10,000
Vertical Scale 1:200

Design Flood Profile for Gillamatong/Monkittee Creek

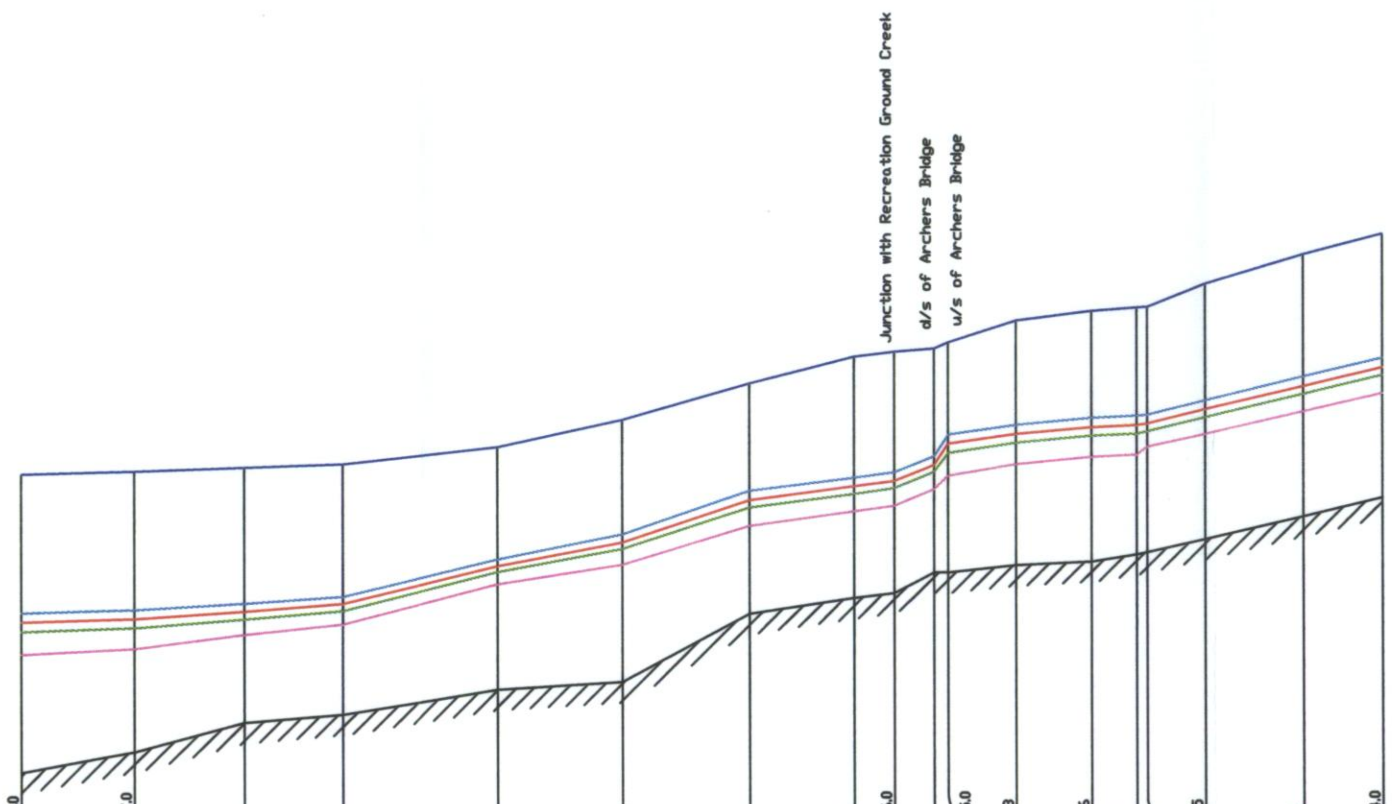


R.L. 625.000

XP-SWMM NODE	M10	GI6.0	M12	M13	M14	M15	M16	GI5.0
PMF FLOOD LEVEL	649.70	651.77	651.90	652.00	652.06	652.29	652.51	652.58
100 YR FLOOD LEVEL	646.43	647.73	647.92	648.06	648.16	648.26	648.56	649.09
50 YR FLOOD LEVEL	646.24	647.38	647.60	647.75	647.88	647.99	648.37	648.95
20 YR FLOOD LEVEL	646.05	646.99	647.26	647.42	647.59	647.72	648.19	648.82
5 YR FLOOD LEVEL	645.60	646.11	646.50	646.74	647.01	647.18	647.87	648.52
CREEK BED LEVEL	642.85	642.91	643.2	643.34	643.83	644.2	644.82	645.48
CHAINAGE	2875	3110	3320	3560	3810	4010	4310	4690

Horizontal Scale 1:10,000
Vertical Scale 1:200

Design Flood Profile for Gillamatong/Monkittee Creek



R.L. 630

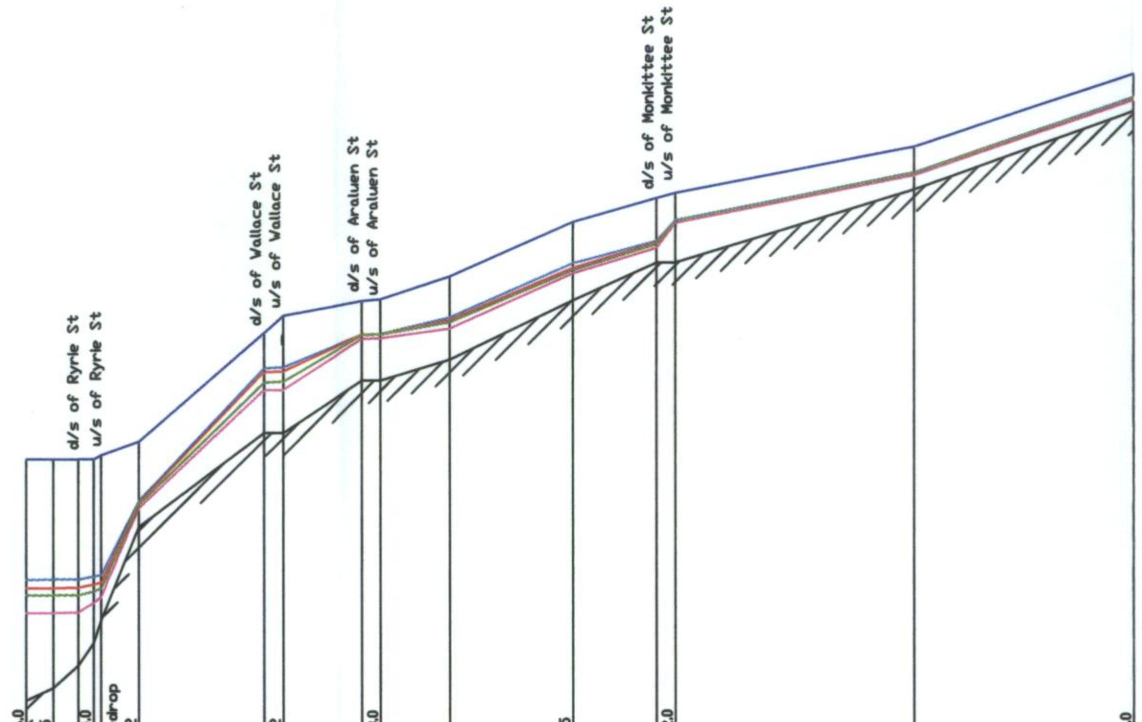
XP-SWMM NODE	G19.0	FL7.0	F1	F2	F3	F4	F5	F6	FL6.0	F7	FL5.0	F7.3	F7.6	F8	F9	F9.5	F10	FL4.0
PMF FLOOD LEVEL	639.56	639.63	639.74	639.84	640.29	641.00	641.95	642.66	642.78	642.87	643.03	643.60	643.86	643.95	643.97	644.58	645.36	645.90
100 YR FLOOD LEVEL	635.86	635.94	636.12	636.31	637.3	637.95	639.1	639.44	639.58	640.01	640.58	640.84	641.02	641.08	641.11	641.49	642.12	642.61
50 YR FLOOD LEVEL	635.61	635.7	635.9	636.11	637.11	637.73	638.85	639.21	639.35	639.77	640.34	640.59	640.77	640.83	640.87	641.25	641.86	642.36
20 YR FLOOD LEVEL	635.36	635.46	635.7	635.93	636.96	637.56	638.65	639.01	639.16	639.59	640.09	640.36	640.55	640.6	640.67	641.04	641.66	642.16
5 YR FLOOD LEVEL	634.75	634.9	635.28	635.56	636.63	637.14	638.16	638.54	638.69	639.13	639.48	639.79	639.98	640.04	640.25	640.59	641.19	641.67
CREEK BED LEVEL	631.6	632.15	632.95	633.17	633.83	634.01	635.82	636.23	636.36	636.91	636.91	637.1	637.2	637.39	637.45	637.8	638.4	638.9
CHAINAGE	0	150	295	425	631	796	963	1101	1154	1206	1225	1315	1415	1475	1489	1565	1695	1800

Horizontal Scale 1:10,000

Vertical Scale 1:200

Design Flood Profile for Flood Creek

FIGURE C.3



R.L. 635

XP-SWMM NODE	FL6.0	R0.5	R1	RG4.0	R2-drop	R2.2	R3	R3.2	R4	RG3.0	R5	R5.5	R6	RG2.0	R7	RG1.0
PMF FLOOD LEVEL	642.78	642.78	642.79	642.79	642.90	643.27	646.15	646.61	647.00	647.04	647.64	649.08	649.71	649.84	651.05	652.98
100 YR FLOOD LEVEL	639.58	639.59	639.59	639.68	639.71	641.70	645.22	645.25	646.11	646.13	646.56	647.99	648.57	649.12	650.38	652.37
50 YR FLOOD LEVEL	639.35	639.36	639.37	639.46	639.51	641.64	645.11	645.13	646.11	646.12	646.49	647.86	648.53	649.10	650.36	652.35
20 YR FLOOD LEVEL	639.16	639.17	639.17	639.28	639.36	641.60	644.84	644.87	646.09	646.11	646.43	647.80	648.49	649.09	650.34	652.33
5 YR FLOOD LEVEL	638.69	638.70	638.71	638.97	639.12	641.49	644.63	644.64	645.99	646.01	646.26	647.72	648.39	649.05	650.29	652.29
CREEK BED LEVEL	636.36	636.7	637.3	637.9	638.5	641	643.5	643.5	644.89	644.89	645.44	647	647.99	648	649.93	652
CHAINAGE	0	36	69	89	99	149	314	339	444	469	561	724	834	859	1174	1464

Horizontal Scale 1:10,000

Vertical Scale 1:200

Design Flood Profile for Recreation Ground Creek