Cardno
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Shaping the Future

NABIAC FLOOD STUDY
Local Catchment Study

Report Prepared for
Great Lakes Council

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Front cover – clockwise from top left – June 2007 flood, courtesy Bruce Weller; February 2002 flood (courtesy SES); February 2002 Flood, courtesy SES; June 2007 flood, courtesy Bruce Weller

FOREWORD

The State Government's Flood Prone Lands Policy is directed towards providing solutions to existing flood problems in developed areas utilising ecologically positive methods wherever possible and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the policy, the management of flood prone land is the responsibility of Local Government. To achieve its primary objective, the policy provides for State Government financial assistance to Councils for flood mitigation works to alleviate existing flooding problems. The policy also provides for State Government technical assistance to Council to ensure that the management of flood prone land is consistent with the flood hazard and that the future developments do not create or increase flooding problems in the flood prone land.

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

1. Formation of a Committee	Consisting of a range of local and state agency representatives and community representatives.
2. Flood Study	Determines the nature and extent of the flood problem.
3. Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed development.
4. Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
5. Implementation of the Plan	Construction of flood mitigation works to protect existing development. Use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The committee for the Nabiac Flood Study is the Great Lakes Floodplain Management Committee.

This Flood Study is the second stage of the management process for the Nabiac study area. This study defines the effect of local catchment flows on flooding within the township. Flooding from the Wallamba River has been defined as a part of DIPNR (2004).

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GLOSSARY OF TERMS*

Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Creek Rehabilitation	Rehabilitating the natural 'biophysical' (i.e. geomorphic and ecological) functions of the creek.
Creek Modification	Widening or altering the creek channel in an environmentally compatible manner (i.e. including weed removal and stabilisation with suitable native endemic vegetation) to allow for additional conveyance.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events, e.g. some roads may be designed to be overtopped in the 1 year ARI flood event.
Development	The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving, rather than how much it is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
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 overland runoff before entering a watercourse and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
Flood hazard	That which has the potential to cause damage to the community. Provisional flood hazard is categorised in the *Floodplain Development Manual* (NSW Govt, 2005) as either High or Low Hazard. Provisional hazard categories are defined as a product of flood velocity and depth. The true hazard incorporates the provisional hazard, as well as other factors such as access, type of development, evacuation problems, effective warning time, flood readiness, rate of rise and flood duration.

Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood-prone land, rather than being restricted to land subject to designated flood events.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain management measures	The full range of techniques available to floodplain managers.
Floodplain management options	The measures which might be feasible for the management of a particular area.
Flood planning area	The area of land below the 100 Year ARI level and thus subject to flood-related development controls.
Flood planning levels	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different floodplains. The concept of FPLs supersedes the “Standard flood event”. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FPLs.
Flood storages	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always, aligned with naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings.

Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. With regard to flooding, the objective of the management plan is to minimise and mitigate the risk of flooding to the community. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.
NPER	National Professional Engineers Register. Maintained by the Institution of Engineers, Australia.
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	The flood calculated to be the maximum that is likely to occur.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Annual Exceedance Probability.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, 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 changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.

* Many terms in this Glossary have been derived or adapted from the NSW Government *Floodplain Development Manual*, 2005.

LIST OF ABBREVIATIONS

AAD	Annual Average Damages
AGL	Australian Gas and Light Limited
AHD	Australian Height Datum
AHIMS	Aboriginal Heritage Information Management System
ARI	Average Recurrence Interval
AWE	Average Weekly Earnings
BoM	Bureau of Meteorology
CPI	Consumer Pricing Index
DCP	Development Control Plan
DECC	Department of Environment and Climate Change (formerly the Department of Environment and Conservation)
DNR	Department of Natural Resources (now DECC and DWE)
DWE	Department of Water and Energy
EPA	Environmental Protection Authority (within DECC)
FPL	Flood Planning Level
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
km	kilometres
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
m	metre
m^2	Square metres
m^3	Cubic metres
mAHD	Metres to Australian Height Datum
mm	millimetres
m/s	metres per second
NSW	New South Wales
OSD	On-site Detention
PMF	Probable Maximum Flood

RTA	Roads and Traffic Authority
SEPP	State Environmental Planning Policy
SES	State Emergency Service

1 INTRODUCTION

Cardno Lawson Treloar were commissioned by the Great Lakes Council to undertake a flood study for Nabiac township. The study has been undertaken to determine the flood behaviour for the 200 year, 100 year, 50 year, 20 year, 10 year and 5 year ARI floods and the Probable Maximum Flood (PMF). The objective of the study is to determine the nature and extent of flooding through the estimation of design flood levels and velocities from the local catchment. The study has also defined the Provisional Flood Hazard and Hydraulic Categories for the flood affected areas. Flooding from the Wallamba River has been analysed in a separate study (DNR, 2004).

Nabiac is located on the Central Coast of New South Wales in the Wallamba River Basin. It is located approximately 16km north-west of Foster, and approximately 230km north of Sydney within the Great Lakes Council Local Government Area (LGA). The area immediately to the north of Nabiac lies in the Taree Council LGA (**Figure 1.1**)

The town of Nabiac has a well-known history of flooding. Many residents of the town have witnessed and been affected by flooding. The flooding behaviour of the Wallamba River has been investigated in several past flood studies (including DIPNR, 2004), and the effect of such flooding on Nabiac has been documented. However, residents report that flooding within Nabiac is influenced more frequently by local catchment flows, rather than flooding from the Wallamba River. Therefore, this Flood Study focuses on the effect of local catchment flows on the Nabiac Township, rather than from the Wallamba River. Of particular interest to the study is the interaction between Town Creek and Woosters Creek - the two main flow paths within the town.

In essence, the objectives of the Nabiac Food Study are to:

- Investigate historical flooding within and around the township of Nabiac;
- Develop a computer model that represents the current flooding mechanisms;
- Provide an analysis of design flood events;
- Define the various levels of flood hazard ;
- Assess flood damages; and
- Provide Council with the knowledge to make effective investments in floodplain risk management.

The various components of this flood study can be grouped together in three main stages, with community consultation undertaken throughout. Firstly, all available data was compiled for the study. This involved the collection of available historical rainfall and flood level data. Secondly, a full hydrologic investigation was carried out for the catchment using a hydrologic computer model to define the catchment flows. Thirdly, a hydraulic computer model of the study area was generated to determine flood depths, velocities and extents. It should be noted that there were two main scenarios to consider during the hydraulic modelling, corresponding to the pre and post Pacific Highway upgrade scenarios. The post Pacific Highway upgrade conditions of the hydraulic model was then used with design rainfall conditions to simulate flood behaviour in the catchment, and an assessment was made of the associated flood hazard and damages. The model can now be used to investigate various management and flood mitigation options for the existing catchment conditions and can assist in defining long term flood management strategies.

2 BACKGROUND

2.1 Catchment Description

The study area for the flood study (i.e. the area for flood behaviour is defined) is the area bounded by the Pacific Highway (approximately forming the northern and western boundaries) and the Wallamba River (approximately forming the southern boundary). The study area extends from the Pacific Highway crossing over the Wallamba River in the west through to the catchment boundary of Pipeclay Creek in the east. The study area is a mix of rural, bushland, low density residential and isolated areas of low density commercial land uses. The study area is shown in **Figure 2.1**.

The catchment draining to the study area is 35 km^2 and incorporates both the local catchments as well as the larger Wallamba River catchment (**Figure 2.2 & Figure 6.1**). The land use in the catchment is predominantly rural with isolated pockets of bushland. The upper reaches of the catchment rise to an elevation of around 433mAHD at Mount Talawahl, while the lower reaches of the catchment have elevations of less than 10mAHD.

There are a number of creeks that flow through the Nabiac study area (**Figure 2.1**). Town Creek is in the western portion of the study area and originates approximately 1km north of the Pacific Highway. Town Creek flows through the Nabiac township, where there are a number of crossings including a road bridge, a foot bridge, and a pipe culvert crossing near the industrial area. The creek then enters private rural land, where it eventually joins with the Wallamba River.

Woosters Creek originates north of the Pacific Highway with a larger catchment area than Town Creek and crosses Clarkson Street at the opposite end from Town Creek. Woosters Creek flows through crown reserve bushland, roughly parallel with Hoskins Street and Donaldson Street. In the lower lying areas, the waterway becomes swampy and marshy. Woosters Creek joins the Wallamba River near the end of Wharf Street.

Pipeclay Creek flows through the eastern portion of the study area, originating upstream of the Pacific Highway. Pipeclay Creek has the largest catchment area of all three creeks. It meanders through private rural lands, before joining with the Wallamba River in the south.

A number of smaller unnamed tributaries exist within the study area, which connect up with the three major tributaries of Town Creek, Woosters Creek and Pipeclay Creek. These tributaries were also included in the analysis.

2.2 Study Objectives

The objectives of the Flood Study are to:

- Identify all the flood-related data by searching all relevant data sources.
- Determine the likely extent and nature of flooding and identify potential hydraulic controls by carrying out detailed site visits of the study area.
- Define existing catchment condition flood behaviour for mainstream flooding in the catchment, with due consideration to the impact of the combined influence of the Wallamba River and local catchment flows on flooding characteristics.
- Define design flood levels, velocities and depths for the catchment.
- Define the extent of flooding for the 200 year, 100 year, 20 year, 10 year and 5 year ARI floods and Probable Maximum Flood (PMF) for the catchment.
- Define Provisional Flood Hazard for the flood-affected areas.
- Define the Hydraulic Categories for the flood-affected areas.
- Assess impacts of culvert blockages on flooding.

Two numerical modelling tools were developed:

- A hydrologic model to convert rainfall on the catchment into runoff. The hydrologic model combines rainfall information with local catchment characteristics to estimate runoff hydrographs.
- A hydraulic model to convert runoff hydrographs into water levels and velocities throughout the study area. The model simulates the hydraulic behaviour of the water within the study area by accounting for flow in the major channels as well as all the potential overland flowpaths, which develop when the capacity of the channels is exceeded.

Section 3 of the report discusses the content and sources of relevant data utilised throughout the study. This section describes historical rainfall and flood level data which was used in the calibration of the established hydrologic and hydraulic models. This section also provides details of the survey data used in the study area.

Sections 6 discuss the catchment characteristics and provides a description of the hydrological model used in the study.

Section 7 describes the hydraulic model utilised for the flood study, its calibration and subsequent use for design rainfall events.

Section 9 provides the results of design flood estimation for the catchment.

Sections 10 and **11** provide details of provisional flood hazard and hydraulic categorisation in accordance with the *Floodplain Development Manual* (NSW Government, 2005).

Section 12 summarises the results of flood damages assessment.

Section 13 quantifies the impact of model sensitivity on design flood estimation.

Section 14 summarises the study results and provides discussion on various aspects of the results.

A number of figures are included to illustrate the study results. Spatially referenced data such as flood extents are represented in a Geographic Information System (GIS) package.

3 DATA

Data has been obtained from a number of sources and includes information required for input to the hydrologic and hydraulic models, together with information required for verification of model results and the adequate representation and presentation of those results.

Data was obtained from the following sources:

- Rainfall data from the Bureau of Meteorology;
- Water level and rainfall data from Manly Hydraulics Laboratory;
- Previous reports prepared for related studies in the area (see **Section 3.1**);
- Ground survey and aerial survey information (see **Section 3.2**);
- Aerial photography; and
- General GIS information (such as cadastre, street names, and etc.) from Great Lakes Council.

3.1 Reports

A number of relevant reports were compiled as a part of this study. These include:

- *Wallamba River Flood Study* (PWD, 1985).
- *Forster/Tuncurry Flood Study* (PWD, 1989).
- *Wallamba River Floodplain Risk Management Study for Nabiac, Failford, and Minimbah Areas* (DIPNR [1], 2004).

The *Wallamba River Flood Study* (PWD, 1985) used both the WBNM (Hydrology) and MIKE11 (hydraulics) models to define the flood behaviour for the Wallamba River downstream of the Pacific Highway crossing. The modelling undertaken in that study was subsequently updated as a part of DIPNR (2004).

The *Forster / Tuncurry Flood Study* (PWD, 1989) was focused further downstream of Nabiac, in the Forster area and for Lake Wallace. However, the WBNM model utilised in PWD (1985) was extended to Lake Wallace and utilised for the PWD (1989) study.

The *Wallamba River Floodplain Risk Management Study for Nabiac, Failford and Minimbah Areas* (DIPNR [1], 2004) is the most recent flood related study undertaken for the area. The study acquired the WBNM and MIKE11 models used for the PWD (1989) and PWD (1985) studies. The models used in those studies were then further refined in order to provide a greater level of detail for the study area. DIPNR [1] (2004) also recommended a number of floodplain risk management options to mitigate the flood risk within the Nabiac area as a result of river flooding. It recommended that a study be undertaken to define the local catchment flooding characteristics in this area.

3.2 Survey Information

Survey information was obtained from a number of sources. The following summarises the information received:

- Mid Coast Water photogrammetry - obtained as part of the survey required to lay a new sewer line – received 27 October 2006, date of survey unknown (circa 2001). This data primarily covers the Nabiac township between Town Creek and Woosters Creek.
- Mid Coast Water Aerial Laser Survey (ALS) - a number of versions of this data was provided, with the most recent version received on 26 October 2007 from Mid Coast Water, flown in middle of 2007. Mid Coast Water have noted that the ALS data is unreliable, particularly in vegetated areas, due to some errors in the collection technique.

Generally, accuracy of ALS data is +/- 0.15m to one standard deviation on hard surfaces, however in this case, the accuracy is unknown.

- Great Lakes Council photogrammetry – undertaken by Great Lakes Council prior to the commencement of the current study. This data covers the entire study area, bounded by the Pacific Highway and the Wallamba River. Note that the data only extends a limited distance north and south of these boundaries. The aerial survey was flown in 2003 or 2004, and includes some of the construction works associated with the Pacific Highway upgrade.
- Pre-upgrade survey of Pacific Highway – received from RTA on 7 April 2006. This survey provides details on the Pacific Highway prior to the upgrade works occurring. Includes surface levels and culvert details.
- Proposed upgrade of Pacific Highway – received from RTA & Maunsell in hard copy format on 11 November 2006 (Drawing Number series 20018704-DR-XXX, dated 13 January 2005). Design details of the proposed upgrade of the highway, including proposed surface levels and culvert details.
- Survey details of the Clarkson Street Bridge over Woosters Creek – Received from Council 1 August 2008. This survey includes surface levels of the Clarkson Street Bridge together with some of the creek bank details prior to its replacement as a part of the Pacific Highway upgrade. There is little information on the invert of the creek near the bridge, and no obvert details are available.
- Additional details of Clarkson Street Bridge over Woosters Creek – Received from Council 10 October 2008. Addition details included photos of the Woosters Creek Bridge, together with the depth of the bridge deck, suitable for determination of the bridge obvert.

Additional ground survey was also collected as a part of this study. This survey was undertaken by Lidbury Summers & Whiteman, and was completed on 31 October 2007. This data included:

- Cross Sections – cross sections of the major creeks and tributaries within the study area were surveyed to define the in-bank details. These details are generally not adequately defined in aerial survey.
- Hydraulic Structures – details of hydraulic structures (such as culverts and bridges) on major tributaries were surveyed.
- Floor Level Survey – some floor levels were available from DIPNR (2004). Additional floor levels were collected as part of this survey where either no floor levels existed or to reflect new development.
- Historical levels – historical levels identified as a part of the resident survey (**Section 4**) were collected where necessary. Additional levels were also collected following the June 2007 storm event.

Details of the Lidbury Summers & Whiteman survey data are provided in **Appendix A**.

3.3 Historical Rainfall Information

Daily rainfall data was obtained from the Bureau of Meteorology (BoM), and pluviometer rainfall information was obtained from the Manly Hydraulics Laboratory (MHL). Three historical events (February 2002, October 2004, and June 2007) were identified through the resident survey (**Section 4**) and rainfall data was obtained for those events. The location of the rainfall gauges is presented in **Figure 3.1**. **Table 3.1** provides details on the gauge data that was obtained.

Table 3.1 Rain Gauges

Station No.[1]	Station Name	Easting	Northing	Type
Source:	***BoM***			
060033	Krambach Bellevue	428861.6	6449093.5	Daily
060030	Taree Radio Station 2re	451144	6470716.8	Daily
060013	Forster Tuncurry RVCP	453674.8	6439845.3	Daily
060021	Krambach Post Office	430114.5	6453690.2	Daily
060148	Willina	432520.5	6440383.5	Daily
Source:	***MHL***			
209404	Wallamba River Nabiac	436831	6446396	Pluviometer (15 min interval)

Daily totals for each historical storm event are summarised in **Tables 3.2 to 3.4**. The gauges in **Table 3.1** have been operational for various time periods and therefore data for the three events is not available for the all of the gauges.

Table 3.2 Daily Rainfall Totals for February 2002 Flood Event

Station No.	Station Name	Total daily Rainfall (mm to 9am)				
		4th Feb	5th Feb	6th Feb	7th Feb	8th Feb
60013	Forster Tuncurry RVCP	6.8	46	83.6	6	14.8
60021	Krambach Post Office	6.2	88	116	12.6	29
60030	Taree Radio Station 2re	3.4	64.3	83.7	6.2	15.3
60033	Krambach Bellevue	3	60.4	108.6	12	22

Table 3.3 Daily Rainfall Totals for October 2004 Flood Event

Station No.	Station Name	Total daily Rainfall (mm to 9am)		
		19th Oct	20th Oct	21st Oct
60013	Forster Tuncurry RVCP	6.8	46	83.6
60021	Krambach Post Office	6.2	88	116
60030	Taree Radio Station 2re	3.4	64.3	83.7
60033	Krambach Bellevue	3	60.4	108.6

Table 3.4 Daily Rainfall Totals for June 2007 Flood Event

Station No.	Station Name	Total Daily Rainfall (mm to 9am)			
		7th June	8th June	9th June	10th June
060013	Forster Tuncurry RVCP	7	130	45	10
060021	Krambach Post Office	156.2	6.6	5	0
060148	Willina	7	90	47.6	24
209404	Wallamba River Nabiac (pluvio)	28.5	183.5	2	4

Figure 3.2 shows the daily rainfall totals and isohyets for the 6th February 2002 (the day with the highest rainfall for the February 2002 flood event). Similarly, **Figure 3.3** shows the 20th October 2004, and **Figure 3.4** contains information for the 8th June 2007. **Figure 3.5** provides the time series of rainfall for Nabiac on 8th June 2007.

Note that the rainfall depths in **Figure 3.4** for Krambach Post Office are actually for the 7 June 2007 (bracketed value is for 8 June 2007). Daily rain gauges report the total rainfall up to 9am each morning. The majority of the rainfall for the June 2007 fell within the morning. As Krambach Post Office received the rainfall the day before, the data suggests that the storm event passed over Krambach first, mostly before 9am, reaching Nabiac a little later. This is in agreement with the weather observations at the time, which showed the rainfall moving from north to south direction.

Based on the resident survey (**Section 4**), the flooding observed within the township was primarily driven by the local catchment. In all three events, the daily total for Nabiac is generally higher than the surrounding gauges. This suggests that, while there was significant rainfall across the entire area, localised heavy rainfall was observed in the Nabiac area.

It is also worth noting that the Wallamba River Nabiac gauge is located upstream of Nabiac. It may therefore not be entirely representative of the rainfall which falls within the local Nabiac catchment.

An average recurrence interval analysis was undertaken on the rainfall data (**Table 3.5**). Based on the average intensities alone, the following provides an indication of the ARI of each of the events. It should be noted however that the ARI of the rainfall does not always correspond with the same ARI for the flood event.

Based on the rainfall analysis alone, the February 2002 event would appear to be the most significant rainfall event out of the three historical rainfall events identified. June 2007 was also a significant event, while based on the rainfall data the October 2004 event appears to have been relatively minor.

Table 3.5 Approximate ARI of Historical Rainfall Events

Storm Event	**Storm Event**	**Duration**			
		1 hour	**2 hour**	**6 hour**	**9 hour**
February 2002	Intensity (mm/hr)	48.5	44.0	28.8	21.6
	Approx. ARI	*5-10yr*	*20-50yr*	*>100yr*	*~100yr*
October 2004	Intensity (mm/hr)	30.0	22.0	13.2	11.3
	Approx. ARI	*~1yr*	*1-2yr*	*~2yr*	*2-5yr*
June 2007	Intensity (mm/hr)	41.0	35.5	24.8	19.1
	Approx. ARI	*2-5yr*	*~10yr*	*~50yr*	*~50yr*

3.4 Calibration Data: Historical Water Level Information

Historical water level information was sourced for the model calibration process. There are a number of water level gauges around Nabiac in streams and tributaries, and in the Wallamba River. Data was sourced from six gauges (**Table 3.6** and **Figure 3.1**), and the water levels for each historical event are presented. For the June 2007 flood event, the majority of the gauges had been removed by the RTA during the Pacific Highway upgrade. Two gauges (Nabiac Street and Nabiac Bakery) remain, and were overtopped during the June 2007 flood event.

Table 3.6 Water Level Gauges near Nabiac Station

Name	Station Owned by	Easting	Northing	Type of Record	Gauge Zero	Level (mAHD) Feb02	Level (mAHD) Oct04	Level (mAHD) June07
Pipeclay Creek	RTA	444399	6449731	Manual	8.940	Over-topped	10.680	RTA Removed
Nabiac Street	RTA	442566	6447840	Manual	8.850	2.550	2.430	Overtopped
Nabiac Bridge	RTA	440966	6447538	Manual	3.450	Nil	3.660	RTA Removed
Nabiac Creek	RTA	440516	6448409	Manual	8.690	Over-topped 8.930	8.290	RTA Removed
Nabiac Bakery	MHL	441166	6448317	Manual	5.820	7.425	7.120	Overtopped
Wallamba River Nabiac	MHL	436831	6446396	Continuous	-	6.70	10.25	10.98 (max WL for flood event)

Figure 3.6 shows the water level time series for the June 2007 event in Wallamba River at Nabiac. The peak of the flood was 10.98mAHD and occurred on 8th June 2007 at 12.45pm.

3.5 Calibration Data: Observed Flood Levels and Observations

A number of historical flood levels were identified during community consultation (**Section 4**), and these were surveyed for use in the calibration process. These are discussed in detail in **Section 4** and **Section 8**.

4 COMMUNITY CONSULTATION

4.1 Community Questionnaire and Information Sheet

Community consultation was undertaken to source useful data for the completion of the Nabiac Flood Study. During the data collection phase of the project, a questionnaire and information sheet was distributed to the Nabiac residents, requesting records of historical flooding (**Appendix B**). A total of 500 surveys were distributed; 350 were delivered by the post office to residents in the township of Nabiac, and the remaining 150 were sent to the Nabiac Village Futures Group (also posted on their website, www.nabiac.com), the Landcare group, and the Neighbourhood Centre for distribution. The surveys were distributed with a reply paid envelope and a total of 42 responses were received. A summary of these responses is presented in **Appendix C**.

Survey questions included details of how and when the residents were affected by flood waters, whether they have evidence such as photographs or floodmarks and a map for identifying flood-prone areas in the study area.

The responses from residents contained significant detail regarding their experiences with flooding in the study area. Follow-up telephone interviews were undertaken with the 24 respondents for additional clarification of flood behaviour and dates of events.

When the residents were asked to highlight the flood-prone areas through the town, the most common response was the intersection of Nabiac and Clarkson Streets in the town centre, (20 respondents). Frequently mentioned flood-prone buildings were Sensations Cafe, Griffo's Meats, Nabiac Bakery, the newsagency/post office building and the general store. The second-most flood prone area was Clarkson St at the bridge over Wooster's Creek (10 respondents). The area between Pipeclay Creek and Lower Woosters Ck (after the confluence of Woosters Ck and the tributary) was also mentioned as flood prone, as were the following areas:

- Playing fields on Hoskins St;
- Along Clarkson St, particularly at the Motorcycle Museum;
- Area surrounding the industrial estate;
- Along Farnell St; and
- Sections along the Pacific Hwy - where the drain, Woosters Ck and Woosters Tributary intersect the road.

There was a general consensus that peak flow from the tributaries, rather than Wallamba River Flooding, is the primary source of flooding, as flood damage has been due to flash flooding rather than longer low-intensity events.

A number of flood marks were identified for survey and a number of photographs of historical floods were received (see **Appendix D** for photos).

Respondents located in the vicinity of the town centre largely agreed that February 2002 and October 2004 were the most significant events (February 2002 being the largest), whereas other respondents recalled the biggest floods in 2000, 2001 and 2003. Two other major events were reported in 2004 – February and May. Residents also recalled significant events in 2005 and 2006.

Table 4.1 summarises reported historical flooding from creeks in the study area (from 1999 onward) and also identifies if the event coincided with a reading from the water level recorder at the Nabiac Bakery.

Table 4.1 Past Flood Events & Waterways Affected

Date	Observed Flooding	Recording from Bakery
Feb-Mar 1999	Town Creek	N
8-Mar-2000	Town, Woosters and Pipeclay Creeks	N
Feb-01	Town Creek	N
Feb-02	All Creeks	Y
May-02	All creeks and Woosters Tributary	N
Feb-03	Town Creek, Woosters Creek & Woosters Tributary	N
Mar-04	Drain behind Motorcycle Museum	N
19-Oct-04	All Creeks	Y
1-Jun-05	Woosters and Pipeclay Creeks	N
17-Dec-2005	Drain behind Motorcycle Museum	N
Jan-06	Drain behind Motorcycle Museum	N
Mar-06	Drain behind Motorcycle Museum	N

In general, respondents believe that common reasons for flooding include inadequate drainage through the industrial estate, weeds and garbage through waterways and lowering of the bridge over Woosters Creek at the Pacific Highway. Respondents located close to the Wallamba River reported that the severity of flooding was influenced by tides.

Appendix E summarises the floodmarks from various events that were identified during the process of community consultation. There are a total of 28 floodmarks from 12 events, a number of the floodmarks are repeated for different events (such as the Clarkson St Bridge over Woosters Ck and Griffo’s Meats), which brings the total number of floodmarks to approximately 22. The flood marks were surveyed as a part of the ground survey undertaken for the creeks in the study area (provided in **Appendix A**).

It should be noted that the brochure identified May 2002 as a possible historical flood event, based on anecdotal evidence. However, later investigation of the rainfall and photographs over this period suggests that in fact February was the critical event in 2002. Where people identified May 2002 as an historical event, it was assumed that this actually corresponded to the February 2002 event.

4.2 Media Release

Concurrent with the community brochure and questionnaire distribution, a media release was posted in the Mayor’s column of the “Great Lakes Advocate.” The media release is included in **Appendix B**.

4.3 Phone Conversations following the June 2007 Flood Event

After the initial community consultation was completed, Nabiac experienced a significant flood event in June 2007. To gather information about this event, residents who were particularly knowledgeable, helpful, or interested in the study as identified in the previous community consultation, were contacted by phone to seek information on the June event.

A summary of each conversation is provided below in **Appendix C**.

4.4 Public Exhibition

The draft version of this report was placed on exhibition from 10th March 2010 to 7th April 2010.

4.4.1 Community Meeting

A meeting was also held with the community on 23rd March 2010 at the Nabiac Showground. It was attended by 15 community representatives, as well as 2 Council representatives and a member of Cardno. A presentation was provided to the community during this meeting, and a copy of this presentation is provided in **Appendix F**. Key notes and discussion items from the meeting are also provided in **Appendix F**.

4.4.2 Submissions

As a part of the exhibition of the draft report, three submissions were received from the community. These included submissions from:

- Col Whittaker
- Malcolm O'Mara
- Nabiac Village Futures Group.

The majority of comments received in the submissions regarded current issues with flooding that the community have experienced and potential options for improving the flooding in the study area. These should be reviewed as a part of the next stage of the Floodplain Management Process, the Floodplain Risk Management Study & Plan.

4.4.3 Key issues

A number of the residents, in both the community meetings and the submissions, identified a number of key issues. These include, but are not limited to:

- The industrial culvert and its affect on Town Creek. The general consensus is that this should be upgraded to reduce the flooding in the township.
- Weeds and growth in the creeks, and their effect on flooding.
- The Nabiac Street Footbridge, and its effect on the flows in this area.
- Reconstructed Woosters Creek Bridge. A number of people noted that this was constructed too low, and does not allow for a flood free access route.
- The general timing for any works that are proposed.

A key issue which was also raised was the modification to Candoormakh Creek Road as a part of the RTA works. This has resulted in a much larger catchment area entering into Town Creek than would have occurred previously. As a result of these comments, this report was reviewed and the catchment area updated to represent what is now the existing scenario.

An analysis has also been undertaken on the effect of the re-direction of flows into Town Creek. This is discussed in **Section 14**.

A more detailed summary of these issues is provided in the minutes and responses provided in **Appendix F**.

5 METHODOLOGY

Two numerical modelling tools were utilised to assess flood behaviour in the catchment:

- Hydrological model (WBNM)
- Hydraulic model (SOBEK)

Both models are described in general below, and in detail in **Sections 6** and **7** respectively.

5.1 Hydrological Model

A hydrological model converts rainfall on the catchment into runoff. The hydrologic model combines rainfall information with local catchment characteristics to estimate a runoff hydrograph. Runoff hydrographs for the flood study were estimated using the WBNM rainfall runoff modelling package.

5.2 Hydraulic Model

A hydraulic model converts runoff into water levels and velocities throughout the major drainage/creek systems in the study area. The model simulates the hydraulic behaviour of the water within the study area by accounting for flow in the major channels as well as potential flow paths, which develop when the capacity of the channels is exceeded. It relies on boundary conditions, which include the runoff hydrographs produced by the hydrologic model and the appropriate downstream boundary.

A 1D/2D fully dynamic hydraulic model was established for the study area. SOBEK 1D/2D, a dynamic hydraulic-routing modelling system developed by WL|Delft Hydraulics of the Netherlands (2004) was used in this study. The system is used world-wide and has been shown to provide reliable, robust simulation of flood behaviour in urban and rural areas through a vast number of applications. The model allows addition of a 2 dimensional (2D) domain (representing the study area topography) to a one dimensional (1D) network (representing the channels in the study area) with the two components dynamically coupled and solved simultaneously using the robust Delft Scheme.

An important feature of the model is the ability to model the hydraulic structures in the 1D component rather than in the 2D domain. The benefit of this approach is that structure hydraulics are modelled more precisely than the approximate representation possible in a 2D domain.

6 HYDROLOGICAL MODELLING

The hydrological modelling was undertaken to develop catchment runoff hydrographs. These hydrographs were then used as inflow boundaries for the hydraulic modelling. Details of hydrological modelling are provided below.

6.1 Update of Previous Model

A WBNM hydrological model was established for the Wallamba River as a part of PWD (1985). This was subsequently utilised for the Forster/Tuncurry Flood Study in PWD (1989). DIPNR [1] (2004) undertook additional refinements and added additional details to the model as a part of the Wallamba River Floodplain Risk Management Study (DIPNR [1], 2004). The DIPNR [1] (2004) WBNM model was provided to Cardno Lawson Treloar by DECC on 22 March 2006.

The hydrological model from DIPNR [1] (2004) was constructed in an older version of WBNM, and was therefore updated to the 2003 version. In order to ensure that there were no significant changes in the discharge estimates, a comparison was made between the reported discharges in PWD (1989) and the updated version (**Table 6.1**). The differences reported in **Table 6.1** (up to 5%) are unlikely to result in a significant difference in the flood.

Table 6.1 Comparison of Peak Discharges from PWD (1989) WBNM and Updated Model

Catchment	**Peak Discharge (m3/s)**					
	100 Year			**20 Year**		
	WBNM 2003	Reported in DIPNR (2004)	% Diff	WBNM 2003	Reported in DIPNR (2004)	% Diff
Upstream of Pacific Highway	1770	1740	2%	1302	1296	0%
Nabiac to Glen Ora	163	169	-4%	122	128	-5%
Glen Ora to Failford	180	186	-3%	134	140	-4%
Failford to Gowack Island	388	398	-3%	290	300	-3%
Gowack Island to Wallis Lake	357	365	-2%	267	276	-3%

6.2 Catchment Definition

The WBNM model from DIPNR (2004) was established for the entire Wallamba River. As a result, the catchment delineation for the Nabiac Study Area and the associated local catchments were relatively coarse. The catchment delineation was therefore refined for the local Nabiac Study area catchments, while the larger catchments upstream of the Wallamba River bridge were left unaltered.

The state of catchment development at the time of capture of the aerial photograph (2003) was considered to be representative of the existing state of the catchment and adopted for the hydrological analysis. Thus the level of catchment development as of March 2003 is assumed to be the existing catchment condition and has been used in the modelling carried out for this study.

The catchment delineation for the current model was based on the 2m LIC contours, aerial photography, aerial survey as well as the previous catchment delineation from DIPNR [1] (2004).

The delineation of the Nabiac sub-catchments is presented in **Figure 6.1**. Subcatchment details are provided in **These** works affect the TOWN1 catchment, and the two catchment areas are shown in **Table 6.2.**

An analysis on the effect of these works on the 100 year ARI event is discussed further in **Section 14.4** of this report.

Table 6.2.

During the community consultation, and following subsequent discussions with Council, it was identified that the catchment which currently applies to Town Creek at the Pacific Highway is larger compared with the pre-highway condition. This occurred towards the end of the highway upgrade works, where changes to culverts under Candoormakh Creek Road had the effect of redirecting flows towards Town Creek.

The catchment area was therefore updated in version 3 of this report, to represent the existing conditions. The calibration runs for 2002 and 2004, however, were based on the pre-Candoormakh Creek Road changes as these events occurred prior to the works. These works affect the TOWN1 catchment, and the two catchment areas are shown in **Table 6.2**.

An analysis on the effect of these works on the 100 year ARI event is discussed further in **Section 14.4** of this report.

Table 6.2 Catchment Areas (ha)

Catchment ID	Area (ha)	Catchment ID	Area (ha)
WallUS1	2232.0	WOOSTERS7	15.3
WallUS2	5972.0	WOOSTERS8	6.0
WallUS3	2741.0	WOOSTERS9	15.7
WallUS5	3383.0	COOPERST1	124.8
WallUS6	2334.0	COOPERST2	12.3
WallUS8	4493.0	COOPERST3	18.6
WallUS7	2667.0	STREAM1	49.4
WallUS4	1388.0	STREAM2	14.9
WallUS10	3160.0	STREAM3	11.8
WallUS9	4022.0	STREAM4	7.4
NABDS1	55.9	WOOSTERS10	15.5
NABDS2	53.4	NABDS6	55.1
TOWN1*	130.4 (51.2)	PIPECLAY1	470.7
TOWN2	30.6	PIPECLAY2	394.2
TOWN3	41.1	PIPECLAY3	68.8
TOWN4	20.6	PIPECLAY4	27.3
NABDS3	69.2	PIPECLAY5	26.32
NABDS4	95.7	PIPECLAY6	11.0
NABDS5	150.6	GLENORA1	58.1
WOOSTERS1	161.2	GLENORA2	47.0
WOOSTERS2	164.3	GLENORA3	31.6
CLARKSONST1	3.4	PIPECLAY7	20.8
CLARKSONST2	13.8	PIPECLAY8	23.2
WOOSTERS3	45.6	NABDS7	28.1
WOOSTERS4	1.8	WallDS2	2800.0
HOSKINSST1	12.3	WallDS3	6700.0
WOOSTERS5	19.7	WallDS4	6100.0
WOOSTERS6	2.9		

*pre-Candoormakh Creek works shown in brackets

6.3 Hydrological Model Parameters

Runoff hydrographs for the study were estimated using the WBNM rainfall – runoff modelling package (Boyd et al, University of Wollongong, 2003).

The losses and storage parameters that were used in DIPNR [1] (2004) were adopted for the current model, and were applied to all sub-catchments within the model. The following parameters were used:

- ARF 0.96
- Storage coefficient C = 1.29
- Initial loss and continuing loss rates 21mm and 2.5mm/hour.

Table 6.3 IFD Parameters

IFD Parameters	Value
ARR	Zone 1
Elevation	270m
Intensity 2y 1h	37mm
Intensity 2y 12h	8 mm
Intensity 2y 72h	2.5mm
Intensity 50y 1h	68mm
Intensity 50y 12h	16mm
Intensity 50y 72h	5.3mm
F2	4.33
F50	16.1
G	0.025

6.4 Direct Rainfall

Due to the flat nature of the floodplain, rainfall was applied directly to the 2D hydraulic model for the extent of the hydraulic model. The WBNM model was therefore used to provide inputs to the hydraulic model at key external locations such as Wallamba River and Town Creek. Local catchment flows within the study area were generated by the hydraulic model.

6.5 PMF Generation

The Probable Maximum Precipitation (PMP) was estimated using the Generalised Short Duration Method (Bureau of Meteorology, 2003) recommended by the Bureau of Meteorology. The study effectively incorporates three separate creek systems. If a study were undertaken separately for each one, then the PMP ellipses would be positioned differently than if they were located for the entire study area. On this basis, the PMP ellipses were located individually for Town Creek, Woosters Creek and Pipeclay Creek. The PMP ellipses are shown in **Figure 6.2**. **Table 6.4** shows the calculated rainfall intensities for the PMP for each of the catchments.

The version of SOBEK that was utilised for the Nabiac flood study does not allow for spatial variation of rainfall. For the PMF event, a weighted average of the PMP intensities was applied to the 2D portion of the model, to overcome this limitation. These PMP intensities are shown in **Table 6.4**.

The critical duration for the PMF event generally ranged from 45 minutes (at Town Creek) through to 2 hours (at Pipeclay Creek).

Table 6.4 PMP Rainfall Intensities (mm/hr)

PMP Ellipse	Area Enclosed	Area Between	Storm Duration (hours)										
			0.25	**0.5**	**0.75**	**1**	**1.5**	**2**	**2.5**	**3**	**4**	**5**	**6**
Town Creek													
A	2.6	2.6	680	500	427	370	320	285	252	230	197.5	174	153.3
Woosters Creek													
A	2.55	2.55	720	520	440	380	320	285	252	230	197.5	174	151.7
B	4.91	2.36	600	480	400	350	300	265	228	210	182.5	160	141.7
Pipeclay Creek													
A	2.6	2.6	680	500	426.7	370	320	285	252	230	197.5	174	153.3
B	9.2	6.6	640	460	400	350	293.33	260	228	206.7	185	156	138.3
2D 'Direct Rainfall'													
N/A	N/A	N/A	672	491	419	365	309	275	242	220	192	166	147

6.6 Calibration of Hydrological Model

As there were no flow gauging stations for the local catchment, it was not possible to directly calibrate the hydrological model for the Nabiac study area. However, an indirect calibration was undertaken through the calibration of the hydraulic model, which is discussed in more detail in **Section 8**.

6.7 Historical Rainfall

An analysis of the historical rainfall data is provided in **Section 3.3.**

6.8 Design and Historical Event Flows

Design and historical event flows were extracted from the WBNM model for input into the SOBEK hydraulic model (**Section 7**). **Table 6.** provides the peak flows and critical durations determined from the WBNM model for the three major tributaries of Town Creek, Woosters Creek and Pipeclay Creek. **Figure 6.3, Figure 6.4** and **Figure 6.5** provides the time series of flows for each of the design storm events at Town Creek, Woosters Creek and Pipeclay Creek respectively. These flows are determined on the upstream side of the Pacific Highway, at the location where the creeks enter the hydraulic model.

Table 6.6 Design & Historical Event Peak Flows - Major Tributaries

Design Event	Town Creek		Woosters Creek		Pipeclay Creek	
	Qp*	Duration*	Qp	Duration	Qp	Duration
PMF	123.3	0.75	260	1.5	563.5	2
200yr	18.8	12	40.7	9	97.6	9
100yr	16.7	12	36.2	9	86.2	9
50yr	14.7	12	31.9	9	75.2	9
20yr	13	12	27.7	9	63.9	9
10yr	10.9	12	23.1	9	52.6	9
5yr	9.3	12	19.7	9	44.2	9
February 2002	7.0	N/A	36.8	N/A	92.4	N/A
October 2004	4.2	N/A	18.0	N/A	38.9	N/A
June 2007	13.1	N/A	29.8	N/A	74.4	N/A

Qp=Peak Discharge (m^3/s)
Duration = Critical Duration (hours)

7 HYDRAULIC MODELLING

7.1 Model Schematisation

A fully dynamic one and two dimensional hydraulic model was developed for the study area using the SOBEK modelling system. The channel (up to the top of bank) has been modelled as a one-dimensional (1D) element with cross-sections defining the channel geometry. Once the channel capacity is exceeded, flow is able to spill into the two-dimensional (2D) overland flow grid, which overlies the 1D elements in the model. During the flood recession, flow is also able to drain from the overland areas back into the defined channel.

The extent of the model is shown in **Figure 7.1**.

7.2 1D Model Set-up

The channel cross sections were located such that flow controls were captured, and so that the cross sections adequately represented variations in the channel definition. Details of structures within the study area (such as bridges and culverts) were also gathered, and included in the model.

The details of the majority of 1D cross sections and structures were based on survey data supplied by Lidbury, Summers & Whiteman (**Section 3.2**). The Pacific Highway culverts and bridges, in both the pre-developed and post-developed scenarios, were based on data supplied by the RTA (**Section 3.2**). Cross sections of the Wallamba River, which acts as a boundary for this study, were taken from the MIKE11 model from DIPNR [1] (2004).

The 1D component of the model includes a number of creeks and drainage channels in the study area. Town, Woosters, and Pipeclay Creek were included in the model, as well as a one tributary of Woosters Creek, and two tributaries of Pipeclay Creek. Stormwater drainage culverts within the study area that were greater than 600mm in diameter were also modelled in the 1D domain. The layout of the channels and stormwater drainage is shown in **Figure 7.1.**

7.3 2D Model Set-up

The 1D component of the model primarily covers the in-bank portion of the major creeks and drainage channels in the study area. All other major flowpaths including the overland flow in the study area were modelled as part of the 2D model component.

The 2D component of the model is available as the topographic grid of the study area. The model grid was developed from the survey data. The civil and surveying package 12D was used to generate a detailed 3D surface (digital terrain model) of the study area.

Important hydraulic controls such as bridge and weir levels were represented at the correct levels in the topographical grid. Buildings in key flowpaths were modelled as completed blocked in the model, while other buildings were modelled as a high roughness area.

A combination of a ‘parent’ and ‘child’ grid was used in the 2D model. The “parent” grid was used for the larger Wallamba river floodplain where as the more refined child grid was used for the Nabiac Township. The ‘parent’ grid had a spacing of 10m, while the ‘child’ grid had a spacing of 5m. This configuration was considered suitable to represent the features within the study area, while allowing for a reasonable computation time (for each model run). The grid details are outlined in **Table 7.1**. The grids are shown in **Figure 7.1**.

Table 7.1 2D Grid Details

Grid Parameter	Value
Parent Grid	
Origin	440 555, 6 446 635
Grid Size	10m
X-Dimension (east-west)	416
Y-Dimension (north-south)	366
Rotation	0
Child Grid	
Origin	440 895, 6 447 940
Grid Size	5m
X-Dimension (east-west)	305
Y-Dimension (north-south)	279
Rotation	0

7.4 Model Terrain

The model terrain was primarily based on the photogrammetry data provided by Council (**Section 3.2**), with some modifications based on the cross sectional ground survey. Areas to the north of the highway and south of the river, outside of the photogrammetry, were defined using the ALS data provided by Mid-Coast Water. While this data is not that accurate (**Section 3.2**), it is outside the study area and is primarily intended for modelling of the River floodplain and for routing flows upstream of the highway.

The design events and the June 2007 event utilised the design highway details supplied by RTA and Maunsell (**Section 3.2**), which was assumed to represent the condition of the highway after the upgrade. The ground survey supplied by RTA for the pre-developed highway was utilised for the February 2002 and 2004 events. Areas outside of the highway were assumed to remain effectively the same.

A few residents noted that the Clarkson Street Bridge over Woosters Creek was replaced by the RTA, after the October 2004 event. Details of the old Clarkson Street Bridge were estimated from data supplied by Council (**Section 3.2**).

7.5 Hydraulic Roughness

The hydraulic roughness for the 1D cross sections and 2D grid were determined from site inspections and aerial photos, and ground photos obtained as a part of the ground survey by Lidbury, Summers, and Whiteman. The 2D roughness grid is shown in **Figure 7.2**. The 1D roughness values are illustrated in **Figure 7.3**.

7.6 Blockage of Hydraulic Structures

The resident survey (**Section 4**) identified that the pipe culverts on Town Creek near the industrial area had blocked on a number of occasions during previous flooding events. This blockage is likely to have been caused by a combination of the debris being washed from upstream as well as the relative small sizes of the two pipes and lack of debris control structures.

During the February 2002 flood event, it was noted by a number of residents that the culverts were blocked by debris from construction that was occurring upstream. The local residents removed this debris during the flood event to assist in alleviate the flooding in the town.

During the June 2007 event, there were no reports of these culverts blocking, although the capacity of the culverts would still have been an issue.

Based on this information, it was assumed that these culverts were effectively blocked for the design runs, based on the historical observations.

For both the February 2002 and October 2004 events, these culverts were assumed to be blocked, based on observations from those two events.

For the June 2007 event, both a blocked an unblocked and blocked scenario were modelled. However, it is expected that the unblocked scenario would likely be more representative in this case.

All other culverts within the study area were assumed to be un-blocked, as there were no reports of other historical blockages within the study area. A sensitivity analysis has been undertaken on culvert blockage and is discussed further in **Section 12.2**

7.7 Boundary Conditions

Inputs to the upstream sections of the model were applied as hydrographs, from the hydrological model. Within the 2D domain, rainfall was applied directly to the grid. Thus rainfall-runoff routing for the modelled area was directly carried out in the hydraulic model. The rainfall loss rates used for the WBNM hydrological model were used to develop the excess rainfall hyetograph, which was used as an input to the hydraulic model.

The focus of the study is on the local flooding within Nabiac from the local creek systems, rather than from the Wallamba River (which has already been analysed by DIPNR (2004)). While the River has been included in the model for this study, this is primarily intended to create an adequate downstream boundary, rather than modelling 100 year flows through the River itself.

The boundary conditions applied for the calibration is discussed in **Section 8.1**.

The boundary conditions applied in the design event modelling is discussed in **Section 9.1**.

8 MODEL CALIBRATION

8.1 Calibration Boundary Conditions

Given the impact of flooding in the Wallamba River on Nabiac, two scenarios were modelled for each of the storm events:

- Flooding in Wallamba River – under this scenario, uniform rainfall was assumed over the entire Wallamba River Catchment including the Nabiac Catchment (i.e. no spatial variation in rainfall was assumed). This effectively creates a conservative estimate off the downstream boundary for the study area.
- No Flooding in Wallamba River – under this scenario, a constant flow of 100m^3/s was assumed within the River, effectively assuming no flooding in the river. This assumes that the downstream boundary, or the River, was not in flood while the local catchment was flooding. This generally agrees with most observations from Residents, where it was observed that the River flooded after the local catchment flooding receded.

These two scenarios provided a sensitivity analysis of the river flooding on the calibration levels.

8.2 Calibration Results

The hydraulic model was calibrated using the June 2007 flood event and verified through the February 2002 and October 2004 events. There were a number of observed flood levels and other anecdotal advice for each event. **Figure 8.1**, **8.2** and **8.3** displays the location of historic flood level information for the 2007, 2002 and 2004 events respectively.

Table 8.1, Table 8.2 and **Table 8.3** shows the comparison between the observed and modelled flood levels. Water level profiles for the June 2007 event for Town Creek are provided in **Figure 8.4** and **8.5** and for Woosters Creek are provided in **Figure 8.6**. The water levels for the February 2002 event are shown in **Figure 8.7**, **8.8** and **8.9**.

Figure 8.10 and **8.11** show the water level time series for 2002 and 2007 at the Town Creek footbridge in the main Nabiac township. The results show that for the June 2007, there is little impact on the peak water level at the footbridge. By comparison, in the February 2002 event, the backwater from the River under the flooding from the River scenario does increase the peak water levels.

While generating the inflow hydrographs for the Wallamba River, it was conservatively assumed that the same intensity rainfall occurs across the entire Wallamba River catchment. It is therefore expected that the actual behaviour of the two events would have been somewhere between the two extremes shown in **Figure 8.10** and **8.11**. Based on observations by residents of timing of peak water levels, it is expected that in both events the peak water levels for the calibration were primarily driven from local catchment flooding. Therefore, in most cases, the 'no flooding in the river' scenario was utilised for the calibration.

Note that the levels are significantly lower in the October 2004 event when compared with the observations. This differs significantly to that of the February 2002 and June 2007 events, where there is a good agreement between the modelled levels and the observed levels. **Figure 8.12** provides a graph of the inflows to Town Creek (upstream of the Highway) for all calibration events. It is noted from this figure that the October 2004 event produces significantly less discharge than the 2002 or 2007 event. Based on this, it may be possible that:

- Observations of this event may have been incorrect, or that this may not have been the same event that caused significant flooding in the township. People may have mistaken this event for another event of higher magnitude,
- The rain gauge may not have been operating correctly during the peak of the storm. The rainfall demonstrates two peaks within a relatively short period, which is replicated in the discharge time series as presented in **Figure 8.12** or,
- The rainfall for the event may have been localised, and therefore not picked up by the pluviometer. Discussions with residents have suggested that the flooding of the local township can occur from very localised events.

8.3 Calibration Summary

The results of the calibration show that the hydraulic model is capable of reproducing the observations from the historical storm events. The majority of peak water level comparisons show that the model reproduces results within +/- 0.10 metres. Larger discrepancies are observed at a few locations, but these are generally expected to be due to measurement and observation errors. These are discussed individually in **Table 8.1, Table 8.2** and **Table 8.3**. In addition to the peak water level comparisons, observations of flood behaviour noted by residents agree well with the flooding behaviour in the model.

A range is provided for the modelled levels on Town Creek for the June 2007 event. This represents the range from the unblocked and blocked Town Creek Industrial Area culvert scenarios (**Section 7.6**). It is expected that the unblocked scenario is more representative in this storm event.

Table 8.1 June 2007 Calibration Results

Location ID	Location	Description	Observed Level (m AHD)	Modelled Level (m AHD)	Difference (m)	Comments
A	Bruce Weller's property		4.95m AHD	6.20	+1.25	Note that this was based on a pegged level of the extent, and may not represent the peak water level
B	Wooster's Creek bridge (underside of railing)	Source : see Photo	7.46m AHD	7.42	-0.04	Resident noted photo taken between 9:32 & 9:48. This corresponds to just after the peak of the storm on Woosters Ck. Peak of storm observed at 9:20am. Modelled level is peak water level.
C	Base of tree near Wooster's Creek	Source : see Photo	7.46m AHD	7.42	-0.04	Resident noted photo taken between 9:32 & 9:48. This corresponds to just after the peak of the storm on Woosters Ck. Peak of storm observed at 9:20am. Modelled level is peak water level.
D	Foot bridge over Wooster's Creek	Source : see Photo	6.60m AHD	6.68	+0.08	Resident noted photo taken between 9:32 & 9:48. This corresponds to just after the peak of the storm on Woosters Ck. Peak of storm observed at 9:20am. Modelled level is peak water level.
E	Window sill of house next to Sensations	Source : see Photo	7.39m AHD	7.52-7.57	+0.13 to +0.18	Resident noted photo taken between 9:32 & 9:48. This corresponds to just after the peak of the storm on Town Ck. Peak of

Location ID	Location	Description	Observed Level (m AHD)	Modelled Level (m AHD)	Difference (m)	Comments
	Cafe					storm observed at 9:20am. Modelled level is peak water level.
F	Nabiac Bakery	Water reached approximately 1 - 2ft in bakery. Occurred between 9 and 10am. Took approximately 1.5 hours for water to rise from driveway to front door.	7.39m AHD	7.53-7.58	+0.14 to +0.19	Resident noted photo taken between 9:32 & 9:48. This corresponds to just after the peak of the storm on Town Ck. Peak of storm observed at 9:20am. Modelled level is peak water level.
G	Base of railing on Nabiac Creek	Source : see Photo	7.38m AHD	7.52-7.59	+0.14 to +0.21	Resident noted photo taken between 9:32 & 9:48. This corresponds to just after the peak of the storm on Town Ck. Peak of storm observed at 9:20am. Modelled level is peak water level.
H	Fence at Rob and Co	Source : See Photo	7.31m AHD	7.40-7.47	+0.09 to +0.16	Resident noted photo taken between 9:32 & 9:48. This corresponds to just after the peak of the storm on Town Ck. Note that this was also the last photo taken, and may have been closer to 9:48am.
I	General Store/Post Office	Nearly entered the post office. Flood did not subside as quickly as previous events. Flood started to subside from 10am, and was mostly drained by 11:30am.	7.41m AHD	7.51-7.57	+0.10 to +0.16	
J	Clarkson Street/ Woosters Creek	At 10:30am, water over Clarkson Street at Woosters creek was halfway up the car wheels. Ground level of bridge ~ 7.24m AHD. Assume this represents approximately 20cm deep	7.44m AHD	7.41	-0.03	Note that this level could be affected by vehicle wash etc.
K	Farnell Street	Water proceeds through motorcycle museum and into Farnell Street. 6 inches in Kevin Crompton yard.				Model shows water proceeding through motorcycle museum. Model shows 15 – 20cm of depth in this area.
L	Pedestrian Walkway under Pacific Highway	Reports that pedestrian underpass at the pacific highway was full of water, 3 - 4 foot deep.	1.2m (depth)	1.8m (depth)		Note that this would be affected by local drainage etc.

Table 8.2 February 2002 Calibration Results

Location ID	Survey ID	Address/ Location	Resident Description	Notes	Observed Level (m AHD)	Modelled Level (m AHD)	Difference (m)	Model Description
A	5	Amish House	Water level 2ft up walls inside Amish house	Ground Level of Amish - 6.68m AHD & FL - 6.85m AHD	7.45	7.46	+0.01	Model shows the peak of the event around 11am
B	8	24 Clarkson Street	Creek broke the banks & came within 3ft of my back steps.	back step level = 7.14m AHD	<7.14	6.63		Difficult to determine exact level. Model shows water in backyard, in close proximity to steps.
C	10	Lot 25 Byron Street	In the 8 years we have lived at Lot 25 Byron St at Nabiac we have had +/- 4 times where pipeclay & Wooster Creeks overflowed. The two biggest we have seen happened in May 2002 & Oct 2004 (2002 was the worst). The water floods the back of our property (Failford Rd) & adjacent farmland. It comes up quickly but also goes down quickly. Approximately 1/3 of his property covered in 2002	Low Point on Property = 0.65m AHD & high point = 3.92m AHD		2.9		Model shows that a portion of the property is under water.
D	14	Butcher and Baker	In 2002 the Bakery & Butcher shop had water through the buildings, with floodwaters reaching the Newsagents in Clarkson St.					Water levels are higher than June 2007, where water entered bakery
E	14	12 Nabiac Street	neighbour had 12" in yard (this is next to butcher/ baker)	Approximate ground level of neighbour ~6m AHD	6.3	7.46		As per A. Note that depth depends on location in property.
F	18	Town Creek	Early Winter 2002. Surgery at 74 Clarkson St not flooded but area outside Amish Building & Bakery badly affected & right up to General Store & Post Office.					Model shows flooding of this entire area. Note that observation may not correspond to the same event.

Location ID	Survey ID	Address/ Location	Resident Description	Notes	Observed Level (m AHD)	Modelled Level (m AHD)	Difference (m)	Model Description
G	19	191 Glen Ora Road	On both occasions (2002 & 2004) part of the farmland on my property was flooded.	On southern Side of Wallamba River				Model shows flooding of this area. Note that model is not established for river flooding.
H	23	Clarkson St Bridge & elsewhere	Old bridge, Clarkson St (over Woosters Creek) used to flood over flooring timber after really heavy rain in a short period (that is water couldn't get away quickly enough). Inconvenience was for short time only. Cliffords residence next to bridge-water comes under house but doesn't flood house.					Model has water overtopping bridge and road. Water enters properties next to the bridge in this area.
I	24	1 Clarkson Street	February 2002-paddock beside house flooded. Clarkson St bridge (Woosters Ck) closed.					This is the same location as above, and shows flooding of the paddock
J	26	37 Martin Street	6 inches of water over entire property	Levels vary significantly across property				Model shows flow through this area, with depths of around 20cm on the property.
K	26	Butcher & Baker	Water through butcher and baker			7.48		As per A
L	30	Town Creek	The water was waist deep across Clarkson St.					Model suggests depths of up to 0.5 metres and above across Clarkson Street
M	32	Town Creek Culvert	Noted that the culvert near the industrial estate was blocked and caused more flooding					Culvert has been blocked in model.
N	32	Amish House	In 2002 floodwater reached about 80mm above windowsill	Windowsill = 7.39m AHD. Resident showed flood mark to surveyors - 7.46m AHD	7.46	7.46	0.00	As per A. Note that both reports are in good agreement.
O	33	9 Abbot Street	Water in yard and lapping at front steps	Front Steps =8.98m AHD	8.98	7.39	-1.59	Note that this water level is quite high, particularly when compared with B which is just downstream. Also, back yard

Location ID	Survey ID	Address/ Location	Resident Description	Notes	Observed Level (m AHD)	Modelled Level (m AHD)	Difference (m)	Model Description
								is quite steep and level could be slightly off. Note that this area does not appear to be affected by backwater from the River.
P	33	Woosters Creek Bridge	Bridge was well under water					Model shows that the Woosters Creek bridge is underwater
Q	33	Highway	Highway under water near caravan park and North of Nabiac in 2 places					
R	34	Lot 1 Nixon Place	has flood mark on property		2.73	3.60	+0.87	Note that this area is primarily impacted by River flooding. Reported level is from river flooding model.
K	35		Both above dates (2002 and 2004), bridge on Clarkson St overtopped, Bakery & Butcher shops inundated. Amish shop inundated.					As per other observations, all locations inundated in model
T	38	Highway	There was water over the highway south of he caravan park as well as Woosters Creek on the Highway					This does not show up on the model. Note that this could be due to local drainage issues (not mainstream flooding)
P	38	Woosters Creek	Photos included. This is Woosters Creek over the old bridge, receeding fairly swift flowing. It had been above marking parts on bridge and under house on Clarkson St.					Note that the old bridge data is unavailable. Water overtops the bridge in the model.
V	38	5 Abbot Street	Water up to tree line on property	Note that it may have been difficult for surveyors to determine actual location of tree	8.45	7.39	1.06	As per note. This area is quite steep and a difference in horizontal location could result in larger difference in vertical levels.

Location ID	Survey ID	Address/ Location	Resident Description	Notes	Observed Level (m AHD)	Modelled Level (m AHD)	Difference (m)	Model Description
W	39	25 Nabiac Street	Floodwaters came to the front door which had to be sandbagged causing us to close shop for the day.		7.47	7.46	-0.01	As per note in A.
X	SES Photos	Town Creek	Shows water over town creek bridge, above lower balustrade	Level of Balustrade is 7.15m AHD		7.46		As per note in A.

Table 8.3 October 2004 Calibration Results

Location ID	Survey ID	Address/ Location	Resident Description	Notes	Observed Level	Modelled Level	Model Description
A	7	35 Clarkson Street	Oct 04 - up to rim of tyre in driveway	backyard level= 8.16m AHD and driveway = 8.02m AHD. Depth of water around 10cm deep perhaps	0.1m depth	Depths of up to 0.2m	Depth depends on location within property
B	10	Lot 25 Byron Street	In the 8 years we have lived at Lot 25 Byron St at Nabiac we have had +/- 4 times where pipeclay & Wooster Creeks overflowed. The two biggest we have seen happened in May 2002 & Oct 2004 (2002 was the worst). The water floods the back of our property (Failford Rd) & adjacent farmland. It comes up quickly but also goes down quickly. We have been so far, not inconvenienced.				Model shows flooding in these areas. Flooding is not as severe as in 2002.
C	19	191 Glen Ora Road	On both occasions (2002 & 2004) part of the farmland on my property was flooded. The 2002 incident was the worst as it coincided with approx. 18 inches of rain over a few days plus a king tide.				Model shows flooding in these areas. Flooding is not as severe as in 2002.
D	23	Clarkson St Bridge & elsewhere	Old bridge, Clarkson St (over Woosters Creek) used to flood over flooring timber after really heavy rain in a short period (that is water couldn't get away quickly enough). Inconvenience was for short time only. Cliffords residence next to bridge-water comes under house but doesn't flood house.				Model shows water under the house in this location. Water overtops Clarkson Street at Woosters Creek.
E	30	Clarkson St & Shops	The Amish family-Griffo's Butcher and the Cake Shop had water up to their waists. The water was waist deep across Clarkson St.				
F	32	Amish House	Reached the windowsill (about 80mm below the 2002 event)		7.39m AHD	6.68m AHD	
G	33	Woosters Creek Bridge	Water lapped bridge and covered much of Clarkson Street				

Location ID	**Survey ID**	**Address/ Location**	**Resident Description**	**Notes**	**Observed Level**	**Modelled Level**	**Model Description**
H	35		Both above dates (2002 and 2004), bridge on Clarkson St, Bakery & Butcher shops. Amish shop.			6.68m AHD	
I	20	26 Martin Street	Localised flooding affecting access on Clarkson St at the butchers and outside the motorcycle museum affecting access into Nabiac. Woosters Creek flooded & backed up due to overgrown & blocked flow line (timber, etc).				
J	24	1 Clarkson Street	October 2004-paddock beside house flooded. Water across Clarkson St. There may have been others but we were either asleep of away. Water usually drops quickly				
K	39	25 Nabiac Street	Floodwaters came to the front door (Hardware Store)	Note that resident made same observation for 2002 and 2004 - other residents observed 2004 as lower	7.47m AHD	6.68m AHD	
L		Butcher/ Baker	Had water through their premises	FL = 7.08m AHD			

9 DESIGN FLOOD MODELLING

9.1 Design Event Boundary Conditions

For the design events, it was assumed that a 100 year ARI design event in the Wallamba River would not occur at the same time as a 100 year ARI design event in the local Nabiac catchment. There are two primary reasons for this:

- The Wallamba River catchment at Nabiac generally has a critical duration of 36 hours, whereas the local catchments are significantly shorter than this. It would be unlikely to have a local 100 year ARI short duration storm at the same time as a 100 year ARI 36 hour storm.
- The timing of peak flows from the Wallamba River catchment are lagged behind the peak flows from the local Nabiac catchments. Therefore, it is unlikely that a Wallamba River 100 year ARI peak flow would occur at the same time as the 100 year ARI local catchment flows.

For the purposes of this study, it has been assumed that a 5 year ARI 36 hour duration storm occurs at the same time as a 100 year ARI design storm in the local catchment.

The outlet for Pipeclay Creek is located over 4 km downstream of the outlet of Town Creek. As such, there would be a lag between the peak level in the river occurring at the outlet of Town Creek and the peak level in the river at Pipeclay Creek.

Given this distributed nature of the inflows into the Wallamba River, it has been conservatively assumed that the peak 5 year ARI 36 hour duration storm flows in the Wallamba River are constant for the full duration of the local flood event. This is a conservative assumption, as it effectively removes some of the available downstream storage in each of the tributaries. Given the uncertainties in this type of joint probability analysis, this assumption is considered reasonable.

Table 9.1 provides a summary of the conditions for each design event. The peak flow for the 5 year ARI 36 hour duration storm in the Wallamba River is 874 m^3/s.

Table 9.1 Boundary Conditions for Each Design Event

Design Event	Local Flows	Wallamba River Flows
PMF	PMF	5 year 36 hour peak flow
200 year ARI	200 year ARI	5 year 36 hour peak flow
100 year ARI	100 year ARI	5 year 36 hour peak flow
50 year ARI	50 year ARI	5 year 36 hour peak flow
20 year ARI	20 year ARI	5 year 36 hour peak flow
10 year ARI	10 year ARI	5 year 36 hour peak flow
5 year ARI	5 year ARI	5 year 36 hour peak flow

Note that it is not possible to directly compared the 5 year 36 hour levels from the model with those of DIPNR (2004), as the DIPNR study did not investigate the 5 year ARI storm event.

It is also noted that the model has not been specifically established to model the Wallamba River flows, as the focus of this study is on the local catchment flooding. Therefore, the 5 year River flows in this study are indicative only, and are utilised to establish an adequate boundary condition.

9.2 Culvert Blockages

The Town Creek Culvert, near the industrial area, was assumed to be 100% blocked for the purposes of the design modelling, as discussed in **Section 7.6**. A sensitivity analysis on culvert blockages is discussed in detail in **Section 12.2.**

9.3 Design Flood Modelling

Design flood modelling was undertaken for the 5, 10, 20, 50, 100 and 200 year ARI and PMF design flood events.

The modelling was undertaken for a range of durations from 15 min to 12 hours for each design event. An envelope of the different durations was taken to determine the peak water level, depth, and velocity in the study area.

The flood extents derived for each of the ARI's is presented in **Figures 9.1** to **9.7**.

The peak water depths results are presented in **Figures 9.8** to **9.14**.

The peak water level results are presented in **Figure 9.15 to 21**

The peak velocity results are presented in **Figures 9.22** to **9.28**.

Design flood profiles of Town Creek and Woosters Creek are provided in **Figure 9.29** and **9.30**.

Rainfall was applied directly to the 2D domain, using the Direct Rainfall approach. This approach effectively results in every 2D cell being inundated with some flood depth. In order to create model extents and provide reasonable results, a filter is applied to separate what is catchment runoff and what is flooding. The flood extents were drawn only for depths greater than 0.05m, together with some manual manipulation to remove small isolated ponding areas. Results are presented only within these extents. Note that these figures are exclusive of the 1D results which include the drainage channels in the study area.

10 PROVISIONAL FLOOD HAZARD

10.1 General

Flood hazard can be defined as the risk to life and limb caused by a flood. The hazard caused by a flood varies both in time and place across the floodplain. The Floodplain Development Manual (NSW Government, 2005) describes various factors to be considered in determining the degree of hazard. These factors are:

1. Size of the flood
2. Depth and velocity of floodwaters
3. Effective warning time
4. Flood awareness
5. Rate of rise of floodwaters
6. Duration of flooding
7. Evacuation problems
8. Access.

Hazard categorisation based on all the above factors is part of establishing a Floodplain Risk Management Plan. The scope of the present study calls for determination of provisional flood hazards only. The provisional flood hazard is generally considered in conjunction with the above listed factors as part of the Floodplain Risk Management Study to provide a comprehensive analysis of the flood hazard.

10.2 Provisional Flood Hazard

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters (Figure L2, NSW Government, 2005). The Floodplain Development Manual (2005) defines two categories for provisional hazard - High and Low.

The model results were processed using an in-house developed program, which utilises the model results of flood level and velocity to determine hazard. Provisional flood hazard was prepared for five design events, namely PMF, 200, 100 year, 20 year and 5 year ARI design events. The provisional hazard is based on the envelope of the hazard at each location for each ARI.

The provisional flood hazard is shown in **Figures 10.1** to **10.5**.

11 HYDRAULIC CATEGORISATION

11.1 General

Hydraulic categorisation of the floodplain is used in the development of a Floodplain Risk Management Plan to assist in defining primary flow paths and flood storage areas. The Floodplain Development Manual (NSW Government, 2005) defines flood prone land as one of the following three hydraulic categories:

Floodway - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.

Flood Storage - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If these areas are substantially removed by levees or fill, there would be resulting elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.

Flood Fringe - Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant affect on the flood pattern or flood levels.

11.2 Hydraulic Category Identification

Floodways were determined for four events, namely PMF, 100 year, 20 year and 5 year ARI by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways was derived from Howells et al. (2003).

As a minimum, the floodway was assumed to follow the creekline from bank to bank. In addition, the following depth and velocity criteria was used to define a floodway:

- Velocity * Depth must be greater than 0.25 m^2/s **and** velocity must be greater than 0.25 m/s, **OR**
- Velocity is greater than 1 m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1 m and/or would cause peak discharge anywhere to increase by more than 10%. This criteria was applied to the model results as described below.

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for flood storage would be satisfied. To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2m
- Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but still fell within the flood extent are represented as Flood Fringe.

The hydraulic categories for PMF, 100 year, 20 year and 5 year ARI are provided as plans in **Figures 11.1** to **11.5**. The hydraulic categories are based on the envelope of the hydraulic categorisation at each location for each ARI.

12 SENSITIVITY ANALYSIS

12.1 Parameter Sensitivity

Sensitivity analysis allows the testing of some of the key assumptions of the modelling. Sensitivity analysis was undertaken on some of the key variables of the modelling, namely:

- Hydraulic Roughness – increase and decrease by 20%.
- Model Inflows – increase and decrease by 20%, both tributary inflows and rainfall applied directly to 2D domain. No modification to Wallamba River flows.
- Downstream Boundary – assume River is not flooding at same time as design storm in catchment. Assumed nominal flow of 50m^3/s.

Appropriate modifications were made in the hydraulic model to assess the impact of the above variables on the model results. The impact assessment was carried out for the 100 and 5 year ARI, 9 hour duration storm.

The results from the sensitivity modelling were compared with the design flood modelling as described in **Section 9**. The results of the sensitivity analysis are shown in terms of the change in peak water level throughout the study area

12.1.1 Roughness Sensitivity

Figure 12.1 to **12.4** show the roughness sensitivity results.

An increase in roughness results in increases in peak water levels across the study area. The largest increases are observed in the lower lying areas near the Wallamba River, where increases of 0.1 to 0.2 metres are observed in the 100 year ARI event.

A decrease in roughness results in a decrease in the peak water levels across the study area. Reductions are relatively uniform at between 0.1 to 0.2 metres across the major flowpaths in the 100 year ARI event.

12.1.2 Model Inflow Sensitivity

Figure 12.5 and **12.8** show the inflow sensitivity results

A 20% increases on the model inflows results in an increase in the peak water levels across the study area. The largest increases are observed on Woosters Creek and the lower lying areas of Pipeclay Creek, with increases of 0.1 to 0.2 metres in the 100 year ARI event.

A 20% decrease in model inflows results in a decrease in peak water levels across the study area. The largest decreases are observed along Woosters Creek, particularly in the lower lying wetland areas north of Donaldson Street, where decreases of 0.1 to 0.2 metres are observed in the 100 year ARI event, with larger decreases of 0.2 to 0.5 metres in the 5 year ARI event.

12.1.3 Downstream Boundary Sensitivity

Figure 12.9 and 12.10 shows the downstream boundary sensitivity results.

A lower downstream boundary (i.e. when River flows are not included), results in decreases in peak water levels, primarily in the lower lying areas of the study area (such as near Donaldson Street on Woosters Creek). It is noted that the decreases do not affect areas around Clarkson Street, where a number of flooding issues have been observed in the past.

12.2 Culvert Sensitivity

Sensitivity analysis was undertaken on the culverts within the study area. This sensitivity analysis investigated the impacts of potential blockages of the flooding within the study area. The following culverts were blocked:

- Clarkson Street culvert over Town Creek.
- Clarkson Street culvert over Woosters Creek.
- Small Pipe culvert on Clarkson Street, near Motorcycle Museum.

The pipe culvert on Town Creek near the industrial area was modelled as blocked for the design model runs, and was therefore not altered for the sensitivity. Other culverts within the study area were not modified, primarily because they would not cause a 'worst-case' scenario. For example, blockage of the highway culverts would detain flows upstream from entering the study area, and would therefore only reduce flood levels.

Figure 12.11 to 12.17 show the results of sensitivity analysis due to culvert blockage.

Blockage of the culverts along Clarkson Street results in an increase in the peak water levels upstream of the culverts. In the 100 year ARI event, these increases are generally between 0.01 to 0.10 metres, while in the 5 year ARI event, the increases are larger between 0.1 to 0.2 metres.

Should a blockage occur at these culverts, then this may pose a risk to existing property. This is particularly the case for the culvert on Town Creek, where there are a number of existing properties which are at risk of inundation.

13 ECONOMIC DAMAGES

The economic impact of flooding can be defined by what is commonly referred to as 'flood damages'. Table 13.1 categorises various types of flood damages.

Table 13.1 Types of Flood Damages

Direct	-Building contents (internal) -Structural (building repair and clean) -External items (vehicles, contents of sheds etc)
Indirect	-Clean-up (immediate removal of debris) -Financial (loss of revenue, extra expenditure) -Opportunity (non-provision of public services)
Intangible	-Social – increased levels of insecurity, depression, stress, health issues -General inconvenience in post-flood stage

The direct damage costs, as indicated in **Table 13.1**, are just one component of the entire cost of a flood event. There are also indirect costs. Both direct and indirect costs are referred to as 'tangible' costs. In addition to this there are also 'intangible' costs such as social distress. The flood damage values discussed in this report are the tangible damages and do not include an assessment of the intangible costs which are difficult to calculate in economic terms.

Tangible damages can further be divided into 'potential' damages and 'actual' damages. Potential damages refer to the maximum possible damages that could occur, while the actual damages refer to the damage that occurs during a flood event, allowing for residents to remove or protect their valuables.

It has been assumed that residents would generally not have sufficient time to respond to a flood event. As such, it has been assumed that the potential flood damages are the same as the actual flood damages. This is a conservative approximation.

Flood damages can be assessed by a number of methods including the use of computer programs such as FLDAMAGE or ANUFLOOD or via more generic methods using spreadsheets. For the purposes of this project, generic spreadsheets have been used based on guidance from DECC and Cardno Lawson Treloar's experience in this area.

13.1 Damage Analysis

A flood damage assessment for the existing catchment and floodplain conditions has been undertaken as part of the current study. The assessment is based on damage curves that relate the depth of flooding on a property, to the likely damage within the property.

Ideally, the damage curves should be prepared for the particular catchment for which the study is being carried out. However, damage data in most catchments is not available and recourse is generally made to damage curves from other catchments. DECC has carried out research and prepared a methodology (draft) to develop damage curves based on state-wide historical data. This methodology is only for residential properties and does not cover industrial or commercial properties.

The DECC methodology is only a recommendation and there are currently no strict guidelines regarding the use of damage curves in NSW.

The following sections provide an overview of the methodology applied for the determination of damages within the Nabiac floodplain.

13.1.1 Residential Damage Curves

The *Floodplain Management Guideline No. 4 Residential Flood Damage Calculation* prepared by DIPNR (now DECC) (DIPNR [2], 2004) has been used in this damages assessment. These guidelines include a template spreadsheet program that determines damage curves for three types of residential buildings:

- Single Storey, slab on ground,
- Two Storey, slab on ground, and
- Single Storey, high-set.

The floor level survey from DIPNR [1] (2004) does not provide details on the residential property construction. For the purposes of this study, it has been assumed that all residential properties are slab on ground.

Damages are generally incurred on a property prior to any over floor flooding. There are two possibilities:

- The flooding overtops the representative ground level but does not necessarily reach the base of the house. When this representative ground level is exceeded by a depth of 10cm, a nominal damage value of $3,000 (May 2008 dollars) has been adopted to represent garden damage.
- The flooding overtops the garden and also reaches the base of the house. The DECC curves allow for a damage of $8,442 (May 2008 dollars) to be incurred when the water level reaches the base of the house (the base of the house is determined by 0.5m below the floor level for slab on ground). This accounts for some garden and structural damage accounted for in the point above, but also includes some damage to cars.

In summary, a cost of $3,000 (May 2008 dollars) when only the ground level of the property is overtopped by a depth of 10cm was adopted. When the flooding reaches the base of the house, the DECC curves have been adopted, with $8,442 (May 2008 dollars) of external damage (i.e. an additional $5,442 over the garden damage).

Other Parameters

There are a number of input parameters required for the DECC curves, such as floor area and level of flood awareness. The damage analysis presented herein has generally kept with the DECC recommended default parameters. The average house size for Sydney is 240 m^2 (Table D2; DIPNR[2], 2004). However, our observations in the Nabiac floodplain suggest a floor area of 150 m^2 as a conservative estimate of the floor area for residential dwellings for the floodplain. Note that this floor area refers to the ground floor only.

The Effective Warning Time has been assumed to be zero. A long Effective Warning Time allows residents to prepare for flooding by moving valuable household contents (e.g. the placement of valuables on top of tables and benches).

The Nabiac Catchment, while rural, is within a short distance of both Taree and Forster/Tuncurry, and it is assumed that there are no post-flood inflation costs. These inflation costs are generally experienced in regional areas, where re-construction resources are limited and large floods can cause a strain on these resources. For the local flooding assessed in this study, it is unlikely that there would be large regional impacts. However, the Wallamba River flooding may cause this type of impact.

Average Weekly Earnings

The DECC curves are derived for late 2001 and, therefore, have been increased to represent May 2008 dollars.

General recommendations by DECC are to adjust values in residential damage curves by the increase in Average Weekly Earnings (AWE), rather than by the inflation rate as measured by the Consumer Price Index (CPI). DECC proposes that AWE is a better representation of societal wealth, and hence an indirect measure of the building and contents value of a home. The most recent data for AWE from the Australian Bureau of Statistics at the start of the study was for May 2008. Therefore all ordinates in the residential flood damage curves were updated to the May 2008 dollars. In addition, all damage curves include GST as per the DECC recommendations.

While not specified, it is assumed that these curves were derived in November 2001, which thereby permits the use of November 2001 AWE statistics (issued quarterly). November 2001 AWE is shown in Table D1 of the Draft DECC guidelines (DIPNR [2], 2004) and May 2008 AWE were taken from the Australian Bureau of Statistics website (www.abs.gov.au; **Table 13.2**).

Table 13.2 AWE Statistics from 2001

Month	Year	AWE
November	2001	$898.50
May	2008	$1183.10
Change	31.68%	

Consequently, all ordinates on the damage curves are increased by 31.68% and GST has been added. It has been assumed that May 2008 is representative of June 2008 dollars, for consistency with the commercial and industrial damages calculated in the following sections.

13.1.2 Commercial Damage Curves

Commercial damage curves are determined based on those included in the *FLDamage Manual* (Water Studies, 1992). FLDamage allows for three types of commercial properties:

- Low Value Commercial,
- Medium Value Commercial,
- High Value Commercial.

It has been assumed that all commercial properties are equivalent to low value commercial properties, based on FLDamage.

In determining these damage curves, it has been assumed that the effective warning time is approximately zero, and the loss of trading days as a result of the flooding has been taken as 10.

These curves are determined based on the floor area of the property. The floor level survey has estimates of the floor area of the individual properties. These will be used to factor these curves. The adopted curves have been determined for 100 m^2.

The Consumer Price Index (CPI) was used to bring the 1990 data to June 2008 dollars (this data was obtained from the Australian Bureau of Statistics website (www.abs.gov.au)). It was assumed that the Water Studies (1992) data was in June 1990 dollars. The CPI data is shown in **Table 13.3**.

Table 13.3 CPI Statistics from 1990

Month	Year	CPI
June	1990	102.50
June	2008	164.10
Change	60.10%	

Consequently, damages have been increased by 60.10% and GST has been included.

13.1.3 Industrial Damage Curves

Industrial damage curves are determined based on those included in the *FLDamage Manual* (Water Studies, 1992). FLDamage allows for three types of industrial properties:

- Low Value Industrial,
- Medium Value Industrial,
- High Value Industrial (e.g. BHP steelworks).

Within the catchment, it has been assumed that there are only low value industrial properties.

To normalise the damages for property size, the curves have been factored to account for floor area, assuming a nominal floor area of 100 m^2.

The values were adjusted to June 2008 dollars using the CPI statistics shown in **Table 13.4**.

Table 13.4 CPI Statistics from 1998

Month	Year	CPI
June	1998	121.00
June	2008	164.10
Change	35.62%	

Consequently, all ordinates on the damage curves were adjusted by 35.62% and GST was added.

13.1.4 Adopted Damage Curves

The adopted damage curves are shown in **Figure 13.1**. As described above, the commercial and industrial damage curves are for a property with a floor area of 100 m^2.

13.2 Annual Average Damage

Annual Average Damage (AAD) is calculated on a probability approach, using the flood damages calculated for each design event.

Flood damages (for a design event) are calculated by using the ‘damage curves’ described in the sections above. These damage curves attempt to define the damage experienced on a property for varying depths of flooding. The total damage for a design event is determined by summing together flood damages for each individual property affected by flooding for that design event.

The AAD value attempts to quantify the flood damage that a floodplain would receive on average during a single year. It does this using a probability approach. A probability curve is drawn, based on the flood damages calculated for each design event (**Figure 13.2**). For example, the 100 year ARI design event has a 1% probability of occurring in any given year and as such the 100 year ARI flood damage is plotted at this point on the AAD curve. AAD is then calculated by determining the area under this curve.

Further information on the calculation of AAD is provided in Appendix M of the *Floodplain Development Manual* (NSW Government, 2005).

13.3 Results

Table 13.5 shows the results of the flood damage assessments. Based on the analysis described in **Section 13.2** above, the average annual damage for the floodplain under existing conditions is approximately **$276,552**.

Table 13.5 Summary of Economic Flood Damages

Property Type	Properties with overfloor flooding	Properties with overground flooding	Total Damage ($ June 2008)
PMF			
Residential	68	106	$3,117,436
Commercial	8	11	$1,505,272
Industrial	1	2	$107,048
PMF Total	**77**	**119**	**$4,729,757**
200 year ARI			
Residential	8	34	$478,967
Commercial	2	5	$488,664
Industrial	0	0	$0
200 Year ARI Total	**10**	**39**	**$967,630**
100 year ARI			
Residential	7	30	$449,190
Commercial	2	5	$471,276
Industrial	0	0	$0
100 Year ARI Total	**9**	**35**	**$920,466**
50 year ARI			
Residential	7	29	$424,503
Commercial	2	4	$453,906
Industrial	0	0	$0
50 Year ARI Total	**9**	**33**	**$878,410**
20 year ARI			
Residential	5	23	$301,573
Commercial	2	4	$426,520
Industrial	0	0	$0
20 Year ARI Total	**7**	**27**	**$728,094**
10 year ARI			
Residential	4	20	$256,053
Commercial	2	4	$426,520
Industrial	0	0	$0
10 Year ARI Total	**6**	**24**	**$682,573**
5 year ARI			
Residential	0	12	$76,953
Commercial	2	4	$426,520
Industrial	0	0	$0
5 Year ARI Total	**2**	**16**	**$503,473**

13.4 Assumptions and Qualifications

A significant assumption in the calculation of the Annual Average Damage is that the damages in the 2 year ARI design event are zero, with a linear increase in damage up to the 5 year ARI design event. Assuming a different design event for zero damages can significantly change the AAD. A 2 year ARI design event was considered to be a reasonable estimate of zero damage in the catchment. A paper was presented at the 2006 Floodplain Management Conference (Thomson *et al*, 2006) highlighting the issues associated with this assumption.

14 DISCUSSION

14.1 General Discussion

Analysis of the rainfall data (**Section 3.3**) and the WBNM historical generated flows (**Section 6.6**) suggests that the residents of Nabiac have experienced significant flooding events within the last 10 years. Analysis of the hydrographs from WBNM would suggest that the February 2002 event was similar in magnitude to a 100 year ARI design event, while the June 2007 event was approximately equivalent a 20 to 50 year ARI design event, although this depends on the location within the study area.

Due to these recent flooding events, discussions as a part of the community consultation have shown that residents are familiar with flooding within the study area, particularly in the township area and residential areas around Town Creek and Woosters Creek. Due to the rural nature of Pipeclay Creek, there is little experience of flooding in this area, with most residents in the lower lying areas of Pipeclay Creek having experience river flooding rather than local catchment flooding.

The hydrological and hydraulic modelling undertaken in this report has defined the flood behaviour for the 200 year, 100 year, 50 year, 20 year, 10 year and 5 year ARI design events, together with the PMF.

The highest risk areas, in terms of risk to property and risk to life, are focused around Clarkson Street, around the crossings of Town Creek and Woosters Creek. Town Creek tends to be controlled by a set of pipe culverts near the Industrial area, which can cause a backwater to form along Nabiac Street and Clarkson Street. This agrees with historical observations, where these roads have been inundated in both the February 2002 and June 2007 events, together with inundation of some of the commercial properties in this area. The critical duration of Town Creek is 9 hours for the 100 year event around Clarkson Street, which is reflective of the storage governed flooding in this area behind both the industrial culverts and the backwater from Wallamba River. However, shorter duration storms also result in significant flooding in this area, as discussed in Section 14.2.

Woosters Creek does not generally create a risk to property, although there is some inundation of properties near Clarkson Street. The critical duration for the Clarkson Street area is 9 hours for the 100 year ARI design event. Further downstream, Woosters Creek is generally confined to bushland areas with fringes of properties affected by flooding. Woosters Creek does, however, overtop Clarkson Street in a 5 year ARI event by with depths of around 0.15m and approximately 0.40m in a 100 year ARI event. This not only creates a potential hazard, it also cuts off access for residents between Town Creek and Clarkson Street.

The areas around Hoskins Street generally experience issues with ponding. This area is particularly flat, and while nominally this area drains to Woosters Creek, the reality in a storm event is that most of the water accumulates through ponding. The critical duration in this area is generally 12 hours in a 100 year ARI event, reflective of the larger volumes required to cause flooding for this area.

Additional flooding of Clarkson Street, between Town Creek and Woosters Creek, is caused by flows from a relatively small catchment near the Motorcycle Museum. This overland flow path causes flooding of Clarkson Street, as well as the properties which are located adjacent to this overland flow path.

The properties in the lower areas of Woosters Creek, in the Donaldson Street Area, are primarily affected where they back onto the bushland/ swamp area. In the 100 year ARI design event, the inundation is minor and generally only affects the fringes of the properties, staying mostly confined to the bushland areas. It is noted that the flooding in this area is likely to be more significant as a result of River flooding rather than local catchment flooding.

Pipeclay Creek conveys a significant volume of the flow, with a peak discharge of 575m^3/s in a 100 year ARI design event. The flooding associated with this flow is contained within rural properties, and does not affect any of the houses in this area in the 100 year event. There are a number of locations where the flows of Pipeclay Creek combine with those of Woosters Creek and its tributaries.

14.2 Critical Duration

The critical duration at Clarkson Street for both Town Creek and Woosters Creek is 9 hours. However, it should be noted that the difference in peak water level between a 9 hour event and shorter duration events may not be that significant. **Table 14.1** and **Table 14.2** provide the peak water levels at Clarkson Street for both Town Creek and Woosters Creek. At Town Creek, for example, the peak water level in a 100 year ARI 9 hour duration event is 7.48m AHD, and in a 2 hour event is only 0.13m lower at 7.35m AHD.

This is important from an emergency planning perspective, that while longer durations are critical for peak water levels, shorter duration events still result in significant flooding in the area. This would have implications on evacuation and emergency planning.

Table 14.1 Town Creek - Peak Water Levels for Different Durations (m AHD)

	5yr	10yr	20yr	50yr	100yr	200yr	PMF
60mins	7.05	7.16	7.28	7.39	7.46	7.57	8.33
90mins	7.16	7.25	7.36	7.48	7.54	7.62	8.37
2hr	7.22	7.31	7.42	7.52	7.58	7.64	8.35
9hr	7.40	7.48	7.55	7.60	7.64	7.69	---
12hr	7.36	7.43	7.51	7.57	7.65	7.68	---

Table 14.2 Woosters Creek - Peak Water Levels for Different Durations (m AHD)

	5yr	10yr	20yr	50yr	100yr	200yr	PMF
60mins	6.85	7.0	7.15	7.27	7.34	7.42	9.28
90mins	6.98	7.10	7.22	7.33	7.40	7.48	9.41
2hr	7.05	7.16	7.27	7.36	7.44	7.52	9.38
3hr	7.08	7.18	7.28	7.38	7.44	7.52	9.24
6hr	7.15	7.25	7.34	7.42	7.50	7.58	8.90
9hr	7.27	7.33	7.41	7.48	7.55	7.63	---
12hr	7.23	7.30	7.37	7.44	7.50	7.59	---

14.3 Properties affected

Table 14.3 provides a summary, for both the 100 year and 5 year ARI events, of the cadastral blocks affected by:

- Flooding
- High Provisional Hazard
- Floodway

It should be noted that the numbers in Table 14.3 are the cadastral blocks, which may incorporate parkland or non-dwelling properties. However, it is a useful gauge on the difference between the flood affected properties which are also exposed to either floodway or provisional high hazard.

While a number of properties are affected by flooding within Nabiac, the large proportion of these are outside of either the floodway or high provisional hazard areas (for example, the properties in the vicinity of Hoskins Street are primarily affected by flood storage and flood fringe, rather than by floodway).

Table 14.3. Cadastral Blocks and Flood Affectation

Extent		High Provisional Hazard		Floodway	
100 year	**5 year**	**100 year**	**5 year**	**100 year**	**5 year**
210	177	90	84	85	79

14.4 Candoormakh Creek Road

As discussed in Section 6.2, changes occurred to Candoormakh Creek Road during the Princes Highway works. This resulted in a larger portion of the upstream catchment being diverted to the Town Creek catchment. An analysis has been undertaken on the impact of this diversion of the flows and flood levels along Town Creek for the 100 year ARI.

The works have resulted in an additional 64.4 ha of catchment applying to Town Creek, and this is demonstrated in **Figure 14.1**. The changes to the peak flow rates for the 100 year ARI are shown in **Table 14.4**.

The effect of these changes to the catchment area result in increases to the peak water levels within Town Creek. These increases are shown in **Figure 14.2**. Typical increases in flood levels in the vicinity of the Clarkson Street culvert over Town Creek are 0.20 metres.

It is recommended that options for modification of these works be considered as a part of the floodplain risk management study and plan.

Table 14.4 Effects of Changes to Candoormakh Creek Road

	Catchment Area (ha)	Peak 100 year Flow (m^3/s)
Pre-Candoormakh Creek Changes	51.2	9.2
Post-Candoormakh Creek Changes	130.4	16.7

QUALIFICATIONS

This report has been prepared by Cardno Lawson Treloar for Great Lakes Council and as such should not be used by a third party without prior approval.

The investigation and modelling procedures adopted for this study follow industry standards and considerable care has been applied to the preparation of the results. However, model set-up depends on the quality of data available. The flow regime and the flow control structures are complicated and can only be represented by schematised model layouts. Hence there will be a level of uncertainty in the results and this should be borne in mind in their application.

Legislation is correct at the time of issue of the report (July, 2009). It is important to note that legislation and planning policies can change at any time.

The study results are dependent on the accuracy of the ground and aerial survey utilised.

The study results should not be used for purposes other than those for which they were prepared.

15 REFERENCES

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