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Bomaderry Creek Flood Study

Final Report

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Bomaderry Creek Flood Study
Final Report

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Title :	Bomaderry Creek Flood Study –Final Report
Author :	Darren Lyons
Synopsis :	Report for the Bomaderry Creek Flood Study covering the development and calibration of computer models, establishment of design flood behaviour and flood mapping.

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EXECUTIVE SUMMARY

Introduction

The Bomaderry Creek Flood Study has been prepared for Shoalhaven City Council (Council) to define the existing flood behaviour in the Bomaderry Creek catchment and establish the basis for subsequent floodplain management activities.

The primary objective of the Flood Study is to define the flood behaviour of the Bomaderry Creek catchment through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- A community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and extreme flood event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating detailed flood mapping.

This Flood study has been adopted by Shoalhaven City Council on 23 November 2010.

Catchment Description

The Bomaderry Creek catchment encompasses an area of approximately 36.2km^2 located in the Shoalhaven River Valley on the New South Wales South Coast. Bomaderry Creek flows in a general south-east direction from its source in the Cambewarra Range to its confluence with the Shoalhaven River at Bomaderry.

Bomaderry Creek is fed by a number of major tributaries, the most significant of these being Good Dog Creek, Browns Creek and Tapitallee Creek. The three tributaries merge to become Bomaderry Creek in the lower catchment, flowing through the steep and narrow Bomaderry Gorge, prior to discharge to the Shoalhaven River.

Land use within the catchment primarily consists of rural pasture (50%), bushland (40%) and urban development (10%). The floodplain area principally remains undeveloped and largely occupied by rural farming.

The main urban communities include Cambewarra and parts of North Nowra and Bomaderry. The existing development is predominantly located on higher ground, somewhat removed from the floodplain. Some development occupying the lower part of the Bomaderry Creek floodplain in the vicinity of Bolong Road, Bomaderry, represents the existing development with the highest flood risk exposure.

Historical Flooding

Much of the data relating to historical flooding in the Bomaderry Creek catchment is associated with major flooding in the Shoalhaven River system. Indeed the lower reaches of Bomaderry Creek, downstream of the Princes Highway, are largely governed by Shoalhaven River flooding.

Major events in the Shoalhaven River catchment include 1860, 1870, 1873, 1916, 1924, 1959, 1974, 1975, 1978, 1988 and 1990. These events largely impacted on the lower floodplain of Bomaderry Creek. Peak water level records at Nowra Bridge and at industrial property along Bolong Road provide a good record of flood history dominated by the Shoalhaven River.

However, there is very little existing flood data for the upper catchment of Bomaderry Creek. A search for historical records including targeted consultation via a community questionnaire failed to identify any definitive flood marks for major historical flood events. Upstream of Bomaderry Gorge, the floodplain remains largely undeveloped, with development such as Cambewarra generally located on higher ground fringing the floodplain. The low exposure to flooding may therefore explain the lack of historical flood data.

Since 2003, the NSW Dept. of Water and Energy (DWE) has operated a streamflow gauge on Bomaderry Creek just upstream of the entrance to Bomaderry Gorge. However, during this time only minor flood events have occurred, with the highest event occurring in February 2008 estimated to be of the order of a 5-year return period.

Community Consultation

Community consultation undertaken during the study has aimed to collect information on historical flooding and previous flood experience, and inform the community about the development of the flood study and its likely outcome as a precursor to floodplain management activities to follow. The key elements of the consultation process have included distribution of a questionnaire relating to historical flooding, and a community information session held at Bomaderry Community Hall during Wednesday 20th February 2008.

The information session was attended by only 2 community attendees in addition to Council staff and the consultant. The relatively poor attendance may be reflective of the limited number of property to have existing flood problems or experienced significant flooding, particularly in the catchment upstream of the Princes Highway. Previous consultation undertaken for the Lower Shoalhaven Floodplain Risk Management Study may have limited the number of interested residents in the lower floodplain of Bomaderry Creek.

Model Development (and additional survey)

Development of hydrologic and hydraulic models has been undertaken to simulate flood conditions in the catchment. The hydrological model developed using RAFTS-XP software provides for simulation of the rainfall-runoff process using the catchment characteristics of Bomaderry Creek and historical and design rainfall data. The hydraulic model, simulating flood depths, extents and velocities utilises the TUFLOW two-dimensional (2D) software developed by BMT WBM. The 2D modelling approach is suited to model the complex interaction between channels and floodplains and converging and diverging of flows through structures and urban environments.

The floodplain topography is defined using a high resolution digital elevation model (DEM) derived from LiDAR survey for greater accuracy in predicting flows and water levels and the interaction of in-channel and floodplain areas. To supplement the LiDAR data, additional cross section survey of the Bomaderry Creek channel and significant hydraulic structures was acquired during the course of the study.

With consideration to the available survey information and local topographical and hydraulic controls, a hydraulic model was developed extending from the Shoalhaven River confluence at the downstream limit, to approximately 14km upstream along the major tributary routes. The floodplain area modelled within the 2D domain comprises a total area of some 22km^2 which represents the lower 60% of the entire Bomaderry Creek catchment.

Model Calibration and Validation

The selection of suitable historical events for calibration of the computer models is largely dependent on available historical flood information. Within the Bomaderry Creek catchment however, there is a distinct lack of historical flood data.

The model calibration and validation is based on the historical data available for the February 2008 and August 1990 events.

The only available water level records considered suitable for model calibration are those associated with the Bomaderry Creek streamflow gauge, in operation since 2003. The highest recorded water level at the gauge is for the event of 5th February 2008. The availability of a continuous recorded water level hydrograph throughout the event, coupled with the rainfall hyetograph recorded at the same gauge, provides a suitable calibration point for the developed models. Accordingly, this event is adopted as the principal calibration event.

A rainfall depth of 165mm was recorded at the Bomaderry Creek streamflow gauge for the 24-hours to 9:00am on 5th February 2008. This included a recorded 127mm over a 6-hour period which approximates a 5-year return period design rainfall.

In absence of detailed data for other historical events, conventional model validation cannot be undertaken. However, the August 1990 event has been simulated for comparison. The August 1990 event is identified as having the highest 1-day (260mm) and 2-day (440mm) rainfall totals on record in the Bomaderry Creek catchment. This 2-day total represents approximately a 30-year return period design rainfall over the 48-hour duration.

A reasonable model calibration has been achieved given the available data for the catchment. The developed models provide a sound representation of the flooding behaviour of the catchment, as demonstrated through comparison of recorded peak water levels for the historical events simulated.

Design Event Modelling and Output

The developed models have been applied to derive design flood conditions within the Bomaderry Creek catchment. Design rainfall depth is based on the generation of intensity-frequency-duration

(IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). A range of storm durations using standard AR&R (2001) temporal patterns, were modelled in order to identify the critical storm duration for design event flooding in the catchment.

The design events considered in this study include the 10% AEP (10-year ARI), 5% AEP (20-year ARI), 2% AEP (50-year ARI), 1% AEP (100-year ARI) 0.5% AEP (200-year ARI) and PMF events. The model results for the design events considered have been presented in a detailed flood mapping series for the catchment. The flood data presented includes design flood inundation, peak flood water levels and peak flood depths.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped for the 20% AEP, 1% AEP and the PMF events, in addition to the hydraulic categories (floodway, flood fringe and flood storage) for flood affected area for the 20% AEP, 1% AEP and the PMF events also.

The simulated flood inundation extents in the Bomaderry Creek catchment for the 5% AEP, 1% AEP and PMF events are shown in Figure 7.3. The Bomaderry Gorge forms a significant control which effectively separates the upper and lower floodplain of Bomaderry Creek. The lower floodplain of Bomaderry Creek broadens downstream of the Princes Highway as it converges with the Shoalhaven River. Extensive flooding around low-lying property along Bolong Road is simulated in major flood events. In the upper catchment, flooding is generally confined along the riparian corridor of the major tributary alignments. The expanse of inundated floodplain increases with flood magnitude, however, even for the PMF event, there is limited exposure to existing property with the main urban community of Cambewarra located on higher ground outside the mainstream flood extents.

Sensitivity Testing

A series of sensitivity tests have been undertaken on the modelled flood behaviour of the Bomaderry Creek catchment. The tests provide a basis for determining the relative accuracy of modelling results, and an initial focus for future floodplain management planning. The tests undertaken include:

- Hydraulic roughness – increases in hydraulic roughness were simulated to represent a more heavily vegetated condition both in-channel and on the floodplain. Given that the catchment is largely undeveloped and occupied by rural pasture and bushland, seasonal variations in vegetation can provide for local increases in water levels;

- Structure blockages – structure blockage due to flood debris can result in significant increases to flood levels and redistributions of flood flows. Blockage scenarios of up to 50% blockage depending on the size of the structure have been simulated for major structures on the main channel alignments; and

- Design rainfall losses – increases in design rainfall losses have been simulated to represent a fully saturated catchment condition. This provides for an increase in effective rainfall and therefore an increase in surface runoff for the design rainfall condition.

The sensitivity tests generally provide only modest changes to simulated design flood conditions. Significantly, increases in simulated inundation extents considering sensitivity tests do not result in any significant increase in flood affectation for existing property. However, for future development in the catchment, increases in design flood conditions over and above the adopted design flood standards should consider the potential impacts of these scenarios.

Conclusions

The objective of the study was to undertake a detailed flood study of the Bomaderry Creek catchment and establish models as necessary for accurate flood level prediction. Central to this was the development of a two-dimensional hydraulic model of the floodplain incorporating both the upper catchment around Cambewarra and lower catchment around Bomaderry.

The findings of the flood study is fully documented in this report, incorporating a review of background data, model development and calibration details, design events simulation and sensitivity testing. A key output of the study is the detailed flood mapping series documenting the simulated flood behaviour in the catchment for the range of design events considered. The flood maps detail peak water level, depth and velocity distribution in the study area for each of the design events. Provisional flood hazard categories and hydraulic categories are derived from the hydrodynamic model results are also presented.

The flood study will form the basis for the subsequent floodplain risk management activities, being the next stage of the floodplain management process. Accordingly, the adoption of the flood study and predicted design flood levels is recommended.

Given the significant influence of Shoalhaven River flooding on the predicted flood behaviour of the Lower Bomaderry Creek catchment, future flood studies and floodplain management studies relating to the broader Shoalhaven River catchment should feed back into the Bomaderry Creek floodplain management process.

The Nowra Bomaderry Structure Plan (Shoalhaven City Council, 2008) provides a framework for the integrated development of the Nowra Bomaderry area, including Cambewarra. Within the Structure Plan, some area along Moss Vale Road is identified as future residential development that lies within the Bomaderry Creek catchment. The Bomaderry Creek catchment is also traversed by a major transport planning corridor that is under investigation to provide a western bypass for the Princes Highway around Bomaderry and North Nowra.

The flooding behaviour of Bomaderry Creek is a key constraint in the future planning and design of infrastructure within the catchment. The completed flood study establishes the design flood conditions and provides the best available information to inform of potential flood risk and set appropriate planning and development controls to accommodate this future development within the catchment.

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GLOSSARY

annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. (see also average recurrence interval)
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
attenuation	Weakening in force or intensity
average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20yr ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also annual exceedance probability)
catchment	The catchment at a particular point is the area of land that drains to that point.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in tems of vollume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as “stage”.
flood liable land	see flood prone land

floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.
floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Management Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
Flood planning levels (FPL)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk 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 landuse and for different flood plans. The concept of FPLs supersedes the “standard flood event”. As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood source	The source of the floodwaters. In this study, Burrill Lake is the primary source of floodwaters.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determing the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
geomorphology	The study of the origin, characteristics and development of land forms.
gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
historical flood	A flood that has actually occurred.

hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrodynamic	Pertaining to the movement of water
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrographic survey	Survey of the bed levels of a waterway.
hydrologic	Pertaining to rainfall-runoff processes in catchments
hydrology	The term given to the study of the rainfall-runoff process in catchments.
isohyet	Equal rainfall contour
morphological	Pertaining to geomorphology
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
pluviometer	A rainfall gauge capable of continously measuring rainfall intensity
probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
riparian	The interface between land and waterway. Literally means "along the river margins"
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
sub-critical	Refers to flow in a channel that is relatively slow and deep
topography	The shape of the surface features of land
velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.
water level	See flood level.

1 INTRODUCTION

The Bomaderry Creek Flood Study has been prepared for Shoalhaven City Council (Council) to define the existing flood behaviour in the Bomaderry Creek catchment and establish the basis for subsequent floodplain management activities.

This project has been conducted under the State Assisted Floodplain Management Program and received State financial support.

This Flood study has been adopted by Shoalhaven City Council on 23 November 2010.

1.1 Study Location

The Bomaderry Creek catchment encompasses an area of approximately 36.2km^2 located in the Shoalhaven River Valley on the New South Wales South Coast as shown in Figure 1-1. Bomaderry Creek flows in a general south-east direction from its source in the Cambewarra Range to its confluence with the Shoalhaven River at Bomaderry.

Bomaderry Creek is fed by a number of major tributaries, the most significant of these being Good Dog Creek, Browns Creek and Tapitallee Creek. The three tributaries merge to become Bomaderry Creek in the lower catchment, flowing through the steep and narrow Bomaderry Gorge, prior to discharge to the Shoalhaven River.

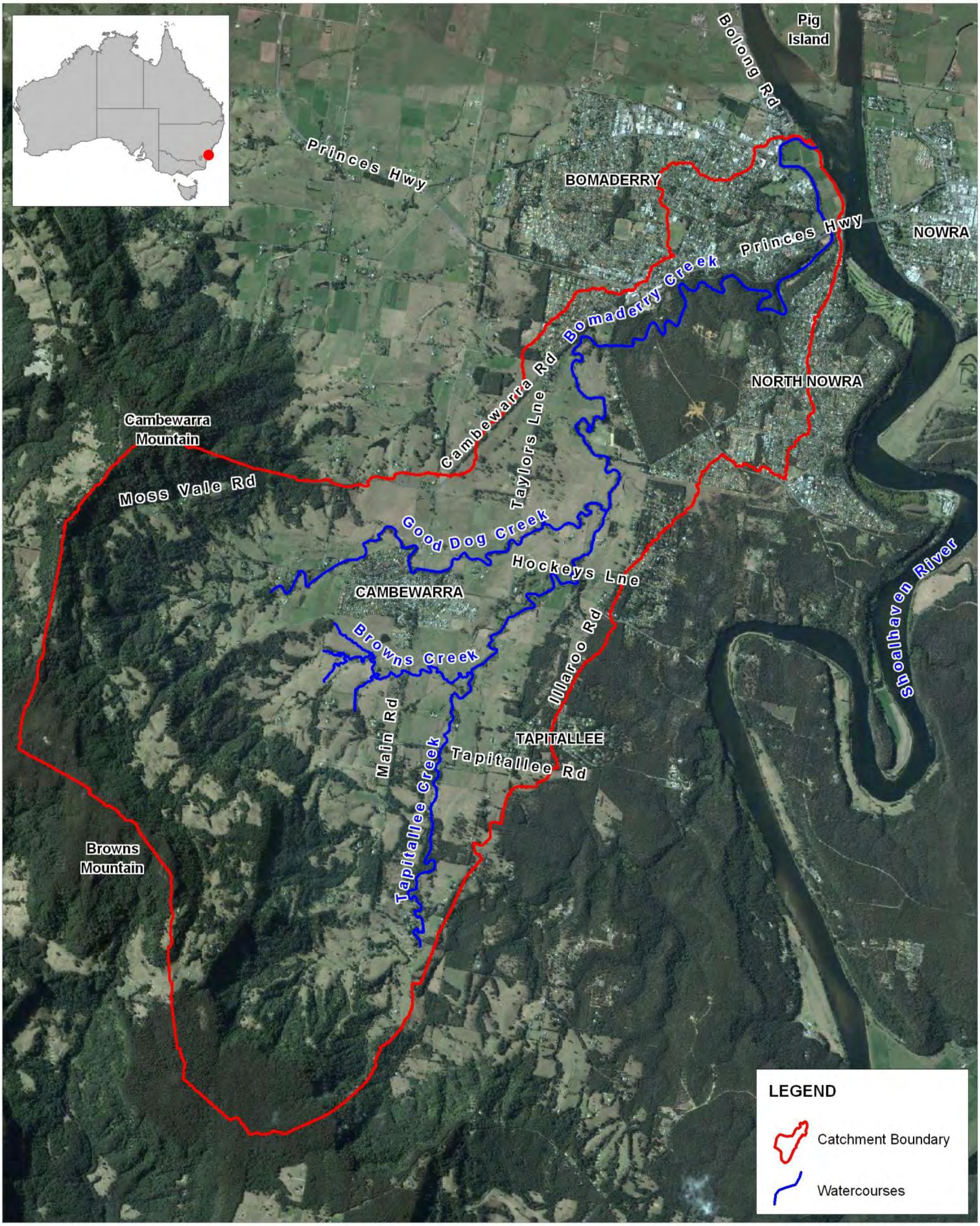
Existing communities within the catchment include Cambewarra, Bomaderry and North Nowra. The village of Cambewarra is a small township located some 12km upstream of the Shoalhaven River confluence, nestled on relatively higher ground between Good Dog Creek and Browns Creek. Bomaderry represents the major residential and commercial centre in the catchment, principally occupying the lower floodplain on the left bank of Bomaderry Creek, itself a part of the wider Shoalhaven River floodplain. North Nowra is largely removed from the influences of mainstream Bomaderry Creek flooding, with existing development located generally at the top of the local catchment.

Apart from the existing development areas discussed above, land use in the catchment is predominantly rural pasture. The upper slopes of the Cambewarra Range remain natural forest with the small forested area of Crown Land incorporating Bomaderry Gorge.

1.2 Study Background

There has been no previous detailed investigation of the flood behaviour of the Bomaderry Creek catchment. Nevertheless, there has been a history of flooding resulting in inundation, particularly in the lower floodplain including properties in parts of Bomaderry.

The majority of significant flooding in Bomaderry has coincided with major flood events in the Shoalhaven River. Major historical flood events to have occurred in the Shoalhaven River include 1974, 1975, 1978, 1988 and 1990.



Title:
Study Locality

Figure:
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Approx. Scale

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The Lower Shoalhaven River Flood Study (WMA, 1990) assessed the flooding behaviour of the Lower Shoalhaven including development of hydrologic and hydraulic models, calibrated to historical events and applied to derive design flood conditions. The design flood conditions derived from the flood study provided the basis for the development of the Draft Lower Shoalhaven River Floodplain Management Study and Plan (WMA, 2007).

The previous flooding investigations of the Lower Shoalhaven River however do not include any detailed assessment of Bomaderry Creek flooding. Accordingly, the flooding behaviour in the Bomaderry Creek catchment was largely undefined, prior to undertaking the current study.

1.3 The Need for Floodplain Management at Bomaderry Creek

Existing communities of Cambewarra and Bomaderry are located on the wider floodplain of Bomaderry Creek and its major tributaries.

Whilst the impacts of major Shoalhaven River flooding on the lower Bomaderry Creek floodplain has been assessed, additional risk may be imposed by the coincident flooding of both systems, particularly for major events emanating from the Bomaderry Creek catchment which has not been investigated in detail to date.

There is likely to be a future increase in development pressures across the wider Shoalhaven LGA, including the Bomaderry Creek catchment to accommodate general population growth expectations. This in time will increase the number of people potentially exposed to flood risk, many of whom would be oblivious to existing flood risk given no previous experience of flooding in the catchment.

The Nowra Bomaderry Structure Plan (Shoalhaven City Council, 2008) provides a framework for the integrated development of the Nowra Bomaderry area, including Cambewarra. Within the Structure Plan, some area along Moss Vale Road is identified as future residential development that lies within the Bomaderry Creek catchment.

The Bomaderry Creek catchment is also traversed by a major transport planning corridor that is under investigation to provide a western bypass for the Princes Highway around Bomaderry and North Nowra. The flooding behaviour of Bomaderry Creek is a key constraint in the future planning and construction of this route.

The potential for climate change impacts is now a key consideration for floodplain management. The NSW Government has released a guideline for practical consideration of climate change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. Accordingly, this increase in design rainfall will translate into increased design flood inundation in the Bomaderry Creek catchment, such that future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

Floodplain risk management considers the consequences of flooding on the community and aims to develop appropriate floodplain management measures to minimise and mitigate the impact of flooding. This incorporates the existing flood risk associated with current development, and future flood risk associated with future development and changes in land use.

Accordingly, Council desires to approach local floodplain management in a considered and systematic manner. This study comprises the initial stages of that systematic approach, as outlined in the Floodplain Development Manual (NSW Government, 2005). The approach will allow for more informed planning decisions within the floodplain of Bomaderry Creek.

1.4 The Floodplain Management Process

The State Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Policy and practice are defined in the Government's Floodplain Development Manual (2005).

Under the Policy the management of flood liable land remains the responsibility of Local Government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

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

Stages of Floodplain Management

	Stage	Description
1	Flood Study	Determines the nature and extent of the flood problem.
2	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
3	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stage 1 of the above process and aims to provide an understanding of flood behaviour within the Bomaderry Creek catchment.

1.5 Study Objectives

The primary objective of the Flood Study is to define the flood behaviour of the Bomaderry Creek catchment through the establishment of appropriate numerical models. The study will produce information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment and floodplain conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertake a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;

- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and extreme flood event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

The principal outcome of the flood study is the understanding of flood behaviour in the catchment and in particular design flood level information that will be used to set appropriate flood planning levels for the study area.

1.6 About This Report

This report documents the Study's objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides an overview of the approach adopted to complete the study.

Section 3 outlines the community consultation program undertaken.

Section 4 provides information on the additional survey collected for this study.

Section 5 details the development of the computer models.

Section 6 details the model calibration and validation process including sensitivity tests.

Section 7 presents the design flood conditions and associated flood mapping.

Section 8 presents a preliminary property inundation and flood damages assessment.

2 STUDY APPROACH

2.1 The Study Area

2.1.1 Catchment Description

Bomaderry Creek is situated on the south coast of NSW approximately 1.5km north of the township of Nowra. The Bomaderry Creek catchment occupies a total catchment area of 36.2km^2, extending from the escarpment at the top of the Cambewarra Range, and flowing generally south-east to Bomaderry at the confluence of the Shoalhaven River.

The topography of the catchment is shown in Figure 2-1. From a high elevation of around 500m AHD at the top of the catchment, the topography grades steeply from the upper slopes to the floodplain around Cambewarra. From Cambewarra the floodplain is very undulating with highly sinuous channels. Approximately 6km upstream of the confluence with the Shoalhaven River, the channel enters the Bomaderry Creek gorge. This relatively narrow and steep channel, with sheer sandstone faces, forms a significant hydraulic control, dropping steeply in elevation to the lower floodplain.

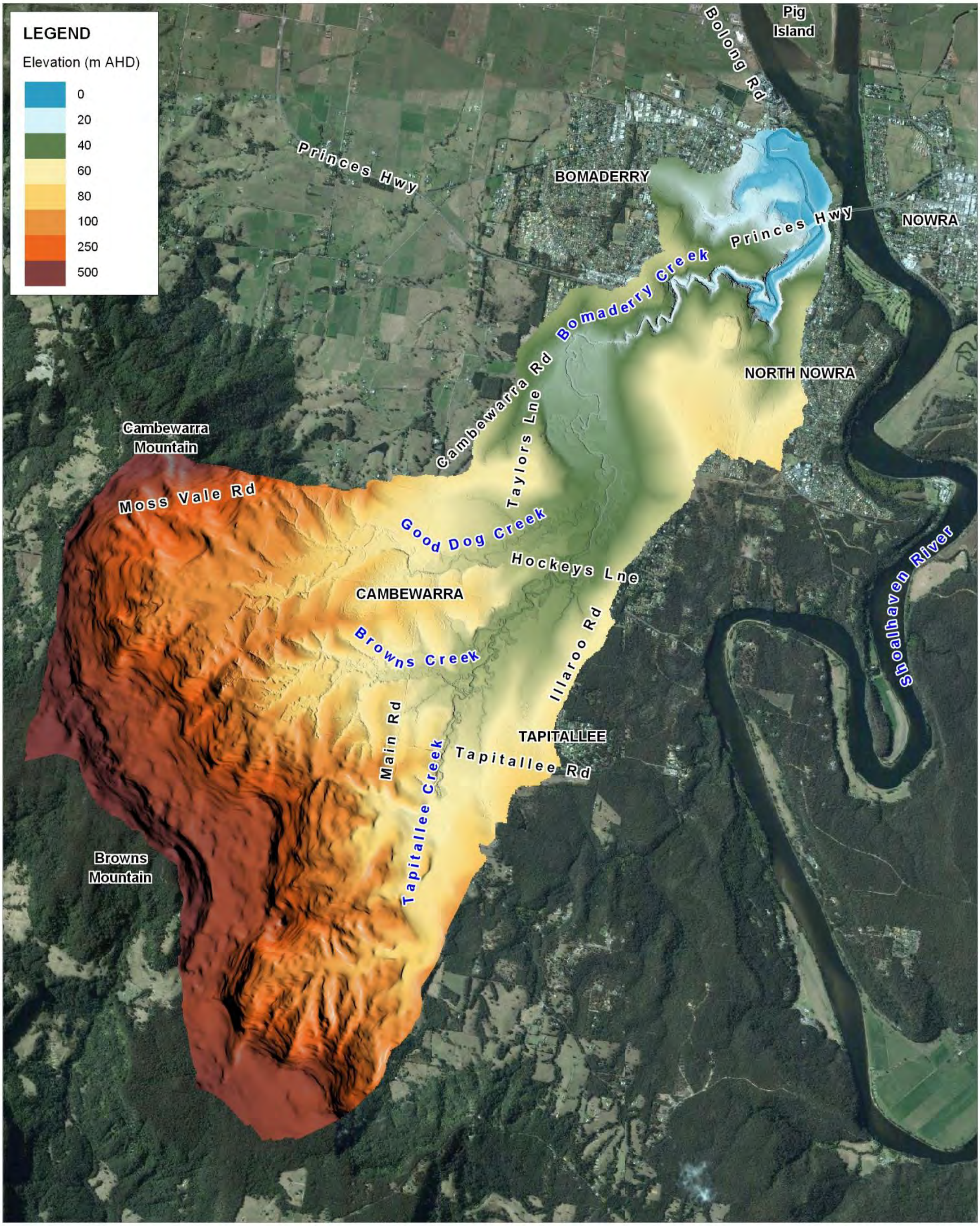
The catchment is drained by Bomaderry Creek and its three major tributaries including Good Dog Creek, Tapitallee Creek and Browns Creek. The watercourses in the upper catchment upstream of the Bomaderry Gorge are typically small and heavily vegetated. After the channel cuts through the Bomaderry Gorge, it widens and deepens on the lower floodplain to the confluence with the Shoalhaven River.

Bomaderry Creek is a tributary of the Shoalhaven River, the confluence approximately 1.3km east of Nowra Bridge and 11 km upstream of Shoalhaven Heads. The Shoalhaven is a major system with a catchment area of the order of 7,000 km^2. Flooding in the lower reaches of Bomaderry Creek is highly influenced by the conditions in the Shoalhaven River. The Shoalhaven River floodplain is relatively constrained upstream of Nowra Bridge, however, from this point downstream the river opens up to an expansive floodplain from Nowra to the Pacific Ocean.

Land use within the catchment primarily consists of rural pasture (50%), bushland (40%) and urban development (10%). The floodplain area principally remains undeveloped and largely occupied by rural farming.

The main urban communities include Cambewarra and parts of North Nowra and Bomaderry. The existing development is predominantly located on higher ground, somewhat removed from the floodplain. Some development occupying the lower part of the Bomaderry Creek floodplain in the vicinity of Bolong Road, Bomaderry, represents the existing development with the highest flood risk exposure.

The catchment is traversed by a number of local transport routes including Main Road, Tapitallee Road, Hockeys Lane and Taylors Lane. As evident in the catchment topography shown in Figure 2-1, these routes are generally constructed at grade and do not incorporate any significant embankments across the Bomaderry Creek and tributary floodplains.



Title:
Topography of the Bomaderry Creek Catchment

Figure: **2-1**

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2.1.2 History of Flooding

Much of the data relating to historical flooding in the Bomaderry Creek catchment is associated with major flooding in the Shoalhaven River system. Indeed the lower reaches of Bomaderry Creek, downstream of the Princes Highway, are largely governed by Shoalhaven River flooding.

Major events in the Shoalhaven River catchment include 1860, 1870, 1873, 1916, 1924, 1959, 1974, 1975, 1978, 1988 and 1990.

There is very little existing flood data for the upper catchment of Bomaderry Creek catchment. To get some perspective on historical rainfall events across the Bomaderry Creek catchment, SILO daily rainfall data has been analysed for the site. The SILO data is broad scale (0.05 degrees spatial resolution – approximately 5km) and is useful for defining large catchment averages. The SILO rainfall data comprises an archive of interpolated rainfall and climate surfaces maintained by the Queensland Department of Natural Resources and Mines. These surfaces were constructed by spatially interpolating observational data collected by the Australian Bureau of Meteorology. The Bureau maintains an archive of observational rainfall and climate records which dates back to the mid-late 1800's. Rainfall surfaces commencing in 1890 have been produced from the analysis. For further details of the processes involved in constructing the interpolated data sets refer to the following web link - http://www.nrw.qld.gov.au/silo/datadrill/index.html

Table 2-1 presents the highest 1-day, 2-day and 3-day rainfall totals from the SILO data set for the Bomaderry Creek catchment and their respective year of occurrence. Historical floods in the wider Shoalhaven catchment have largely emanated from major storm durations of the order of 2 to 3 days. Given the size of the Bomaderry Creek catchment major flooding would be expected to be associated with a shorter duration.

Table 2-1 Major Rainfall Event Totals

	1-day Total		2-day Total		3-day Total	
Rank	Year	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)
1	1930	274	**1990**	442	**1990**	467
2	**1990**	258	1959	395	1943	423
3	1911	252	1943	384	1991	405
4	1959	244	**1974**	369	1959	397
5	1943	241	**1975**	340	**1974**	384
6	1925	230	1991	335	**1975**	366
7	1915	211	1911	332	1925	341
8	1963	210	1930	331	1911	340
9	1992	207	1925	322	1930	335
10	1898	206	1951	302	1922	330

The August 1990 rainfall features prominently in the list of highest 1-day, 2-day and 3-day rainfall events within the Bomaderry Creek catchment. The majority of the rainfall for this event fell within a 2-

day period, with the estimated 2-day total significantly higher than other event rainfall recorded in the catchment.

Significantly there are no major recent events (since 1991) within Table 2-1. Some high rainfall events have occurred within the Bomaderry Creek catchment within this time, however, in relation to long term historical records, recent rainfall events have in general been less severe. Further discussion on more recent rainfall events to have occurred in the catchment, including 2005, 2007 and 2008 is provided in Section 2.2.3.

It is important to recognise that local rainfall variations across the catchment may be “smoothed out” from the spatially averaged SILO data, and indeed shorter (<24 hours) more intense rainfall resulting in significant flooding will not be evident in the daily total time series.

Nevertheless, the data is indicative of broad scale weather systems and does provide some resemblance to known flooding patterns in the valley. Some of the largest 2-day/3-day rainfall events within the Bomaderry catchment identified in the SILO data analysis correspond to known major events across the lower Shoalhaven Valley including the 1974, 1975, and 1990 floods.

2.1.3 Previous Investigations

There has been no previous detailed investigation of the flooding characteristics of the Bomaderry Creek catchment. Some minor hydrological investigations associated with development in Cambewarra have been undertaken, however, these generally do not consider the flooding characteristics of the wider catchment and indeed the potential flooding impact on the existing communities at the lower end of the catchment.

A detailed investigation of Lower Shoalhaven River flooding was undertaken by Webb McKeown and Associates (WMA) (1990). This study incorporated the development of hydrologic and hydraulic models over the Lower Shoalhaven River.

WMA then prepared a Floodplain Risk Management Study (2007) and Floodplain Risk Management Plan (2007) based on the outcomes of the flood study modelling. No specific floodplain management measures were recommended for the Bomaderry Creek catchment, however various recommendations in regard to catchment wide planning were provided. The study only largely considered the Bomaderry Creek floodplain impacted upon by Shoalhaven River flooding (approx. downstream of the Princes Highway).

Whilst not specifically addressing flooding in the Bomaderry Creek catchment, the Nowra Bomaderry Structure Plan (SCC, 2008) identifies areas of future development in the catchment and wider Nowra Bomaderry region. One of the constraints to development is flood risk, and accordingly the location and extent of potential development area identified in the Structure Plan generally has a buffer to identified watercourses and associated floodplain. Future development opportunities within the catchment would be subject to further detailed assessment of flood risk, such as the current flood study.

Further details of these previous investigations and their relevance in the context of the current flood study are presented in Section 2.2.1.

2.2 Compilation and Review of Available Data

2.2.1 Previous Studies

2.2.1.1 Lower Shoalhaven River Flood Study (WMA, 1990)

A flood study of the Lower Shoalhaven River was undertaken to determine design flood conditions for a range of design event magnitudes including 5% AEP, 2% AEP, 1% AEP and extreme flood. The lower limit of the study was the Pacific Ocean at Shoalhaven and Crookhaven Heads. The upper limit was approximately 2km upstream of Nowra Bridge.

The developed hydrologic (WBNM) and hydraulic (CELLS) models were calibrated using the March 1978 and April 1988 flood events. Further model validation was undertaken for the August 1974, June 1975 and October 1976 events.

The only reach of Bomaderry Creek included in the hydraulic model was the short 1.5km downstream of the Princes Highway to the Shoalhaven River confluence. The composite cross sections representing the combined channel and floodplain of Bomaderry Creek extended from the left bank of the Shoalhaven River to Bolong Road.

Similarly, the hydrological model included only a relatively coarse representation of the Bomaderry Creek catchment, incorporating a single sub-catchment. This provided the hydraulic model with a single point inflow for Bomaderry Creek at the Princes Highway.

Table 2-2 presents the predicted design flood levels for the Shoalhaven River at Nowra Bridge. This data is relevant to the Bomaderry Creek flood study, providing downstream boundary conditions within the lower floodplain of Bomaderry Creek for consideration of coincident Bomaderry Creek and Shoalhaven River flooding.

Table 2-2 Design Flood Levels at Nowra Bridge

Design Event	Water Level (m AHD)
5% AEP	5.3
2% AEP	5.8
1% AEP	6.3
0.5% AEP	6.8*
Extreme Flood	8.9

* - estimated as part of the Floodplain Management Study (WMA, 2007)

The flood study noted that the Shoalhaven Heads entrance condition had a significant affect on the flood behaviour in the lower reaches. However, this impact becomes insignificant upstream of Pig Island. Accordingly, the entrance condition is assumed to have no impact on the Bomaderry Creek catchment.

2.2.1.2 Lower Shoalhaven River Floodplain Risk Management Study and Plan (WMA, 2007)

The primary objectives of this study were to define the nature and extent of the flood hazard and identify appropriate measures to reduce the potential impact of flooding for both existing and future development.

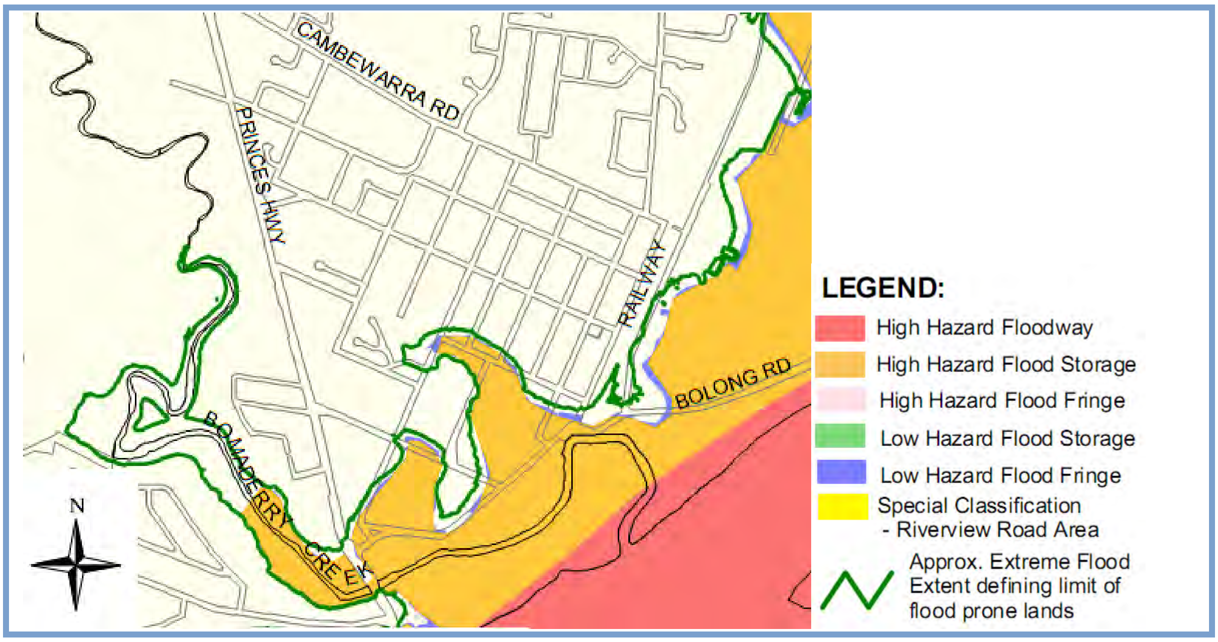
No specific floodplain management measures were recommended for the Bomaderry Creek catchment. The flood volumes emanating from the Bomaderry Creek catchment are relatively minor in relation to the flood volumes generated for the wider Shoalhaven River catchment. Accordingly, catchment specific measures for Bomaderry provide little benefit in considering the Shoalhaven River flooding.

As noted, the models developed as part of the Lower Shoalhaven River flood study only have a limited representation of Bomaderry Creek, downstream of the Princes Highway. Accordingly, the flood risk categorisations presented in the floodplain risk management study are limited to the area downstream of the Princes Highway for Bomaderry Creek, and are derived from simulated flood conditions controlled by the flooding behaviour of the Shoalhaven River.

Figure 2-2 shows an extract of the hydraulic and hazard classification for the Shoalhaven River, including the lower reach of Bomaderry Creek. The classification for the part of the Bomaderry Creek floodplain shown is “high hazard flood storage”, described in the report as:

High hazard flood storage - those parts of the floodplains that are important for temporary storage of floodwaters, floodwaters tend to rise slowly, have low velocities but large depths.

The classification and mapping extent is based on the 1% AEP design event.



Adapted from Lower Shoalhaven River Floodplain Management Study (WMA, 2007)

Figure 2-2 Hydraulic and Hazard Classification from Lower Shoalhaven FRMS

2.2.1.3 Nowra Bomaderry Structure Plan (SCC, 2007)

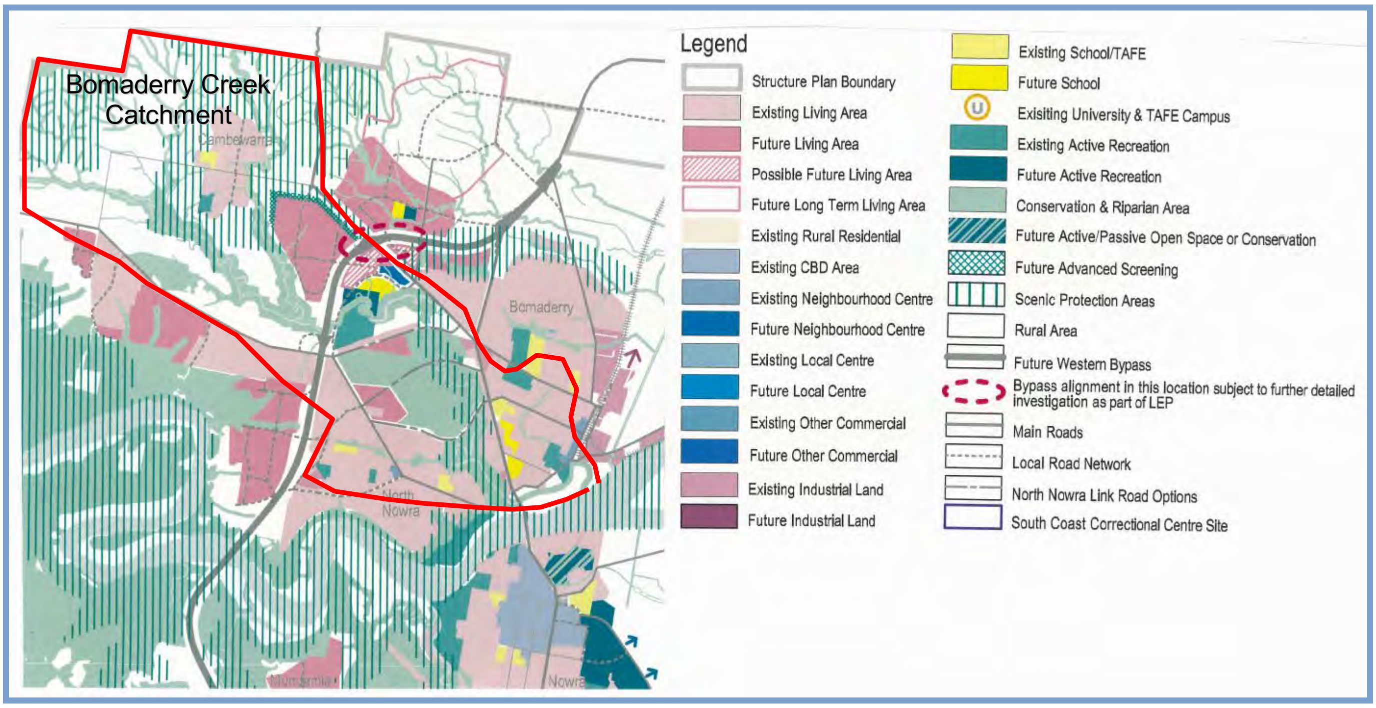
The Nowra Bomaderry Structure Plan provides the framework for growth and development opportunities and conservation measures in the Nowra Bomaderry area. An extract of the adopted Plan is shown in Figure 2-3, focusing on the Bomaderry Creek catchment area.

The majority of the catchment remains largely unchanged in the current plan incorporating:

- Conservation and riparian area along all major tributaries including Tapitallee Creek, Browns Creek, Good Dog Creek and Bomaderry Creek;
- Scenic protection areas occupying a large proportion of the upper catchment and also including the Bomaderry Gorge area;
- Undeveloped rural area; and
- Existing development centred around Cambewarra, North Nowra and Bomaderry.

In terms of future development in the catchment, the principal components identified in the Plan are:

- Future western bypass corridor that traverses the Bomaderry Creek catchment with a single major crossing of Bomaderry Creek just downstream of the confluence of Tapitallee and Good Dog Creeks;
- Future living area adjacent to Good Dog Creek extending to Cambewarra Road (north side of proposed bypass), that is centred around the higher ground in the vicinity of Taylors Lane; and
- Mixed zone of possible future living area, school and neighbourhood centre (south side of proposed bypass) again centred on higher ground around Taylors Lane but extending to the south towards the Bomaderry Creek floodplain.



Adapted from Nowra Bomaderry Structure Plan (SCC, 2007)

Figure 2-3 Nowra Bomaderry Structure Plan for Bomaderry Creek Catchment

Flooding considerations will have been one of the inputs/constraints on the location of this infrastructure in the Plan. Accordingly, the Plan shows this infrastructure located outside the riparian area of the major watercourses in the catchment. With reference to the catchment topography shown in Figure 2-1, the development is largely located on higher ground. Nevertheless, in determining the detailed flooding characteristics of the catchment, the full extent of floodplain inundation for a range of design event magnitudes has been determined, providing further detail for future development planning in the catchment.

2.2.2 Historical Flood Levels

There is limited historical flood level data available for Bomaderry Creek. The majority of available data is related to Shoalhaven River flooding incorporating significant inundation of the lower floodplain of Bomaderry Creek downstream of the Princes Highway.

The highest events in the lower part of the Bomaderry Creek catchment correspond to the years of significant flooding of the Shoalhaven River. Table 2-3 shows historical peak flood water levels at Nowra Bridge, and at the factory at 41 Bolong Road Bomaderry. Flood levels at the factory were surveyed following the response to the community questionnaire in which a history flood records at the factory site was noted.

Table 2-3 Historical Peak Flood Levels (m AHD)

Date	Nowra Bridge	41 Bolong Road
August 1998	3.3	3.2
October 1999	3.5	3.4
June 1991	4.0	3.9
April 1988	4.6	4.0
August 1990	4.3	4.4
June 1975	4.9	n/a
August 1974	4.9	n/a
March 1978	5.3	n/a

Note: factory floor level at 41 Bolong Road Bomaderry is 2.96m AHD

Flood classifications in the form of locally-defined flood levels are used in flood warnings to give an indication of the severity of flooding (minor, moderate or major) expected. These levels are used by the NSW State Emergency Service (SES) and the Australian Government Bureau of Meteorology (BoM) in flood bulletins and flood warnings. The flood classification levels are described by:

- **Minor flooding:** flooding which causes inconvenience such as closing of minor roads and the submergence of low-level bridges. The lower limit of this class of flooding, on the reference gauge, is the initial flood level at which landholders and/or townspeople begin to be affected in a significant manner that necessitates the issuing of a public flood warning by the BoM.
- **Moderate flooding:** flooding which inundates low-lying areas, requiring removal of stock and/or evacuation of some houses. Main traffic routes may be flooded.
- **Major flooding:** flooding which causes inundation of extensive rural areas, with properties, villages and towns isolated and/or appreciable urban areas flooded.

The SES classifies major, moderate and minor flooding according to the gauge height values at Nowra Bridge as detailed in Table 2-4.

Comparing the flood classification levels with the historical flood heights at Nowra Bridge presented in Table 2-3, the events of April 1988, August 1990, June 1975, August 1974 and March 1978 are all considered major flooding.

Table 2-4 Flood Classification Levels for Shoalhaven River at Nowra

Flood Classifications (gauge readings in metres AHD)		
Minor	**Moderate**	**Major**
2.3	3.3	4.3

2.2.3 Rainfall Data

There is an extensive network of rainfall gauges across the wider Shoalhaven area operated by the Bureau of Meteorology (BoM) and the Sydney Catchment Authority (SCA). The full list of rainfall stations, including closed stations, within approximately a 20km radius of the Bomaderry Creek catchment is shown in Table 2-5 with their respective period of record. The distribution of these gauges is shown in Figure 2-4.

The only active rainfall gauge within the Bomaderry Creek catchment is that associated with the Dept. Water and Energy (DWE) streamflow gauging station. The length of available rainfall record for this site is limited to since 2003. However, in conjunction with the corresponding period of streamflow data, this continuous rainfall data set provides useful information for simulating catchment response, albeit at minor flood levels.

Aside from the Bomaderry Creek gauge, the only other rainfall gauges within or at the boundary of the Bomaderry Creek catchment are the discontinued stations for Browns Mountain (daily read), Tapitallee (daily read) and Bomaderry (continuous). Each of these stations has only a relatively short period of record, generally not coinciding with known major flooding events supported by other data.

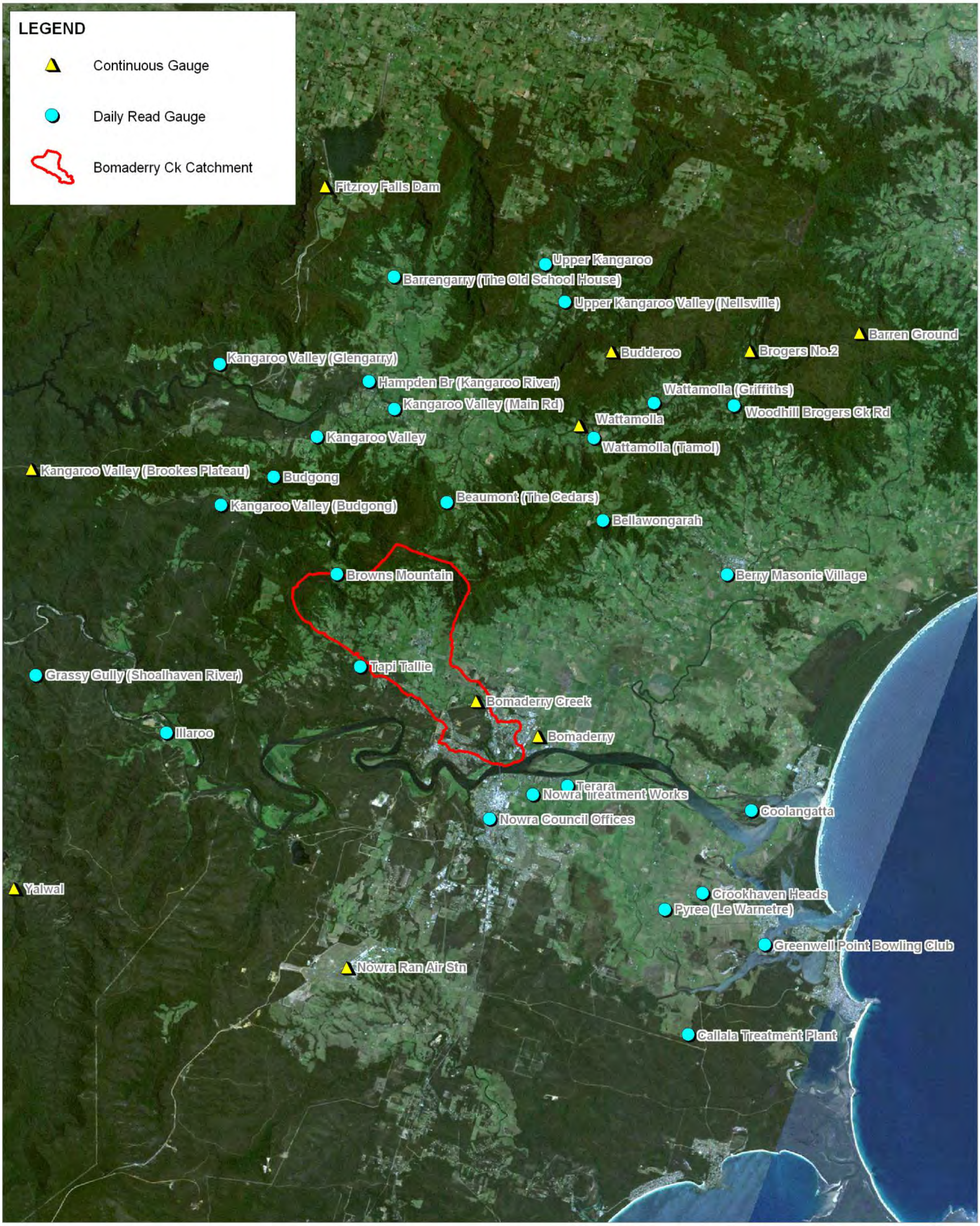
Beyond the catchment boundary, there is an extensive network of daily read rainfall gauges. Many of these stations are discontinued, however, between both discontinued and existing gauges, a long period of daily rainfall record is available.

The distribution of continuous rainfall gauges in the vicinity of the Bomaderry Creek catchment is much sparser. The majority of the stations operated by the Sydney Catchment Authority are located 15 to 20km from the centre of the Bomaderry Creek catchment. The stations generally have data from the early 1980's, such that there period of record covers significant rainfall events in the broader Shoalhaven including 1988 and 1990 flood events.

Further discussion on recorded rainfall data for historical events is presented with the calibration and validation of the models developed for the study in Section 6.

Table 2-5 Summary of Rainfall Gauges in the Bomaderry Creek Locality

Station No.	Name	Operator	Type	Start Year	End Year
215016	Bomaderry Creek At Bomaderry	DWE	Pluvio	2003	current
568076	Brogers No.2	SCA	Pluvio	1981	current
568078	Budderoo	SCA	Pluvio	1981	current
568124	Fitzroy Falls Dam	SCA	Pluvio	1992	current
568128	Barren Ground	SCA	Pluvio	1981	current
568132	Kangaroo Valley (Brookes Plateau)	SCA	Pluvio	1981	current
568146	Yalwal	SCA	Pluvio	1982	current
68076	Nowra Ran Air Station	BoM	Pluvio	1964	1997
68136	Bomaderry	BoM	Pluvio	1969	1972
68161	Wattamolla	BoM	Pluvio	1968	1970
68003	Berry Masonic Village	BoM	Daily	1886	current
68021	Crookhaven Heads	BoM	Daily	1904	1958
68029	Kangaroo Valley (Budgong)	BoM	Daily	1999	current
68031	Burruer (Illaroo)	BoM	Daily	1902	1963
68036	Kangaroo Valley (Main Rd)	BoM	Daily	1914	2003
68048	Nowra Treatment Works	BoM	Daily	1896	current
68072	Nowra RAN Air Station AWS	BoM	Daily	2000	current
68076	Nowra RAN Air Station	BoM	Daily	1942	2000
68077	Kangaroo Valley	BoM	Daily	1899	1919
68080	Greenwell Point Bowling Club	BoM	Daily	1960	current
68084	Terara	BoM	Daily	1961	1965
68105	Nowra Council Offices	BoM	Daily	1884	1935
68111	Budgong	BoM	Daily	1962	1971
68118	Cambewarra (Tapi Tallie)	BoM	Daily	1962	1978
68124	Upper Kangaroo River	BoM	Daily	1962	1992
68136	Bomaderry	BoM	Daily	1903	1938
68137	Brogers Creek Upper (Cookville)	BoM	Daily	1890	1930
68139	Browns Mountain	BoM	Daily	1903	1915
68161	Wattamolla	BoM	Daily	1966	1975
68167	Kangaroo Valley (Glengarry)	BoM	Daily	2000	2002
68174	Woodhill Brogers Creek Road	BoM	Daily	1967	1994
68181	Hampden Bridge (Kangaroo River)	BoM	Daily	2000	current
68190	Wattamolla (Tamol)	BoM	Daily	1970	current
68196	Bellawongarah	BoM	Daily	1903	1919
68210	Coolangatta	BoM	Daily	1891	1910
68213	Nowra Boat Shed (Shoalhaven River)	BoM	Daily	2000	current
68217	Barrengarry (The Old School House)	BoM	Daily	1982	current
68218	Wattamolla (Griffiths)	BoM	Daily	1993	current
68233	Grassy Gully (Shoalhaven River)	BoM	Daily	2000	current
68238	Upper Kangaroo Valley (Nellsville)	BoM	Daily	1992	2002
68244	Pyree (Le Warnetre)	BoM	Daily	2001	current
68245	Callala Treatment Plant	BoM	Daily	2001	current
68247	Beaumont (The Cedars)	BoM	Daily	1993	current



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Rain Gauges in the Vicinity of the Bomaderry Creek Catchment

Figure: **2-3**

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N

0 5 10km

Approx. Scale

BMT WBM

www.wbmpl.com.au

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2.2.4 Streamflow Data

The Department of Water and Energy (DWE) operate a streamflow gauge on Bomaderry Creek which is located just upstream of the Bomaderry Creek Gorge area (Station No 215016 - Bomaderry Creek at Bomaderry). The gauge has been in operation since July 2003. The gauge is a continuous water level recorder, with stage heights converted to streamflow through derived rating curves based on on-site flow gaugings.

Unfortunately during this period of operation, no major flood events have occurred within the Bomaderry Creek catchment. However, there have been a number of smaller events as indicated in the time series of water level from the gauge data shown in Figure 2-5.

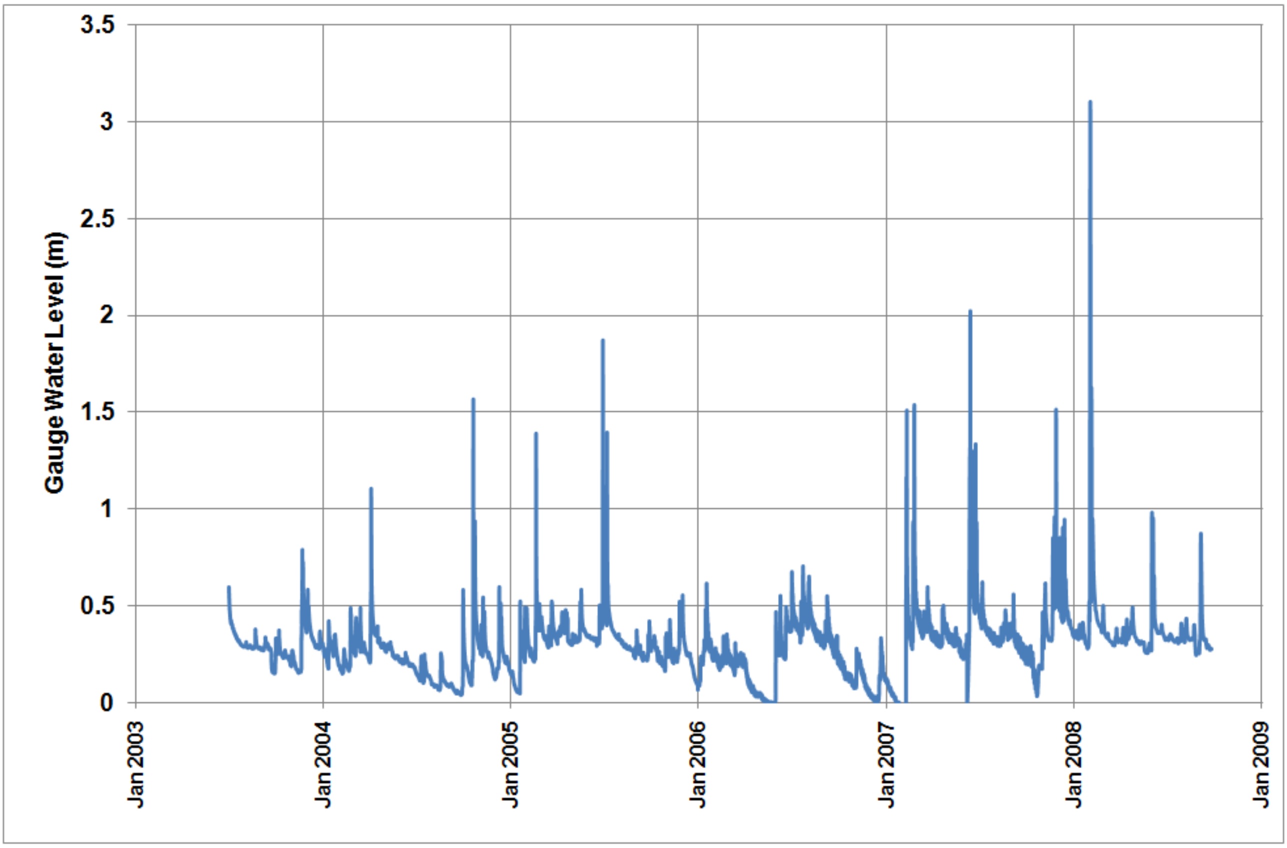


Figure 2-5 Water Level Time Series Bomaderry Creek Gauging Station

The three highest recorded events (water level) at the gauge station are 30th June 2005, 16th June 2007 and 5th February 2008. These events had 24-hour rainfall totals of 83mm, 87mm and 168mm respectively. Compared with the major event rainfall totals shown in Table 2-1, the recent rainfall history is of little significance when considering major flooding in the catchment. Nevertheless, the streamflow information coupled with the rainfall data from the same station, provide useful data for model calibration, albeit at minor flows (<5-year return period).

Given the relatively short period of operation of the Bomaderry Creek gauge, there is only a limited gauging record. Accordingly, the stage-discharge relationship derived for the site is limited to low stage values only. The existing stage-discharge relationship for the Bomaderry Creek gauge is shown in Figure 2-6. The maximum stage of the existing rating table is 2.1m, however, the highest gauging undertaken at the site is at a considerably lower stage of 0.6m. The existing rating therefore has been extrapolated to its current maximum stage limit. The stage recorded during the February 2008 event of 3.1m far exceeds the limit of the existing rating.

In order to derive a corresponding flow rate for the highest recorded stage, the existing rating curve needs to be extended further into the high flow range. In order to do this, either high flow gaugings need to be obtained, or the rating extended based on empirical data or modelled flow condition.

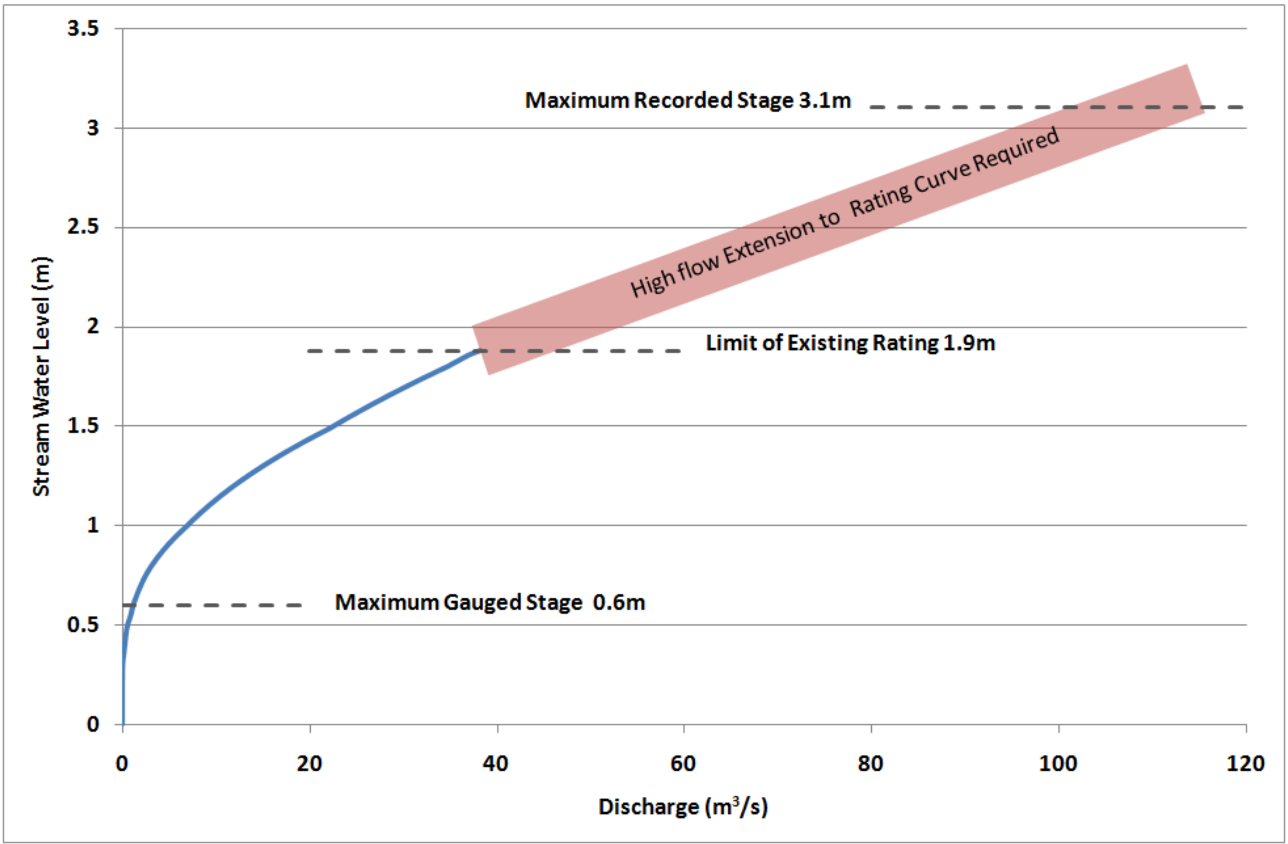


Figure 2-6 Rating Curve for Bomaderry Creek Gauging Station

2.2.5 Council Data

Digitally available information such as aerial photography, cadastral boundaries, topography, watercourses, drainage networks, land zoning, vegetation communities and soil landscapes were provided by Council in the form of GIS datasets.

A variety of relevant planning documents, where available, were also reviewed and considered as part of the study. These documents include Council's LEP, Council's Flood Policy, Development Control Plans, and SES Flood Plan.

LiDAR land survey data has also been made available for the floodplain relatively recently. Flood behaviour is inherently dependent on the ground topography. Advanced GIS analysis also allows the LiDAR imagery to be assessed in concert with spatial 2-D flood model data, facilitating mapping, categorisation, and overall flood management.

2.2.6 Other Information

A search of available records at the Shoalhaven City Council library in Nowra provided some anecdotal information in regard to previous flooding in the catchment.

Bayley (1975) noted the history of development in the lower Shoalhaven Valley, including Bomaderry Creek, in which the risk of flooding guided placement of settlements, and reflects the relative flood immunity afforded to present day communities. “Towards the closing quarter of the nineteenth century the Shoalhaven River had revealed to its pioneers the pattern of its hitherto unpredictable perilous behaviour and established its habitual high floodwater levels which guided the further use of its rich lands on the floodplain….Villages planned on areas entirely flood-subject were soon forsaken and became, as they remain, pasturelands..”. Upstream of Bomaderry gorge, the floodplain largely remains undeveloped, with development such as Cambewarra, generally located on higher ground fringing the floodplain.

More specifically in the Bomaderry Creek catchment, Clark (1983) described the nature of flooding as “spreading like sheets over the flatter country after water leaves the mountainside”, with it being said that below the junction of Tapitallee Creek and Brown’s Creek the water at flood time is as wide as the Shoalhaven River at the bridge. The destructive nature of the flooding and indicative flood depth was noted with repeated unsuccessful efforts in the 1920’s to keep a footbridge over Good Dog Creek on Tannery Road, although some of the structures were built 12 feet above the normal height of the stream.

These observations of flooding provide a useful reference for comparing predicted flood behaviour in the catchment.

2.3 Site Inspections

A number of site inspections were undertaken during the course of the study to gain an appreciation of local features influencing flooding behaviour. Some of the key observations to be accounted for during the site inspections included:

- Presence of local structural hydraulic controls such as bridges, culverts, road embankments and natural topographical controls such as channel/floodplain constrictions or steep reaches;
- General nature of the river channel and floodplain noting river plan form, vegetation type and coverage and the presence of significant flow paths;
- Location of existing development and infrastructure on the floodplain.

This visual assessment was useful for defining hydraulic properties within the hydraulic model and ground-truthing of topographic features identified from survey.

2.4 Additional Survey

The review of available topographic data identified the requirement for additional survey to be undertaken to provide the necessary coverage and detail required to build the hydraulic model. The additional survey incorporated:

- Cross sections of the Bomaderry Creek channel and major tributaries to supplement the existing LiDAR topographical data. Due to limitations in the aerial survey method, the detail of watercourses is often obscured (e.g. by standing water, vegetation etc). Ground survey is required to provide the required detail of the watercourses to integrate with the LiDAR data; and

- A number of flood drainage structures (including bridges and culverts) for which no existing details were available.

The acquisition of the additional survey is discussed in further detail in Section 4.

2.5 Community Consultation

The success of a floodplain management plan hinges on its acceptance by the community, residents within the study area, and other stake holders. This can be achieved by involving the local community at all stages of the decision-making process. This includes the collection of their ideas and knowledge on flood behaviour in the study area, together with discussing the issues and outcomes of the study with them.

The key elements of the consultation process in undertaking the flood study have been:

- Issue of a questionnaire to obtain historical flood data and community perspective on flooding issues;

- Community information session to gain feedback on the flood questionnaire and provide information to the public on the direction of the flood study; and

- Public exhibition of Draft Report and community information session.

These elements are discussed in further detail in Section 3.

2.6 Development of Computer Models

2.6.1 Hydrological Model

For the purpose of the Flood Study, a hydrologic model (discussed in Section 5.1) was developed to simulate the rate of storm runoff from the catchment. The model predicts the amount of runoff from rainfall and the attenuation of the flood wave as it travels down the catchment. This process is dependent on:

- Catchment area, slope and vegetation;
- Variation in distribution, intensity and amount of rainfall; and
- Antecedent conditions of the catchment.

The output from the hydrologic model is a series of flow hydrographs at selected locations such as at the boundaries of the hydrodynamic model. These hydrographs are used by a hydrodynamic model to simulate the passage of a flood through the Bomaderry Creek catchment to the downstream study limits at the confluence with the Shoalhaven River.

2.6.2 Hydraulic Model

The hydraulic model (discussed in Section 5.3) developed for this study includes:

- two-dimensional (2D) representation of the Bomaderry Creek floodplain covering an area of approximately 22 km^2 of the catchment (approximately 60% of total catchment area), which includes all of the floodplain in the developed areas of Cambewarra and Bomaderry.; and
- one-dimensional (1D) representation of the main channels of Bomaderry Creek from the downstream model limit at the Shoalhaven River to approximately 14km upstream at the top of each of the main tributaries if Good Dog Creek, Browns Creek and Tapitallee Creek..

The hydraulic model is applied to determine flood levels, velocities and depths across the study area for historical and design events.

2.7 Calibration and Sensitivity Testing of Models

The hydrologic and hydrodynamic models were calibrated and verified to available historical flood event data to establish the values of key model parameters and confirm that the models were capable of accurately predicting real flood events.

The following criteria are generally used to determine the suitability of historical events to use for calibration or validation:

- The availability, completeness and quality of rainfall and flood level event data;
- The amount of reliable data collected during the historical flood information survey; and
- The variability of events – preferably events would cover a range of flood sizes.

There is limited available data for major flood events within the Bomaderry Creek catchment. Following review of available data and further attempts to acquire additional flood information through the community questionnaire, there remains no available flood data in the form of peak flood levels, flows, or detailed anecdotal evidence of major flooding in the catchment. The gauging station in operation since only 2003 provides some flow data, although as discussed, the peak flows to have occurred within this operational period have been relatively minor. The highest event recorded in the operational period was 16th June 2007. This event was used as a calibration event. Although the peak flow represents only a return period of less than 2-years (50% AEP), the recorded hydrograph provides a useful reference to calibrate the simulated catchment response, including timing, peak flow and runoff volumes. Confirmation that the developed models can simulate the catchment response at this level of flow magnitude provides some confidence that it can be transferred to simulation of higher magnitude events.

In the lower Bomaderry Creek floodplain, in the vicinity of Bolong Road, there is available data during major Shoalhaven River floods which is the dominant flooding mechanism in this part of Bomaderry creek. The previous Lower Shoalhaven River Flood Study utilised the March 1978 and April 1988 floods as calibration events, with further model validation undertaken for the August 1974, June 1975, and October 1976 events. Following completion of this previous study in April 1990, another significant Shoalhaven River flood occurred in August 1990.

The calibration and validation of the models is presented in Section 6. A series of sensitivity tests were also carried out to evaluate the model. These tests were conducted to examine the performance and determine the relative importance of different hydrological and hydrodynamic factors. The sensitivity testing of the models is detailed in Section 7.

2.8 Establishing Design Flood Conditions

Design floods are statistical-based events which have a particular probability of occurrence. For example, the 1% Annual Exceedance Probability (AEP) event, which is sometimes referred to as the 1 in 100 year Average Recurrence Interval (ARI) flood, is the best estimate of a flood with a peak discharge that has a 1% (i.e. 1 in 100) chance of occurring in any one year. For the Bomaderry Creek catchment, design floods were based on design rainfall estimates according to Australian Rainfall and Runoff (IEAust, 2001).

The design flood conditions form the basis for floodplain management in the catchment and in particular design planning levels for future development controls. The predicted design flood conditions are presented in Section 7.

2.9 Mapping of Flood Behaviour

Design flood mapping is undertaken using output from the hydrodynamic model. Maps are produced showing water level, water depth and velocity for each of the design events. The maps present the peak value of each parameter. Provisional flood hazard categories and hydraulic categories are derived from the hydrodynamic model results and are also mapped. The mapping outputs are described in Section 7.3 and presented in Appendix A.

3 COMMUNITY CONSULTATION

3.1 The Community Consultation Process

Community consultation has been an important component of the current study. The consultation has aimed to inform the community about the development of the flood study and its likely outcome as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on their flood experience, their concern on flooding issues and to collect feedback and ideas on potential floodplain management measures and other related issues.

The key elements of the consultation process have been as follows:

- Distribution of a questionnaire to landowners, residents and businesses within the study area;
- An information session for the community to present information on the progress and objectives of the flood study and obtain feedback on historical events in the catchment and other flooding issues; and
- Public exhibition of the draft Flood Study.

These elements are discussed in detail below.

3.2 Community Questionnaire

In February 2008, a short questionnaire was sent to landowners, residents and businesses located within the study area. The questionnaire was sent to approximately 200 property holders (Council to confirm), with Council receiving 18 responses.

The questionnaire asked residents to provide as much information as possible in regard to historical flood events within the catchment. A detailed summary of responses to the questionnaire is included in Appendix D. Provided hereunder is a summary of the key information provided in the responses.

Historical Flooding

- Years of flooding – respondents were asked to acknowledge dates of previous flood events within the catchment from personal experience. The majority of respondents confirmed experience of the most recent significant flood events in the catchment being 2008, 2007, 1990 and 1981. Only 1 respondent noted the 1949 flood reflecting the lack of personal experience of this event by respondents, and not unexpected given the progression of time since the event.
- Flood marks – a key objective of the flood questionnaires was to obtain peak flood level reference points for model calibration purposes. The only detailed flood level information received was for the factory at 41 Bolong Road Bomaderry (refer Section 2.2.2). The recorded flood marks for the 1988, 1990, 1991, 1998 and 1999 events were later surveyed to obtain peak flood levels.

3.3 Community "Drop-in" Session

A community "drop-in" session was held at Bomaderry Community Hall during Wednesday 20th February 2008 to:

- Provide the community with an overview of the study and objectives; and
- Provide the study team with a means to obtain feedback from the local community on the direction of the study and additional information/comment arising from flooding in the catchment.

The information session was attended by only 2 community attendees in addition to Council staff and the consultant. The relatively poor attendance may be reflective of the limited number of property to have existing flood problems or experienced significant flooding, particularly in the catchment upstream of the Princes Highway. Previous consultation undertaken for the Lower Shoalhaven Floodplain Risk Management Study may have limited the number of interested residents in the lower floodplain of Bomaderry Creek.

The primary issues and concerns raised by the community attendees during the information session were drainage issues at Brinawarr St and Tarawara Rd, not specifically related to mainstream Bomaderry Creek flooding, and water quality and vegetation issues in the lower reaches of Bomaderry Creek adjacent to Bolong Road. Photographs of flooding in Brinawarr St and Tarawara Road were provided for the February 2008 event.

3.4 Public Exhibition

The Draft Flood Study was placed on exhibition for a period of 4 weeks from 21st June 2010. A community information session was held at Council offices during the exhibition period. Only minor comments were received in relation to mapping output detail which have been addressed in the Final Report.

4 ADDITIONAL SURVEY

The following sections outline the additional survey data collected to supplement the existing data and enable the establishment of a suitable two-dimensional model representation of the Bomaderry Creek channel and floodplain.

4.1 Channel Cross Sections

The effectiveness of aerial data capture is often limited in the vicinity of the main creek alignment due to the presence of water and dense vegetation. In these instances cross-section surveys are required to accurately define the shape of the watercourse.

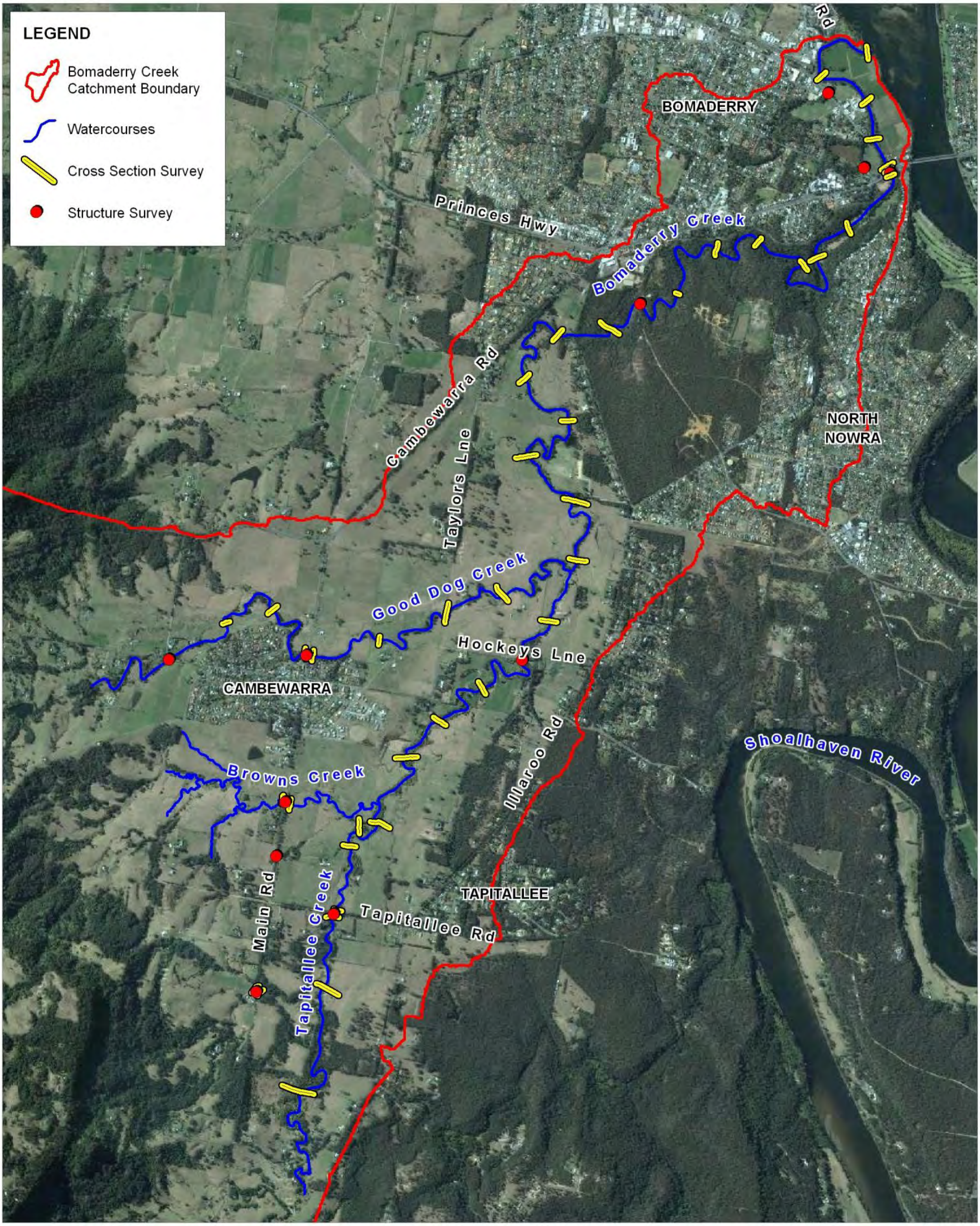
Figure 4-1 shows the location of cross sections that were surveyed by Allen, Price and Associates to provide additional waterway information for Bomaderry Creek and significant tributaries. Some of the deeper and wider sections in the lower Bomaderry Creek were surveyed by boat to provide appropriate representation of the waterway geometry.

The sections extend from the confluence of Bomaderry Creek and the Shoalhaven River to approximately 14km upstream on Good Dog Creek, Browns Creek and Tapitallee Creek respectively. These limits correspond to the extent of the modelled 1D channel network. The distribution of cross sections shown represents an average cross section spacing of 200m along the main tributary alignments in the catchment. The cross section locations also coincide with the location of major hydraulic structures as discussed in Section 4.2. This distribution and average spacing of cross sections was defined to provide an appropriate level of detail to develop the hydraulic model.

4.2 Structures

There are numerous hydraulic structures on the main channels within the study area for which limited existing survey detail was available. Accordingly, the ground survey undertaken by Council included the survey of numerous structures to provide the structure details required to build the hydraulic model such as dimensions, waterway areas and invert levels.

Twelve (12) structures in total were surveyed including bridges and culverts on main channel and tributary alignments. Further structure details and their respective model configuration are presented in Section 5.3.4.



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Location of Cross Section and Structure Survey

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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5 MODEL DEVELOPMENT

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. For this study, two types of models were used:

- A hydrologic model of the entire Bomaderry Creek catchment; and
- A hydraulic model extending from just upstream of the coal haulage road to the downstream boundary of Bomaderry Creek at the confluence with the Shoalhaven River.

The **hydrologic model** simulates the catchment rainfall-runoff processes, producing the river/creek flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the channel and floodplains, producing flood levels, flow discharges and flow velocities.

Both of these models were calibrated interactively.

Information on the topography and characteristics of the catchments, watercourses and floodplains are built into the models. Recorded historical flood data, including rainfall, flood levels and river flows, are used to simulate and validate (calibrate and verify) the models. The models produce as output, flood levels, flows (discharges) and flow velocities.

Development of a hydraulic model follows a relatively standard procedure:

1. Discretisation of the catchment, watercourses, floodplain, etc.
2. Incorporation of physical characteristics (river cross-sections, floodplain levels, structures etc).
3. Establishment of hydrographic databases (rainfall, river flows, flood levels) for historic events.
4. Calibration to one or more historic floods (calibration is the adjustment of parameters within acceptable limits to reach agreement between modelled and measured values).
5. Verification to one or more other historic floods (verification is a check on the model's performance without further adjustment of parameters).
6. Sensitivity analysis of parameters to measure dependence of the results upon model assumptions.

Once model development is complete it may then be used for:

- establishing design flood conditions;
- determining levels for planning control; and
- modelling development or management options to assess the hydraulic impacts.

5.1 Hydrological Model

The hydrologic model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff and the attenuation of the flood wave as it travels down the catchment is dependant on:

- the catchment slope, area, vegetation and other characteristics;

- variations in the distribution, intensity and amount of rainfall; and
- the antecedent conditions (dryness/wetness) of the catchment.

These factors are represented in the model by:

- Sub-dividing (discretising) the catchment into a network of sub-catchments inter-connected by channel reaches representing the creeks and rivers. The sub-catchments are delineated, where practical, so that they each have a general uniformity in their slope, landuse, vegetation density, etc;
- The amount and intensity of rainfall is varied across the catchment based on available information. For historical events, this can be very subjective if little or no rainfall recordings exist.
- The antecedent conditions are modelled by varying the amount of rainfall which is "lost" into the ground and "absorbed" by storages. For very dry antecedent conditions, there is typically a higher initial rainfall loss.

The output from the hydrologic model is a series of flow hydrographs at selected locations such as at the boundaries of the hydraulic model. These hydrographs are used by the hydraulic model to simulate the passage of the flood through the Bomaderry Creek catchment.

The RAFTS-XP software was used to develop the hydrologic model using the physical characteristics of the catchment including catchment areas, ground slopes and vegetation cover as detailed in the following sections.

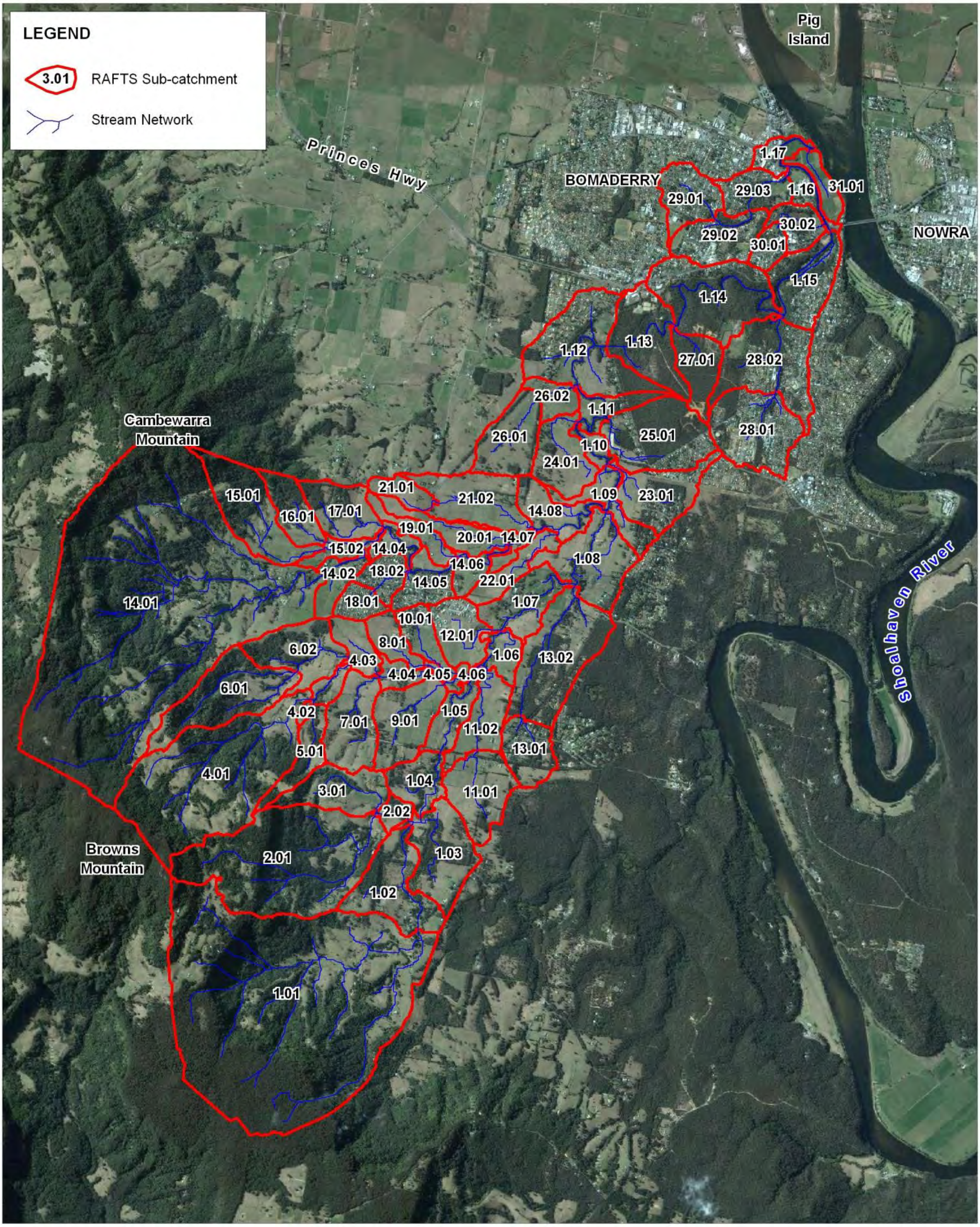
5.1.1 Catchment Delineation

The Bomaderry Creek catchment drains an area of approximately 32.6km^2 to its confluence with the Shoalhaven River. For the hydrological model this area has been delineated into 71 sub-catchments as shown in Figure 5-1. The sub-catchment delineation provides for generation of flow hydrographs at key confluences or inflow points to the hydraulic model.

Table 5-1 summarises the key catchment parameters adopted in the RAFTS-XP model, including catchment area, vectored slope and PERN (roughness) value estimated from the available topographic information and aerial photography. The adopted PERN values considered the proportion of forested catchment to cleared/pasture area. As indicated in the table and evident from aerial photography, the greater proportion of the Bomaderry Creek catchment is largely cleared rural pasture.

Table 5-1 RAFTS-XP Sub-catchment Properties

Catchment Label	Area (ha)	Slope (%)	PERN	Catchment Label	Area (ha)	Slope (%)	PERN
1.01	496.9	4.9	0.09	13.01	31.2	2.2	0.06
1.02	59.0	2.1	0.06	13.02	85.0	1.0	0.06
1.03	56.7	1.3	0.06	14.01	602.1	4.6	0.09
1.04	27.8	1.8	0.06	14.02	19.1	1.3	0.06
1.05	23.8	0.7	0.06	14.03	2.9	1.1	0.06
1.06	16.9	1.0	0.06	14.04	12.7	1.0	0.06
1.07	38.5	0.5	0.06	14.05	25.9	1.5	0.04
1.08	57.5	0.7	0.06	14.06	14.5	1.0	0.06
1.09	26.7	1.0	0.06	14.07	9.7	1.2	0.06
1.1	9.8	0.5	0.06	14.08	29.8	0.8	0.06
1.11	19.5	1.1	0.06	15.01	60.2	6.0	0.08
1.12	85.1	1.5	0.06	15.02	10.4	2.0	0.06
1.13	56.4	2.0	0.1	16.01	27.5	5.4	0.08
1.14	82.8	1.1	0.1	17.01	36.4	2.4	0.07
1.15	48.8	1.3	0.06	18.01	14.8	4.9	0.04
1.16	13.7	0.2	0.04	18.02	18.1	2.3	0.04
1.17	14.8	0.4	0.04	19.01	17.5	1.4	0.06
2.01	175.4	9.1	0.09	20.01	25.5	1.5	0.06
2.02	9.1	2.8	0.06	21.01	14.7	2.1	0.06
3.01	41.6	5.3	0.06	21.02	51.9	1.2	0.06
4.01	185.6	10.7	0.09	22.01	22.4	1.3	0.06
4.02	11.9	1.7	0.06	23.01	45.5	1.3	0.05
4.03	19.8	1.9	0.06	24.01	38.9	0.9	0.06
4.04	12.0	0.8	0.06	25.01	68.5	1.8	0.07
4.05	2.6	1.3	0.06	26.01	43.5	1.7	0.06
4.06	4.8	0.8	0.06	26.02	15.8	1.4	0.06
5.01	24.8	9.4	0.07	27.01	30.0	6.4	0.1
6.01	70.0	8.0	0.09	28.01	63.0	3.1	0.04
6.02	47.0	2.2	0.06	28.02	71.6	6.3	0.05
7.01	47.0	2.1	0.06	29.01	33.6	2.0	0.04
8.01	18.7	1.9	0.06	29.02	40.5	3.8	0.04
9.01	48.1	1.5	0.06	29.03	27.6	1.5	0.04
10.01	20.6	1.4	0.05	30.01	13.2	7.6	0.04
11.01	47.5	1.7	0.06	30.02	19.6	1.4	0.04
11.02	34.8	0.7	0.06	31.01	15.6	0.3	0.05
12.01	32.4	1.2	0.05				



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RAFTS Model Sub-catchment Layout

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5.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrological model which simulates the catchments response in generating surface run-off. Rainfall characteristics for both historical and design events are described by:

- Rainfall depth – the depth of rainfall occurring across a catchment surface over a defined period (e.g. 270mm in 36hours or average intensity 7.5mm/hr); and

- Temporal pattern – describes the distribution of rainfall depth at a certain time interval over the duration of the rainfall event.

Both of these properties may vary spatially across the catchment.

The procedure for defining these properties is different for historical and design events. For historical events, the recorded hyetographs at continuous rainfall gauges provide the observed rainfall depth and temporal pattern. Where only daily read gauges are available within a catchment, assumptions regarding the temporal pattern may need to be made.

For design events, rainfall depths are most commonly determined by the estimation of intensity-frequency-duration (IFD) design rainfall curves for the catchment. Standard procedures for derivation of these curves are defined in AR&R (2001). Similarly AR&R (2001) defines standard temporal patterns for use in design flood estimation.

The rainfall inputs for the historical calibration/validation events are discussed in further detail in Section 6 and design events discussed in Section 7.

5.3 Hydraulic Model

BMT WBM has applied the fully 2D software modelling package TUFLOW. The 2D model has distinct advantages over 1D and quasi-2D models in applying the full 2D unsteady flow equations. This approach is necessary to model the complex interaction between rivers, creeks and floodplains and converging and diverging of flows through structures. The channel and floodplain topography is defined using a high resolution DEM for greater accuracy in predicting flows and water levels and the interaction of in-channel and floodplain areas.

5.3.1 Extents and Layout

Consideration needs to be given to the following elements in constructing the model:

- location of available data (e.g. river section surveys);
- location of recorded data (e.g. levels/flows for calibration);
- location of controlling features (e.g. dams, levees, bridges);
- desired accuracy to meet the study's objectives;
- computational limitations.

With consideration to the available survey information and local topographical and hydraulic controls, a linked 1D/2D model was developed extending from the Shoalhaven River confluence at the downstream limit, to approximately 14km upstream along the major tributary routes. The model layout is presented in Figure 5-2.

The floodplain area modelled within the 2D domain comprises a total area of some 22km^2 which represents the lower 60% of the entire Bomaderry Creek catchment. A high resolution DEM was derived for the study area from the LiDAR data provided by Council. The ground surface elevation for the TUFLOW model grid points are sampled directly from the DEM's established for each model area.

A TUFLOW 2D domain model resolution of 5m was adopted for study area. It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so a 5m cell size results in DEM elevations being sampled every 2.5m. This resolution was selected to give necessary detail required for accurate representation of floodplain topography and its influence on out-of-bank flows.

5.3.2 Topography

The ability of the model to provide an accurate representation of the flow distribution on the floodplain ultimately depends upon the quality of the underlying topographic model. For the Bomaderry Creek catchment, a high resolution DEM (2m by 2m grid) was derived from LiDAR survey provided by Council.

As discussed in Section 4.1, additional cross section survey of the watercourses was required to supplement the LiDAR data and provide the necessary detail on channel shape and dimensions for representation in the hydraulic model. The 1D model reaches were constructed to coincide with the locations of available cross section survey as presented in Figure 4-1.

5.3.3 Hydraulic Roughness

The development of the TUFLOW model requires the assignment of different hydraulic roughness zones. These zones are delineated from aerial photography and cadastral data identifying different land-uses (e.g. forest, cleared land, roads, urban areas, etc) for modelling the variation in flow resistance.

The hydraulic roughness is one of the principal calibration parameters within the hydraulic model and has a major influence on flow routing and flood levels. The roughness values adopted from the calibration process is discussed in Section 6.

5.3.4 Structures

There are numerous bridge and culvert crossings over the main channel alignments within the model extents as detailed in Table 5-2 (refer to Figure 5-2 for locations). These structures vary in terms of construction type and configuration, with varying degrees of influence on local hydraulic behaviour. Incorporation of these major hydraulic structures in the models provides for simulation of the hydraulic losses associated with these structures and their influence on peak water levels within the study area.

Table 5-2 Major Hydraulic Structures within Model Area

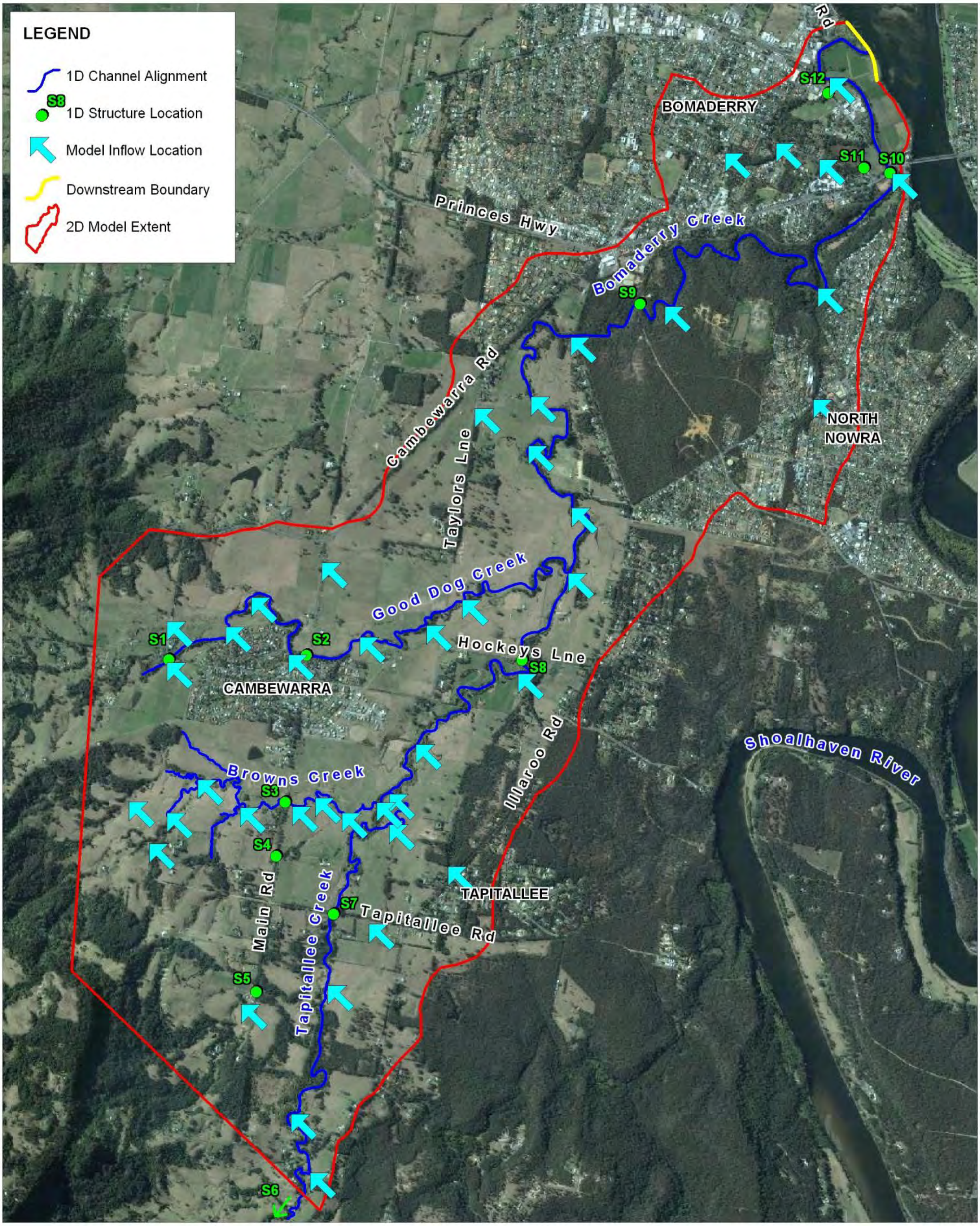
ID	Location	Structure
S1	Tannery Rd Causeway (Good Dog Creek)	Causeway (approx. 15m width)
S2	Main Rd Bridge (Good Dog Creek)	Concrete bridge (approx. 17m span)
S3	Main Rd Bridge (Browns Creek)	Timber bridge (approx. 13m span)
S4	Main Rd Culvert (unnamed tributary)	Box culvert 1.9m wide x 1.6m high
S5	Main Rd Bridge (unnamed tributary)	Timber bridge (approx. 8m span)
S6	Browns Mountain Rd Culvert (Tapitallee Creek)	Box culvert 2 cell 3.9m x 3.5m
S7	Tapitallee Rd Bridge (Tapitallee Creek)	Concrete bridge (approx. 28m span)
S8	Hockeys Lne Causeway (Tapitallee Creek)	Causeway (approx. 17m width)
S9	Narang Rd Weir (Bomaderry Creek)	Broad Crested Weir (approx. 30m width)
S10	Princes Hwy Bridge (Bomaderry Creek)	Concrete bridge (approx. 45m span)
S11	Bolong Rd Culvert (unnamed tributary)	Pipe culvert 2 x 1050mm diameter
S12	Bolong Rd Culvert (unnamed tributary)	Pipe culvert 1 x 625mm diameter

5.3.5 Boundary Conditions

The model boundary conditions are derived as follows:

- Inflows - the rainfall runoff calculated by the hydrologic model at major sub-catchment inflow points and along the modelled watercourse alignments of the Bomaderry Creek channel and significant tributaries. (refer Figure 5-2 for inflow locations); and
- Downstream Water Level– the downstream model limit corresponds to the discharge of Bomaderry Creek to the Shoalhaven River. A short reach of the Shoalhaven River from Nowra Bridge to Pig Island has been included in the model configuration. A water level time series at Nowra Bridge has been applied at the top of this reach with a rating curve adopted at the downstream end.

The adopted water levels for the downstream boundary condition (i.e. Shoalhaven River at Nowra Bridge water level) for the calibration and design events are discussed in Section 6 and Section 7 respectively.



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Linked 1D/2D Model Layout

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6 MODEL CALIBRATION AND VALIDATION

6.1 Selection of Calibration Events

The selection of suitable historical events for calibration of the computer models is largely dependent on available historical flood information. Ideally the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design event magnitudes to be considered.

Within the Bomaderry Creek catchment however, there is a distinct lack of historical flood data. As previously discussed, much of the existing flood information in the lower part of the catchment downstream of the Princes Highway is related to major Shoalhaven River flooding. Shoalhaven River flooding tends to emanate from catchment rainfall events of a few days duration. In terms of Bomaderry Creek catchment rainfall, the August 1990 event is identified as having the highest 1-day and 2-day rainfall totals on record. For this event however, there is no detailed historical flood data suitable for model calibration.

The only available water level records considered suitable for model calibration are those associated with the Bomaderry Creek streamflow gauge, in operation since 2003. The highest recorded water level at the gauge is for the event of 5th February 2008. The availability of a continuous recorded water level hydrograph throughout the event, coupled with the rainfall hyetograph recorded at the same gauge, provides a suitable calibration point for the developed models. Accordingly, this event is adopted as the principal calibration event.

In absence of detailed data for other historical events, conventional model validation cannot be undertaken. However, the August 1990 event has been simulated for comparison.

The model calibration and validation therefore is based on the historical data available for the February 2008 and August 1990 events. The available data, modelling approach and model results for each of these events are discussed in further detail in the following sections.

6.2 February 2008 Model Calibration

6.2.1 Rainfall Data

The adopted February 2008 event hyetograph for the Bomaderry Creek catchment is shown in Figure 6-1. The hyetograph is that recorded at the Bomaderry Creek streamflow gauge. The main rainfall burst over the catchment occurred during a 7-hour period between approximately 3am February 5th and 10am February 5th 2008. A rainfall depth of 138mm was recorded during this 7-hour period.

The following daily rainfall totals in neighbouring catchment gauges were recorded for the 24hours to 9am 5th February 2008:

- 156mm Nowra Boat Shed;
- 141mm Berry Masonic Village;
- 113mm Nowra RAN Air Station AWS;

- 104mm Nowra Treatment Works;
- 97mm Hampden Bridge (Kangaroo River);
- 89mm Beaumont (The Cedars);
- 84mm Grassy Gully (Shoalhaven River) and
- 75mm Kangaroo Valley (Budgong).

The corresponding Bomaderry Creek gauge total (165mm in 24 hours to 9:00am 5th February) is similar to those recorded across the region for the event, in particular the closest active gauge being Nowra Boat Shed.

The recorded totals at stations including Beaumont (The Cedars), Kangaroo Valley (Budgong) and Grassy Gully, are significantly lower than the Bomaderry Creek gauge, and generally reflect a decrease in rainfall away from the coastal zone. Accordingly, rainfall in the upper catchment of Bomaderry Creek is expected to have been lower than that recorded at the Bomaderry Creek gauge. Whilst the hyetograph at the Bomaderry Creek gauge is adopted globally across the entire Bomaderry creek catchment, the rainfall totals have been adjusted to reflect the lower rainfall in the upper catchment based on the spatial distribution recorded in the wider gauge network.

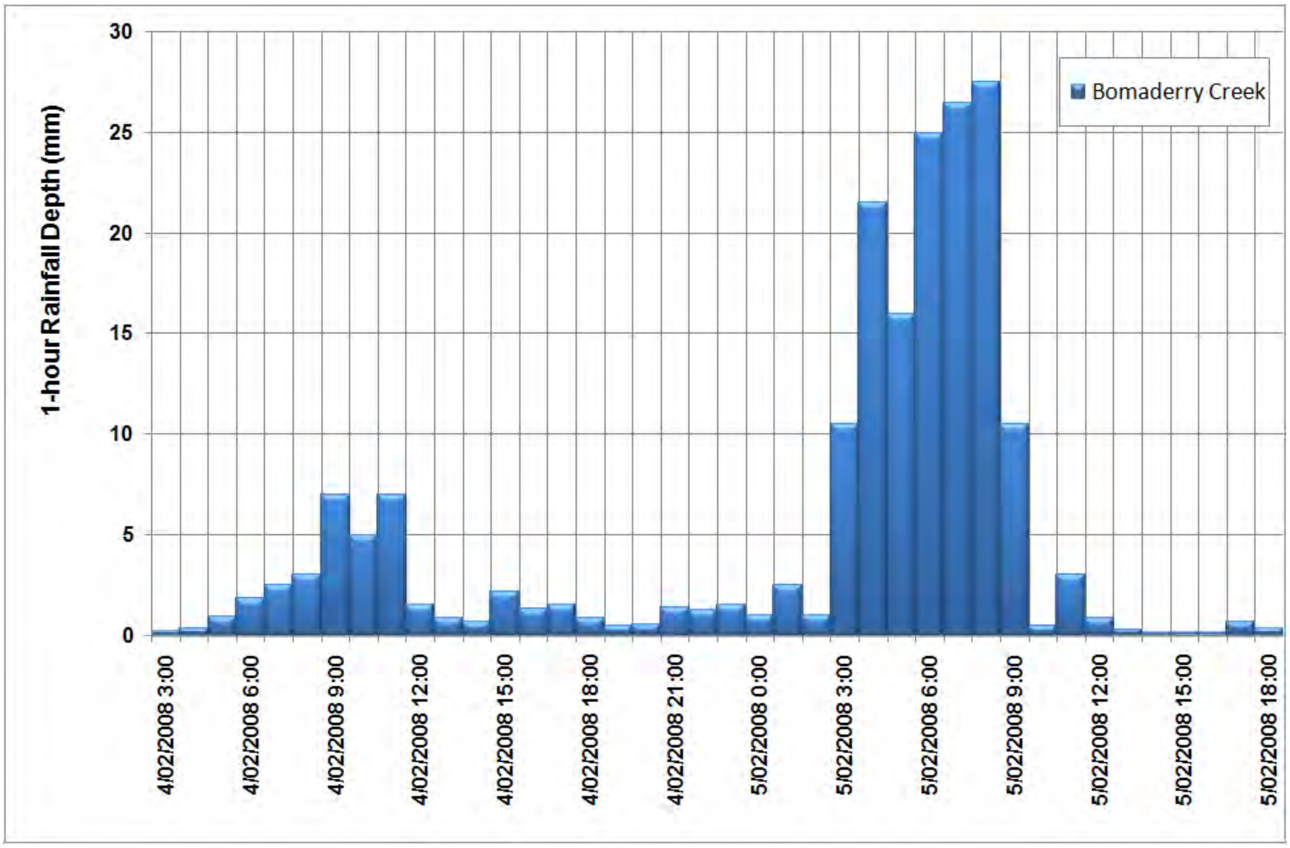


Figure 6-1 Rainfall Hyetograph for February 2008 Calibration Event

To gain an appreciation of the relative intensity of the February 2008 event, the recorded rainfall depths for various storm durations is compared with the design IFD data for the Bomaderry Creek catchment as shown in Figure 6-2.

The recorded depth vs. duration profile for the February 2008 events shows it tracking above the design 20% AEP (5-year ARI) rainfall. The recorded depth for the 6 hour period of 127mm represents approximately 5% higher rainfall than the 20% AEP design rainfall depth.

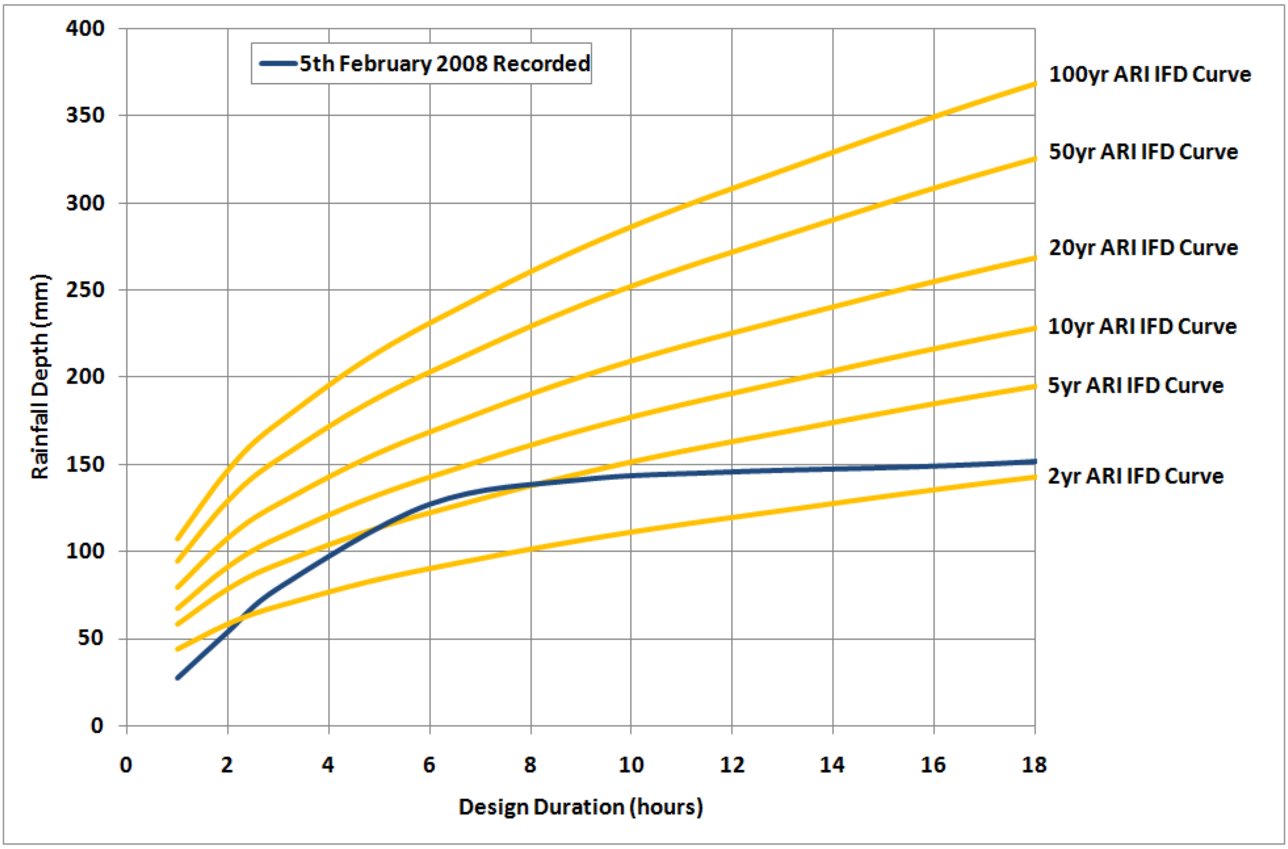


Figure 6-2 Comparison of February 2008 Rainfall with IFD Relationships

6.2.2 Antecedent Conditions

The antecedent catchment condition reflecting the degree of wetness of the catchment prior to a major rainfall event directly influences the magnitude and rate of runoff. The initial loss-continuing loss model has been adopted in the RAFTS-XP hydrological model developed for the Bomaderry Creek catchment. The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff and simulates the wetting up of the catchment to a saturated condition. The continuing loss represents the rainfall lost through soil infiltration once the catchment is saturated and is applied as a constant rate (mm/hr) for the duration of the runoff event.

Typical design loss rates applicable for NSW catchments east of the western slopes are initial loss of 10 to 35 mm and continuing loss of 2.5mm/hr (AR&R, 2001). For historical events however, the initial loss is indicative of the catchment wetness and prior rainfall to the modelled storm burst.

Figure 6-3 shows the monthly rainfall recorded at the Bomaderry Creek streamflow gauge prior to the February 2008 event. Generally the months preceding the flood event were characterised by below average rainfall, except for a significantly wetter than average November.

The main rainfall burst that occurred over the catchment between approximately 3am February 5th and 10am February 5th 2008 was preceded by approximately 45mm of rainfall across the catchment in the 24 hours prior. In considering the catchment wetness condition at the start of the event, an initial loss value of 10mm was adopted. This is similar to that adopted for design event conditions discussed in Section 7.

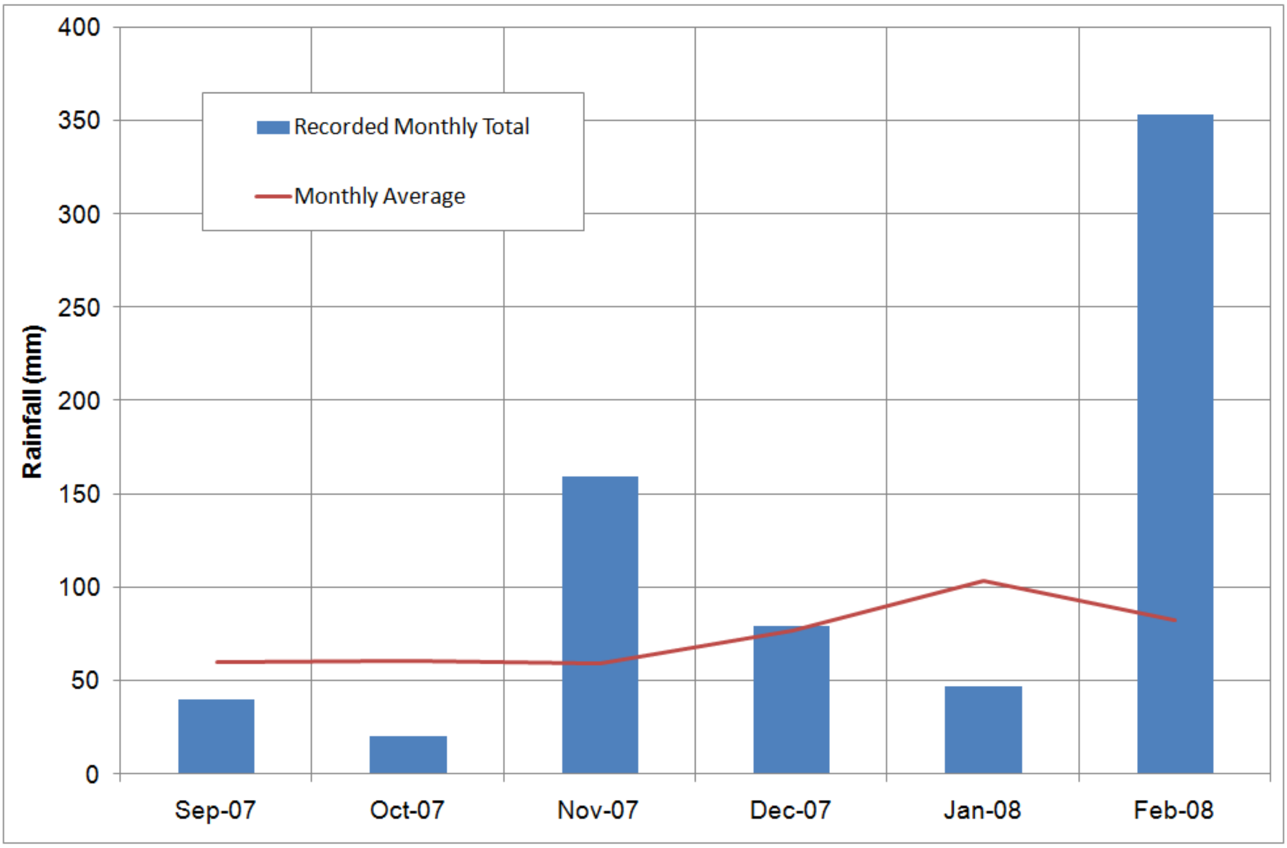


Figure 6-3 Monthly Rainfall Preceding February 2008 Event

6.2.3 Downstream Boundary Condition

The water level condition at Nowra Bridge is defined as a model input that controls the downstream boundary condition at Bomaderry Creek. The peak water level for the February 2008 event was approximately 1.05m AHD (10am February 5th) at Nowra Bridge based on the MHL gauge data. With reference to the design peak flood levels at Nowra Bridge as discussed in Section 2.2.1, this level does not represent any significant flood condition in the Shoalhaven River.

6.2.4 Adopted Model Parameters

The model calibration centred around the adjustment of the rainfall losses, the sub-catchment PERN values and Bx storage routing factor (hydrological model parameters) and the Manning's „n' values for the floodplain and channel (hydraulic model parameter).

The final values adopted, as shown in Table 6-1 were found to give a good result in representing the recorded water level hydrograph at the Bomaderry Creek gauge.

Table 6-1 February 2008 Model Calibration Parameters

Parameter	Value	Comment
Initial Loss (mm)	10	Approximately 40mm of rainfall fell over the catchment in the 24 hours preceding the main storm burst. Most of this will be removed as the initial loss for the modelled storm before the continuing loss is applied for the remainder of the storm duration.
Continuing Loss (mm/hr)	2.5	Similar to adopted design continuing loss rate as recommended in AR&R (2001).
PERN Forested Cleared Urban (pervious) Urban (impervious)	 0.1 0.06 0.04 0.02	The PERN factors are used to adjust the catchment routing factor to allow for catchment roughness. Catchment average values were estimated based on representative land use/ground coverage.
Bx (storage routing parameter)	1.0	The adopted value was applied globally for the entire catchment and provided the best fit of catchment response in terms of flow magnitude and timing.
Manning's n (channel)	0.025 – 0.08	Variable adjusted locally (within reasonable bounds) to provide best fit for peak water level profiles. Variability largely reflects degree of channel vegetation, channel size and sinuosity.
Manning's n (floodplain)	0.035 – 0.10	Variable adjusted locally (within reasonable bounds) to provide best fit for peak water level profiles. Variability largely reflects land use on the floodplain (cleared, forested, roads, urban lots)

6.2.5 Observed and Simulated Flood Conditions (February 2008)

The recorded water level hydrograph at the Bomaderry Creek gauging station provides the principal calibration data for this event. The gauging section is located on a reach with a well defined channel section just upstream of the natural control through the constriction into Bomaderry Creek gorge.

As discussed in Section 2.2.4, the recorded peak water levels at the gauge for this event exceed the upper limit of the existing rating curve. Accordingly, a comparison of recorded and simulated peak flow is not possible. However, applying a simple extrapolation of the existing rating curve, an estimated flow hydrograph has been derived utilising the recorded water levels. The accuracy of the rating extrapolation into a higher stage range is somewhat uncertain; however, considering the relatively uniform shape of the channel in this reach and that the peak water levels remain in-bank for the event, the estimated hydrograph is expected to provide a reasonable representation of the event flow conditions.

A comparison of simulated and recorded water level and flow hydrographs at the Bomaderry Creek gauge for the February 2008 event is shown in Figure 6-4 and Figure 6-5.

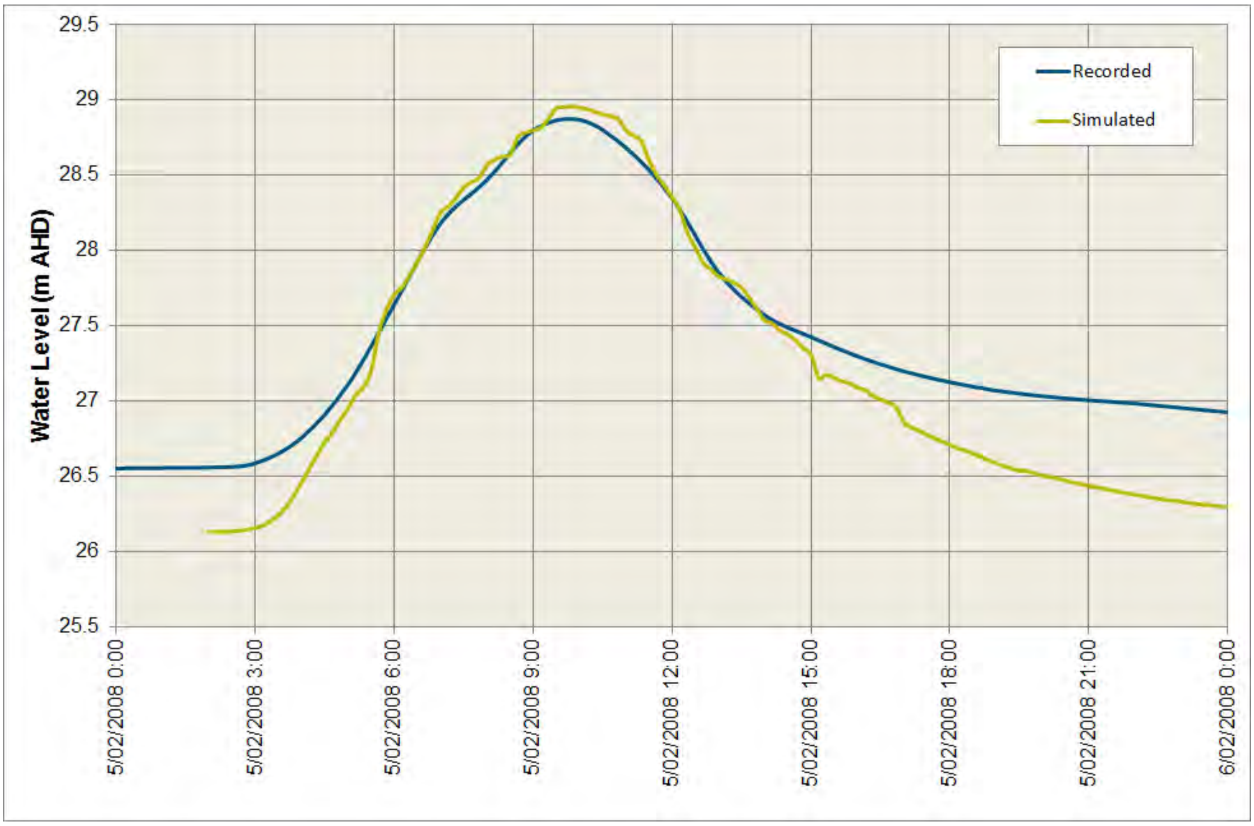


Figure 6-4 Comparison of Observed and Simulated Stage at Gauge Station February 2008 Event

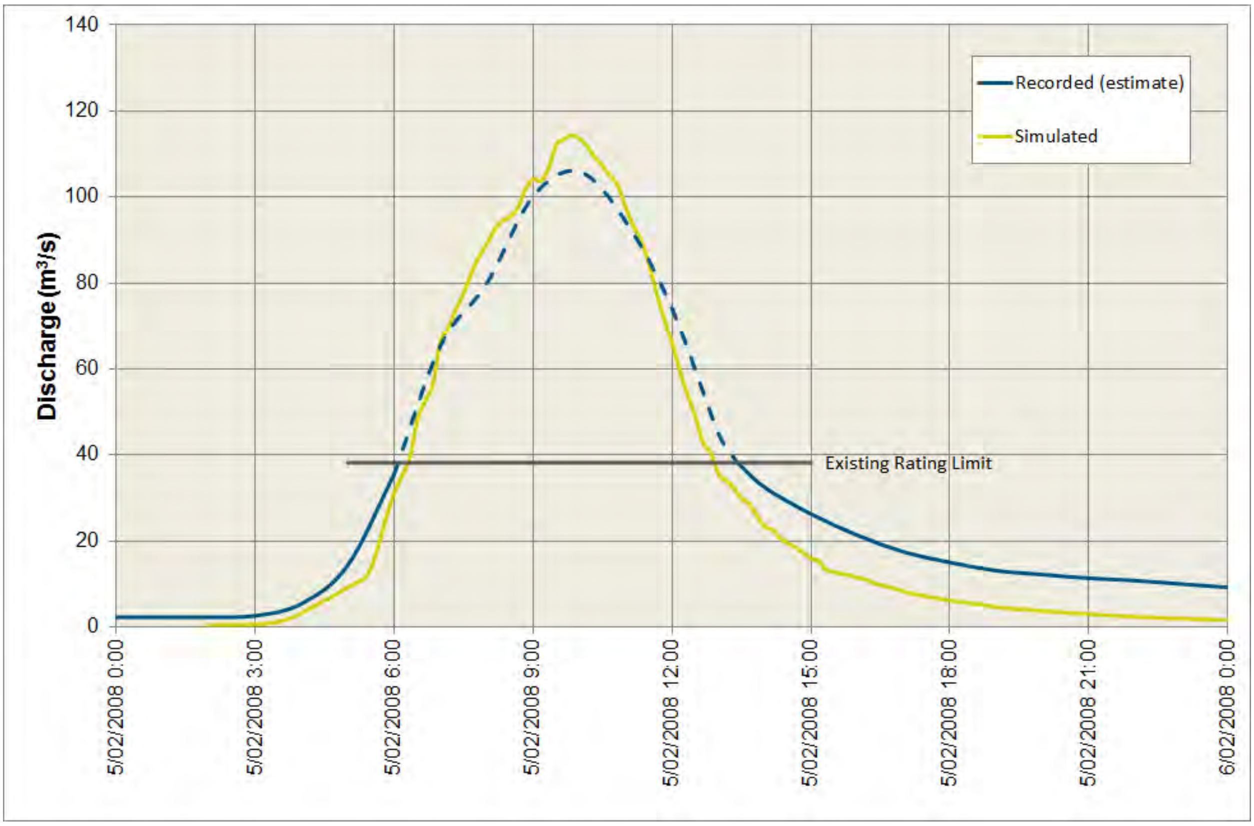


Figure 6-5 Comparison of Observed and Simulated Flow at Gauge Station February 2008 Event

The results indicate a relatively good agreement between observed and simulated conditions. The timing and shape of the hydrograph conform to the observed conditions with some minor discrepancy towards the peak of the hydrographs.

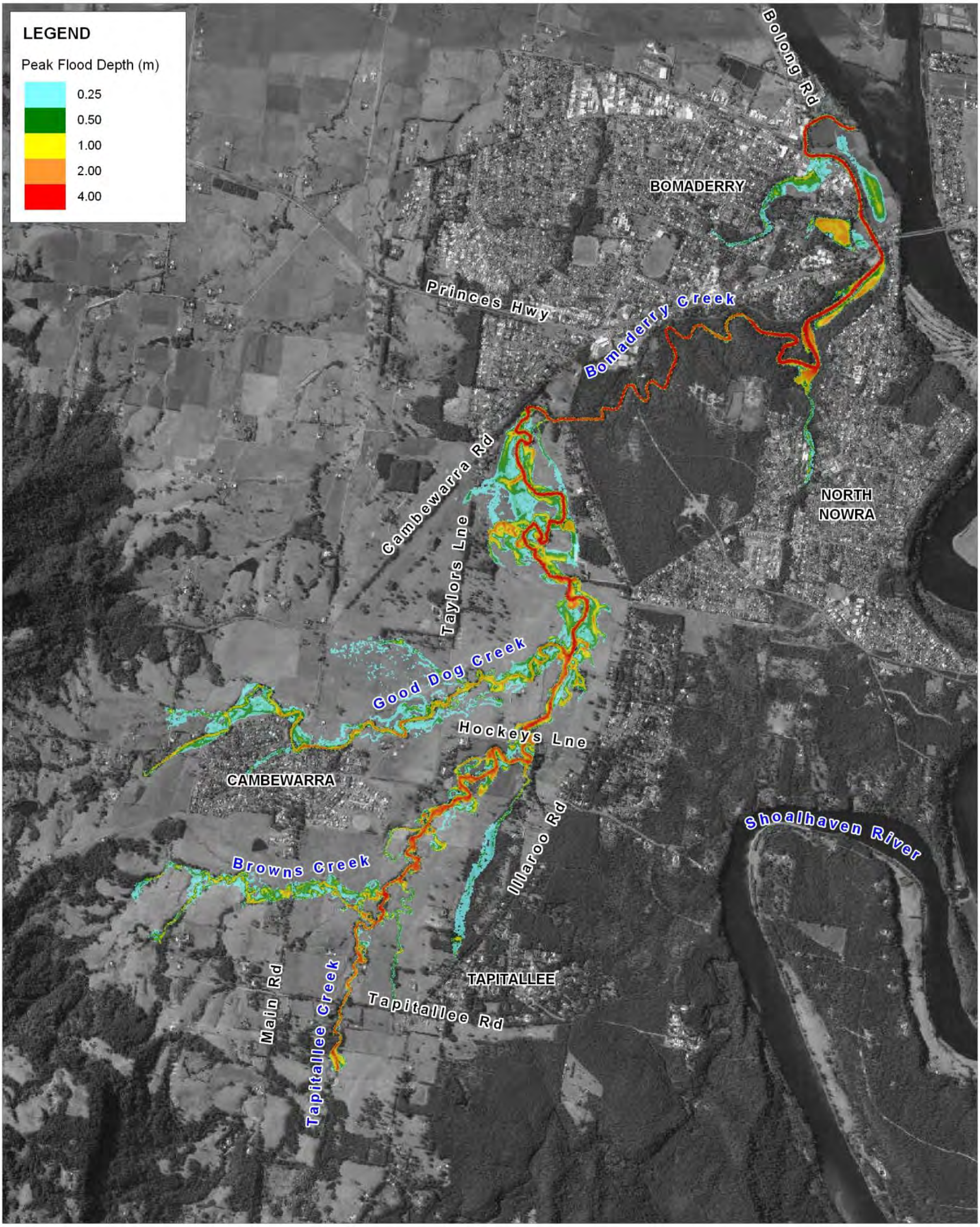
The simulated peak flood level is within +0.3m of the observed peak level from the gauging station record. This represents a discrepancy of less than 10% in terms of relative depth. The overestimation of water level in the model simulation corresponds to an overestimation in the peak flow at the gauging station as shown in Figure 6-5. The simulated peak flow of 118m^3/s represents approximately a 12% increase above the observed gauge conditions. However, it is reiterated that the observed flow is an estimate based on extrapolation of the existing rating curve (refer Section 2.2.4).

The simulated recession tails off quicker than the observed conditions at the gauging station. This is largely due to the adopted event rainfall. The main rainfall period occurred in the catchment prior to 9:00am on 5th February 2008 as shown in the event hyetograph (refer to Figure 6-1). The Bomaderry Creek gauge recorded only 8mm in the next 24-hours to 9:00am on 6th February 2008. This total is less than the corresponding total at other gauges in the region, including Nowra Boat Shed 46mm, Beaumont (The Cedars) 37mm, Kangaroo Valley (Budgong) 11mm and Grassy Gully 9mm. It is apparent there is some variability across the region, and in the distribution of the daily rainfall total over the two recording days during the event. Indeed, the recorded Bomaderry Creek hyetograph is weighted more heavily to rainfall to occurring to 9:00am on 5th February 2008 given the low recorded total on the 6th February. This may explain the over-prediction of the peak and subsequent under-prediction of the recession in the model simulation compared to observed conditions at the gauge.

There are a number of uncertainties in the simulated hydrological conditions, not in the least the assumed spatial and temporal distribution of rainfall which may have a significant influence on the catchment generated runoff. Overall the simulated catchment response is considered a good representation of the observed conditions. The deviations in the timing, shape and peak levels of simulated hydrographs from observed conditions are within acceptable bounds considering uncertainties in the data such as spatial and temporal variations in rainfall across the catchment.

From the design flood analysis presented in Section 7, the critical duration for the Bomaderry Creek catchment is of the order of 6-9 hours. This is significant in the context of the February 2008 event which is of a similar duration/temporal pattern. For the Bomaderry Creek catchment, the critical duration generally represents the design event conditions that provides for coincident timing of peak flows at the confluence of the Tapitallee Creek and Good Dog Creek catchments. The good calibration results achieved in the simulation of the catchment response for the February 2008 event is expected to transfer to the design event analysis utilising similar storm durations for simulation of peak design event flood conditions.

The peak stage height of approximately 3.1m represents a completely in-bank flow at the gauging station. The gauging station is located around the entrance to Bomaderry Gorge where the channel section generally deepens with a corresponding increase in gradient along the channel alignment. Upstream of the gauging station where there is generally a flatter channel gradient and smaller cross section, and hence lower in-channel conveyance, overbank flooding is simulated (albeit at minor levels) for the February 2008 event. The simulated peak flood inundation extents and depths for the February 2008 calibration event are shown in Figure 6-6.



Title:

February 2008 Simulated Peak Flood Inundation

Figure: **6-5**

Rev: **A**

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Approx. Scale

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Whilst some overbank flooding is simulated in the upper reaches for the February 2008 event, there is no significant inundation of property. The lack of response in the community questionnaire, distributed just after the February 2008 event, reflects the relatively low impact of this event on property holders, particularly in the upper catchment.

In the lower catchment there is also minimal flood impact. There was no significant flow in the Shoalhaven River to affect property along Bolong Road, and the Bomaderry Creek flows remained in-bank in the lower reach downstream of the Princes Highway. During the community consultation, some residents noted flooding in Brinawarr Street and Tarawara Road on 5th February 2008. There is a significant tributary channel through this developed area in Bomaderry which has been incorporated into the TUFLOW model.

Figure 6-7 shows a photograph taken by local residents of the flow down Tarawara Road around the peak of the event. The simulated peak flood depth in this vicinity is shown for comparison. Both the photograph and the simulated flood condition show the capacity of the drainage channel adjacent to the road being exceeded, with the flooded width extending across Tarawara Road. Depths of flooding across the road are relatively shallow, less than 0.2m, with depth increasing in the road verge on the southern side of the road and into the main channel itself to a depth in excess of 0.5m.

Figure 6-7 Observed and Simulated Flooding Tarawara Road 5th February 2008

6.3 August 1990 Model Validation

The objective of the model validation is to test the appropriateness of the adopted calibration parameters for a different historical event. Given the lack of available data, a conventional model validation is not possible for the Bomaderry Creek catchment. Nevertheless, a second historical event has been simulated, at least to provide some relative comparison to other historical and design event magnitudes.

The August 1990 event has been selected for this purpose. Section 2.1.2 presented an analysis of historical daily rainfalls across the Bomaderry Creek catchment. The August 1990 event was identified as the highest recorded 1-day and 2-day rainfall for the catchment. This rainfall event also resulted in a major flood event in the Shoalhaven River, with a peak flood level of 4.71m AHD recorded at Nowra Bridge.

Whilst there is little historical data available, it is envisaged that there has been no major changes in the Bomaderry Creek waterway in the period between the August 1990 and February 2008 events. Accordingly, the same topographical information acquired for this study and used to build the hydraulic models has been applied for both the 1990 and 2008 events.

Within the lower floodplain of Bomaderry Creek, there is likely to have been some minor changes to the floodplain largely associated with development in Bomaderry. However, for the greater majority of the floodplain there have been no major changes that would substantially influence flood behaviour. The upper catchment remains largely undeveloped, with the exception of Cambewarra that is largely located on higher ground above the adjacent floodplains of Good Dog Creek and Browns Creek.

6.3.1 Rainfall Data

There was no active rainfall station in the Bomaderry Creek catchment during the period of the August 1990 flood event. However, there were numerous daily read gauges surrounding the catchment to enable interpolation of daily rainfall totals for the event. Indeed, this is the basis of the SILO data discussed in Section 2.1.2. The estimated catchment average rainfall totals for Bomaderry Creek are 184mm, 258mm and 29mm to 9:00am on the 1st, 2nd and 3rd August 1990 respectively.

Whilst estimated daily rainfall totals for the Bomaderry Creek catchment are available, the temporal pattern for this rainfall is unknown. The nearest active continuous rainfall station is the Sydney Catchment Authority (SCA) gauge located at Budderoo, some 15km from the centre of the Bomaderry Creek catchment.

The recorded temporal pattern at Budderoo has been applied to the estimated daily rainfall totals for the Bomaderry Creek catchment to derive an event hyetograph. It is acknowledged there is considerable uncertainty in applying this temporal pattern to the Bomaderry Creek catchment. However, the daily distribution of rainfall at the Budderoo gauge is similar to Bomaderry Creek, being 250mm, 255mm, and 28mm for the 1st, 2nd and 3rd August 1990 respectively.

Figure 6-8 shows the estimated hourly rainfall totals for Bomaderry Creek for the period 9am July 31st and 9am August 3rd 1990. The hyetograph shows a continuous period of rainfall of approximately 48-hours during which some 440mm of rainfall fell. The rainfall intensity was relatively consistent over this period, with some higher intensity periods of a couple of hours. Significantly there did not appear to be any major bursts of short duration.

To gain an appreciation of the relative intensity of the August 1990 event, the recorded rainfall depths for various storm durations is compared with the design IFD data for the Bomaderry Creek catchment as shown in Figure 6-9.

The recorded depth vs. duration profile for the August 1990 event shows it generally tracking above the design 5% AEP (20-year ARI) rainfall for durations in excess of 30-hours. The recorded depths for the 36 hour and 48 hour periods generally recorded approximately 10% higher rainfall than the 5% AEP design rainfall depth:

- 36-hour duration - 391mm recorded compared with 359mm design 5% AEP; and
- 48-hour duration - 447mm recorded compared with 403mm design 5% AEP.

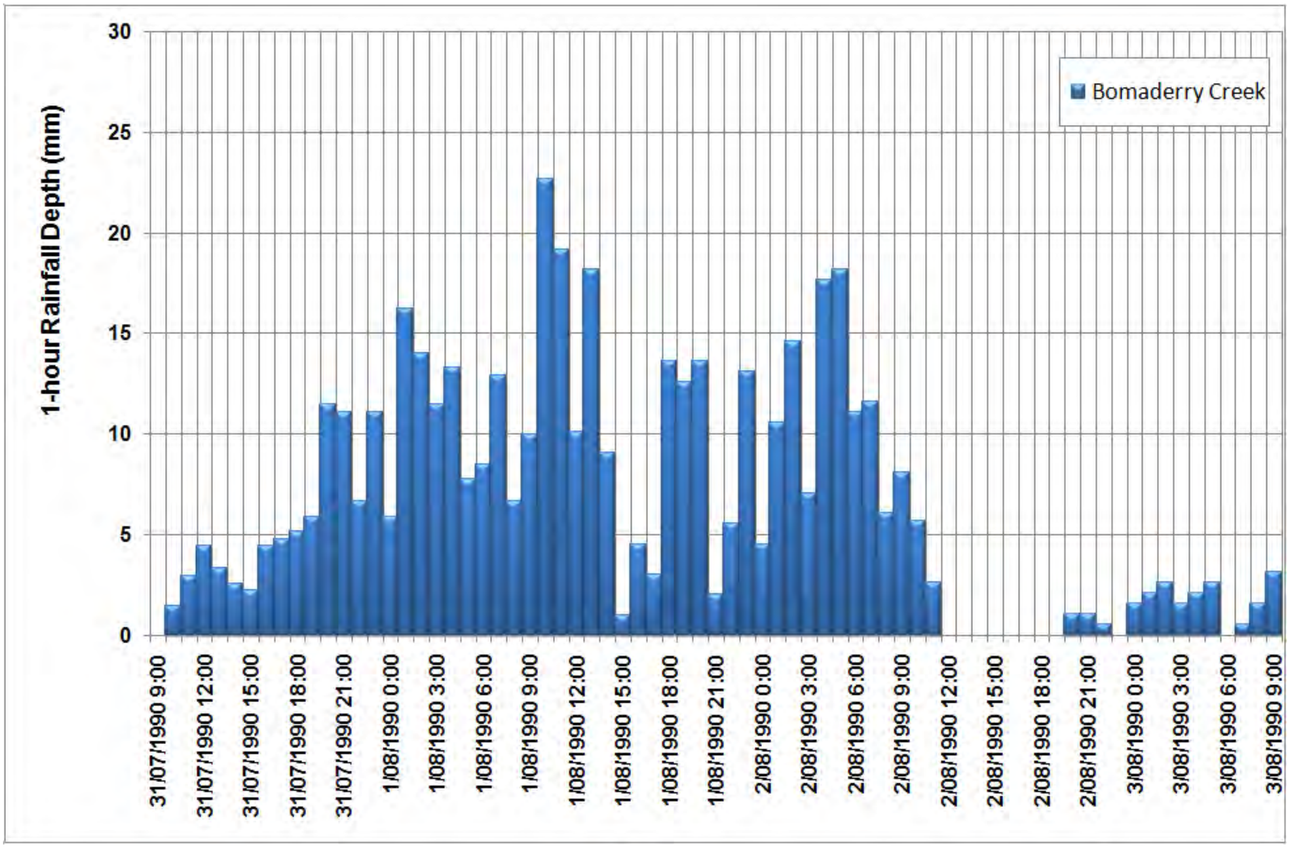


Figure 6-8 Adopted Rainfall Hyetograph for August 1990 Calibration Event

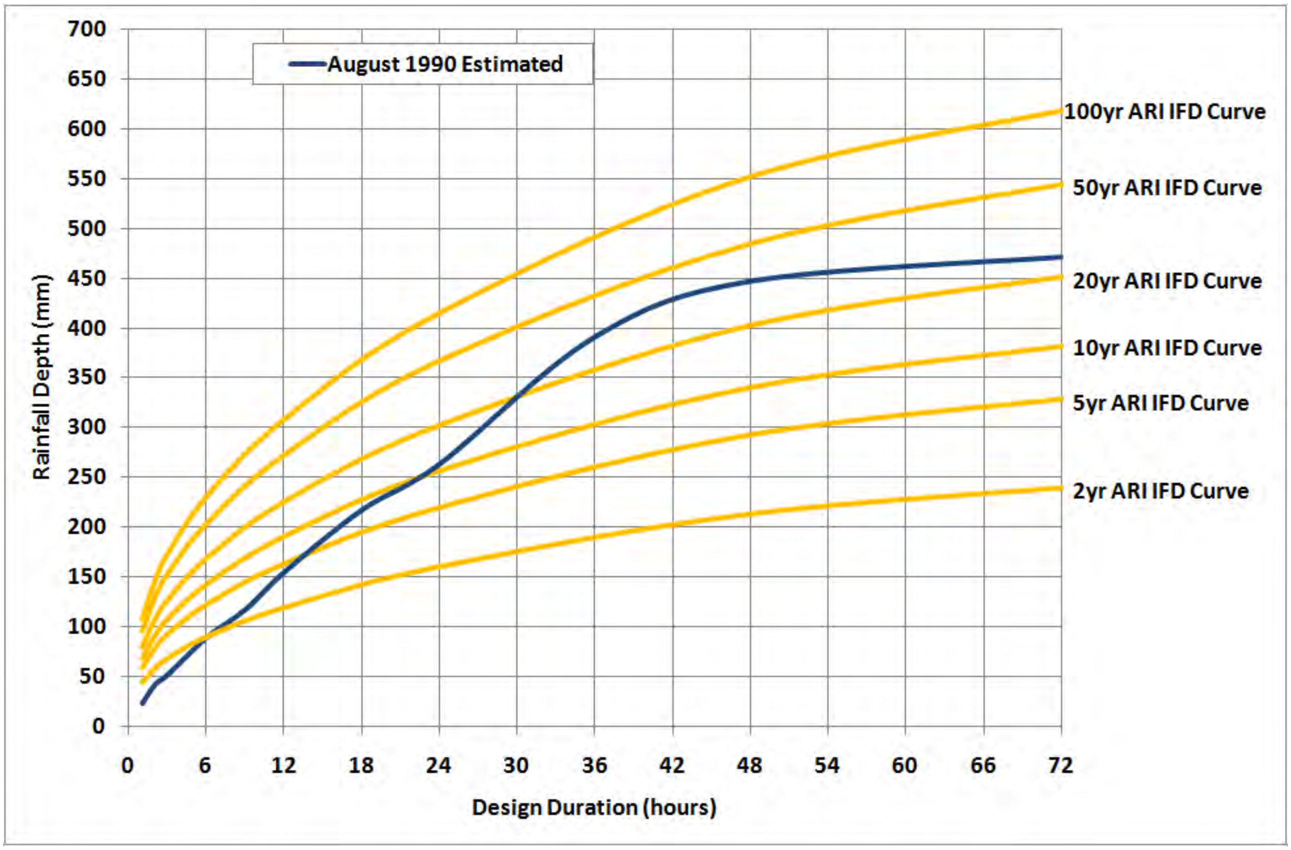


Figure 6-9 Comparison of Adopted August 1990 Rainfall with IFD Relationships

For shorter design durations less than 6hours, the August 1990 rainfall represents a return period of less than 2 years. The estimated 6-hour rainfall depth for the August 1990 event is approximately 90mm, significantly less than the 127mm recorded in the February 2008 event over a similar 6-hour period.

6.3.2 Antecedent Conditions

The antecedent catchment condition reflecting the degree of wetness of the catchment prior to a major rainfall event directly influences the magnitude and rate of runoff.

Figure 6-10 shows the monthly rainfall recorded at Nowra Treatment Works (assumed representative of Bomaderry Creek catchment) prior to the August 1990 event. April and May 1990 represented significantly higher than average rainfall, whilst generally the other months preceding were characterised by below average rainfall.

As shown Figure 6-8 the main period of rainfall occurred over an extended period of 48-hours. Given this long duration and large rainfall depth event, the initial loss conditions adopted for the simulation would have minimal impact on the peak flood conditions. Accordingly, a nominal 10mm initial loss and 2.5mm/hr continuing loss was maintained as per the previous calibration event.

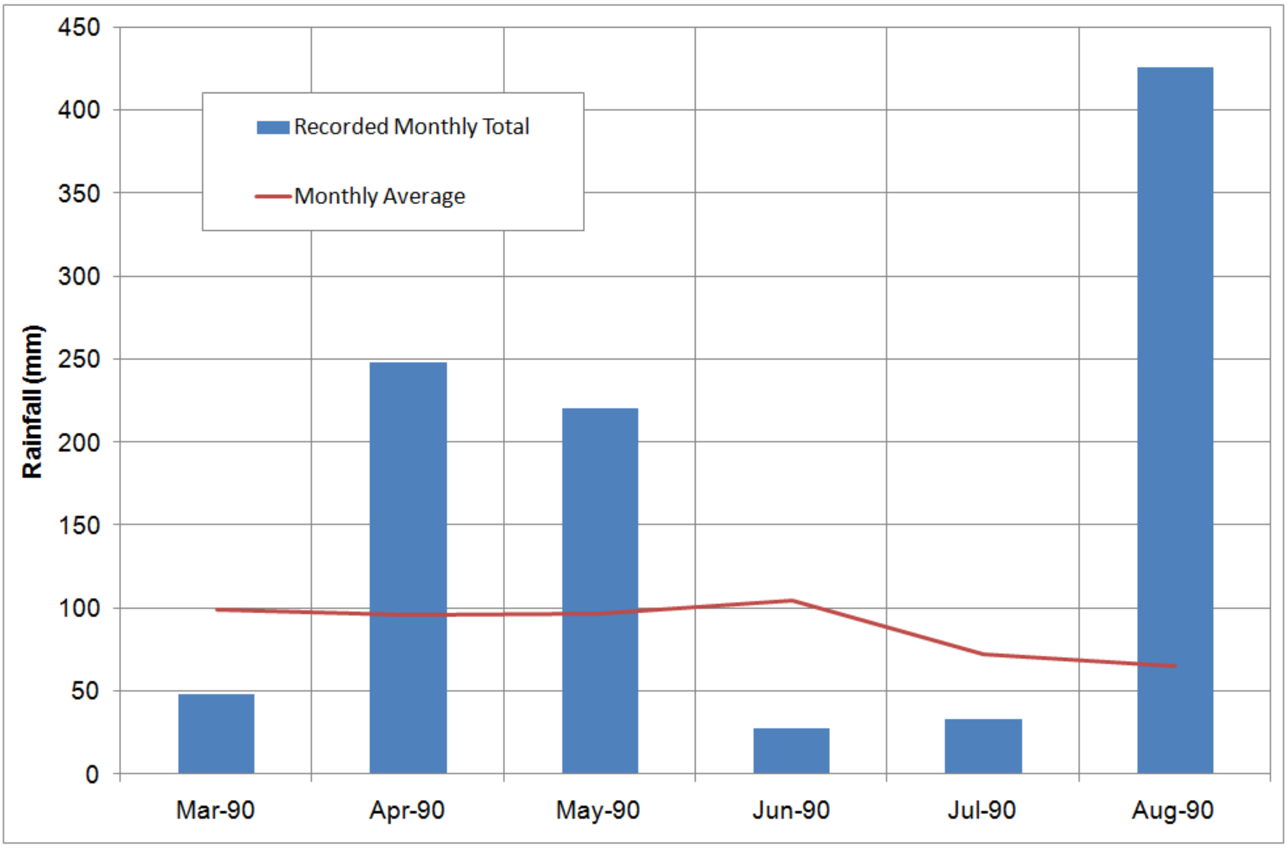


Figure 6-10 Monthly Rainfall Preceding August 1990 Event

6.3.3 Observed and Simulated Flood Conditions (August 1990)

There is limited observed flood data available for the August 1990 event. The only peak flood level that has been identified following review of available data is the 4.4m AHD peak flood level recorded at the factory at Bolong Road. Given the flood level record of 4.7m AHD at Nowra Bridge, it is evident that the Shoalhaven River flooding condition is the dominant mechanism of the flooding observed along Bolong Road.

The lack of peak flood level data elsewhere in the catchment may again be explained by the limited number of properties exposed to flooding for this event. As for the February 2008 event, much of the flooding in the upper catchment is limited to rural pasture land. Existing rural dwellings in addition to the main Cambewarra township are generally located on higher ground outside the flood inundation extents as shown in Figure 6-11.

The simulated inundation extent shown in Figure 6-11 indicates that out-of-bank flooding is relatively minor in the upper catchment and generally occurs along the riparian corridor of the Bomaderry Creek and tributary alignments. However, towards the lower floodplain of Bomaderry Creek, the influence of major Shoalhaven River flooding is evident with significant inundation of the floodplain including a considerable stretch of Bolong Road.

In comparison to the simulated inundation extent for the February 2008 event, there is considerably less out-of-bank flooding simulated in the upper catchment for the 1990 event. This is reflective of the lower effective return period of the August 1990 event for shorter durations less than about 6-hours. Given the size of the Bomaderry Creek catchment, in particular the three converging tributaries of Good Dog Creek, Browns Creek and Tapitallee Creek, the critical duration of the catchment is of the order of 6 to 9 hours. Whilst the August 1990 rainfall event is estimated as being in excess of a 5% AEP (20-yr ARI) event for the 36-hour to 48-hour duration, the lower intensities for this event over the critical shorter durations (i.e. less than 50% AEP (2-year ARI) for 6-hour durations) results in only relatively minor out-of-bank flooding in the upper catchment.

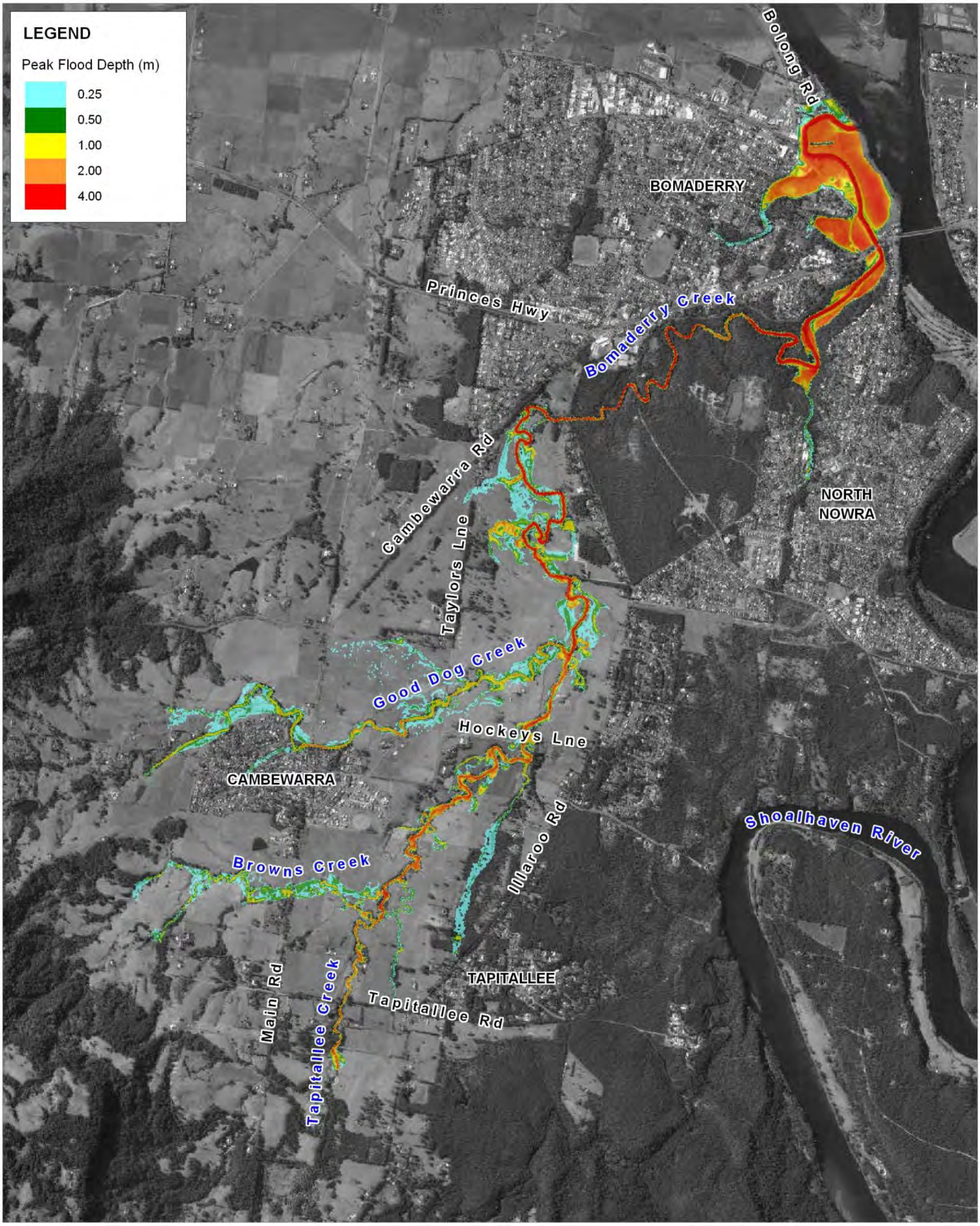
6.4 Determination of Design Model Parameters

In calibrating the models emphasis was placed on reaching agreement between recorded and simulated flood conditions with respect to peak water levels and relative timing of occurrence. The availability of a continuous recorded water level profile also enabled hydrograph shape to be considered.

The model calibration achieved good agreement in regards to observed conditions at the Bomaderry gauge for the principal calibration event of February 2008. The model calibration centred around the adjustment of the rainfall losses, the sub-catchment PERN values, routing adjustment parameter (BX value) and the Manning's „n' values for the channel and floodplain. The final values adopted, as shown in Table 6-1, were found to give an adequate result.

The adopted parameters have been maintained (as per the calibration events) for design event simulation.

Given the limited amount of calibration data available, it is important to acknowledge the limitation of the calibration process undertaken. All of the parameters have been kept within normal bounds generally considered for a catchment study of this nature. In the absence of detailed calibration data, further consideration has been given to sensitivity testing of key model parameters on design flood conditions as presented in Section 7.4.



Title:

August 1990 Simulated Peak Flood Inundation

Figure: **6-11**

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Approx. Scale

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7 DESIGN FLOOD CONDITIONS

Design floods are hypothetical floods used for planning and floodplain management investigations. They are based on having a probability of occurrence specified either as:

- Annual Exceedance Probability (AEP) expressed as a percentage; or
- Average Recurrence Interval (ARI) expressed in years.

This report uses the AEP terminology. Refer to Table 7-1 for a definition of AEP and the ARI equivalent.

Table 7-1 Design Flood Terminology

ARI[1]	AEP[2]	Comments
200 years	0.5%	A hypothetical flood or combination of floods which represent the worst case scenario likely to occur on average once every 200 years.
100 years	1%	As for the 0.5% AEP flood but with a 1% probability or 100 year return period.
50 years	2%	As for the 0.5% AEP flood but with a 2% probability or 50 year return period.
20 years	5%	As for the 0.5% AEP flood but with a 5% probability or 20 year return period.
10 years	10%	As for the 0.5% AEP flood but with a 10% probability or 10 year return period.
Extreme Flood / PMF[3]		A hypothetical flood or combination of floods which represent an extreme scenario.

1 Average Recurrence Interval (years)
2 Annual Exceedance Probability (%)
3 A PMF (Probable Maximum Flood) is not necessarily the same as an Extreme Flood.

In determining the design floods it is necessary to take into account:

- The critical storm duration of the catchment (small catchments are more prone to flooding during short duration storms while for large catchments longer durations will be more critical. For example, considering the relatively small size of the Bomaderry Creek catchment, it is potentially more prone to higher flooding from intense storms extending over several hours rather than a couple of days as for the larger Shoalhaven River catchment); and
- The relative timing and magnitude of flooding in the Shoalhaven River in relation to Bomaderry Creek catchment flooding (although this influence is only experienced in the lower floodplain of Bomaderry Creek).

7.1 Coincident Shoalhaven River Flooding

The coincident Bomaderry Creek and Shoalhaven River flooding condition is an important consideration in defining design flood event conditions for the lower Bomaderry Creek catchment. As discussed previously, some of the significant flood events in lower Bomaderry along Bolong Road have been primarily driven by Shoalhaven River flooding. Table 7-2 presents a comparison of observed peak flood levels in the Shoalhaven River at Nowra Bridge for historical events and design flood levels provided in the Lower Shoalhaven River FRMS (WMA, 2007).

Table 7-2 Comparison of Historical and Design Event Flood Levels at Nowra Bridge

Event	River Level
Extreme Flood	8.9m AHD
April 1870	*6.5m AHD*
1% AEP	6.3m AHD
February 1860	*5.5m AHD*
5% AEP	5.3m AHD
March 1978	*5.3m AHD*
August 1974	*4.9m AHD*
10% AEP	4.8m AHD
June 1975	*4.8m AHD*
August 1990	*4.7m AHD*

Of the historical events included in Table 7-2, the relative contribution of flows from the Bomaderry Creek catchment is unknown. However, given the events generally correspond to long duration rainfall events of the order of a few days, it is unlikely that the Bomaderry Creek flooding condition is as severe in terms of equivalent design magnitude as the Shoalhaven River flood condition. It has been noted previously that much shorter duration rainfall events represent the critical duration for major flooding in Bomaderry Creek.

Given the differences in scale of the catchments, and the subsequent differences in critical rainfall duration, it is unlikely that a 1% AEP event would occur simultaneously. Nevertheless, there remains the opportunity for coincident major flooding in both the Bomaderry and Shoalhaven catchments. Accordingly, the design event simulations for Bomaderry Creek have adopted a tailwater condition in the Shoalhaven River corresponding to the design peak 5% AEP (20-year ARI). Tidal influence on the Shoalhaven River has not been considered.

Whilst a 5% AEP Shoalhaven River flooding condition would result in significant inundation in the lower part of Bomaderry Creek, the extent of the influence of the tailwater condition is limited by the Bomaderry Creek gorge. Accordingly, the adopted boundary condition has no effect on the design flood condition in the upper catchment.

7.2 Design Rainfall

Design rainfall parameters are derived from standard procedures defined in AR&R (2001) which are based on statistical analysis of recorded rainfall data across Australia. The derivation of location specific design rainfall parameters (e.g. rainfall depth and temporal pattern) for the Bomaderry Creek catchment is presented below.

7.2.1 Rainfall Depths

Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). These curves provide rainfall depths for various design magnitudes (up to the 1% AEP) and for durations from 5 minutes to 72 hours.

The Probable Maximum Precipitation (PMP) is used in deriving the Probable Maximum Flood (PMF) event. The theoretical definition of the PMP is "the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of year" (AR&R, 2001). The ARI of a PMP/PMF event ranges between 10^4 and 10^7 years and is beyond the "credible limit of extrapolation". That is, it is not possible to use rainfall depths determined for the more frequent events (100 year ARI and less) to extrapolate the PMP. The PMP has been estimated using the Generalised Short Duration Method (GSDM) derived by the Bureau of Meteorology.

A range of storm durations were modelled in order to identify the critical storm duration for design event flooding in the catchment. Design durations considered included the 1-hour, 2-hour, 3-hour, 4.5-hour, 6-hour, 9-hour and 12-hour durations.

Table 7-3 shows the average design rainfall intensities based on AR&R adopted for the modelled events. The full IFD table with durations from 5-minutes to 72-hours derived for the Bomaderry Creek catchment is included in Appendix C.

Table 7-3 Average Design Rainfall Intensities (mm/hr)

Duration (hours)	Design Event Frequency					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
1	59	68	80	96	108	121
2	39.3	45.6	54	65	73	82
3	30.9	35.9	42.3	51	58	65
4.5	24.3	28.2	33.3	40.2	45.5	51
6	20.5	23.8	28.1	34.0	38.5	43.2
9	16.1	18.8	22.2	26.8	30.4	34.2
12	13.6	15.8	18.8	22.7	25.8	29.0

7.2.2 Temporal Patterns

The IFD data presented in Table 7-3 provides for the average intensity (or total depth) that occurs over a given storm duration. Temporal patterns are required to define what percentage of the total rainfall depth occurs over a given time interval throughout the storm duration. The temporal patterns adopted in the current study are based on the standard patterns presented in AR&R (2001).

The same temporal pattern has been applied across the whole catchment. This assumes that the design rainfall occurs simultaneously across each of the modelled sub-catchments. The direction of a storm and relative timing of rainfall across the catchment may be determined for historical events if sufficient data exists, however, from a design perspective the same pattern across the catchment is generally adopted.

7.2.3 Rainfall Losses

The hydrologic model parameters adopted for the design floods were similar to those used in the hydrologic model calibration and verification. For the initial and continuing rainfall losses, values of 10mm and 2.5mm/h were used. These are consistent with the recommended ranges for design event losses in AR&R (2001). The 10mm initial loss is at the lower end of the range of generally adopted values and is therefore relatively conservative.

7.3 Design Flood Results

A range of design event durations were simulated to determine the critical duration for flooding along Bomaderry Creek. In general, the model simulations indicated the peak water levels in the channel and inundated areas of the floodplain corresponded to the 9 hour duration (6-hour for the PMF event).

This conforms to the general rainfall pattern occurring during the February 2008 event. The design results presented in the remainder of the report are for the 9-hour critical duration for events up to the 0.5% AEP event and 6-hour duration for the PMF.

7.3.1 Peak Flood Levels, Depths and Velocities

The design flood results are presented in a flood mapping series in Appendix A. For the simulated design events including the 10% AEP (10-year ARI), 5% AEP (20-year ARI), 2% AEP (50-year ARI), 1% AEP (100-year ARI) 0.5% AEP (200-year ARI) and PMF events, a map of peak flood level, depth and velocity is presented covering the modelled area.

Predicted flood levels at selected locations are shown in Table 7-4 for the full range of design event magnitudes considered. Longitudinal profiles showing predicted flood levels along Bomaderry Creek and its tributaries are also shown in Figure 7-1 and Figure 7-2. Only the 5% AEP, 1% AEP and PMF event peak flood level profiles are shown for clarity.

Key reference points for flood levels are at road crossings over major tributaries. The majority of peak water level locations shown in Table 7-4 correspond to these locations in the catchment.

The Princes Highway crossing of Bomaderry Creek is elevated well above the channel and surrounding floodplain at over 8m AHD. The bridge approaches are on constructed embankment above the natural floodplain level of around 2m AHD thereby providing a significant flow constriction and limiting flow to the bridge opening only. For the simulated design events, overtopping of the approaches only occurs for the PMF event.

The minimum road deck level of Main Road over Good Dog Creek is approximately 60m AHD. As shown in Table 7-4, the simulated peak water level only exceeds this height for the PMF event. However, there is the opportunity for flow to by-pass the structure across Main Road on the floodplain to the east of the bridge. The sag point on the approach approximately 50m east of the bridge has low point of approximately 59.4m AHD. This by-pass flow route is substantial providing for a flow width of some 100m up to the bridge deck level of 60m AHD. Accordingly, peak flood levels at the bridge are somewhat limited by the activation of this by-pass flow route for events of the order of the 2% AEP and above. On the western side of the bridge, the road level and natural topography rises steeply on the Cambewarra township side. All property in this area lies above 65m AHD and is protected from mainstream flooding of Good Dog Creek, including up to the PMF event.

Table 7-4 Estimated Peak Flood Levels for Design Events

Location	Design Event Frequency					
	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Bomaderry Creek						
Princes Highway	5.4	5.6	5.9	6.1	6.4	9,6
Gauging Station	30.6	31.1	31.7	32.1	32.5	36.0
Good Dog Ck Confluence	39.1	39.2	39.4	39.5	39.6	40.6
Tapitallee Creek						
Hockeys Lane	42.6	42.8	43.0	43.2	43.3	44.1
Browns Creek Confluence	50.6	50.9	51.1	51.2	51.4	52.2
Tapitallee Road	55.0	55.4	55.6	55.8	56.0	57.4
Good Dog Creek						
Taylors Lane	48.4	48.5	48.7	48.8	48.8	49.5
Main Road	59.0	59.2	59.4	59.6	59.7	60.5
Tannery Road	74.7	74.9	75.0	75.1	75.2	76.0

The Tapitallee Road bridge over Tapitallee Creek lies some 8m above the creek bed at this location (deck level at approx. 59m AHD). The channel is highly incised with a significant in-bank flow capacity. As a result overtopping of the bridge is not expected for the design events considered. Major out-of-bank flows (in excess of the 0.5% AEP event) bypass the structure on the southern side of the bridge. An effective floodway of some 400m width across Tapitallee road extends from the bridge to Illaroo Road, with a level of approximately 57.5m AHD at its lowest point.

The other major road crossing points on the main tributaries are the causeway crossings at Hockeys Lane (Tapitallee Creek) and Tannery Road (Good Dog Creek). With invert levels of 38.7m AHD and 72.7m AHD for Hockeys Lane and Tannery Road respectively, significant flood depths are simulated for the major events summarised in Table 7-4. Given that these structures are defined low flow crossings, temporary road closures would be expected for even relatively minor events.

Aside from the major road crossings, open rural pasture represents the majority of land use elsewhere in the catchment. Perhaps the most significant other location for peak water level reporting and comparison is the gauging station at the entrance to Bomaderry Creek Gorge. Out-of-bank flooding occurs at the gauging station for the major design events with top of bank levels of the order of 30m AHD. As discussed previously, water levels of this height well exceed the existing rating curve for the gauging station, at which point high flow extension to the rating curve is required that incorporates both channel and floodplain flows for out-of-bank events.

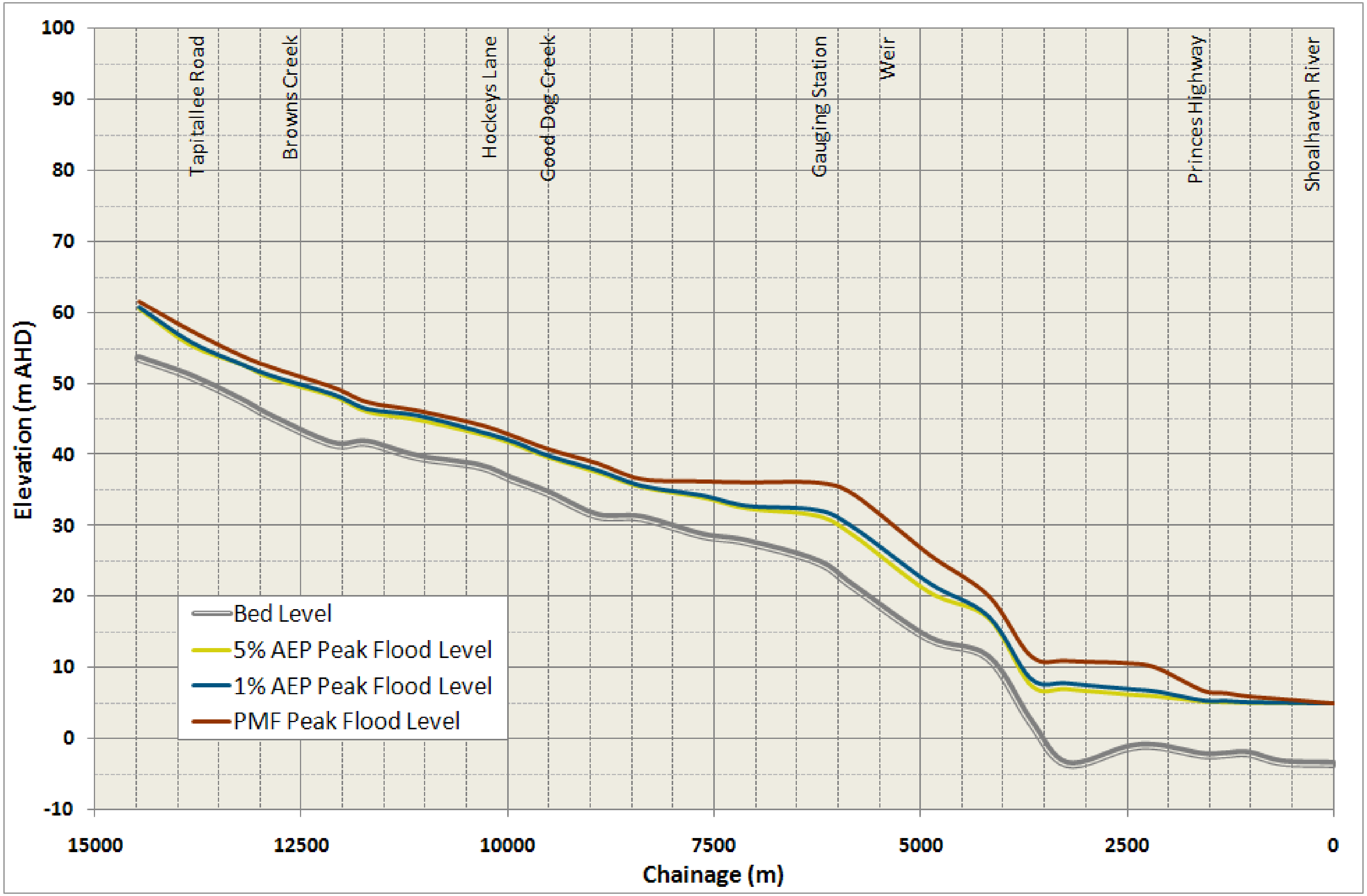


Figure 7-1 Design Flood Level Profiles for Bomaderry Creek/Tapitallee Creek

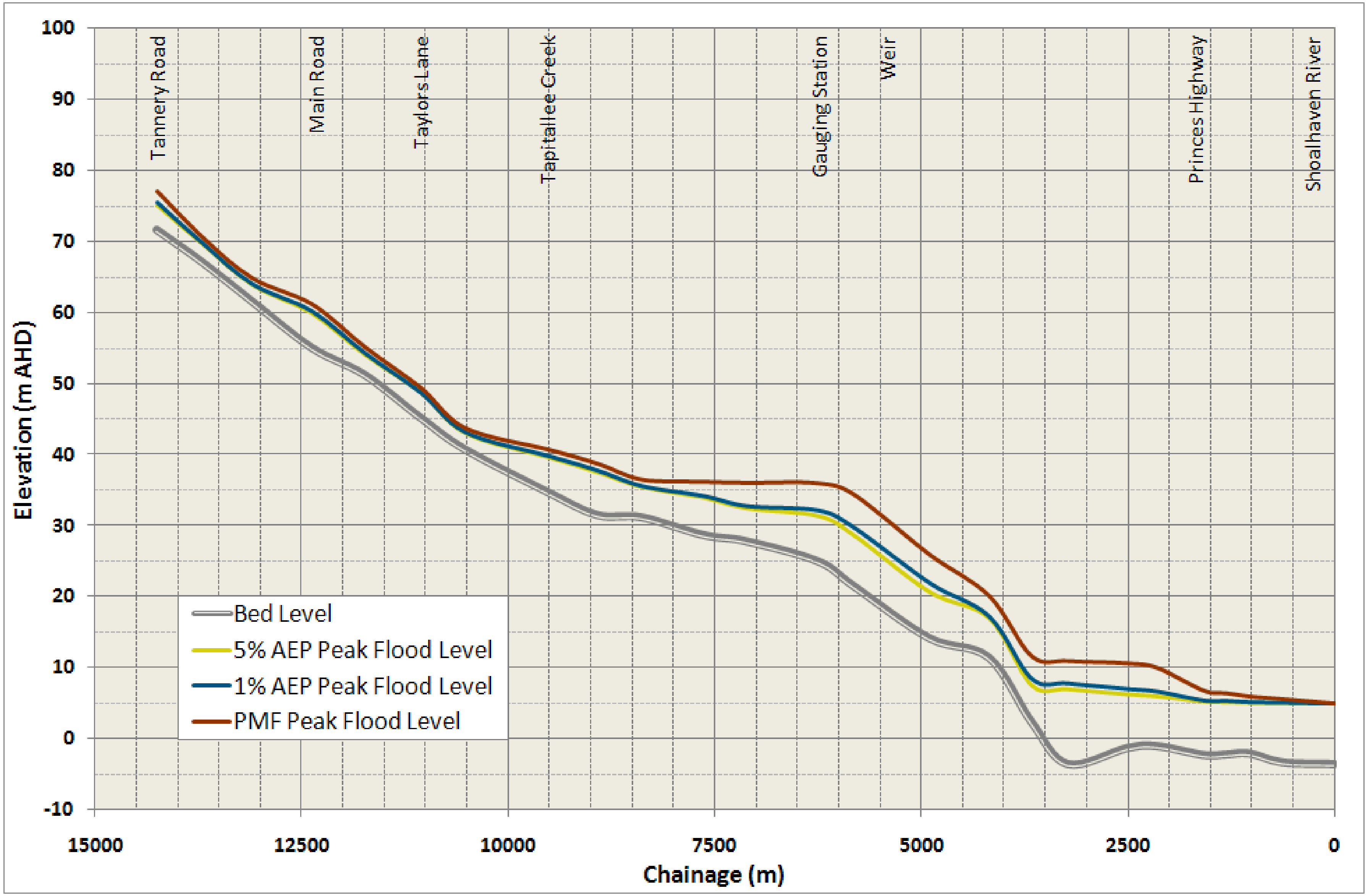


Figure 7-2 Design Peak Flood Level Profiles for Bomaderry Creek/Good Dog Creek

The topography of the Bomaderry Creek catchment and the associated flood behaviour can be characterised by four distinct geographical sections including:

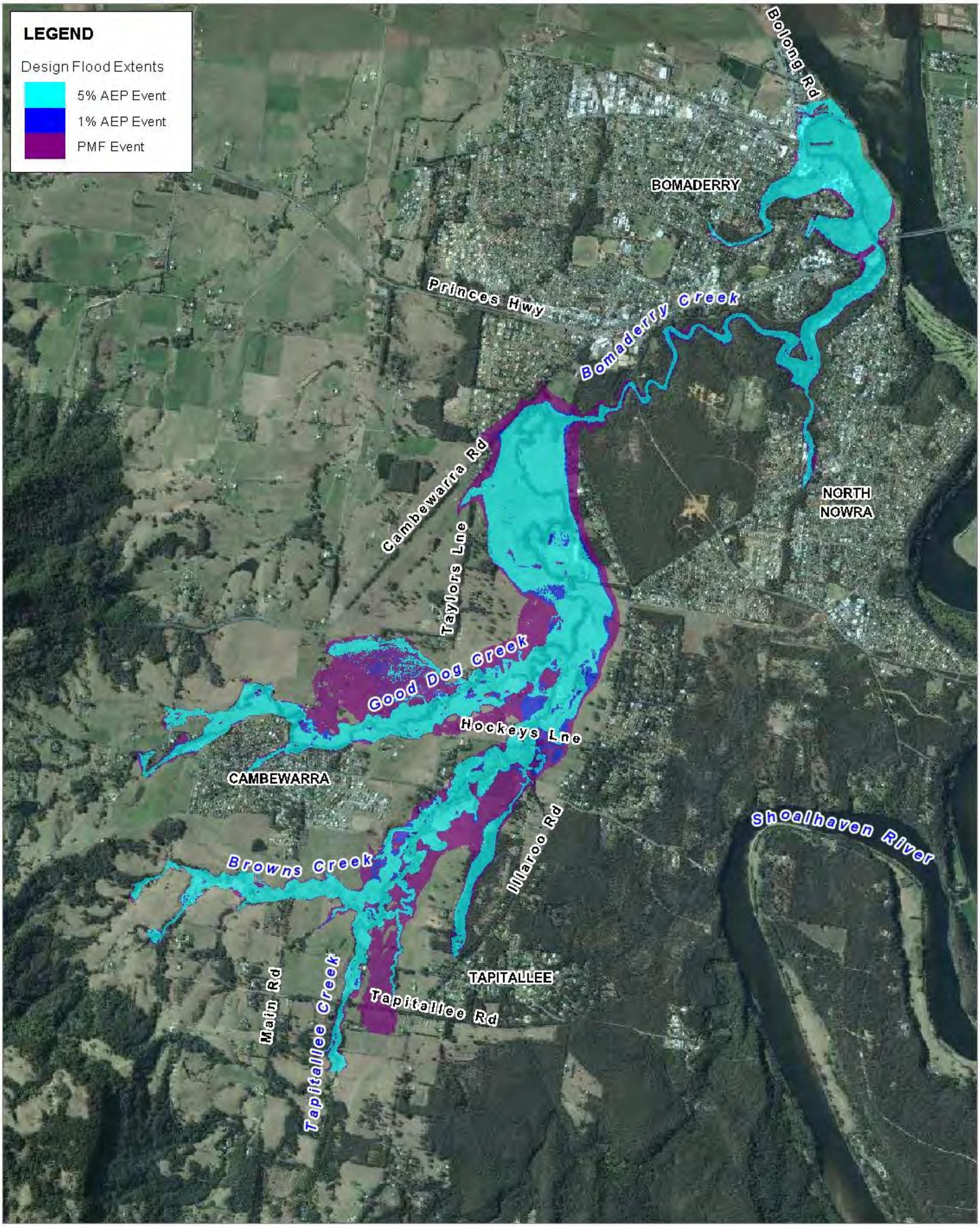
- Relatively steep upper catchments on all of the main tributaries including Good Dog Creek and Tapitallee Creek;
- A generally flatter "middle floodplain" from the confluence of Good Dog Creek and Tapitallee Creek (start of Bomaderry Creek) to the entrance to Bomaderry Gorge;
- Highly incised steep and narrow gully through Bomaderry Gorge; and
- Relatively flat "lower floodplain" from approximately 1.5km upstream of the Princes Highway Bridge that broadens to the confluence with the Shoalhaven River.

These distinct sections are evident in the bed profiles shown in Figure 7-1 and Figure 7-2, and further identifiable on the simulated design flood inundation extents for the Bomaderry Creek catchment shown in Figure 7-3. The simulated flood inundation extents for the 5% AEP, 1% AEP and PMF events are shown for comparison.

In the upper catchments, characterised by relatively steep topography, there is only a small increase in the inundation extent for the 1% AEP event compared with the 5% AEP extent. Floodwaters are effectively conveyed within the main channel and fringing floodplain, without widespread inundation. Significantly, there is no major property inundation with little existing development occupying the active floodplain areas. Under the simulated PMF conditions, the extent of flood inundation increases considerably, but again given the low level of development in the upper catchment, no major risk to existing development is identified. As noted previously, the main Cambewarra township generally occupies higher ground, and is removed from the active floodplain areas of the adjacent Good Dog Creek and Browns Creek even under simulated PMF conditions.

A minor tributary of Good Dog Creek flows through the Cambewarra village, mainly through the open parkland incorporating Howels Faulks Park. This watercourse has not been modelled in detail in the current study (not considered mainstream flooding of the Good Dog Creek/Bomaderry Creek system) and accordingly simulated flood conditions presented should be viewed with caution. A more locally detailed study of this minor catchment would be more appropriate in defining design flood conditions through the village.

In the reach from the confluence of Good Dog Creek and Tapitallee Creek to the entrance to Bomaderry Creek Gorge, the natural topography generally flattens with a widening of the floodplain and a corresponding increase in design flood inundation extents and flow depths. The broader floodplain area bounded by Cambewarra Road and Taylors Lane to the north and West Cambewarra Road to the south, some 500m to 600m becomes active floodplain in major events. Flooding in this region is exacerbated by the natural control formed by the constriction into the Bomaderry Creek Gorge. This is particularly evident for the PMF event. The design peak water level profiles for the PMF event shown in Figure 7-1 and Figure 7-2 indicate an extensive backwater influence from the constriction at the head of the Bomaderry Creek Gorge. The backwater influence extends to the confluence of Good Dog Creek and Tapitallee Creek from which point the stream profiles rise relatively steeply thereby limiting further backwater influence upstream.



Title:
Design Flood Inundation Extents for Bomaderry Creek

Figure:
7-3

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A

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0 0.75 1.5km
Approx. Scale

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The Bomaderry Creek Gorge is a highly incised, steep sided and narrow valley. The hydraulic control imposed by the Bomaderry Creek gorge effectively separates the lower floodplain of Bomaderry Creek from the middle and upper parts of the catchment. Flood extents are limited to within the Gorge driven by the natural topography, with no impact on adjacent development sited on the higher ground along the Princes Highway. There is a low flow weir within the Bomaderry Creek Gorge reach. At flood magnitudes however, the structure would effectively be drowned out and given the steepness of the channel, the hydraulic effect of the weir does not extend beyond the Gorge reach even for low flow regimes.

Downstream of the Bomaderry Creek Gorge there is a gradual flattening of the water level profile on the lower floodplain also reflected by the bed profile. The simulated design flood conditions adopted a 5% AEP flooding condition in the Shoalhaven River (approximately 5m AHD at Bomaderry Creek confluence). Accordingly there is significant backwater influence from this coincident Shoalhaven River flooding condition that extends some 1.5km upstream of the Princes Highway Bridge shown in the design flood water level profiles. In the absence of major flooding condition in the Shoalhaven, the Bomaderry Creek water level profiles would show a similar low gradient extending from downstream of the Gorge to the Shoalhaven River confluence, corresponding to the deepening and widening of the channel in this reach and the lower gradient of the bed profile.

Design flood velocities for the range of events simulated are included in the mapping series presented in Appendix A. The flood velocity distributions also generally reflect the four distinct reaches as discussed above, being the upper reaches of the major tributaries, the middle floodplain of Bomaderry Creek, the Bomaderry Creek Gorge and the lower floodplain around the Shoalhaven River confluence.

The velocity distributions for the upper reaches of the tributary channel generally show higher velocities in the channel, however, often the channel is not well defined within the undulating topography along the general channel alignment. As the flood extents increase on the middle floodplain, generally high velocities are retained in-channel and within the riparian corridor, but reduce towards the outer limits of the inundation where the floodplain largely provides a storage function. The channel also becomes better defined such that higher in-channel velocities are maintained within the reach.

As expected in the Bomaderry Creek Gorge, the steep narrow channel section exhibits high peak flow velocities under design flood conditions. Flow velocities in excess 5m/s may be expected in the steepest sections of this reach.

Downstream of the Bomaderry Creek Gorge, in-channel velocities remain relatively high as the bulk of the flow is conveyed in the wider and deeper channel section of this reach. Floodplain velocities, particularly downstream of the Princes Highway Bridge, are generally low, reflecting the storage function provided by the floodplain area such as along Bolong Road.

The same general patterns of velocity distribution are seen across the range of events, albeit increasing in actual peak velocity with increasing design flood magnitude. For the PMF event, higher velocities extend across a greater width of floodplain as more of the floodplain is required for peak flood conveyance. The PMF peak flood velocity distribution shows some reduced flood velocities upstream of Bomaderry Creek Gorge. This reduction in velocity corresponds to the backwater influence of the constriction of flows through the entrance to the Gorge.

7.3.2 Flood Hydrographs

The simulated design hydrographs at the entrance to Bomaderry Creek Gorge, just downstream of the gauging station, are shown in Figure 7-4. This is a useful reference point for comparison of peak flows simulated for historical events. The peak flow simulated for the February 2008 event 118 m^3/s represents a flow approximately 40% lower than the 10% AEP event. As discussed previously, the February 2008 event has been estimated to be around a 20% AEP event based on comparison of the recorded rainfall and design rainfall estimates. Similarly, the August 1998 event represents only a minor event for the Bomaderry Creek catchment, estimated to be something of the order of a 50% AEP event.

The relative contributions of the Tapitallee Creek and Good Dog Creek to the peak flow in Bomaderry Creek at the gauging station is summarised in Table 7-5. Note that the flow for Bomaderry Creek presented in the table is slightly higher than the combined totals from the main tributary catchments. This corresponds to the additional flow contribution from the small local catchment area (3.5km^2) from downstream of the confluence of Tapitallee Creek and Good Dog Creek to the gauging station.

Table 7-5 Design Peak Flows for Bomaderry Creek

Sub-catchment	Design Event Frequency					
	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Tapitallee Creek	156	194	234	273	317	741
Good Dog Creek	92	110	133	154	174	366
Bomaderry Creek	250	309	375	441	505	1133

The Tapitallee Creek catchment, incorporating Browns Creek also, provides the majority of the flow to Bomaderry Creek. The contributing catchment areas to the confluence are 17.5km^2 and 10.2km^2 respectively for Tapitallee Creek and Good Dog Creek.

An example of the relative timing of the contributions from Tapitallee Creek and Good Dog Creek to the combined Bomaderry Creek flow at the entrance to the Gorge is shown in Figure 7-5 for the 1% AEP design event. The peak flows from both catchments occur relatively simultaneously at the confluence. This is largely a product of the similar mainstream lengths of Tapitallee Creek and Good Creek.

The 9-hour design event has been simulated as the critical duration event for the Bomaderry Creek catchment (6-hour for the PMF), resulting in the highest peak flow conditions in the lower floodplain where existing development is concentrated. The simulated hydrographs shown in Figure 7-5 have a relatively rapid rise. This has consequences in terms of flood warning and response which should be considered in future floodplain management investigations.

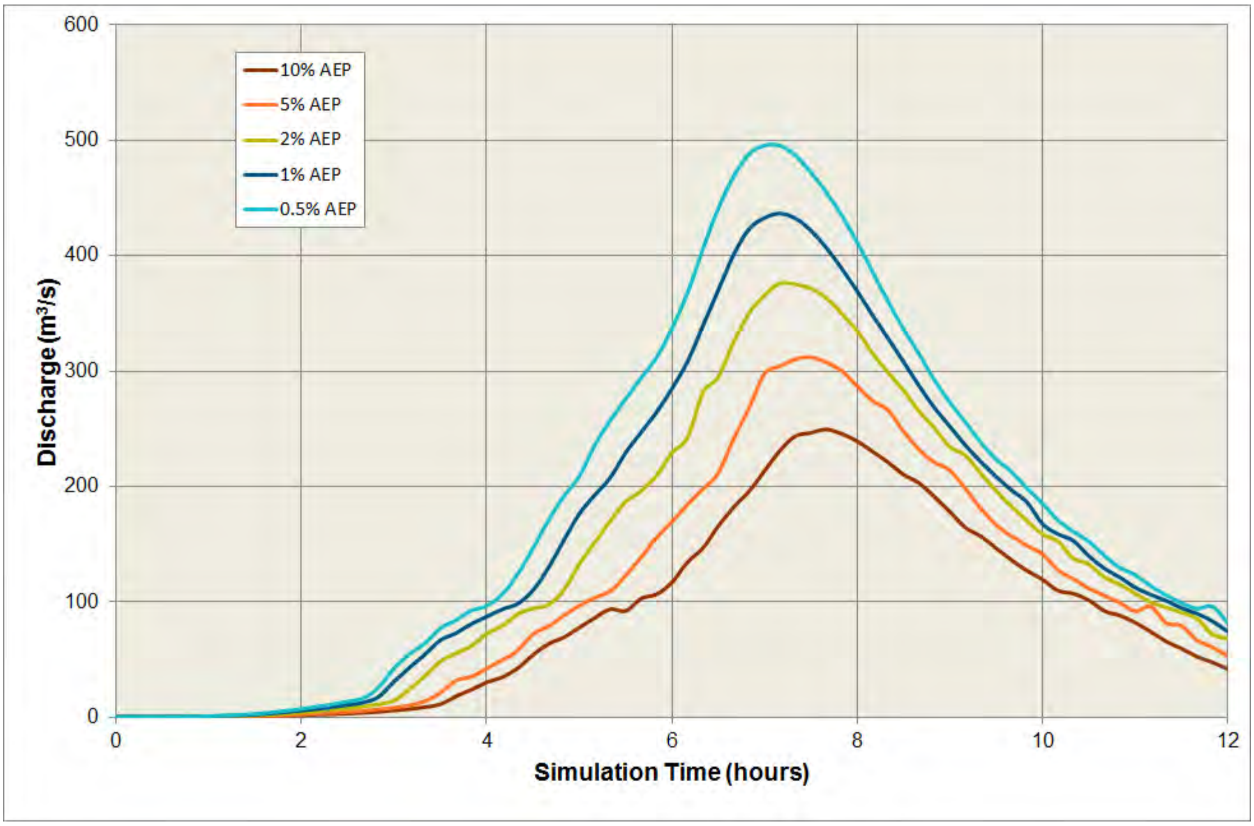


Figure 7-4 Design Flood Hydrographs for Bomaderry Creek (U/S Bomaderry Gorge)

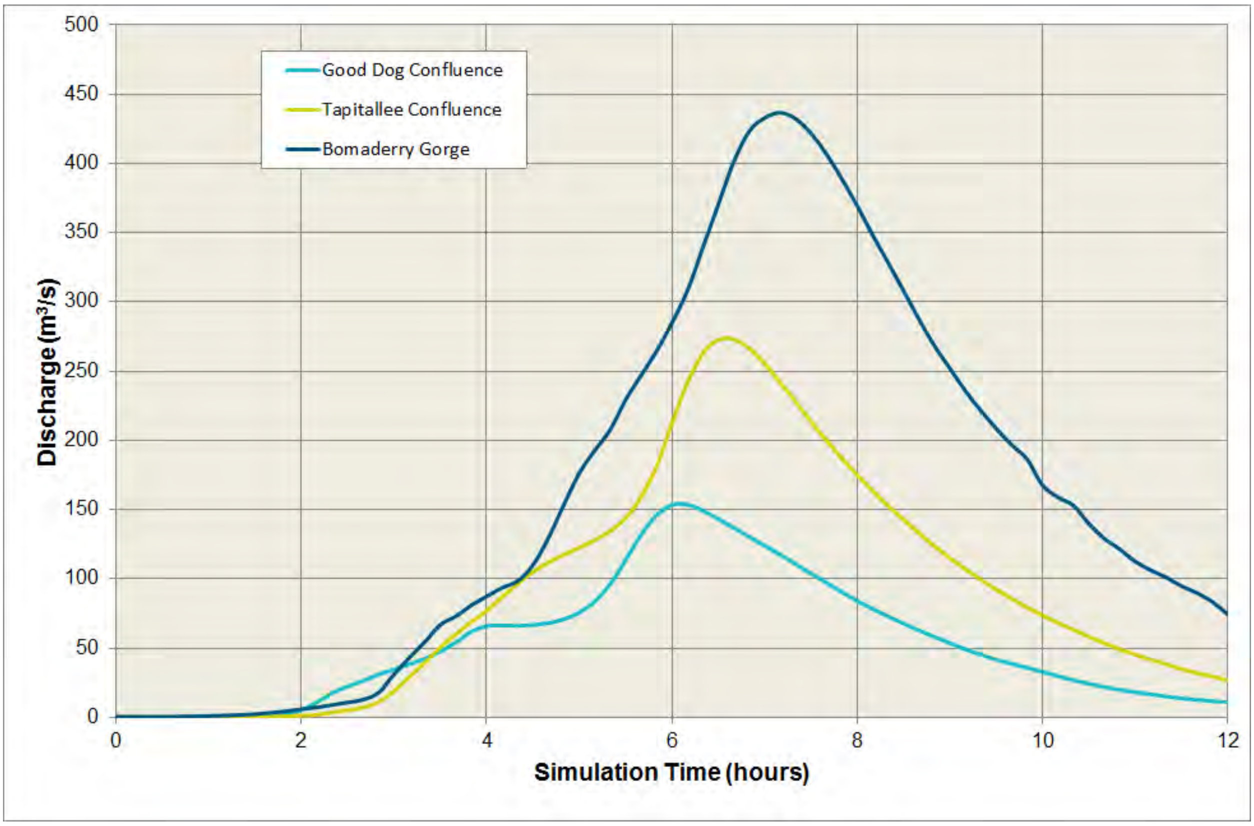


Figure 7-5 Timing of Design 1% AEP Hydrographs for Bomaderry Creek

7.3.3 Hydraulic Categorisation

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the Floodplain Development Manual (NSW Government, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

The hydraulic categories as defined in the Floodplain Development Manual are:

- **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 the area is substantially removed by levees or fill it will result in 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.

A number of approaches were considered when attempting to define flood impact categories across the Bomaderry Creek catchment. Approaches to define hydraulic categories that were considered for this assessment included partitioning the floodplain based on:

- Peak flood velocity;
- Peak flood depth;
- Peak velocity * depth (sometimes referred to as unit discharge);
- Cumulative volume conveyed during the flood event; and
- Combinations of the above.

The definition of flood impact categories that was considered to best fit the application within the Bomaderry Creek catchment, was based on a combination of velocity*depth and depth parameters. The adopted hydraulic categorisation is defined in Table 7-6.

Hydraulic category mapping for the 5% AEP, 1% AEP and PMF design events is included in Appendix A. It is also noted that mapping associated with the flood hydraulic categories may be amended in the future, at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts (e.g. if it is to change from floodway to flood storage).

Table 7-6 Hydraulic categories

Floodway	Velocity * Depth > 0.5	Areas and flowpaths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 0.5 and Depth > 0.5 metres	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Velocity * Depth < 0.5 and Depth < 0.5 metres	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

7.3.4 Provisional Hazard

The NSW Government's Floodplain Development Manual (2005) defines flood hazard categories as follows:

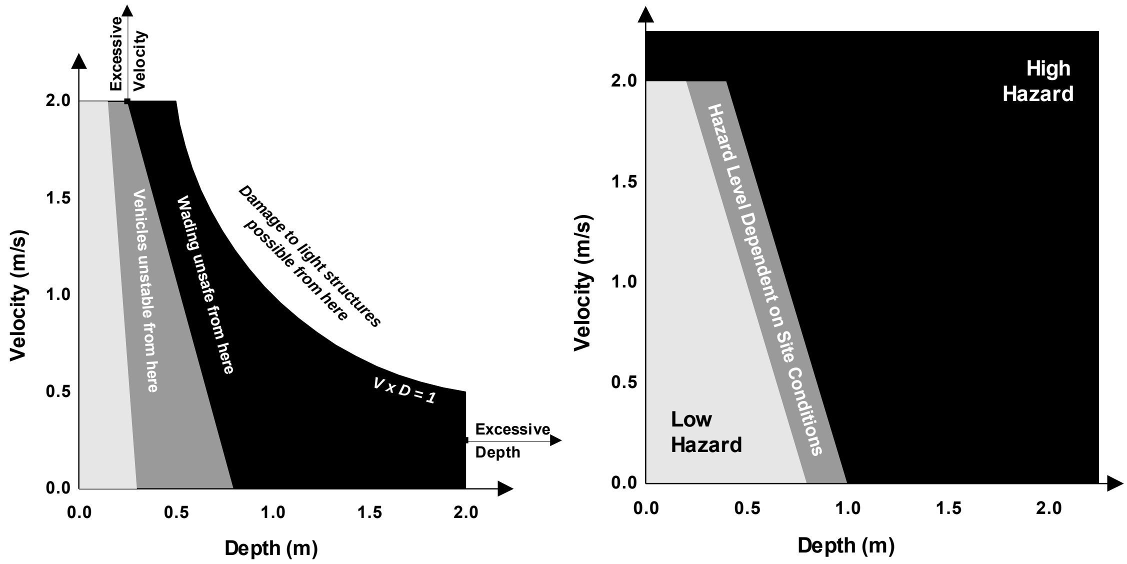
- **High hazard** – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and
- **Low hazard** – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

- Size of the Flood
- Rate of Rise - Effective Warning Time
- Community Awareness
- Flood Depth and Velocity
- Duration of Inundation
- Obstructions to Flow
- Access and Evacuation

The provisional flood hazard level is often determined on the basis of the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities have no major threat.

Figures L1 and L2 in the Floodplain Development Manual (NSW Government, 2005) are used to determine provisional hazard categorisations within flood liable land. These figures are reproduced in Figure 7-6.



Velocity Depth Relationships **Provisional Hazard Categories**

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Figure 7-6 Provisional Flood Hazard Categorisation

The provisional hydraulic hazard is included in the mapping series provided in Appendix A for the 5% AEP, 1% AEP and PMF events.

7.4 Sensitivity Tests

A number of sensitivity tests have been undertaken on the modelled flood behaviour in Bomaderry Creek. In defining sensitivity tests, consideration is given to the most appropriate tests taking into account catchment properties and simulated design flood behaviour. The tests undertaken have included:

- increased hydraulic roughness;
- structure blockage; and
- reduced design rainfall losses.

The rationalisation for each of these sensitivity tests along with adopted model configuration/parameters and results are summarised in the following sections. The impact of the sensitivity tests on the standard design 1% AEP flood condition is also presented in Appendix B as a series of peak water level afflux diagrams.

7.4.1 Hydraulic Roughness

The Bomaderry Creek catchment remains largely undeveloped with the predominant land use being rural pasture. Accordingly, there is likely to be a significant seasonal variation in floodplain vegetation. In addition the major watercourses are predominantly tree lined, with varying degrees of in-channel vegetation dependent on the local conditions. An example of some typical channel and floodplain conditions with respect to vegetation coverage is shown in Figure 7-7.

Figure 7-7 Tapitallee Ck D/S Hockeys Lane and Browns Ck/Tapitallee Ck Floodplain

The lack of historical flood water levels throughout the study has limited the degree of model calibration with respect to hydraulic conditions, in particular the adopted hydraulic roughness parameters. The design parameters adopted have been based on standard literature values and previous experience in modelling floodplains of this nature. Nevertheless, the potential variance of this property for on-ground conditions warrants consideration of its impact on design flood conditions.

The objective of the hydraulic roughness sensitivity is to assess the impact on peak flood water levels of a highly vegetated state for the channel and floodplain. For this analysis, a 50% increase in the adopted design values has been assumed. For example an in-bank Manning's „n' value may be increased from 0.06 to 0.09 and floodplain value of 0.1 increased to 0.15.

The peak water levels with the increased hydraulic roughness conditions and relative change from standard conditions is summarised at key locations in Table 7-7 for the 20% AEP, 1% AEP and PMF events simulated, with afflux mapping included in Appendix B for the 1% AEP event only.

As indicated in Table 7-7, there is a general increase in flood water levels across the study area as expected for higher roughness conditions. The afflux is generally of the order of 0.3m for the 5% AEP and 1% AEP flood condition. Higher affluxes are simulated for the PMF event where the inundation extents are significantly wider with a corresponding increase in the influence of higher floodplain roughness.

Whilst general peak water levels are increased across the study area for the higher roughness conditions adopted, significantly there are no major increases in design flood extents or activation of alternative flow paths.

The increased roughness also has a minor influence on design flow rates, essentially providing for increased attenuation of flood flows through the catchment by reduced flow velocities, increased flow depths and accordingly an increase in temporary flood storage.

Table 7-7 Peak Flood Levels with 50% Increase in Adopted Hydraulic Roughness

Location	Design Event Frequency		
	20% AEP	1% AEP	PMF
Bomaderry Creek			
Princes Highway	5.7 (0.07)	6.2 (0.10)	10.2 (0.53)
Gauging Station	31.3 (0.14)	32.3 (0.17)	36.5 (0.42)
Good Dog Ck Confluence	39.5 (0.27)	39.8 (0.32)	41.1 (0.49)
Tapitallee Creek			
Hockeys Lane	43.1 (0.32)	43.5 (0.31)	44.6 (0.42)
Browns Creek Confluence	51.1 (0.27)	51.5 (0.27)	52.5 (0.31)
Tapitallee Road	55.8 (0.41)	56.3 (0.48)	58.1 (0.69)
Good Dog Creek			
Taylors Lane	48.7 (0.21)	49.0 (0.21)	49.8 (0.31)
Main Road	59.6 (0.47)	59.9 (0.35)	61.0 (0.45)
Tannery Road	75.2 (0.32)	75.5 (0.35)	76.6 (0.53)

Note: Bracketed value is change in peak flood level from standard design conditions (ref: Table 7-4)

7.4.2 Structure Blockage

Debris conveyed in floodwater has the potential to partially or totally obstruct the waterway area at existing hydraulic structures. Most structures are associated with embankments such that a full or even partial blockage of these structures is likely to provide significant attenuation of peak flood flows as storage builds up behind the embankments. These blockages have the potential to substantially increase the magnitude and extent of property inundation through local increases in water level, redistribution of flows on the floodplain, and activation of additional flow paths.

The major hydraulic structures incorporated in the hydraulic model were summarised in Table 5-2, that vary in both size and configuration. The following blockage assumptions have bee applied for the sensitivity tests:

- 50% blockage for structures with a major diagonal opening width less than 6m;
- 25% bottom up blockage for structures with a major diagonal opening width greater than 6m; and
- 50% blockage for handrails over structures where overtopping occurs.

The change in peak water levels with the assumed blockage conditions is summarised at key locations (generally corresponding to the structure locations) in Table 7-8 for the 20% AEP, 1% AEP and PMF events simulated. Mapping of the extents of the simulated afflux is included in Appendix B for the 1% AEP event. Table 7-8 shows the simulated peak flood level with the assumed structure blockage, along with the change from the standard (no blockage) flood conditions shown in brackets.

Table 7-8 Peak Flood Levels with Structure Blockage

Location	Design Event Frequency		
	20% AEP	1% AEP	PMF
Bomaderry Creek			
Princes Highway	5.9 (0.26)	6.6 (0.47)	10.0 (0.34)
Gauging Station	31.1 (0.00)	32.1 (0.00)	36.0 (0.00)
Good Dog Ck Confluence	39.2 (0.00)	39.5 (0.00)	40.6 (0.00)
Tapitallee Creek			
Hockeys Lane	42.8 (0.00)	43.2 (0.00)	44.1 (-0.01)
Browns Creek Confluence	50.9 (0.00)	51.2 (0.00)	52.2 (0.00)
Tapitallee Road	55.5 (0.13)	55.9 (0.10)	57.8 (0.37)
Good Dog Creek			
Taylors Lane	48.5 (-0.01)	48.7 (0.00)	49.5 (-0.01)
Main Road	59.4 (0.18)	59.6 (0.02)	60.6 (0.05)
Tannery Road	74.9 (0.01)	75.1 (0.01)	76.1 (0.01)

Note: Bracketed value is change in peak flood level from standard design conditions (ref: Table 7-4)

As indicated in Table 7-8 and the map in Appendix B, afflux attributable to the adopted structure blockage scenarios result in only a localised impact. This is particularly the case on Tapitallee Creek and Good Dog Creek. Both of these tributaries have a relatively steep flood water level profiles (0.5% to 1%). Accordingly, generated afflux is limited in extent of upstream influence. The flatter profile of the lower Bomaderry Creek upstream of the Princes Highway Bridge results in a greater extent of afflux for blockage of this structure. However, again the extent is limited by the steeper profile of the channel through the Bomaderry Gorge.

The largest afflux is associated with the blockage of the Tapitallee Road bridge over Tapitallee Creek. For the 5% AEP and 1% AEP flood magnitudes, flow is largely contained in-bank in this highly incised reach. As such, direct blockage of the channel at the structure results in substantial increases in local flood water levels. As noted however, the extent of the afflux is limited by the relatively steep gradient of the channel upstream.

At the Main Road crossing of Good Dog Creek, the main bridge structure is by-passed in major flood events through overtopping of Main Road to the east of the bridge. Accordingly, the impact of structure blockage at this location is somewhat limited. A similar affect is noted at all structures for the PMF condition, where extensive structure by-pass (major overtopping and floodplain flows) limits the influence of blockage of the bridge waterway opening only.

7.4.3 Design Rainfall Losses

There are a number of potential sensitivity tests related to the hydrological parameters. The model simulation of catchment response provided a relatively good comparison with observed conditions at the Bomaderry Creek gauge. As such the general catchment properties and routing parameters adopted in the models are considered to be representative of the catchment. In considering different events, the most influential variable will be the antecedent conditions and adopted rainfall losses (initial and continuing loss in developed model). For the design simulations undertaken, the initial loss of 10mm and continuing loss of 2.5mm/hr are towards the lower end of normally adopted ranges, thus more conservative in terms of design flood inundation. Further reduction in these losses would approach a fully saturated catchment condition.

For the sensitivity test, an initial loss of 0mm and continuing loss of 0mm/hr is adopted to represent a fully saturated catchment condition. This provides for an increase in effective rainfall and therefore an increase in surface runoff for the design rainfall condition. The change in peak water levels with the reduced rainfall losses is summarised at key locations in Table 7-9 for the 20% AEP, 1% AEP and PMF events simulate, with mapping of the extents of the simulated afflux for the 1% AEP included in Appendix B.

Table 7-9 Peak Flood Levels with Reduced Rainfall Losses

Location	Design Event Frequency		
	20% AEP	1% AEP	PMF
Bomaderry Creek			
Princes Highway	5.7 (0.09)	6.2 (0.10)	9.7 (0.09)
Gauging Station	31.3 (0.21)	32.3 (0.17)	36.2 (0.12)
Good Dog Ck Confluence	39.3 (0.06)	39.6 (0.05)	40.6 (0.03)
Tapitallee Creek			
Hockeys Lane	42.9 (0.08)	43.2 (0.05)	44.2 (0.02)
Browns Creek Confluence	51.0 (0.08)	51.3 (0.05)	52.2 (0.02)
Tapitallee Road	55.5 (0.11)	55.8 (0.05)	57.5 (0.05)
Good Dog Creek			
Taylors Lane	48.6 (0.06)	48.8 (0.03)	49.5 (0.02)
Main Road	59.3 (0.11)	59.6 (0.08)	60.6 (0.02)
Tannery Road	74.9 (0.05)	75.2 (0.05)	76.1 (0.02)

Note: Bracketed value is change in peak flood level from standard design conditions (ref: Table 7-4)

Design flows are increased by the reduction in adopted rainfall losses. As expected this results in a general increase in the simulated peak flood water level condition throughout the study area. The magnitude of the water level increases (generally <0.2m) for this sensitivity test is significantly less than the corresponding impact of the hydraulic roughness sensitivity test presented in Section 7.4.1.

7.5 Future Development

The principal components of future development in the Bomaderry Creek catchment identified in the Nowra Bomaderry Structure Plan include:

- Future western bypass corridor that traverses the Bomaderry Creek catchment with a single major crossing of Bomaderry Creek just downstream of the confluence of Tapitallee and Good Dog Creeks;

- Future living area adjacent to Good Dog Creek extending to Cambewarra Road (north side of proposed bypass), that is centred around the higher ground in the vicinity of Taylors Lane; and
- Mixed zone of possible future living area, school and neighbourhood centre (south side of proposed bypass) again centred on higher ground around Taylors Lane but extending to the south towards the Bomaderry Creek floodplain.

The general footprints of this development are shown in comparison to the simulated 1% AEP and PMF inundation extents. The development area on the north side of Cambewarra Road lies outside the Bomaderry Creek floodplain in a neighbouring catchment. Most of the development appears to be suitably sited with respect to Bomaderry Creek flooding. However, there are potentially significant flooding risks associated with the semi-circular footprint south of Taylors Lane identified as “Future School” and also the future western by-pass corridor that traverses the floodplain.

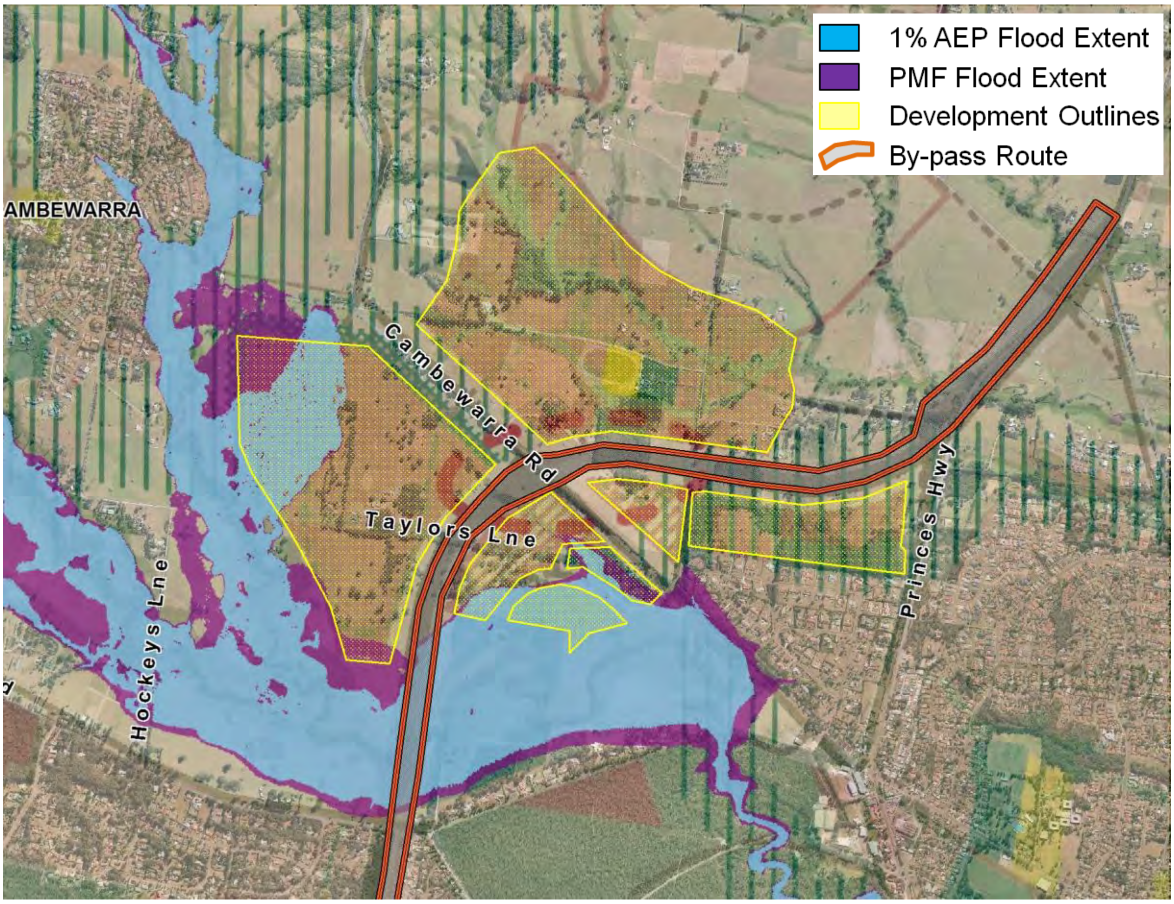

Figure 7-8 Structure Plan Future Development and Design 1% AEP and PMF Inundation Extents

Detailed consideration of potential future development with respect to flooding is beyond the scope of the flood study. Future floodplain management activities within the catchment would be expected to address future development and identify suitable controls for reducing flood risk.

8 CONCLUSIONS

The objective of the study was to undertake a detailed flood study of the Bomaderry Creek catchment and establish models as necessary for accurate flood level prediction. Central to this was the development of a two-dimensional hydraulic model of the floodplain incorporating both the upper catchment around Cambewarra and lower catchment around Bomaderry.

In completing the flood study, the following activities were undertaken:

- Collation of database of historical flood information for the Bomaderry Creek catchment;
- Acquisition of topographical data for the catchment including cross section and hydraulic structure survey;
- Consultation with the community to acquire historical flood information and liaison in regard to flooding concerns/perceptions and future floodplain management activities;
- Development of a hydrological model (using RAFTS-XP software) and hydraulic model (using TUFLOW software) to simulate flood behaviour in the catchment;
- Calibration of the developed models using the February 2008 and August 1990 flood events;
- Prediction of design flood conditions in the catchment using the calibrated models; and
- Production of design flood mapping series.

The model calibration process was somewhat constrained by the lack of adequate historical flood data. Nevertheless for the principal calibration event, the developed models provided a good representation of the catchment response to flood event magnitude rainfall.

The developed models have been applied to derive design flood conditions within the Bomaderry Creek catchment. Whilst there is significant inundation of the floodplain for major design flood events, the extent of property affected is largely limited to undeveloped open space. The major urban centres of Cambewarra and parts of North Nowra and Bomaderry, are principally located on higher ground within the catchment, and largely removed from mainstream Bomaderry Creek flooding. The lack of historical flood data, particularly in the upper catchment, is considered to be an indication of the relatively limited extent of flood affectation for existing property.

The majority of flood data available for the catchment lies at the lower of Bomaderry Creek (e.g. Bolong Road) corresponding to major events in the Shoalhaven River. Indeed the dominant flood mechanism in terms of peak flood water levels in the lower floodplain of Bomaderry Creek is Shoalhaven River backwater flooding.

The flooding behaviour of Bomaderry Creek is a key constraint in the future planning and design of infrastructure within the catchment. The completed flood study establishes the design flood conditions and provides the best available information to inform of potential flood risk and set appropriate planning and development controls to accommodate this future development within the catchment. Some of this future development has already been defined in the Nowra Bomaderry Structure Plan

(Shoalhaven City Council, 2008) that provides a framework for the integrated development of the Nowra Bomaderry area, including Cambewarra.

The flood study will form the basis for the subsequent floodplain risk management activities, being the next stage of the floodplain management process. Accordingly, the adoption of the flood study and predicted design flood levels is recommended.

Given the significant influence of Shoalhaven River flooding on the predicted flood behaviour of the Lower Bomaderry Creek catchment, future flood studies and floodplain management studies relating to the broader Shoalhaven River catchment should feed back into the Bomaderry Creek floodplain management process.

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