“Where will our knowledge take you?”

Wollombi Brook Flood Study

Final Report

R.N2390.001.04 November 2016

Singleton COUNCIL
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Wollombi Brook Flood Study

Prepared for:	Singleton Council
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Synopsis:	**Final Report for the Wollombi Brook Flood Study covering the development and calibration of hydrologic and hydraulic models, establishment of design flood behaviour and flood mapping.**	

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	09/02/2015	DJL		JDE	
1	09/03/2015	DJL		JDE	
2	04/07/2016	DJL		JDE	
3	25/07/2016	DJL		JDE	
4	30/11/2016	DJL		JDE	

DISTRIBUTION

Destination	Revision										
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Executive Summary

Introduction

The Wollombi Brook Flood Study has been prepared for Singleton Council to define the existing mainstream flood behaviour in the Wollombi Brook catchment and establish the basis for subsequent floodplain management activities.

The primary objective of this Flood Study is to define the mainstream flood behaviour under historical, existing and future conditions (incorporating potential impacts of climate change) in the Wollombi Brook catchment for a full range of design flood events. The study provides information on flood levels and depths, velocities, flows, hydraulic categories and provisional hazard categories. The Flood Study has also identified the impact on flood behaviour as a result of future climate change. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertaking of 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 hydrological and hydraulic models;
- Determination of design flood conditions for a range of design events including the Extreme Flood (3 x 1% AEP), 0.5%, 1%, 2%, 5%, 10% and 20% AEP events; and
- Assessment of potential impact of climate change using the latest guidelines.

Catchment Description

The Wollombi Brook catchment is located within the Hunter Valley of New South Wales draining a catchment area of some 1,870km^2. The Wollombi Brook catchment is divided between the Singleton LGA (51% of catchment area) and the Cessnock LGA (49% of catchment area). The LGA boundary is located on Wollombi Brook at Paynes Crossing.

The Wollombi Brook flows in a general south-north direction from its source in the Watagan Ranges to its confluence with the Hunter River near Warkworth, some 16km upstream of Singleton.

A number of townships are located within the Wollombi Brook catchment including Warkworth, Bulga, Fordwich and Broke in the Singleton LGA and Wollombi, Paxton, Millfield and Laguna in the Cessnock LGA.

Community Consultation

Community consultation is an important component of the Flood Study. The consultation has aimed to inform the community about the development of the Flood Study and predicted flood behaviour as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on their flood experience, their concerns on flooding issues and to collect feedback on the draft flood study.

Model Development

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. For the purpose of the Flood Study, a hydrological model and a hydraulic model have been developed.

The **hydrological model** simulates the catchment rainfall-runoff processes, producing the stormwater flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the overland flow paths, creeks and lagoon producing flood inundation extents, levels and velocities.

Information on the topography and characteristics of the catchments and floodplains are built into the hydraulic model. Recorded historical flood data, including rainfall and flood levels, are used to simulate and validate (calibrate and verify) the model. The model produces as outputs, the distribution of flood levels, flow rates (discharges) and flow velocities.

With consideration to the available survey information and local topographical and hydraulic controls, a two-dimensional model was developed extending from the confluence of the Wollombi Brook and the Hunter River at Warkworth at the downstream limit, to eight kilometres upstream of Paynes Crossing. The floodplain area modelled within the 2D domain comprises a total area of approximately 320km^2.

Model Calibration and Validation

The selection of suitable historical events for calibration and validation of flood models is largely dependent on the availability of relevant 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 events to be considered.

Review of the available rainfall and water level data for the Wollombi Brook catchment highlighted three flood events with sufficient data to support a calibration process – the June 2007, April 2015 and June 1949 event. The June 2007 event has been selected as the primary calibration event with the April 2015 and June 1949 event used for model validation.

The models were found to provide a reasonable representation of the observed flood behaviour in the catchment.

Design Event Modelling and Output

The developed models have been applied to derive design flood conditions within the Wollombi Brook catchment. Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in Australian Rainfall and Runoff (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.

A suite of design event scenarios was defined that is most suitable for future floodplain management planning in the Wollombi Brook catchment. The design events simulated include the extreme flood event (3 x 1% AEP), 0.5%, 1%, 5%, 10% and 20% AEP events.

The model results for the design events considered have been presented in a detailed flood mapping series for the catchment (see separate mapping compendium). The flood data presented includes design flood inundation extents, peak flood water levels and depths and peak flood velocities.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped in addition to the hydraulic categories (floodway, flood fringe and flood storage) for flood affected areas.

Sensitivity Testing

A number of sensitivity tests have been undertaken to identify the impacts on the design flood levels. Sensitivity tests included:

- hydraulic roughness;
- structure blockage;
- design continual / infiltration loss;
- downstream Hunter River boundary; and
- 2013 Intensity–Frequency–Duration (IFD) Design Rainfall.

Climate Change

Regional climate change studies (e.g. CSIRO, 2004) indicate that there may be an increase in the maximum intensity of extreme rainfall events. This may include increased frequency, duration and height of flooding and consequently increased number of emergency evacuations and associated property and infrastructure damage.

An assessment of the potential impact of future climate change on future flooding conditions in the Wollombi Brook catchment has been undertaken for consideration in the ongoing floodplain risk management process.

Conclusions

Provided below is a summary of the key findings of the Flood Study, in particular some of the important considerations for future floodplain risk management in the catchment:

- The model simulations indicated the peak flood levels in the Wollombi Brook corresponded to the 36 hour duration with peak flood levels reached in the key locations of Paynes Crossing, Broke and Bulga at approximately 39 hours, 44 hours and 50 hours after the onset of rainfall respectively.
- Flooding in Broke and the surrounding floodplain emanates from both the Wollombi Brook and Yellow Rock Creek. Floodwaters overtop the banks of the Wollombi Brook and begin inundating areas of the Broke township in events greater than the 1% AEP design event (the 1% AEP event is generally contained within the Wollombi Brook with some out of bank flooding and inundation of the floodplain along the western bank and along Yellow Rock Creek to the north of the township).
- The design flood inundation extents for the 20% AEP, 1% AEP and Extreme Flood events are broadly similar within much of the catchment (particularly upstream of Brickmans Bridge). The floodplain upstream of the Brickmans Bridge is well-defined, with relatively steep sides. Although the flood depths increase significantly with event magnitude, there is little change in

the flood extents across the valley floor. However, downstream of Brickmans Bridge where the floodplain begins to widen, the change in flood extents is more pronounced (especially the increase in flood extents associated with the Extreme Flood event). This includes floodplain areas near Broke, the confluence with Parsons Creek, Bulga and the lower catchment around Warkworth.

- It should be noted that the defined flood extents and reported flood behaviour relates to mainstream flooding emanating from the Wollombi Brook with the critical flood conditions corresponding to a 36-hour duration storm event. It is expected that the critical flood conditions along the tributary alignments would correspond to storms of a much shorter duration. As such it is recommended that further investigations be undertaken to define the existing flood behaviour along the major tributary alignments, particularly Yellow Rock Creek and Parsons Creek, to be included in subsequent floodplain management activities.
- The model sensitivity testing showed that the model is particularly sensitive to the adopted continual rainfall loss parameter and hydraulic roughness (Manning's 'n') values (particularly in the upper catchment upstream of Brickman's Bridge).
- It should be noted that the model sensitivity is not an artefact of the adopted hydraulic modelling approach but rather a representation of the actual sensitivity of the catchment to changes in the type and distribution of in-channel and floodplain vegetation; changes to channel dimensions as a result of bank erosion or deposition of sediment; antecedent rainfall conditions and the volume and temporal distribution of rainfall across the catchment; and the level of blockage at major structures (each of these characteristics can vary between different flood events).
- The climate change analysis showed that although the simulated increases in design rainfall result in significant increases in simulated flood levels, there is limited change to the design flood extents.
- Based on the sensitivity of the simulated flood levels to structure blockage levels, it is recommended that the 1% AEP design event incorporating the blockage levels based on the recently released AR&R guidelines be adopted for use in flood planning.
- Furthermore, based on the sensitivity of the model and the significant increase in simulated peak flood levels between the 1% AEP and 0.5% AEP design event (up to 1.0m in some parts of the study area), it is recommended that consideration be given to an increased freeboard from the standard 0.5m to a more conservative 1.0m in establishing the Flood Planning Area (FPA) and associated Flood Planning Levels (FPLs).

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Glossary

afflux	The change in water level from existing conditions resulting from a change in the watercourse or floodplain – e.g. construction of a new bridge.
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.
astronomical tide	Astronomical tide is the cyclic rising and falling of the Earth's oceans water levels resulting from gravitational forces of the Moon and the Sun acting on the Earth.
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)
Australian Rainfall and Runoff (AR&R)	Engineers Australia publication pertaining to rainfall and flooding investigations in Australia
calibration	The adjustment of model confuguration and key parameters to best fit an observed data set
catchment	The catchment at a particular point is the area of land that drains to that point.
critical duration	The critical duration is the design storm duration which provides the highest peak water levels for a given design flood (e.g. 1% AEP) at a given location. For example, if the following design durations were modelled - 2-hour, 6-hour, 9-hour and 12-hour – and the 9-hour duration resulted in the highest peak water level at a given location then the critical duration for that location would be 9-hours.
design flood event	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).
Extreme Flood	An extreme flood deemed to be the maximum flood likely to occur (for this study the Extreme Flood event was defined as three times the 1% AEP event).
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) or extreme flood (3 x 1% AEP) 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 (FPLs)	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 or Extreme Flood 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, Narrabeen Lagoon 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.

hyetograph	A graph showing the depth of rainfall over time.
Intensity Frequency Duration (IFD) Curve	A statistical representation of rainfall showing the relationship between rainfall intensity, storm duration and frequency (probability) of occurrence.
isohyet	Equal rainfall contour
LiDAR	Light Detection and Ranging –a remote sensing method used to generate ground surface elevation. Typically acquired through airborne surveys from which an aeroplane can cover large areas.
morphological	Pertaining to geomorphology
overland flow	Overland flow is surface run off before it enters a waterway. It is caused by rainfall which flows downhill along low points concentrating in gullies, channels, surface depressions and stormwater systems.
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.
validation	A test of the appropriateness of the adopted model configuration and parameters (through the calibration process) for other observed events.
water level	See flood level.

1 Introduction

The Wollombi Brook Flood Study is being prepared for Singleton Council (Council) to define the existing flood behaviour in the Wollombi Brook catchment and establish the basis for subsequent floodplain management activities.

The study is being prepared to meet the objectives of the NSW State Government's Flood Prone Land Policy. This project has been conducted under the State Assisted Floodplain Management Program and received State financial support.

It should be noted that the objective of this flood study was to define the critical mainstream flood behaviour of the Wollombi Brook (i.e. the existing critical flood behaviour along the smaller tributary alignments was not defined). As such, further investigations are recommended to define the existing critical flood behaviour along the major tributary alignments, including the flooding emanating from Yellow Rock Creek around Broke and from Parsons Creek around Milbrodale, to be included in subsequent floodplain management activities.

1.1 Study Location

The Wollombi Brook catchment is located within the Hunter Valley of New South Wales draining a catchment area of some 1,870km^2 as shown in Figure 1-1. The Wollombi Brook catchment is divided between the Singleton LGA (51% of catchment area) and the Cessnock LGA (49% of catchment area). The LGA boundary is located on Wollombi Brook at Paynes Crossing (as shown in Figure 1-1).

The Wollombi Brook flows in a general south-north direction from its source in the Watagan Ranges to its confluence with the Hunter River near Warkworth, some 16km upstream of Singleton. The Wollombi Brook is fed by a number of tributaries as shown in Figure 1-1.

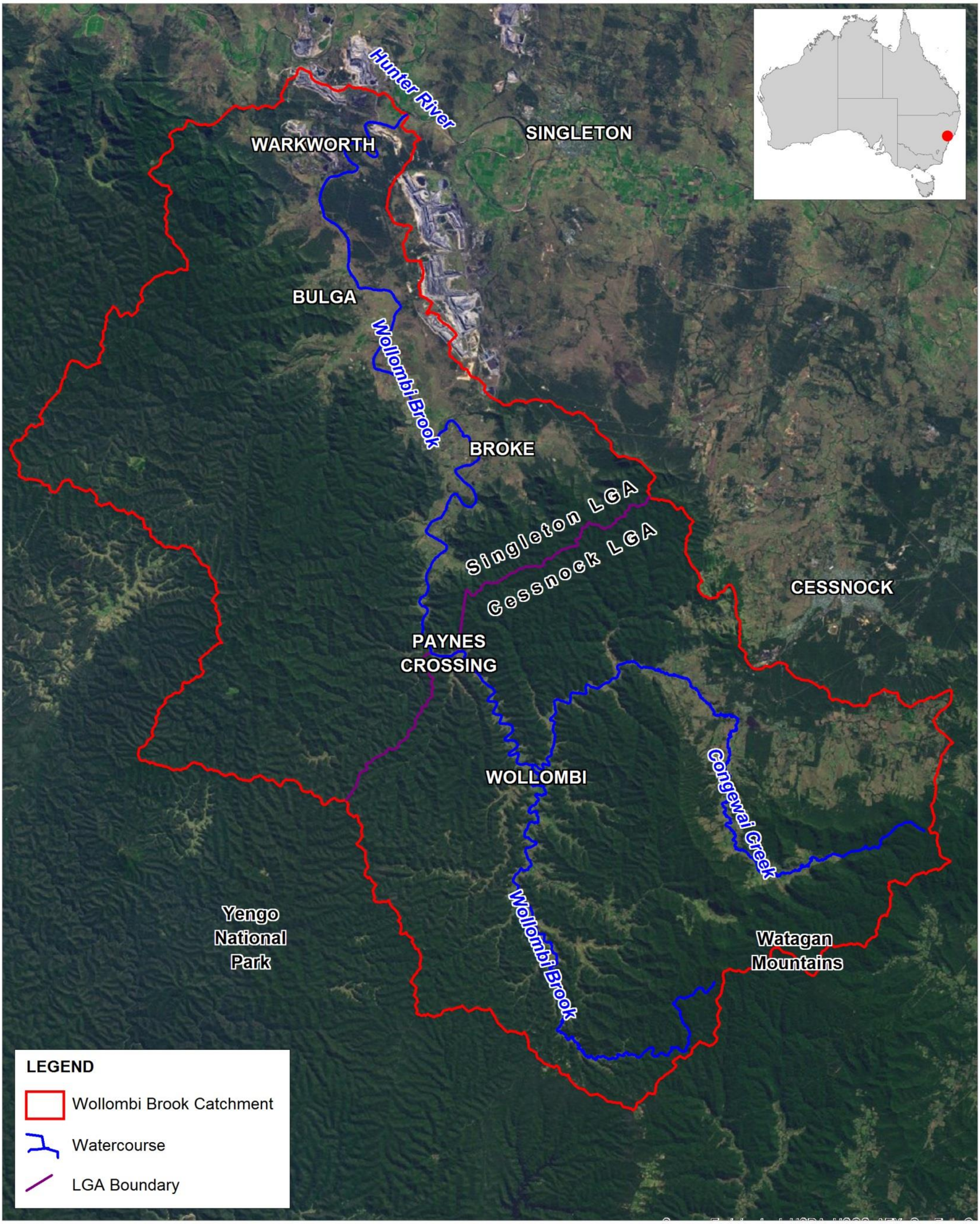
A number of townships are located within the Wollombi Brook catchment including Warkworth, Bulga, Fordwich and Broke in the Singleton LGA and Wollombi, Paxton, Millfield and Laguna in the Cessnock LGA.

The nominal limits for the hydraulic modelling undertaken in this Flood Study were defined by Council as Paynes Crossing (upstream limit) and the confluence with the Hunter River near Warkworth (downstream limit).

A more detailed description of the study area is presented in Section 2.1.

1.2 Study Background

The increasing popularity of the Wollombi Brook catchment has resulted in a steady rise in the number of development applications for residential dwellings, weekenders and farm buildings within the catchment. No flood studies have previously been undertaken within the Singleton LGA portion of the Wollombi Brook catchment and therefore no design flood data was available for Council's planning purposes. Without the use of design flood data Council has only been able to advise residents of historical flood levels where peak flood levels have been recorded.



Title:
Wollombi Brook Catchment Locality

Figure: 1-1

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This Flood Study will define the flood behaviour in the Wollombi Brook catchment and provide Council with information to enable informed management of flood risk and form the basis for a subsequent floodplain risk management study where detailed assessment of flood mitigation options and floodplain risk management measures will be undertaken.

1.3 The Need for Floodplain Risk Management in the Wollombi Brook Catchment

As evidenced in the June 2007 flood, a significant flood risk is posed to residents in the Wollombi Brook catchment. In addition to the primary concern of the safety of people and property, flooding can result in significant isolation and access problems and a disruption to services such as electricity, water supply and telecommunications.

In recent times there have been increased development pressures in the Wollombi Brook catchment with increasing demand for residential dwellings, weekenders and farm buildings. 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.

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 Wollombi Brook.

1.4 The Floodplain Risk Management Process

The NSW Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding problems in developed areas and potential future increases in flood risk and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Consideration is also given to the change in flood risk to existing and future development through potential climate change. Policy and practice are defined in the NSW Government's Floodplain Development Manual (2005).

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

The Policy provides for technical and financial support by the NSW Government through the six sequential stages shown in Table 1-1.

Table 1-1 Stages of Floodplain Management

	Stage	Description
1	Formation of a Committee	Established by Council and includes community group representatives and State agency specialists.
2	Data Collection	Past data such as flood levels, rainfall records, land use, soil types etc.
3	**Flood Study**	**Determines the nature and extent of the flood problem.**
4	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
5	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
6	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of local environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stage 3 of the above process and aims to provide an understanding of existing and future flood behaviour within the Wollombi Brook catchment.

1.5 Study Objectives

The primary objective of this Flood Study is to define the mainstream flood behaviour under historical, existing and future conditions (incorporating potential impacts of climate change) in the Wollombi Brook catchment for a full range of design flood events. The study will provide information on flood levels and depths, velocities, flows, hydraulic categories and provisional hazard categories. 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, advise on the outcomes of the flood study and flood behaviour predictions, and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrological and hydraulic models;
- Determination of design flood conditions for a range of design events including the Extreme Flood (3 x 1% AEP), 0.5%, 1%, 2%, 5%, 10%, and 20% AEP events; and
- Examine potential impact of climate change using the latest guidelines.

The models and results produced in this study are intended to:

- Outline the flood behaviour within the catchment to aid in Council's management of flood risk; and
- Form the basis for a subsequent floodplain risk management study where detailed assessment of flood mitigation options and floodplain risk management measures will be undertaken.

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 study and summary of background information.

Section 3 outlines the community consultation program undertaken.

Section 4 details the additional survey undertaken.

Section 5 details the streamflow gauge background and analysis undertaken.

Section 6 details the development of the computer models.

Section 7 details the hydraulic model calibration and validation process.

Section 8 details the design flood conditions.

Section 9 details the design flood results and associated flood mapping including sensitivity tests.

Section 10 details the climate change analysis.

Section 11 details the conclusions of the study.

2 Study Approach

2.1 The Study Area

2.1.1 Catchment Description

As shown in Figure 1-1, the upper reaches of the Wollombi Brook catchment is drained by two main tributaries:

- Wollombi Brook South Arm (also known simply as Wollombi Brook): This tributary drains the southern and western sections of the catchment; and
- Congewai Creek (also known as the northern arm of Wollombi Brook): This tributary drains areas of the catchment to the east of Wollombi Village.

The confluence of these two tributaries occurs at the Wollombi Village. Downstream of the confluence, Wollombi Brook, also known as Cockfighter's Creek, flows northwards for some 45km to its confluence with the Hunter River at Warkworth around 16km to the west of Singleton.

The topography of the catchment is shown in Figure 2-1, including the upper catchment and lower floodplain areas. From the highest point in the upper catchment in the Watagan Ranges, at some 640m AHD, the Wollombi Brook catchment rapidly descends to Wollombi Village at approximately 100m AHD.

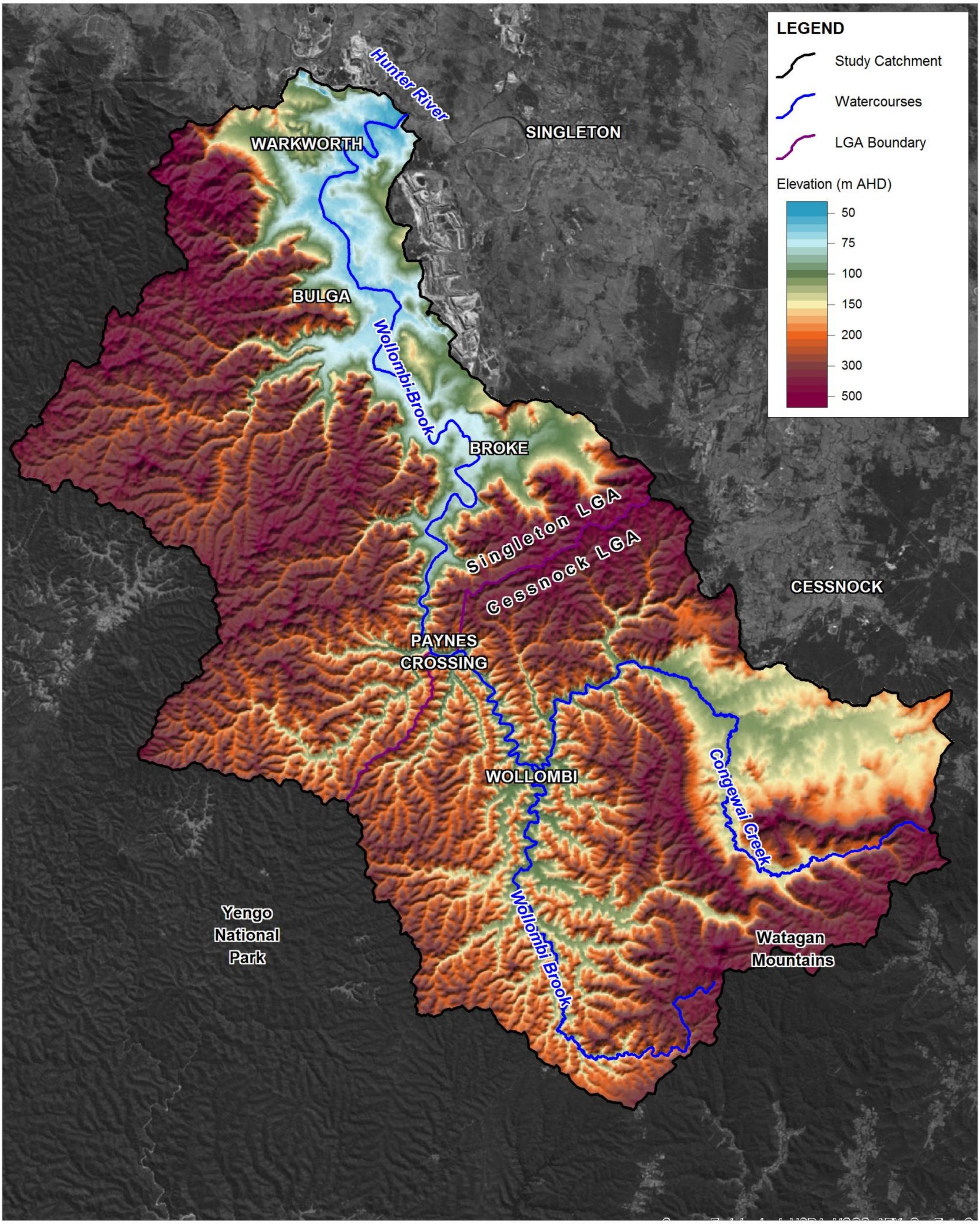
The catchments of the two tributaries upstream of Wollombi Village are typically steep sided and forested with a cleared, relatively narrow floodplain on the valley floors. The combination of these features results in a 'flashy' catchment that converts rainfall rapidly into relatively large flow rates and elevated flood levels.

In the locality of Wollombi Village, the Wollombi Brook, Congewai Creek and Yango Creek converge. The total contributing catchment area to the confluence is some 815km^2.

Downstream of Wollombi Village, Wollombi Brook remains a highly incised channel with a narrow floodplain until Broke. Downstream of Broke the floodplain widens progressively for the remaining 42km to the confluence with the Hunter River passing through the townships of Fordwich, Bulga and Warkworth.

The Wollombi Brook downstream of Payne's Crossing is fed by a number of tributaries draining areas of the Yengo and Pokolbin State Forests and Yengo National Park as shown on Figure 2-2. These tributaries include Stockyard Creek, Werong Creek, Drews Creek, Parsons Creek and Wambo Creek that each drain significant areas of the forested slopes to the west of the floodplain (Yengo National Park and Yengo State Forest); and Yellow Rock Creek and Monkey Place Creek which drain the Pokolbin State Forest south-east of Broke. Each of the above mentioned tributaries are fed by a series of small tributaries in the forested upper catchment.

The great majority of the catchment is forested, particularly beyond the floodplain fringes. Land use on the floodplain is predominantly livestock grazing and other farming enterprises including wineries; and sparse rural development. Coal mining is also undertaken in parts of the lower catchment around Warkworth and to the east of the catchment as shown in Figure 2-2.



Title:

Wollombi Brook Catchment Topography

Figure: 2-1

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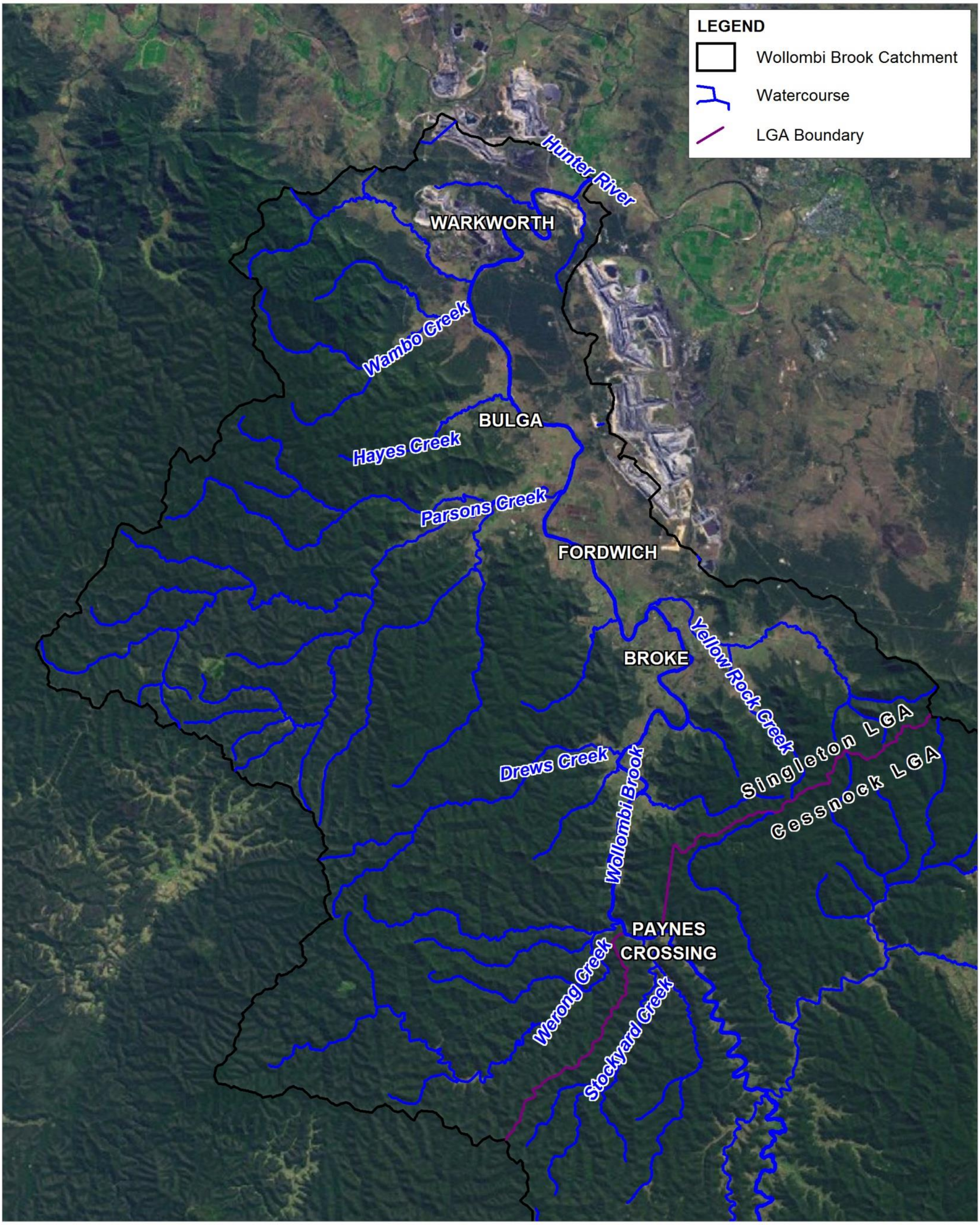

Title:

Wollombi Brook Catchment – Singleton LGA

Figure: **2-2**

Rev: **A**

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2.2 Compilation and Review of Available Data

2.2.1 Previous Studies

As previously stated in Section 1.2, no previous floodplain management studies have been completed for the portion of the Wollombi Brook catchment located in the Singleton LGA. However, a number of studies have previously been completed in the portion of the Wollombi Brook located in the Cessnock LGA as outlined below.

2.2.1.1 Wollombi Valley Flood Study (PBP, 2005)

In 2005 Patterson Britton & Partners (PBP) were engaged by Cessnock Council to undertake the Wollombi Valley Flood Study. The study originated from the requirement to determine appropriate flood planning levels in the assessment of development applications. The study area was defined as the Wollombi Brook catchment area upstream of Paynes Crossing.

The main components of the 2005 study included:

- Flood Study – historical background, rainfall and streamflow data, cross section survey, model build and calibration, compilation of historical flood levels
- Review of historical flooding in the catchment and community perspectives and experiences in previous events;
- Collation of historical flood level data, through identification and survey of flood levels, particularly for the 1949 flood;
- Summary of rainfall and streamflow gauges within the catchment and review of data for historical flood calibration;
- Development of a database of surveyed cross sections to define the topography of Wollombi Brook and Congewai Creek for developing hydraulic models;
- Development and preliminary calibration of hydrologic (XP-RAFTS) and hydraulic (HEC-RAS) models using available data; and
- Presentation of design flood information in the form of peak flood levels and inundation extents within the study area.

The results of the models developed for the 2005 Wollombi Valley Flood Study provided preliminary flood planning advice to Cessnock Council. Based on the study findings Cessnock Council adopted the 1 in 100 year design flood as the basis for planning levels at Wollombi Village rather than the higher 1949 historical flood levels.

2.2.1.2 Wollombi Flood Study Review and Model Upgrade (BMT WBM, 2010)

Given limitations in available historical flow data for model calibration purposes, and the limited initial scope of the location for flood level prediction, the Wollombi Valley Flood Study (PBP, 2005) concluded that the analysis could be improved by incorporating additional cross sections and additional hydrological analysis and calibration.

Accordingly, as part of the preparation of a Floodplain Risk Management Plan, Cessnock Council decided to review the Wollombi Valley Flood Study (PBP, 2005) and develop a more refined (2D) hydraulic model for the Wollombi Village area to better model the complex flood behaviour due to the confluence of flows in this area.

Cessnock Council engaged BMT WBM to undertake the Wollombi Village Floodplain Risk Management Study and Plan as a two stage commission:

- Flood Study Review and Model Upgrade: A comprehensive review of the Wollombi Valley Flood Study results, data and computer modelling techniques to establish the existing models as necessary, and the development of a two-dimensional (2D) hydraulic model for the Wollombi Village area. The study aimed to produce information on flood flows, velocities, levels and extents for a full range of flood magnitudes under existing catchment and floodplain conditions.
- Floodplain Risk Management Study and Plan (see Section 2.2.1.3): The outcomes of the Flood Study Review and Model Upgrade then formed the basis for the Floodplain Management Study and Plan. This study aimed to derive an appropriate mix of management measures and strategies to effectively manage flood risk in accordance with the Floodplain Development Manual. The findings of the study were then incorporated in a Plan of recommended works and measures and program for implementation.

The study area for the Flood Study Review was defined as the Wollombi Brook floodplain within a 5km radius of Wollombi Village and incorporated the following activities:

- Collation of database of historical flood information for the June 2007 flood in the Wollombi Brook;
- Acquisition of topographical data for the catchment including photogrammetric analysis and cross section 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 XP-RAFTS software) and hydraulic model (using TUFLOW software) to simulate flood behaviour in the catchment;
- Calibration of the developed models using the June 2007 flood event and model validation using the June 1949 flood event;
- Prediction of design flood conditions in the catchment, particularly at Wollombi Village, using the calibrated models, and
- Production of design flood mapping series.

The flood levels determined in Wollombi Flood Study Review and Model Upgrade (BMT WBM, 2010) have been utilised for flood planning purposes since the adoption of the study by Cessnock Council.

2.2.1.3 Wollombi Floodplain Risk Management Study and Plan (BMT WBM, 2012)

The outcomes of the Wollombi Flood Study Review and Model Upgrade (BMT WBM, 2010) formed the basis of the Wollombi Floodplain Risk Management Study and Plan (Wollombi FRMS&P) (BMT WBM, 2012).

The objectives of the Wollombi FRMS&P were to:

- Identify and assess measures for the mitigation of existing flood risk;
- Identify and assess planning and development controls to reduce future flood risks; and
- Present a recommended floodplain management plan that outlines the best possible measures to reduce flood damages in the Wollombi locality.

The study area of the Wollombi FRMS&P comprised of the village of Wollombi and the surrounding floodplain within a five kilometre radius of the village.

The nature of flooding in the Wollombi Valley, characterised by high flood volumes, flow depths and velocities, limit the opportunities for implementation of effective flood modification measures (e.g. flood mitigation dams, detention basins, levees and channel improvements). Rather the recommended measures focused on property modification (e.g. development controls) and response modification (e.g. local flood plans, emergency response and community awareness) measures.

The recommended measures included in the Wollombi FRMS&P include:

- Changes to Planning and Development Controls including adoption of a 100-year flood level pus 0.5m freeboard as the flood planning level; and inclusion of a number of floodplain risk management controls in Cessnock Councils consolidation Development Control Plan (2010).
- Improved public awareness
- Flood warning enhancements
- Improved emergency management operations including additional detail for the Wollombi Village in the Cessnock Local Flood Plan; and
- Investigation of improved emergency egress and voluntary house raising.

2.2.1.4 The Way of the River (Wollombi Valley Landcare Group, 1994)

“The Way of the River – Environmental Perspectives on the Wollombi” (Wollombi Valley Landcare Group, 1994) was a publication that arose out of the Landcare Group project to “audit” the environmental health of the Wollombi Valley through accessing available information from both community and expert sources. The publication contains a community’s perspective of the Wollombi Valley’s natural systems and how they should be nurtured, in addition to invited papers from people with specialist expertise in various environmental management fields.

In the context of the current Flood Study, the publication has interesting historical perspectives from long-term residents of previous major floods and their association with major changes to the stream morphology.

2.2.2 Rainfall Data

The Bureau of Meteorology (BoM) operates an extensive network of rainfall gauges across Australia, including the Wollombi Brook catchment. At present, there are ten operational rainfall gauges in the Wollombi Brook catchment (four of these are located within the Singleton LGA and the remaining six in the Cessnock LGA), with another 28 gauges being discontinued sometime previously. The full list of rainfall stations, including closed stations, is shown in Table 2-1 with their respective period of record. The location of the gauges is shown in Figure 2-3.

Whilst there have been a large number of rainfall gauges installed in the catchment, unfortunately the length of record for most of the sites are short, and more significantly, tend not to correspond to periods in which major floods have occurred. Limited daily rainfall totals at a few stations are available from the BoM database for the 1949, 1955 and 1978 flood events as detailed below:

- 1949 event – Wollombi (Mulla Villa), Olney State Forest
- 1955 event – Olney State Forest
- 1978 event – Congewai (Greenock), Laguna (Kalongba), Yallambie (Mount Auburn), Wollombi (Rosedale), Watagan Central

Additional rainfall data for the 1949 flood event is presented by Bernard (1950) and Reddoch and Milston (1953). Both reports have reconstructed a map of isohyets across the catchment using available rainfall data. Further information from these sources is presented in Section 7.

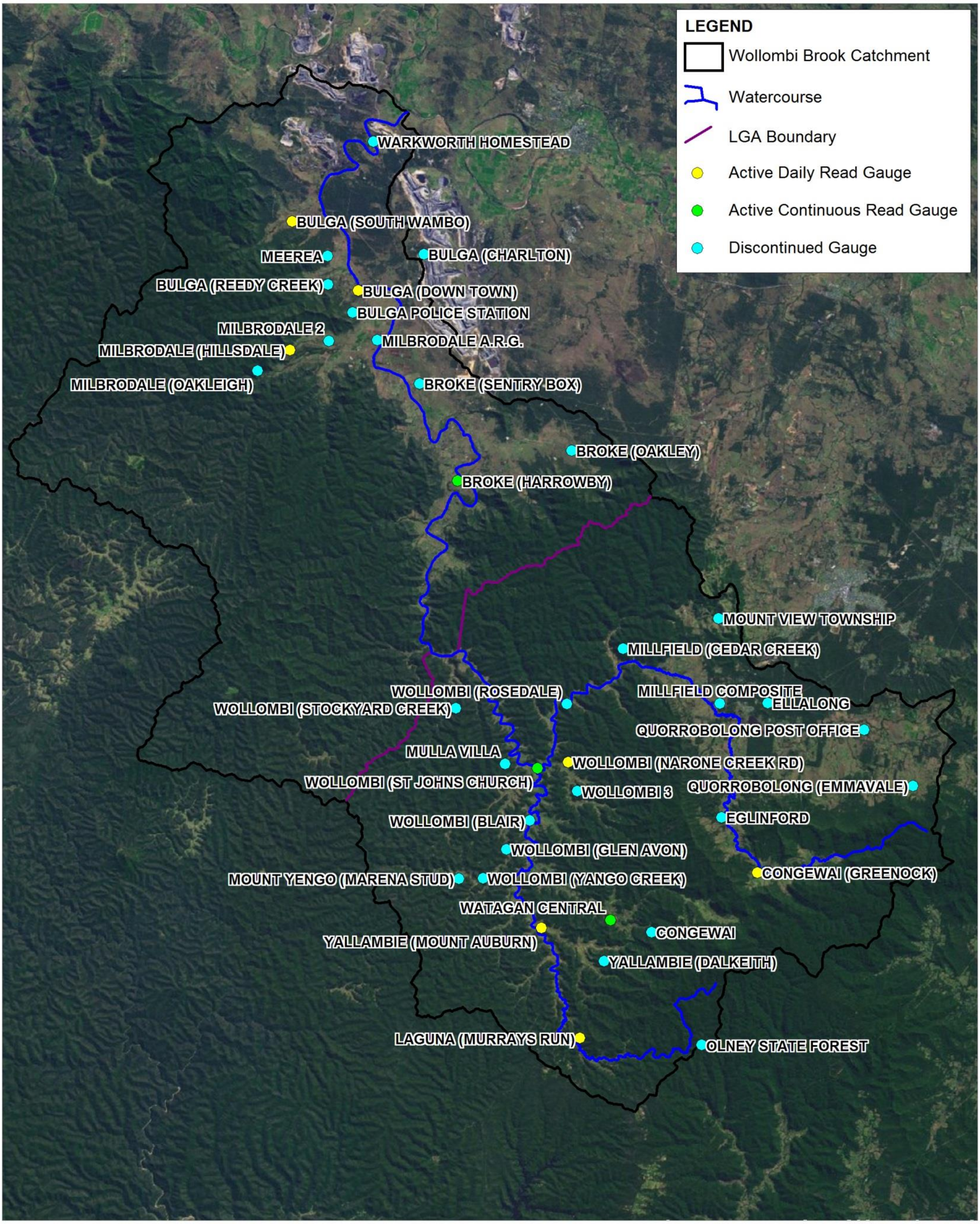
Fortunately for the June 2007 flood event, the ten operational gauging stations in the catchment all provided recorded rainfall depths for the event.

In addition to the rainfall gauges located within the Wollombi Brook catchment there is also an extensive network of rainfall gauges located in the wider region surrounding the study catchment that provide further indication of the distribution of rainfall across the catchment for historical rainfall events.

Further discussion on recorded rainfall data for historical events are discussed with the calibration and validation of the models developed for the study in Section 7.

Table 2-1 Summary of Rainfall Gauges in the Wollombi Brook Catchment

ID	Station No.	Name	Type	Start Year	End Year
1	61049	Mulla Villa	Daily	1946	1953
2	61057	Olney State Forest	Daily	1938	1966
3	61085	Yallambie (Dalkeith)	Daily	1929	1951
4	**61090**	**Wollombi (Narone Creek Rd)**	**Daily**	**1953**	**current**
5	61091	Wollombi (Glen Avon)	Daily	1951	1960
6	**61100**	**Broke (Harrowby)**	**Continuous**	**1887**	**current**
7	61103	Ellalong	Daily	1895	1931
8	61127	Wollombi 3	Daily	1889	1923
9	61132	Wollombi (Yango Creek)	Daily	1959	1973
10	61139	Mount Yengo (Marena Stud)	Daily	1959	1972
11	61141	Quorrobolong (Emmavale)	Daily	1959	1971
12	**61143**	**Bulga (Down Town)**	**Daily**	**1963**	**current**
13	61150	Bulga (Charlton)	Daily	1959	1973
14	**61152**	**Congewai (Greenock)**	**Daily**	**1959**	**current**
15	61154	Eglinford	Daily	1959	1970
16	61159	Wollombi (Rosedale)	Daily	1959	2005
17	**61164**	**Laguna (Murrays Run)**	**Daily**	**1959**	**current**
18	61172	Meerea	Daily	1959	1960
19	61173	Milbrodale 2	Daily	1959	1967
20	61174	Millfield Composite	Daily	1959	1983
21	61177	Mount View Township	Daily	1959	1961
22	61181	Broke (Oakley)	Daily	1959	1974
23	61182	Milbrodale (Oakleigh)	Daily	1959	1975
24	61188	Broke (Sentry Box)	Daily	1959	1996
25	**61191**	**Bulga (South Wambo)**	**Daily**	**1959**	**current**
26	61193	Wollombi (Stockyard Creek)	Daily	1959	1970
27	61200	Warkworth Homestead	Daily	1959	1980
28	**61201**	**Watagan Central**	**Continuous**	**1959**	**current**
29	**61205**	**Yallambie (Mount Auburn)**	**Daily**	**1959**	**current**
30	61224	Congewai	Daily	1898	1924
31	**61226**	**Wollombi (St Johns Church)**	**Continuous**	**2001**	**current**
32	61240	Wollombi (Blair)	Daily	1959	1981
33	61245	Milbrodale A.R.G.	Daily	1965	1969
34	61252	Bulga (Reedy Creek)	Daily	1968	1974
35	61289	Quorrobolong Post Office	Daily	1959	1981
36	61293	Bulga Police Station	Daily	1968	1975
37	**61309**	**Milbrodale (Hillsdale)**	**Daily**	**1965**	**current**
38	61313	Millfield (Cedar Creek)	Daily	1971	1982
39	**61422**	**Millbrodale School**	**Continuous**	**2010**	**Current**



Title:

Locations of Rainfall Gauges in the Wollombi Brook Catchment

Figure: **2-3**

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Approx. Scale

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2.2.3 Streamflow Data

The streamflow gauges located in the Wollombi Brook catchment that are included in the NSW Office of Water PINEENA database are listed in Table 2-2. The location of these gauges is shown in Figure 2-3.

Table 2-2 Stream Gauges in the Wollombi Brook Catchment

Station No.	Station Name	Period of Record
Wollombi Brook Operational Sites		
210135	Wollombi Brook @ Brickman's Bridge	1908 - Present
210028	Wollombi Brook @ Bulga	1949 - Present
210004	Wollombi Brook @ Warkworth	1995 - Present
Wollombi Brook Discontinued Sites		
210017	Congewai Creek @ Dam Site	1948 - 1963
210026	Congewai Creek @ Eglinford	1948 - 1979
210048	Wollombi Brook @ Paynes Crossing	1940 - 1999
210051	Congewai Creek @ Hanging Rock	1958 - 1979
210106	Wollombi Brook @ Blair's	No data available

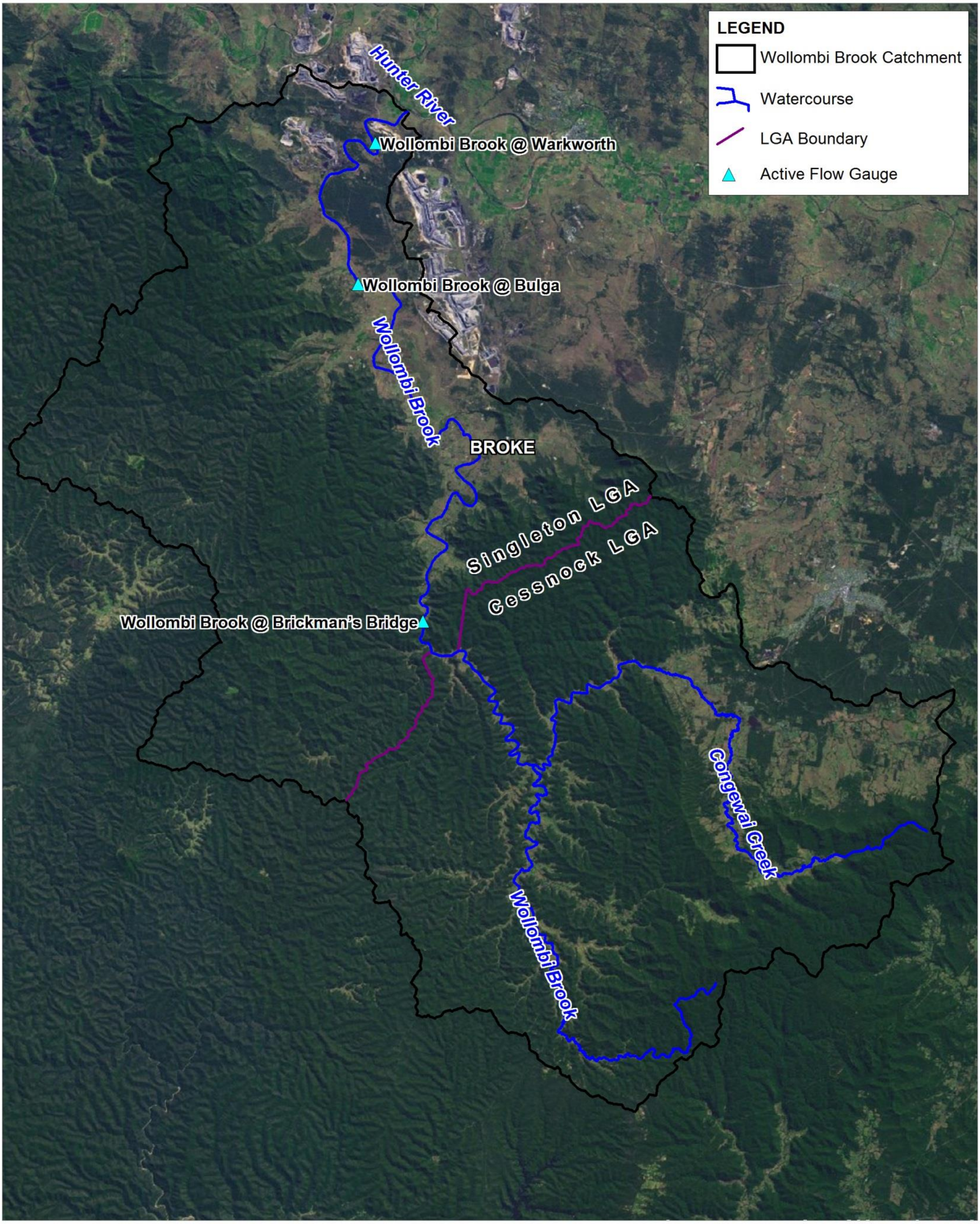
For many of the gauge sites, including the remaining operational stations, the period of record is incomplete with numerous interruptions most commonly from equipment failure. These periods often coincide with significant flood events in the catchment where damage to the equipment has occurred or, as in the case of the Payne's Crossing gauge, being washed away in the 1949 flood, and the Brickmans Bridge gauge failing during the June 2007 event.

2.2.4 Topographic Data

LiDAR data was provided for the floodplain area of the Wollombi Brook shown in Figure 2-5. The total area covered by the LiDAR data is some 563.5km^2 and includes catchment areas in both the Singleton and Cessnock LGA. The LiDAR data for the Singleton LGA were collected between the 19th October and 29th October 2011 by Land and Property Information and for the Cessnock LGA between the 12th January and 17th February 2012. The LiDAR data was supplied on a 1m grid resolution with a stated horizontal accuracy of 0.8m and a vertical accuracy of 0.3m.

The LiDAR data was used to derive a high resolution (5m grid) digital elevation model (DEM) for the Wollombi Brook floodplain.

Further reference to the available topographic data and it use in the model development is provided in Section 6.2.



Title:

Locations of Flow Gauges in the Wollombi Brook Catchment

Figure: 2-4

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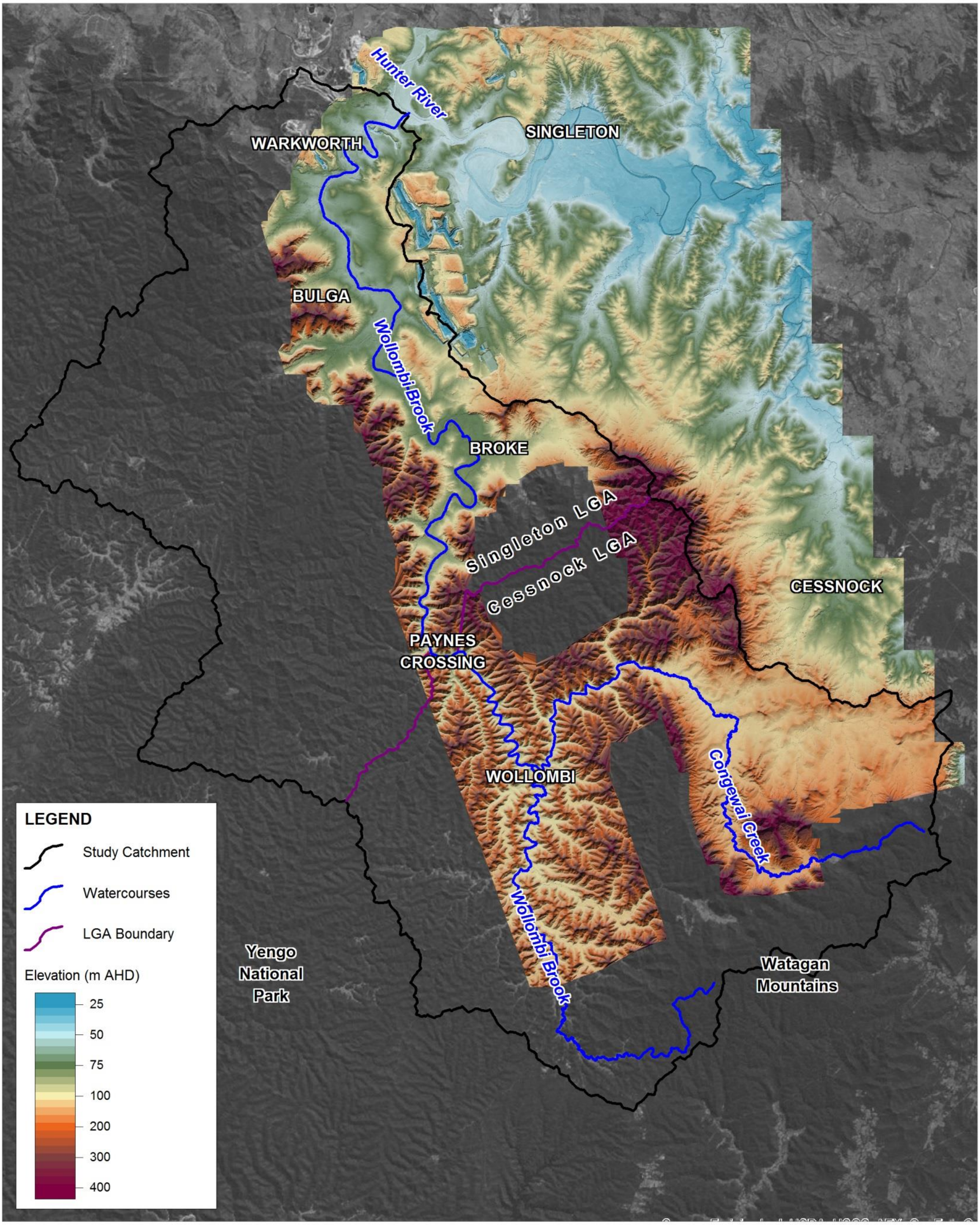

Title:
Extent of LiDAR Topographic Data

Figure: **2-5**

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2.2.5 OEH Historical Files

As part of the Wollombi Flood Study (BMT WBM, 2010), the NSW Office of Environment and Heritage (OEH) provided a file of historical notes on flooding in the Wollombi Brook. This data has been utilised in the present study also. The data included various extracts from reports, notes from calculation files and survey data. Some of the more significant information in these files included:

- Peak 1949 flood level profile along Wollombi Brook from Paynes Crossing to Warkworth;
- Connection of various gauging station control levels and peak flood levels to AHD from other datums; and
- Estimated rainfall distribution for June 1949 flood.

2.2.6 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.

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.

Site inspections were also previously carried out by BMT WBM team members in the days following the June 2007 flood. The primary focus of these inspections was to record peak flood levels from visible flood debris marks and note significant damage to infrastructure.

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 undertake the model upgrade. The additional survey incorporated:

- Structure survey to ascertain the details of a number of bridge and culvert structures that traverse the Wollombi Brook and its tributaries; and
- Flood level survey to record peak flood levels observed for historical flood events.

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 review have been:

- Issue of a community information brochure and questionnaire to inform the community of the study and obtain historical flood data and community perspective on flooding issues;
- Landholder interviews following up information provided in the questionnaires; and
- Information session to provide feedback on the results of the Flood Study and inform the community of the next stage in the floodplain management process (Floodplain Risk Management Study and Plan).

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 6.1) 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 slope, area 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 hydraulic model. These hydrographs are used by a hydraulic model to simulate the passage of a flood through the Wollombi Brook catchment to the downstream study limits at the confluence with the Hunter River.

2.6.2 Hydraulic Model

The hydraulic model (discussed in Section 6.1.3) developed for this study comprises a two-dimensional (2D) representation of the Wollombi Brook and its floodplain extending from approximately 8km upstream of Paynes Crossing to the confluence with the Hunter River at Warkworth some 69 kilometres downstream.

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 hydraulic models were calibrated and verified to historical flood events 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.

The available historical information highlighted three floods with sufficient data to potentially support a calibration process. These floods were the June 2007 event, April 2015 event and the June 1949 event being the largest recorded in the catchment to date.

The calibration and validation of the models is presented in Section 7. 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 hydraulic model parameters. The sensitivity testing of the models is presented in Section 9.6.

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 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 Wollombi Brook catchment, design floods were based on design rainfall estimates according to Australian Rainfall and Runoff (IEAust, 2001). The design flood discharges were compared with flood-frequency analysis of long-term stream flow records for gauging stations within the catchment.

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 8.

2.9 Mapping of Flood Behaviour

Design flood mapping is undertaken using output from the hydraulic model. Maps are produced showing water level, water depth and velocity vectors 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 hydraulic model results and are also mapped. The mapping outputs are described in Section 9 and presented in a separate Mapping Compendium.

3 Community Consultation

3.1 The Community Consultation Process

Community consultation is an important component of the Flood 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 risk management investigations. It has provided an opportunity to collect information on their flood experience, their concerns 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:

- Meeting with, and presentations to, the Floodplain Management Committee;
- Distribution of a questionnaire to all landowners, residents and businesses located within the preliminary extreme flood extents for the Wollombi Brook;
- An information session for the community to present the outcomes of the Flood Study; and
- Public exhibition of the draft Flood Study.

These elements are discussed in detail below. Copies of relevant consultation material are included in Appendix A.

3.2 Floodplain Management Committee

The study has been overseen by the Floodplain Management Committee (Committee). The Committee has assisted and advised Council in the development of the Wollombi Brook Flood Study. Members of the Floodplain Management Committee include representatives from the following:

- Staff from Singleton Council;
- Staff from NSW Office of Environment and Heritage (OEH);
- A representative from the State Emergency Service (SES); and
- Community representatives.

The Committee is responsible for recommending the outcomes of the study for formal consideration by Council.

3.3 Community Questionnaire

A questionnaire and community information brochure (presented in Appendix A) were distributed to all landowners, residents and businesses located within the preliminary extreme flood extents for the Wollombi Brook catchment. The purpose of the questionnaire was to collect information on previous flood experience and flooding issues. The focus of the questionnaire was to find any historical flooding information that may be useful for correlating with predicted flooding behaviour from the modelling.

Council received back 36 responses to the community questionnaire. The responses have been compiled into a GIS layer by BMT WBM.

The focus of the questionnaire was to gather relevant flood information from the community, including photographs, observed flood depths and descriptions of flood behaviour within the catchment. Photographs and comments relating to flood behaviour contained within the responses were extracted where useful for model calibration purposes.

Following review of the 36 responses received by Council, follow up interviews (both via phone conversations and on-site meetings) were held to discuss previous flood experience and flooding issues and identify historical flood levels to be surveyed and used for model calibration purposes. A total of eleven historical flood level points were identified and subsequently surveyed (three flood levels for the June 1949 flood event and eight flood levels for the June 2007 flood event). The historical flood levels surveyed are presented in Appendix C. The location of the surveyed flood levels are shown in Figure 4-1.

3.4 Community Information Session

Two community information sessions were held on Monday 31st October 2016. The first of these sessions was held at Bulga Hall from 10am-12pm, with second held at Broke Hall from 1pm-3pm. The purpose of the information sessions was to:

- notify the community of the Draft Flood Study and encourage constructive feedback;
- inform flood affected property owners of the flood risk to their property;
- engage with flood affected property owners on the impact of the predicted flood behaviour on their property;
- assist residents understanding of the predicted flood risk and behaviour within the catchment; and
- inform the community of the next stage in the floodplain risk management process.

The information sessions were supported by approximately 14 community attendees in addition to representatives from Council, OEH and BMT WBM.

3.5 Public Exhibition

The Draft Flood Study was placed on public exhibition for the period 20th October 2016 to 18th November 2016. No formal submissions from the public exhibition were received.

4 Additional Survey

The following sections outline the additional survey data collected to supplement the existing data and enable the establishment and calibration of a suitable two-dimensional model representation of the Wollombi Brook catchment.

LiDAR survey provides complete coverage of the modelled study area, producing detailed topographic models of the existing ground levels. This LiDAR data provided sufficient detail to represent the conveyance and condition of the Wollombi Brook and its tributaries.

A total of thirteen structures were identified within the study area that needed to be represented within the TUFLOW hydraulic model. Of these thirteen structures Council was able to supply survey details for only one. Therefore additional structure survey was required to provide structure details required to build the hydraulic model.

In addition, there were number of historical flood marks identified during the community consultation process for which survey details are required. The historical flood marks represented peak flood levels reached within the catchment during the June 2007 and 1949 flood events. These historical flood levels were used during the calibration and validation of the TUFLOW hydraulic model.

4.1 Structures

There are numerous hydraulic structures that traverse Wollombi Brook and its tributaries within the modelled study area for which limited existing survey detail was available. Accordingly, the ground survey undertaken by Carman Surveyors 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. The locations of the structures surveyed are presented in Table 4-1 and shown in Figure 4-1. Note that property access was not granted to Carman Surveyors by Wambo Coal to undertake the survey of Structure 9.

Further structure details and their respective model configuration are presented in Section 6.2.3.

4.2 Historical Flood Levels

As previously stated, a total of eleven historical flood marks were identified from the community questionnaire responses. These marks generally comprise recorded marks (scratches, lines drawn with marker on a wall), photographic evidence or points reconstructed from the memory of community members. The levels which these marks represent provide critical information on peak flood levels to be used during the calibration and validation of the TUFLOW hydraulic model.

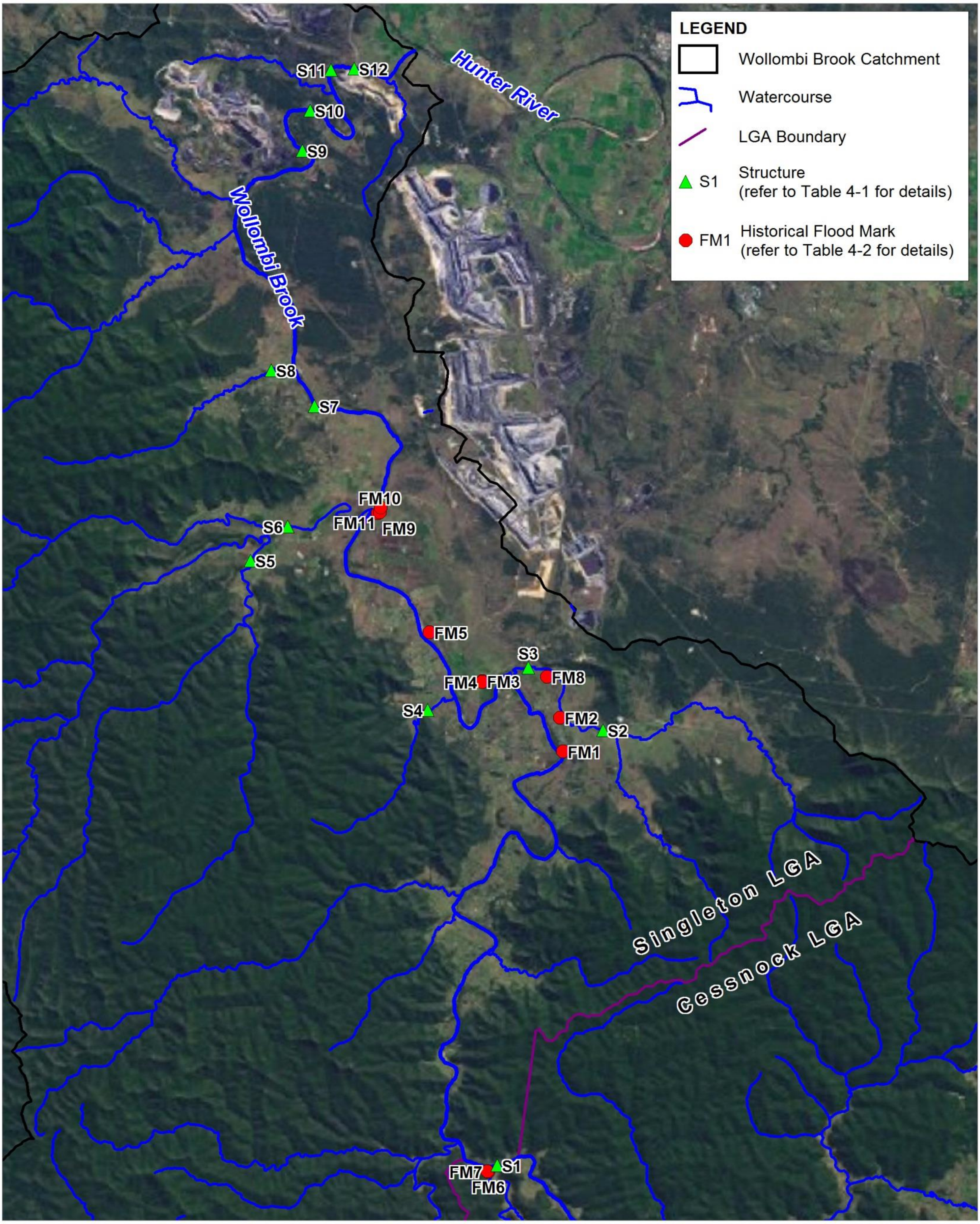
The locations of the eleven historical flood marks surveyed are presented in Table 4-2 and shown in Figure 4-1 and detailed further in Appendix C.

Table 4-1 Hydraulic Structures Surveyed

ID	Location	Watercourse
S1	Paynes Crossing, Wollombi Road	Wollombi Brook
S2	Broke-Cessnock Road, Broke	Yellow Rock Creek
S3	Wollombi Road (near Charlton Rd intersection)	Yellow Rock Creek
S4	Milbrodale Road	Watts Creek
S5	Putty Road, Milbrodale	Bulga Creek
S6	Putty Road, Milbrodale	Parsons Creek
S7	Putty Road (Bulga Bridge), Bulga	Wollombi Brook
S8	Wambo Road	Hayes Creek
S9	Mine Access Road (off Golden Highway)**	Wollombi Brook
S10	Golden Highway (Cockfighter Bridge), Warkworth	Wollombi Brook
S11	Mine Access Road (off Comleroi Road), Warkworth	Wollombi Brook
S12	Mine Access Road (off/parallel to Comleroi Road), Warkworth	Wollombi Brook

Table 4-2 Historical Flood Marks

ID	Location	Event
FM1	Broke Fire Station, Wollombi Road, Broke	June 1949
FM2	Cochrane Street, Broke	June 2007
FM3	Butlers Road, Broke	June 1949
FM4	Butlers Road, Broke	June 2007
FM5	185 Fordwich Road, Fordwich	June 2007
FM6	80 Stockyard Creek Road, Paynes Crossing	June 2007
FM7	80 Stockyard Creek Road, Paynes Crossing	June 2007
FM8	1249 Broke Road, Broke	June 2007
FM9	‘Charlton’ 154 Cobcroft Road, Broke	June 2007
FM10	‘Charlton’ 154 Cobcroft Road, Broke	June 2007
FM11	‘Charlton’ 154 Cobcroft Road, Broke	June 1949



Title:
Surveyed Structures and Historical Flood Marks

Figure: **4-1**

Rev: **A**

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 Streamflow Gauge Analysis

The NSW Office of Water operates and maintains an extensive network of streamflow gauge stations across NSW. Water levels at each gauge location are measured and recorded using a range of measurement systems with the majority of the gauges managed by computers (loggers) and having telecommunications access to transmit the water levels from remote locations. Recorded water levels are converted to a corresponding streamflow using developed stage-discharge relationships for each gauge. Stage-discharge relationships (also known as rating curves) are derived from individual streamflow gaugings measuring discharge at a particular stage height. Regular streamflow gauging's are required to confirm the calibration or recalibrate the stage-discharge relationship at each gauge location over time, due to potential changing conditions at the gauge location (e.g. channel cross section change, vegetation growth). .

As previously presented in Section 2.2.3, there are three active streamflow stations on Wollombi Brook within the modelled study area. The stations include D/S Brickmans Bridge (Station no. 210135), Bulga (210028) and Warkworth (210004). There is also a discontinued gauge located at Paynes Crossing (210048). The location of these gauges is shown in Figure 2-3.

In 2015 BMT WBM completed a significant amount of analysis on streamflow gauges located within the Hunter River system (including Wollombi Brook) as part of flood modelling assessments within the Singleton region and in broader context developing a Hunter River regional model. This analysis identified significant shifts in the derived stage-discharge relationships (i.e. rating curve) at a number of gauging stations.

Discussions with the hydrographers at the NSW Office of Water confirmed that there have been significant changes to the gauging site rating curves for the Hunter River and Wollombi Brook based on recent gauged flow data collected during flood events in 2011 and 2012. There has been significant recovery of riparian vegetation over the last 20 years or so, following changes in catchment management practices and an extended period without a major flood event. This recovery of riparian vegetation is clearly evident in the photographic comparisons at the Bulga and Warkworth gauges presented in Figure 5-1 to Figure 5-3.

The increase in in-channel vegetation provides for increased flow resistance, providing for higher water levels for a give flow magnitude. This is clearly evident in the gauge data presented in Figure 5-4, Figure 5-5 and Figure 5-6 for the Bulga, Brickman's Bridge and Warkworth gauges respectively. The figures show the spot gaugings relative to selected historical rating curves as included in the PINENNEA database (rating curve number and period shown for reference). The spot gauging's post June 2007 have been highlighted and clearly follow a different rating curve to the older gauging's. For example, at the Bulga gauge the recorded maximum water level for the June 2007 event (64.07m AHD) equates to a streamflow of ~1,300m^3/s using the derived rating #10, ~875m^3/s using the derived rating #280 and 600m^3/s using the current rating (derived rating #285). This equates to a difference of 700m^3/s, with the derived streamflow using the derived rating #10 being more than double the derived streamflow using the current rating (derived rating #285). A similar shift is evident at both the Brickman's Bridge and Warkworth gauges.

(1)

(2)

Figure 5-1 Bulga Bridge Looking Upstream (1) 1967 (2) 2014

(1)

(2)

(3)

Figure 5-2 Bulga Bridge Looking Downstream (1) 1984 (2) 2014 (3) 2014

(1)

(2)

Figure 5-3 Warkworth Gauge Looking Upstream (1) 1983 (2) 2014

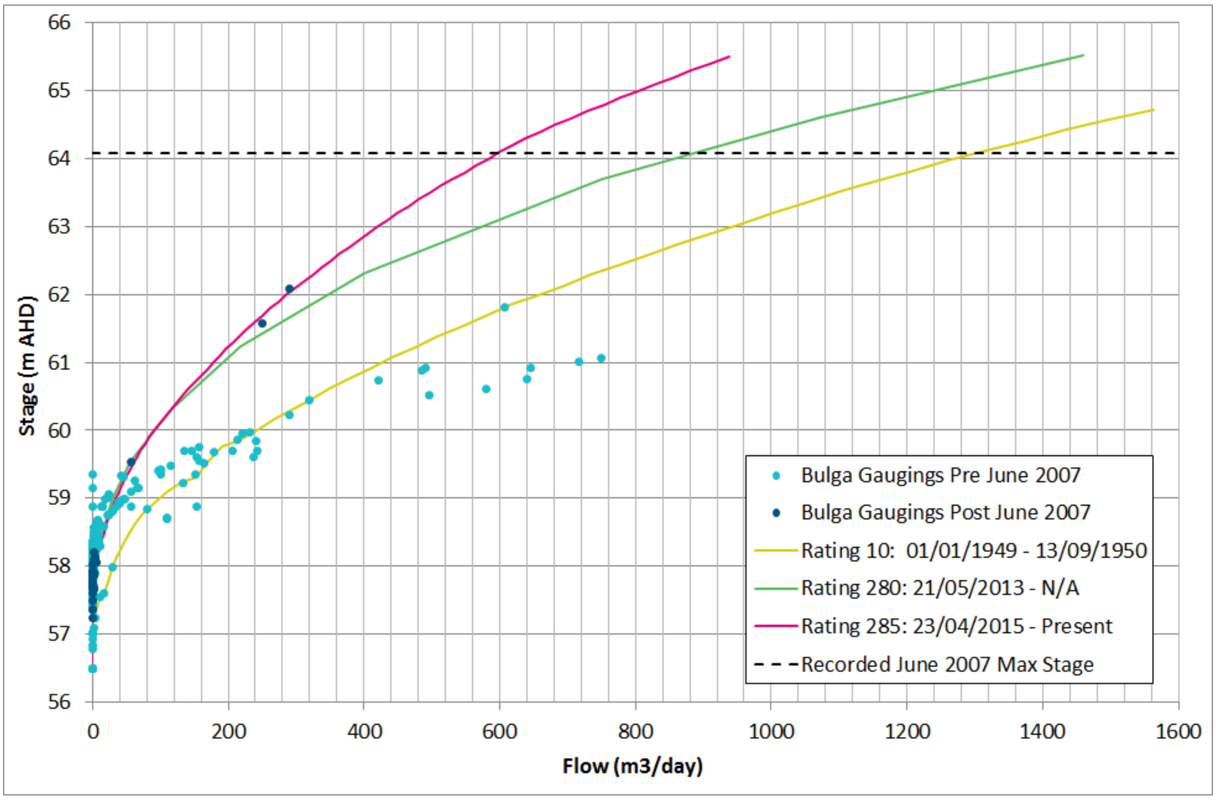


Figure 5-4 Bulga Gauge (210028) Analysis

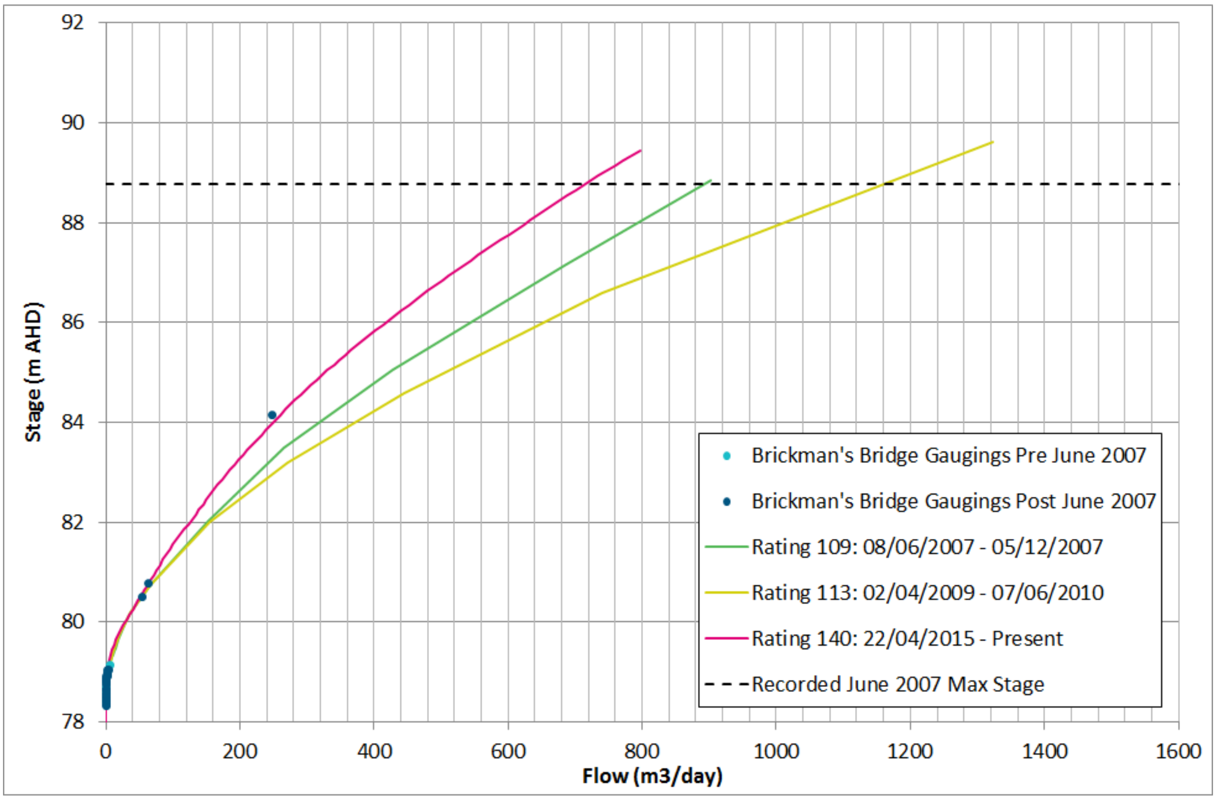


Figure 5-5 Brickman's Bridge Gauge (210135) Analysis

Figure 5-6 Warkworth Gauge (210004) Analysis

In order to identify the most appropriate rating curve to be used to calibrate and validate the TUFLOW hydraulic model for the Wollombi Brook, model simulations were undertaken representing recent and historic vegetation conditions (i.e. varying the adopted model roughness distribution) in order to derive modelled rating curves for comparison with the gauged data. The adopted model derived rating curves and corresponding model roughness values used for the calibration and validation of the TUFLOW hydraulic model are discussed in detail in Section 7.

6 Model Development

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. Traditionally, for the purpose of the Flood Study, a hydrological model and a hydraulic model are developed.

The **hydrological model** simulates the catchment rainfall-runoff processes, producing the stormwater flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the overland flow paths, creeks and lagoon producing flood inundation extents, levels and velocities.

Information on the topography and characteristics of the catchments and floodplains are built into the hydraulic model. Recorded historical flood data, including rainfall and flood levels, are used to simulate and validate (calibrate and verify) the model. The model produces as outputs, the distribution of flood levels, flow rates (discharges) and flow velocities.

Development of hydrological and hydraulic models follows a relatively standard procedure:

(1) Discretisation of the catchment, floodplain, etc.

(2) Incorporation of physical characteristics (floodplain levels, structures etc).

(3) Establishment of hydrographic databases (rainfall, flood 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). The hydrological and hydraulic models were calibrated interactively.

(5) Validation to one or more other historic floods (validation is a check on the performance of the model 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 (as part of the current Flood Study); and
- assessing the hydraulic impacts of proposed management options(as part of the floodplain risk management study).

6.1 Hydrological Model

The hydrological model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff from the catchment is dependent on:

- the catchment slope, area, vegetation, urbanisation and other characteristics;
- variations in the distribution, intensity and amount of rainfall; and
- the antecedent moisture 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 moisture conditions are modelled by varying the amount of rainfall which is "lost" into the ground and "absorbed" by storages. For very dry antecedent moisture conditions, there is typically a higher initial rainfall loss.

The output from the hydrological 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 Wollombi Brook catchment.

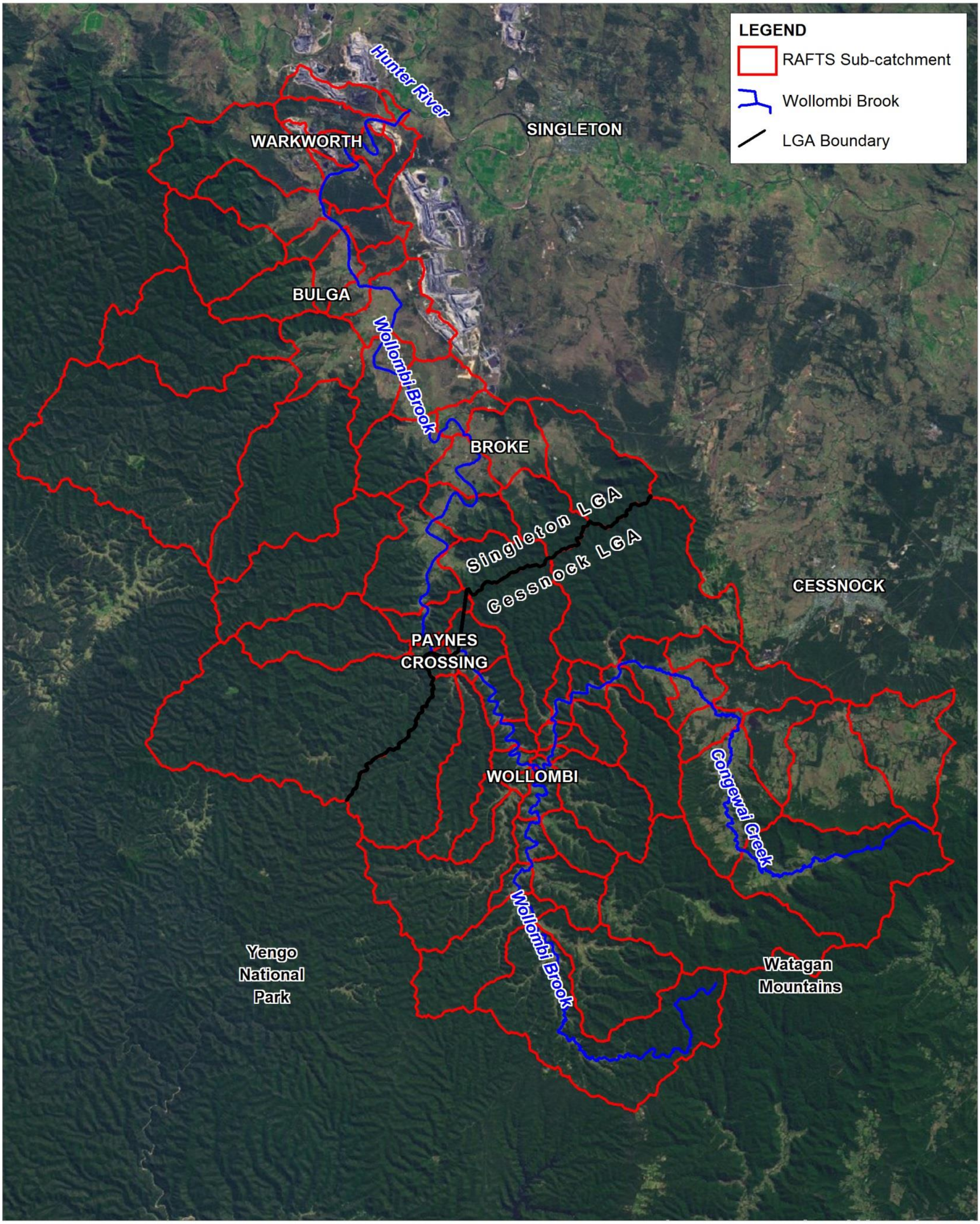
The XP-RAFTS software was used to develop the hydrological model using the physical characteristics of the catchment including catchment areas, ground slopes and vegetation cover as detailed in the following sections.

6.1.1 Catchment Delineation

The Wollombi Brook catchment drains an area of approximately 1870km^2 to its confluence with the Hunter River, downstream of Warkworth. In order to ascertain the flow hydrographs for the catchment area located in the Singleton LGA a XP-RAFTS model was constructed that includes the Wollombi Brook catchment in its entirety. The catchment has been delineated into 76 sub-catchments as shown in Figure 6-1.

6.1.2 Catchment Properties

Table 6-1 summarises the key catchment parameters adopted in the XP-RAFTS model, including catchment area, vectored slope and PERN 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 Wollombi Brook catchment is largely forested.



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Wollombi Brook RAFTS Model Sub-catchment Layout

Figure: 6-1

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Table 6-1 XP-RAFTS Sub-catchment Properties

Catchment Label	Area (ha)	Slope (%)	Impervious Area (%)	PERN	Catchment Label	Area (ha)	Slope (%)	Impervious Area (%)	PERN
WB1.01	7188.2	1	0	0.1	**WB2.03**	1643.1	0.34	0	0.09
WB1.02	3799.7	0.74	0	0.09	**WB3.01**	1807.3	0.64	0	0.1
WB1.03	914.1	1.5	0	0.07	**WB4.01**	816.2	2.4	0	0.09
WB1.04	976.5	0.87	0	0.07	**WB5.01**	8410.5	1.72	0	0.11
WB1.05	1198.1	2.62	0	0.1	**WB6.01**	2442.4	2.56	0	0.12
WB1.06	321.8	4.75	0	0.1	**WB7.01**	3620.3	1.67	0	0.12
WB1.07	590.6	2.51	0	0.11	**WB8.01**	897.8	3.83	0	0.12
WB1.08	498.9	2.15	0	0.11	**WB9.01**	286.9	4.51	0	0.12
WB1.09	261.6	4.17	0	0.1	**WB10.01**	8625.4	0.47	0	0.11
WB1.10	135.6	4.17	0	0.08	**WB10.02**	3211.9	1.06	0	0.11
WB1.11	167.1	2.06	0	0.08	**WB10.03**	459.0	1	0	0.09
WB1.12	419.1	2.55	0	0.09	**WB10.04**	607.5	1.03	0	0.08
WB1.13	496.7	1.81	0	0.1	**WB10.05**	583.9	0.31	0	0.08
WB1.14	982.7	2.07	0	0.11	**WB11.01**	3966.2	0.65	0	0.1
WB1.15	1162.7	4.16	0	0.11	**WB12.01**	8220.4	0.78	0	0.11
WB1.16	320.1	4.06	0	0.1	**WB12.02**	1479.9	0.86	0	0.1
WB1.17	197.4	8.01	0	0.1	**WB13.01**	1179.0	1.84	0	0.1
WB1.18	956.8	6.07	0	0.12	**WB14.01**	4837.5	0.6	0	0.12
WB1.19	3181.5	1.66	0	0.1	**WB14.02**	230.1	1.27	0	0.08
WB1.20	1539.6	3.29	0	0.1	**WB15.01**	928.1	2.1	0	0.12
WB1.21	1142.4	0.38	0	0.06	**WB16.01**	2872.7	1.1	0	0.12
WB1.22	651.4	0.96	0	0.06	**WB17.01**	2529.6	0.99	0	0.12
WB1.23	2311.9	2.21	0	0.1	**WB18.01**	4374.0	0.97	0	0.12
WB1.24	1611.0	0.64	0	0.06	**WB19.01**	12769.3	0.53	0	0.12
WB1.25	1712.3	1.06	0	0.09	**WB20.01**	3262.5	1.12	0	0.12
WB1.26	2453.6	0.3	0	0.07	**WB21.01**	5459.1	2.07	0	0.12
WB1.27	1049.1	1.42	0	0.08	**WB22.01**	1634.1	4.51	0	0.11
WB1.28	1079.4	0.48	0	0.07	**WB23.01**	3609.0	2.06	0	0.1
WB1.29	1465.3	1.4	0	0.09	**WB23.02**	1953.6	0.6	0	0.07
WB1.30	2352.4	1.74	0	0.1	**WB24.01**	1859.1	4.19	0	0.11
WB1.31	1150.3	0.31	0	0.1	**WB25.01**	13850.4	1.23	0	0.12
WB1.32	637.3	1.26	0	0.07	**WB25.02**	2095.3	1.34	0	0.08
WB1.33	516.4	0.06	0	0.09	**WB26.01**	5479.9	2.28	0	0.12
WB1.34	1150.9	0.3	0	0.09	**WB27.01**	7296.2	2.31	0	0.12
WB1.35	653.6	1.06	0	0.09	**WB28.01**	1801.1	5.97	0	0.11
WB1.36	155.3	0.64	0	0.06	**WB29.01**	3299.6	4.64	0	0.12
WB2.01	3615.8	0.71	0	0.07	**WB30.01**	4007.8	1.3	0	0.1
WB2.02	4326.8	0.65	0	0.08	**WB31.01**	1054.1	0.29	0	0.07

6.1.3 Rainfall Data

Rainfall information is the primary input and driver of the hydrological model which simulates the catchments response to rainfall. 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 during any given event and between different events.

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, as presented in Section 7.3 for the June 2007 event. 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 7 and design events discussed in Section 8.

6.1.4 Rainfall Losses

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 during the hydrological modelling process. 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.

The rainfall loss parameters for the historical calibration/validation events and design events are discussed in further detail in Section 7 and Section 8 respectively.

6.2 Hydraulic Model

BMT WBM has applied the fully 2D software modelling package TUFLOW. TUFLOW was developed in-house at BMT WBM and has been used extensively for over fifteen years on a commercial basis by BMT WBM. TUFLOW has the capability to simulate the dynamic interaction of in-bank flows in open channels, major underground drainage systems, and overland flows through complex overland flowpaths using a linked 2D / 1D flood modelling approach. TUFLOW is specifically orientated towards establishing flow and inundation patterns in coastal waters, estuaries, rivers, floodplains and urban areas where the flow behaviour is essentially 2D in nature and cannot or would be awkward to represent using a 1D model, and accordingly is well suited to model the conditions in the Wollombi Brook catchment.

6.2.1 Model Configuration

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

- location of available data (eg. river section surveys);
- location of recorded data (eg. river flow gauging site);
- location of controlling features (eg. dams, levees, bridges);
- desired accuracy to meet the study's objectives;
- computational limitations.

The nominal modelling boundaries defined in Council's brief extend from Paynes Crossing to the confluence with the Hunter River at Warkworth. With consideration to the available survey information and local topographical and hydraulic controls, the model covers the extent of the available LiDAR data from 8 kilometres upstream of Paynes Crossing to the confluence with the Hunter River (including a section of the Hunter River extending from 3km upstream of the confluence to 1km downstream of the confluence).

A linked 1D/2D model was developed covering the study extent defined above. Two culvert structures (see Table 6-2) have been modelled as 1D structures linked to the 2D domain that comprises the channel alignments, floodplain areas and major bridge structures. This approach enables the hydraulic capacity of the culvert structures to be accurately defined by surveyed structure details, whilst enabling the channel alignments and floodplain area to be represented in 2D. The model layout is presented in Figure 6-2.

The floodplain area modelled within the 2D domain represents a total area of some 320km^2. A high resolution DEM was derived for the study area from the LiDAR survey data provide by Council. The ground surface elevation for the TUFLOW model grid points are sampled directly from the DEM.

A TUFLOW 2D domain model resolution of 20m was adopted for Wollombi area. It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so a 20m cell size results in DEM elevations being sampled every 10m. This resolution was selected in order to keep run times within acceptable limits whilst still maintaining the necessary detail required for accurate representation of floodplain topography and its influence on out-of-bank flows.

6.2.2 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 Wollombi Brook floodplain area, a high resolution DEM (2m by 2m grid) was derived from LiDAR survey provided by Council (refer Section 2.2.6).

The area of capture for the LiDAR data was limited to the Wollombi Brook floodplain area as shown in Figure 2-5.

6.2.3 Structures

There are numerous bridge crossings of the main creek channels within the model extents as detailed in Table 6-2. 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.

There are numerous other small access structures / causeways over Wollombi Brook and its tributaries which have not been incorporated into the hydraulic model. These are considered to have negligible influence on major flooding behaviour within the Wollombi Brook catchment.

It should be noted that a nominal blockage factor was applied to some structures to account for the overestimation of conveyance capacity afforded by the adopted 20m model resolution. The nominal blockage factor therefore effectively represents a nil blockage condition at these structures.

Table 6-2 Major Hydraulic Structures within Model Area

ID	Location	Watercourse	Structure Type
S1	Paynes Crossing, Wollombi Road	Wollombi Brook	Bridge (approx 36m span)
S2	Broke-Cessnock Road, Broke	Yellow Rock Creek	Bridge (approx 36m span)
S3	Wollombi Road (near Charlton Rd intersection)	Yellow Rock Creek	Bridge (approx 24m span)
S4	Milbrodale Road	Watts Creek	Culvert (3 x 2.15m x 2.12m box)
S5	Putty Road, Milbrodale	Bulga Creek	Bridge (approx 48m span)
S6	Putty Road, Milbrodale	Parsons Creek	Bridge (approx 112m span)
S7	Putty Road (Bulga Bridge), Bulga	Wollombi Brook	Bridge (approx 126m span)
S8	Wambo Road	Hayes Creek	Bridge (approx 7.5m span)
S9	Mine Access Road (off Golden Highway)	Wollombi Brook	Bridge (approx 120m span)**
S10	Golden Highway (Cockfighter Bridge), Warkworth	Wollombi Brook	Bridge (approx 185m span)
S11	Mine Access Road (off Comleroi Road), Warkworth	Wollombi Brook	Culvert (9 x 1.05m pipe)
S12	Mine Access Road (off/parallel to Comleroi Road), Warkworth	Wollombi Brook	Bridge (approx 105m span)
S13	Milbrodale Road, Broke	Wollombi Brook	Bridge (approx 80m span)

6.2.4 Hydraulic Roughness

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

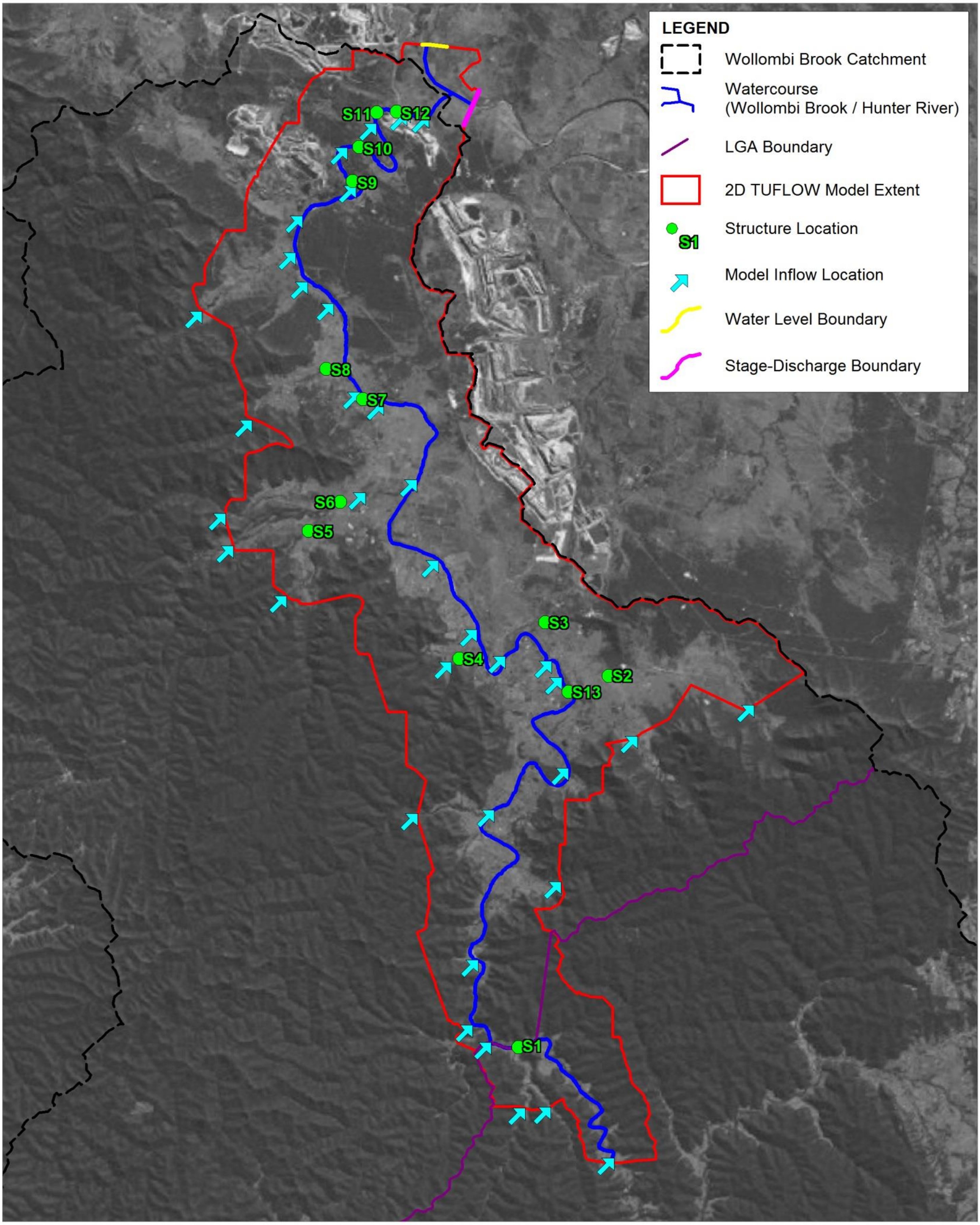
The hydraulic roughness is one of the principal calibration parameters within the hydraulic model and has a major influence on flow routing and flood levels. During the model calibration process the Manning's 'n' surface roughness values are adjusted locally (within reasonable bounds) to provide best fit for peak water level profiles. The degree of variability largely reflects the degree of channel vegetation, channel size and sinuosity. The roughness values adopted from the calibration process are discussed in Section 7.2.

6.2.5 Boundary Conditions

The model boundary conditions are derived as follows:

- Inflows (Rainfall runoff) - the rainfall runoff calculated by the hydrologic model at major sub-catchment inflow points and along the modelled reach of the main Wollombi Brook channel.
- Inflows (Wollombi Brook upstream of Paynes Crossing) - a time series of flow in the Wollombi Brook has been applied at this location for the duration of modelled events.
- Inflows (Hunter River upstream of Wollombi Brook confluence) – a time series of water levels in the Hunter River based on analysis of the Mason Dieu streamflow gauge has been applied at this location for the duration of modelled events.
- Downstream Boundary (Hunter River) – a stage-discharge relationship has been derived for the downstream Hunter River boundary based on uniform flow conditions (Manning's equation) using an assumed flood slope and cross section.

The adopted Hunter River boundary condition values for the calibration and design events are discussed in Section 7 and Section 8 respectively.



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TUFLOW Model Layout

Figure: **6-2**

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N

0 3.75 7.5km

Approx. Scale

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7 Model Calibration and Validation

7.1 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.

Significant flooding in the Wollombi Brook catchment has occurred on numerous occasions, with the most severe events including 1893, 1927, 1930, 1949, 1978 and 2007. However, for the Wollombi Brook catchment there is little data available for historical events other than the June 1949 and June 2007 floods.

Recorded rainfall for historical events is the key data requirement for flood simulation utilising rainfall-runoff modelling. As discussed in Section 2.2.2, the periods of available rainfall data for the rainfall gauges within the catchment provide a relatively poor coverage of historical flood events.

To get some perspective on historical rainfall events across the catchment, SILO daily rainfall data has been analysed for the catchment. The SILO data is broad scale (0.05 degrees spatial resolution – approximately 5km) and is useful for defining large catchment averages. However, it is important to recognise that local rainfall variations may be "smoothed out". Nevertheless, the data is indicative of broad scale weather systems and does provide some resemblance to known flooding patterns in the Wollombi Brook catchment.

Table 7-1 presents the highest 1-day and 2-day rainfall totals from the SILO data set for three locations in the Wollombi catchment (Bulga, Paynes Crossing and the Watagan Mountains) and their respective year of occurrence. Historical floods in the catchment have largely emanated from major storm durations between 1 and 2 days, exemplified by the 1949 and 2007 events. This is a characteristic of the catchment and representative of the duration resulting in the largest flooding (critical duration).

The largest flood events within the Wollombi catchment identified in the SILO data analysis correspond to known major events including the 1893, 1927, 1930, 1949 and 2007 floods.

The rainfall totals presented in Table 7-1 demonstrate the variation in historical rainfall totals across the Wollombi Brook catchment. This is clearly evident when comparing the 2-day total rainfall for Bulga and the Watagan Mountains for the 1949 and 2007 events with much higher rainfall totals occurring in the upper catchment. For the major flood events in the Wollombi catchment the rainfall totals are typically higher in the upper catchment (including the Watagan Mountains) than the lower catchment (including Bulga and Warkworth).

To demonstrate the broad scale nature of the SILO data and the smoothing of high localised rainfall, reference is made to the recorded rainfall for the 1949 and 2007 flood events. The 2-day rainfall in the upper catchment for the 1949 and 2007 events is estimated at 375mm and 275mm respectively. However from available records, it is estimated up to 500mm fell in the upper catchment around the Letter A in the 1949 event, and upwards of 300m for the 2007 event.

Given the broad scale nature of the SILO data, there is also the potential to "miss" flood events derived from very high localised rainfall in some parts of the catchment.

Table 7-1 Major Rainfall Event Totals – Bulga, Paynes Crossing and Watagan Mountains

Rank	Bulga				Paynes Crossing				Watagan Mountains (Upper Catchment)			
	1-day Rainfall Total		2-day Rainfall Total		1-day Rainfall Total		2-day Rainfall Total		1-day Rainfall Total		2-day Rainfall Total	
	Year	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)
1	**2007**	**152.1**	1893	220.8	**2007**	**175.4**	**1949**	**243.4**	1893	248.9	**1949**	**375.4**
2	1930	146.6	1930	207	**1949**	**138.1**	**2007**	**225.3**	1927	230	1990	302.4
3	1893	133.9	**2007**	**206.8**	1889	137.6	1930	196.8	1950	218.8	1893	300.5
4	1955	128.8	1889	184.2	1893	135.2	1893	193.4	**2007**	**212.3**	1930	284
5	1889	115	1926	179.8	1930	125.8	1889	188.5	**1949**	**200**	**2007**	**275.3**
6	1904	108.3	1889	153.1	1927	124.7	1926	174	1978	196.3	1945	274.4
7	1926	108.1	1913	152.9	1981	124.1	1913	160.3	1952	179.7	1952	270.4
8	1964	104.3	**1949**	**150.2**	1977	116.1	1990	157.1	1930	177.1	1953	267.1
9	2013	97.9	1964	149.9	1926	107.2	1909	154.2	1945	176.5	1964	264.4
10	**1949**	**96.9**	1904	141	1931	105	1955	150.6	1990	161.8	1927	251.1

Despite such a long history of flooding in the Wollombi Brook catchment, available data suitable for model calibration is somewhat limited. This was noted in the 2005 Wollombi Flood Study in which only the June 1949 event was simulated for model calibration in the absence of a suitable data set for any other event. Fortunately, from a model calibration perspective, the June 2007 event yielded a comprehensive data set for this purpose. Accordingly, the June 2007 event has been used for calibrating the hydrological and hydraulic models given the extensive data set available, with the June 1949 event used for model validation.

A significant flood event also occurred in April 2015 during the undertaking of the current study. This event was subsequently also used as a model validation event.

The 1949, 2007 and 2015 events were major floods in the Wollombi Brook catchment. 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 Bulga as detailed in Table 7-2.

Table 7-2 Flood Classification Levels for Wollombi Brook at Bulga

Flood Classifications (gauge readings in metres)		
Minor	Moderate	Major
3.0	3.7	4.6

A peak flood gauge reading at Bulga of 7.24m, 7.57m and 8.29m was reached for the April 2015, June 2007 and June 1949 flood events respectively, with all three events within the major flood classification.

7.2 Channel Roughness

The calibration process included the determination of the most appropriate set of flow and roughness conditions in order for the model to reasonably reproduce observed flood behaviour within the catchment. Assuming channel shape/dimension properties remain stable, the observed flood levels are largely a function of both flow magnitude and hydraulic roughness condition. From a model calibration perspective, similar water levels can be derived from various combinations of flow and roughness value. Spot gaugings provide a useful dataset for determining appropriate model roughness values. A large number of gaugings across range of water levels will provide a good rating curve (flow vs. level relationship), which can be matched within the model by selecting an appropriate roughness value.

Unfortunately, for the stream gauges in the study catchment there is not a large spot gaugings database to work with, especially at high flows. Accordingly, there is significant uncertainty regarding the adopted high flow rating curves which often rely on extrapolation to stages well above the highest spot gauging.

As previously discussed, there have been significant changes to the gauging site rating curves for the Wollombi Brook as a result of significant recovery of riparian vegetation over the last 20 years or so. Accordingly, flows of a given magnitude now result in much higher water levels than they would have done previously, due to the increased flow resistance afforded by the increase in in-channel vegetation.

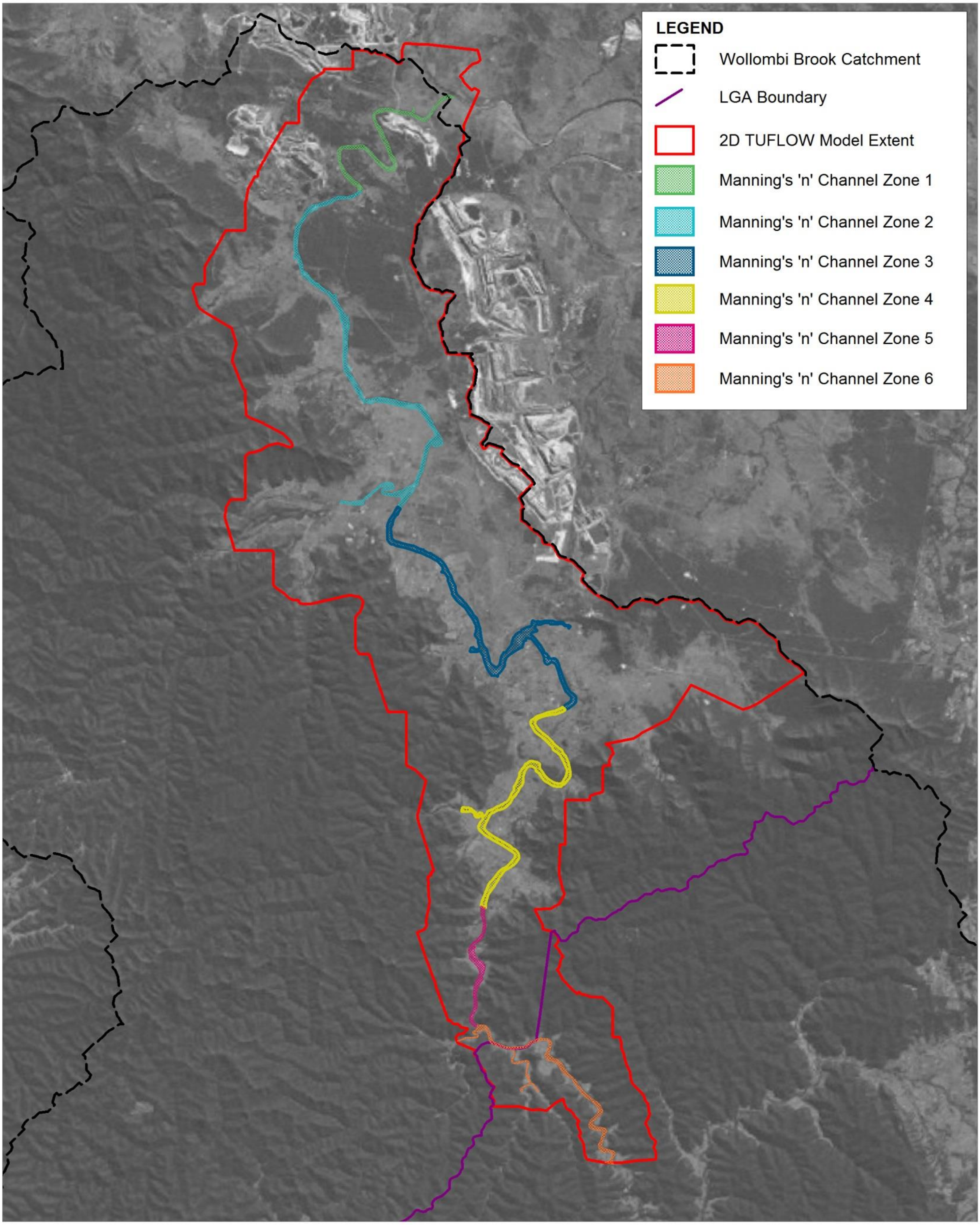
In order to identify the most appropriate rating curve to be used to calibrate and validate the TUFLOW hydraulic model for the Wollombi Brook, model simulations were undertaken representing recent and historic vegetation conditions (i.e. varying the adopted model roughness distribution) in order to derive a modelled rating curve for comparison with the gauged data.

The derivation of the low to moderate flow rating (up to the highest recorded spot gaugings) is based on calibration to the recorded spot gaugings. The derivation of the high flow rating extensions (above the limit of highest recorded spot gaugings) is based on the event calibration and subsequent derivation of the adopted model roughness distribution presented in detail in the following sections.

Of the three active gauges, the gauge at Warkworth provides the longest term and most complete record. However, at high flood stages, the site is affected by backwater from the Hunter River. Accordingly, extrapolation of the spot gauging data to high flow stages overestimate the actual flow in the Wollombi Brook at this location. It is also noted that the D/S Brickman's Bridge gauge has only been in operation since 1995 and therefore has a limited gauging record. The gauge also failed during the June 2007 flood event with no water level time series recorded at the site.

Based on the above limitations of the Warkworth and D/S Brickmans Bridge gauges, the Bulga gauge is considered to be the most reliable gauge location at which to compare the model derived rating curves with the recorded gauged data. The Warkworth and Brickmans Bridge gauge sites were then used to validate the model derived rating curves.

Roughness distributions (defined by Manning's 'n' parameter) were defined for two conditions: representative of the existing dense riparian vegetation channel condition and the other representative of the previous/historic channel condition characterised by significantly less in-channel vegetation. The adopted Manning's 'n' roughness values are based on the most appropriate values from the available spot gauging data, technical and industry guides and previous experience with channels of a similar nature. In order to assign the Manning's 'n' roughness distribution, the modelled reach of the Wollombi Brook was delineated into six regions as shown in Figure 7-1. Each of the individual regions was identified to have slight differences in channel shape, in-channel vegetation and surrounding floodplain topography and vegetation.



Title:
Manning's 'n' Roughness Distribution Delineated Regions

Figure: 7-1

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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.

N

0 3.75 7.5km

Approx. Scale

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For the existing dense riparian vegetation channel condition, a depth varying Manning's 'n' roughness was adopted which allows the in-channel Manning's 'n' value to be varied depending on the simulated in-channel depth of floodwaters. This allows for the influence of the in-channel vegetation on the channel roughness to be reduced as the flood depth increases.

For the previous/historic channel condition a single Manning's 'n' value was adopted for each of the delineated channel reaches (i.e. no need for a depth varying Manning's 'n' to be defined). This was considered to be representative of the historic condition which was generally characterised by a wide sandy channel with significantly less in-channel vegetation than current conditions (as shown in the photographs presented in Section 5).

The adopted Manning's 'n' values for each of the delineated channel reaches under the existing and historic channel conditions are presented in Table 7-3. The initial selection of Manning's 'n' values was based on achieving a good match to spot gauging data.

Table 7-3 Adopted Manning's 'n' Roughness Values

Channel Region ID	Existing Channel Condition	Historic Channel Condition
1	0.09 up to 4m flood depth and 0.04 above 6m flood depth (gradual transition from 0.09 to 0.04 between 4-6m flood depth)	0.04
2	0.10 up to 4m flood depth and 0.05 above 6m flood depth (gradual transition from 0.10 to 0.04 between 4-6m flood depth)	0.04
3	0.10 up to 4m flood depth and 0.05 above 6m flood depth (gradual transition from 0.10 to 0.04 between 4-6m flood depth)	0.04
4	0.11 up to 5m flood depth and 0.10 above 7.5m flood depth (gradual transition from 0.11 to 0.10 between 5-7.5m flood depth)	0.09
5	0.11 (constant adopted based on highly incised channel reach with limited floodplain area and dense in-stream vegetation)	0.09
6	0.10 up to 5m flood depth and 0.05 above 7.5m flood depth (gradual transition from 0.10 to 0.05 between 5-7.5m flood depth)	0.04

The simulated rating curves at the Brickmans Bridge, Bulga and Warkworth gauges on the Wollombi Brook are shown in Figure 7-2 to Figure 7-4. The figures include:

- the simulated current and historic rating curves according to the adopted roughness distributions,
- a selection of the previously derived rating curves from the PINEENA database;
- the available spot gaugings from the PINEENA database;
- the recorded peak water levels for the April 2015, June 2007 and June 1949 flood events; and
- points showing the recorded peak flood level for the calibration events and the corresponding peak flow estimate based on the appropriate rating curve (see discussion below).

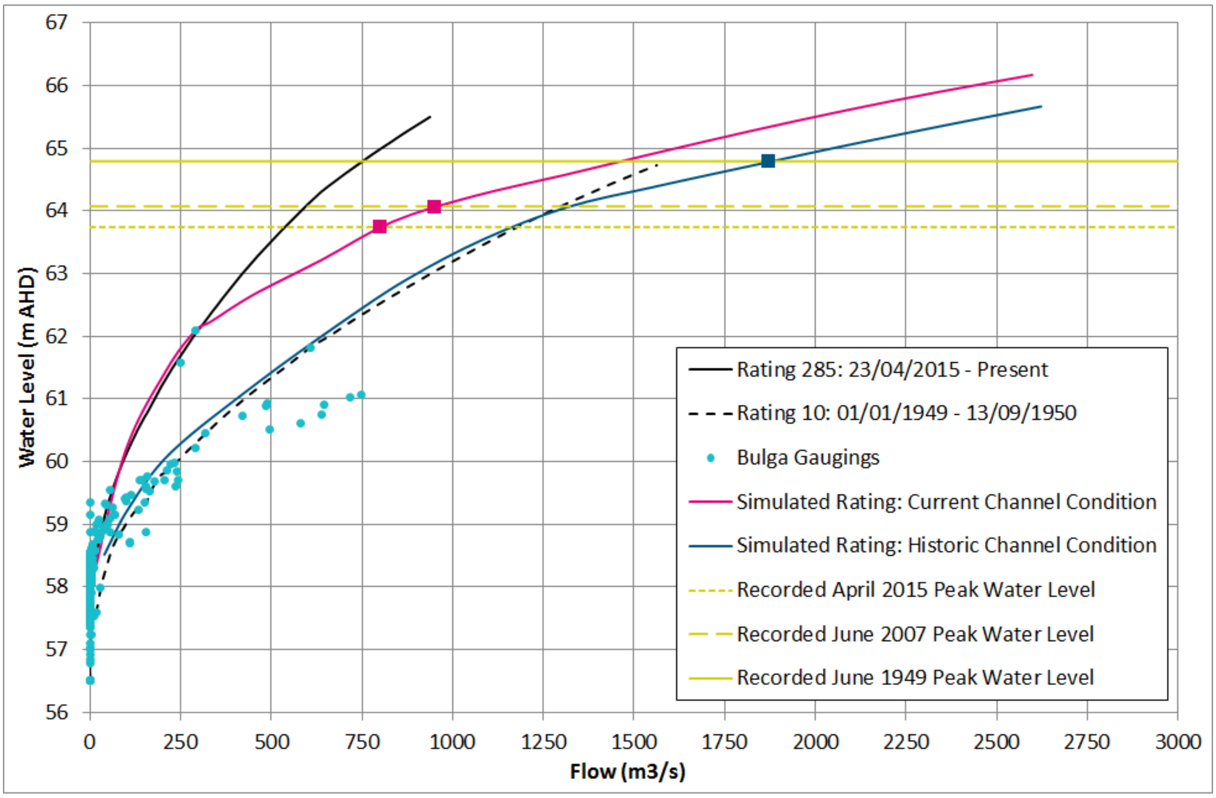


Figure 7-2 Rating Curve Analysis for the Wollombi Brook at Bulga

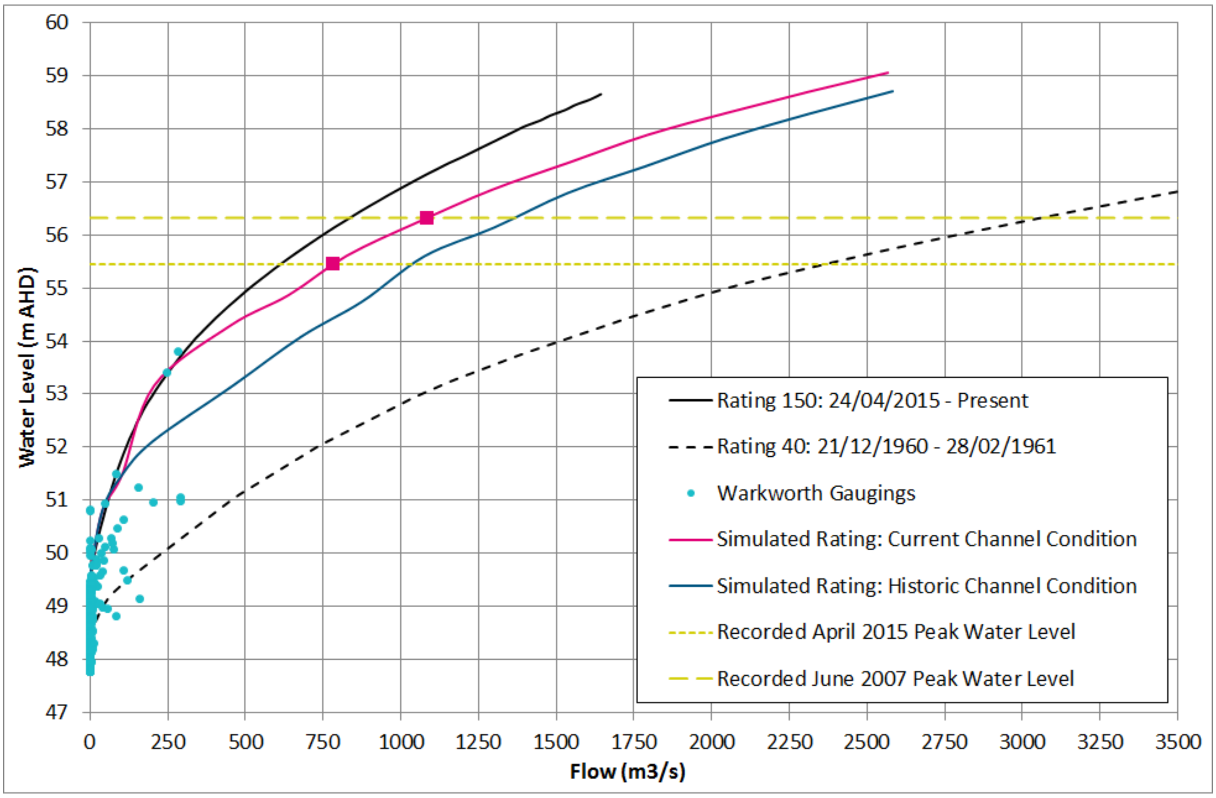


Figure 7-3 Rating Curve Analysis for the Wollombi Brook at Warkworth

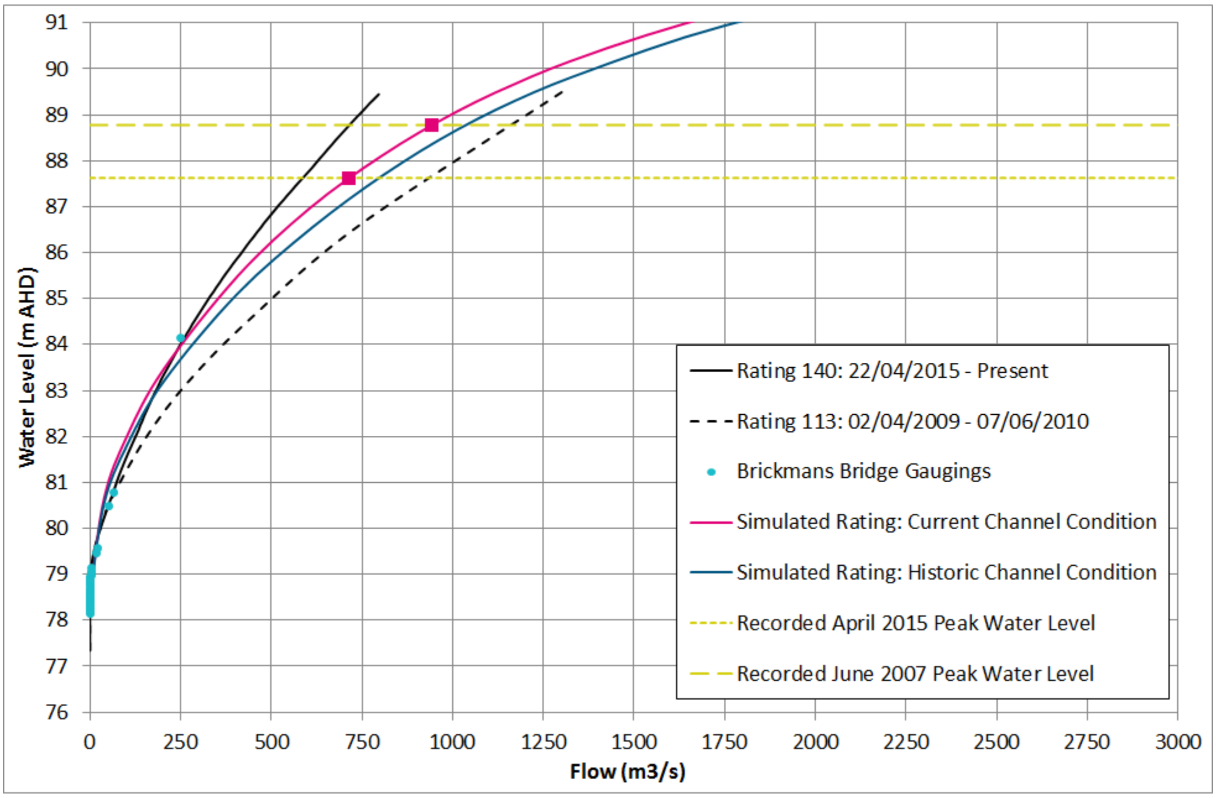


Figure 7-4 Rating Curve Analysis for the Wollombi Brook at D/S Brickmans Bridge

The simulated rating curves have been derived to match well with the spot gauging data. Accordingly, the simulated rating curves also show a general agreement with the corresponding PINEENA rating curves for the corresponding current or historical condition up to the maximum gauged stages. The high flow rating extensions show the most deviation from the previously adopted PINEENA ratings. As previously noted, the modelled rating curves taking into account the full floodplain conveyance properties at high stages are expected to provide a better representation.

The appropriateness of the simulated high flow rating extensions is further considered in the comparison of derived peak flows at each of the gauging stations for the calibration events. The converted flows (based on the simulated rating curves) for the three events used in conjunction with the recorded water levels to calibrate and validate the hydrological and hydraulic models are presented in Table 7-4. The estimated peak flows at the gauging stations show a general consistency in each of the events. For example, for the principal June 2007 calibration event, the estimated flows at Brickmans Bridge, Bulga and Warkworth are 944 m^3/s, 950 m^3/s and 1,084 m^3/s respectively. Similarly, for the April 2015 event the corresponding flows are 800 m^3/s, 714 m^3/s and 782 m^3/s. The relative consistency of the peak flow estimates (typically within +/-10%) based on the peak water levels at each gauge location indicate the general appropriateness of the simulated stage-discharge relationship at each gauge location.

Table 7-4 Recorded Flood Levels and Corresponding Streamflow Estimates

Event	Recorded Peak Water Level (m AHD)	Estimated Peak Flow (m^3/s)
Bulga Gauge		
April 2015	63.7	800
June 2007	64.1	950
June 1949	64.8	1,870
Warkworth Gauge		
April 2015	55.4	782
June 2007	56.3	1,084
June 1949	N/A	N/A
D/S Brickmans Bridge Gauge		
April 2015	87.6	714
June 2007	88.8	944
June 1949	N/A	N/A

The estimate of peak flow based on the recorded water level is sensitive to the adopted channel roughness conditions as shown by the variation in ratings for the current and historical condition. The change in vegetation throughout the reaches of Wollombi Brook can therefore influence local peak flood level conditions. This sensitivity to local vegetation conditions presents some uncertainty in comparing simulated and observed peak flood levels along the study reach for the calibration events. The vegetation conditions within any given reach of the Brook are not known at the time of each calibration event. Accordingly, this uncertainty should be considered in assessing the model calibration.

To further demonstrate the dynamic nature of the channel vegetation and inherent uncertainty in defining appropriate channel roughness conditions for the calibration events, Figure 7-5 shows aerial photography of the channel reach at the Bulga gauge between 2002 and 2006. As evidenced in the photography, this period was characterised by gradual increase in riparian vegetation in the channel at Bulga. The photographs included in Figure 5-1 and Figure 5-2 around 2014 show a further increase in the local channel vegetation at Bulga to what now may be representative of the current condition.

Figure 7-5 Wollombi Brook Riparian Vegetation Growth at Bulga (Google Earth Imagery)

(1) 30/12/2002 (2) 07/01/2004 (3) 11/07/2006

7.3 June 2007 Model Calibration

A major storm event occurred over Friday 8th and Saturday 9th June 2007 with sustained heavy rains, strong winds and large ocean waves and swell causing widespread damage in the Hunter, Central Coast and Sydney Metropolitan areas.

Significant flooding occurred throughout the Lower Hunter Region, including the Wollombi Brook catchment. After consistent rainfall across the catchment throughout the day of Friday 8th, the heaviest rainfall followed during the night of 8th-9th June 2007.

The June 2007 flood in the Wollombi Brook catchment was the largest event experienced since 1949 and subsequently for many residents the largest flood of personal experience.

7.3.1 Calibration Data

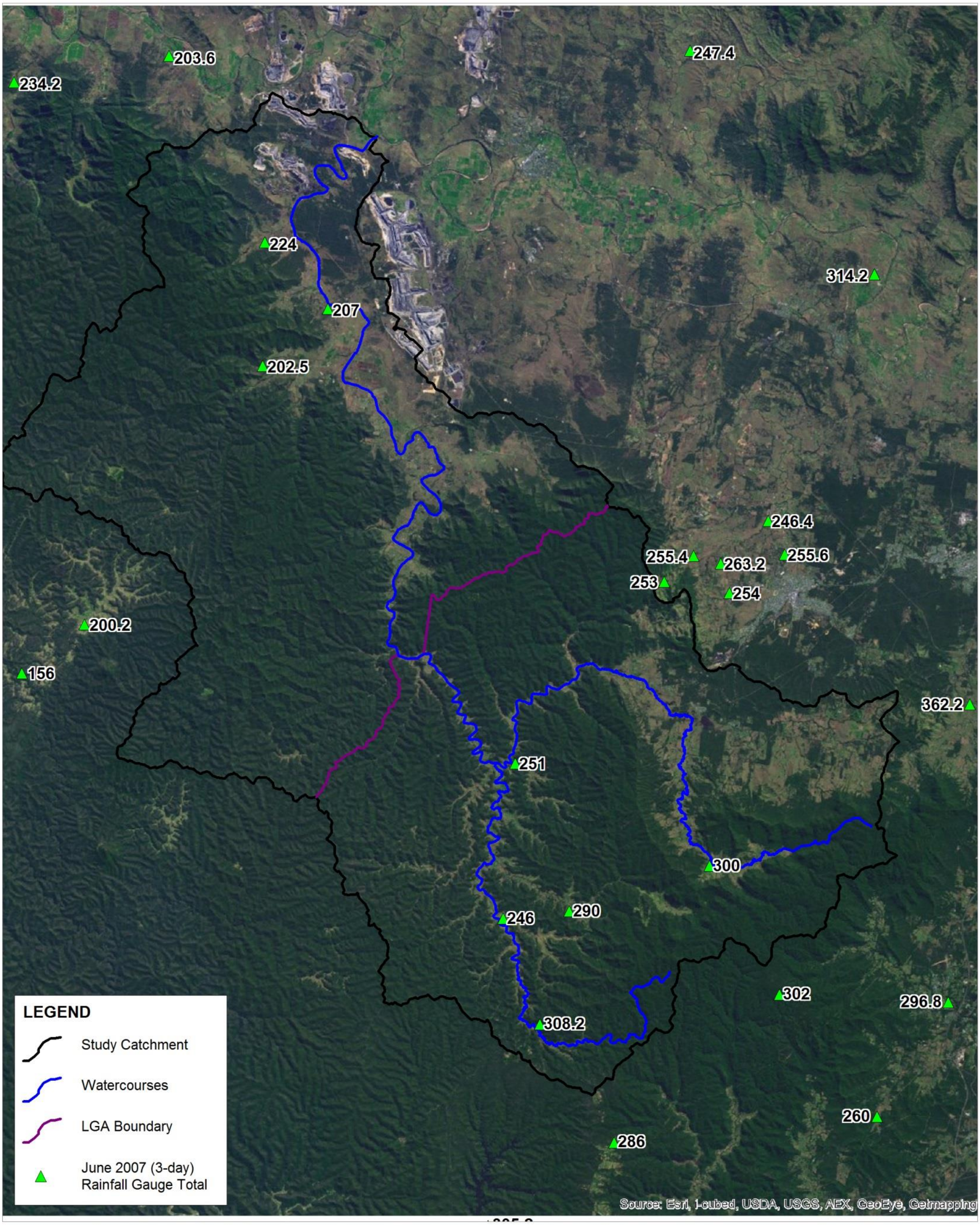
7.3.1.1 Rainfall Data

The recorded daily totals (for the 24 hours to 9am) for the period 9am 6th June – 9am 12th June 2007 for rainfall gauges in the vicinity of the Wollombi Brook catchment are summarised in Table 7-5. Of the eighteen rainfall gauges listed in Table 7-5, three are continuous read rainfall gauges (Wollombi (St Johns Church), Watagan Central and Broke (Harrowby)) and the remaining fifteen gauges are daily read gauges. It should be noted that no continuous rainfall record is available for the Broke (Harrowby) gauge for the June 2007 event with only a three day combined total available for the period 9am 8th June – 9am 11th June 2007. The distribution of the rainfall gauges is shown in Figure 7-6 displaying three totals from 9am 7th June – 9am 10th June 2007.

The recorded hyetographs at the Wollombi (St Johns Church) and Watagan Central continuous rainfall gauges are shown in Figure 7-7. The hyetograph period shown is from 9am 7th June to 9am 9th June 2007, corresponding to the period of the main rainfall in the Wollombi Brook catchment. The similarity of the hyetographs at Wollombi and Watagan Central is apparent, indicating a relatively uniform rainfall depth and temporal pattern across this part of the catchment.

Table 7-5 Recorded Rainfall for June 2007 Event

Station No.	Station Name	6th June	7th June	8th June	9th June	10th June	11th June	Total
61226	Wollombi (St Johns Church)	0.2	11	42.8	174	-	-	**228**
61152	Congewai (Greenock)	0	17	60	200	40	0	**317**
61164	Laguna (Murrays Run)	0	10.4	63	221.6	23.6	0	**318**
61201	Watagan Central	0	9.8	51	216.4	22.6	0	**300**
61205	Yallambie (Mount Auburn)	0	10	41	185	20	0	**256**
61110	Howes Valley Repeater	0	12	35	120	1	0	**168**
61242	Cessnock (Nulkaba)	0.2	9.2	53.8	189.8	12	0.1	**265**
61382	Wyong (Kulnura (Jeavons))	0	16	65	196	25	0	**302**
61385	Wyong (Olney Forest)	0	14	66	215	21	1	**317**
61100	Broke (Harrowby)	0	8.6	293 (3 day total)			0	**302**
61143	Bulga (Down Town)	0	7.8	53	151	3	0	**215**
61162	Howes Valley (Putty Rd)	0	9	46.4	151.4	2.4	0.2	**209**
61327	Pokolbin (Myrtledale)	0	13	51	191	11	0	**266**
61357	Mandalong (Mandalong Road)	0	17	65	165	30	0	**277**
61012	Cooranbong (Avondale)	0	20	61.4	201	34.4	0	**317**
61048	Mulbring (Stone Street)	0	14	66	280	16.2	0	**376**
61309	Milbrodale (Hillsdale)	0	11	53	145	4.5	0	**214**
61226	Wollombi (St Johns Church)	0.2	11	42.8	174	-	-	**228**



Title:
June 2007 Rainfall Distribution

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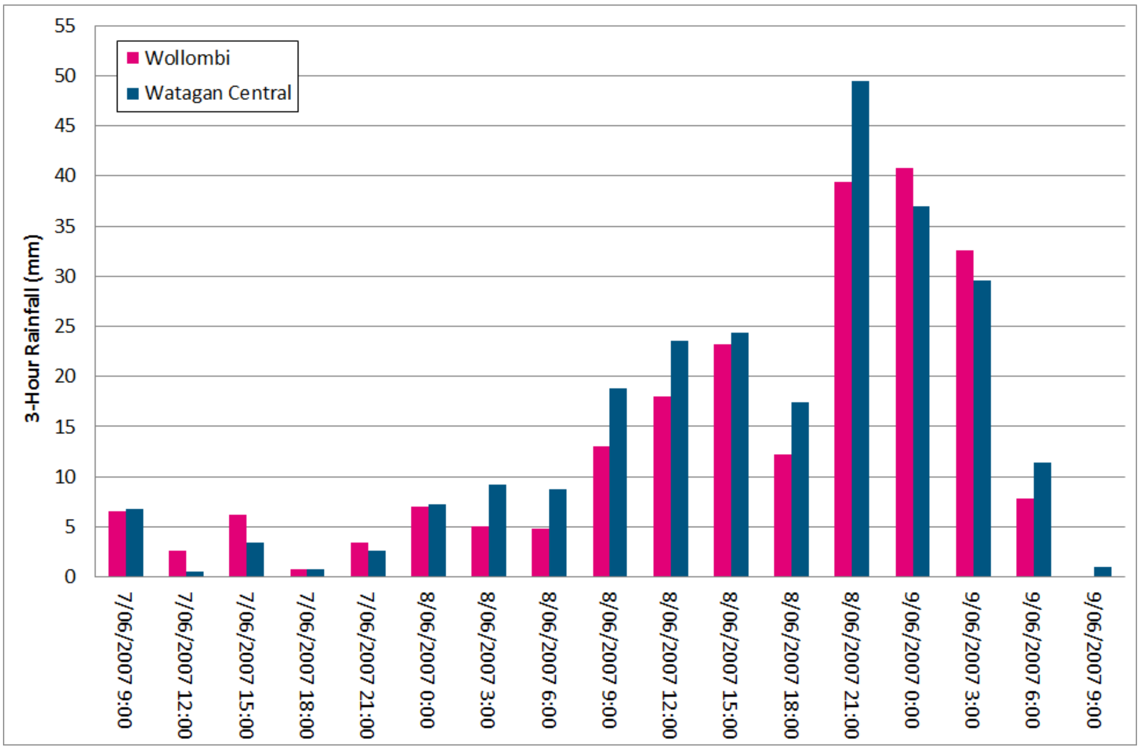


Figure 7-7 Recorded Rainfall Hyetograph (Wollombi and Watagan Central)

Consistent light rainfall fell across the catchment throughout the day or so leading up to the main storm event. This provided for a "wetting-up" period for the catchment which ultimately would lead to higher run-off during the main storm burst that occurred during the evening and early morning of the 8th and 9th June. The most intense period of rainfall as indicated by the recorded hyetographs occurred in the period between 6pm and 12am on Friday 8th, with 80mm and 86mm recorded at the Wollombi and Watagan Central gauges respectively.

Given the number and location of daily read rainfall gauges, a good representation of the daily total rainfall distribution across the catchment is available. It is noted there is a significant spatial variation in total rainfall across the catchment. For example, moving down the catchment the relative total storm rainfall (9am 7th June to 9am 10th June 2007) for Laguna (Murray's Run), Wollombi (Narone Creek Rd) and Bulga were 308mm, 251mm and 207mm respectively.

In addition to the spatial variation across the catchment, there is also the temporal variation in rainfall to consider in defining rainfall inputs to the hydrological model. Whilst the Watagan Central and Wollombi continuous read gauges provide the temporal pattern of rainfall for these localities, it is unlikely that they are representative for the entire catchment. The adoption of a single temporal pattern across the study area catchments may not be representative of the actual June 2007 storm conditions and may provide difficulties in calibrating/validating the models to observed conditions.

The BoM rainfall radar data was used to estimate the temporal variation of rainfall across the catchment. When coupled with on-ground gauges within the catchment and neighbouring catchments, the radar data can be utilised to derive event hyetographs that reflect both the temporal and spatial variation of the actual rainfall that occurred throughout the rainfall event. This provides the opportunity for improved calibration of models and representation of actual flood conditions.

A sample plot of the BoM rainfall data is shown in Figure 7-8. The radar data provides indicative rainfall intensities across the catchment. The data has been collected at 10 minute intervals, such that the temporal distribution of rainfall intensity over the course of the rain event is also recorded.

The aggregated daily rainfall totals from the radar data do not match the on-ground readings. Generally it was found that the radar total was in the order of two to three times larger than the rain gauge total. The radar data is only indicative of relative intensities and generally not used to define actual total rainfall. However, in the absence of extensive pluviograph data, the aggregated radar data is considered to provide a reasonable estimate of relative rainfall depth and temporal variation across the catchment.

Utilising on-ground rainfall gauge data, a daily rainfall grid was created for the daily totals to 9am on the 8th, 9th and 10th of June 2007. The daily rainfall grids were used to define a daily rainfall depth for each of the XP-RAFTS sub-catchments. The BoM radar rainfall data was interrogated in order to obtain an average radar rainfall depth for each sub-catchment for each 10 minute radar data interval. The interrogated values provided a daily temporal pattern for each sub-catchment. The daily temporal patterns were adjusted using the daily rainfall grid values so that the total depth of rainfall defined by the temporal pattern was equal to the daily rainfall grid value for each sub-catchment. The adjusted temporal patterns were then used to define a hyetograph for each of the XP-RAFTS sub-catchments.

Generating an adjusted radar hyetograph for each of the XP-RAFTS sub-catchment provides the best model representation of the spatial and temporal variation of rainfall for the June 2007 event.

To gain an appreciation of the relative intensity of the June 2007 event, the recorded rainfall depths at the Wollombi (St Johns Church) and Watagan Central continuous read rainfall gauges for various storm durations were compared with the design IFD data for the same locations as shown in Figure 7-9 and Figure 7-10.

The Wollombi (St Johns Church) gauge recorded a total of 187mm for the 24 hours 6:00am 8th June to 6:00am 9th June, whilst the Watagan Central gauge recorded a total of 212 mm for the same period. With reference to the IFD relationships at each site, this corresponds to approximately a 50-year ARI rainfall for Wollombi and 30-year ARI rainfall for Watagan Central. This duration provides for the highest estimate of design return period for the storm event.

It is interesting also to note the variation in design rainfall depth between the Wollombi and Watagan Central gauge locations. This is typical of the spatial variation in design rainfall parameters across the catchment. The Wollombi and Watagan gauges are separated by a distance of some 11km, however the proximity of the Watagan Central gauge to the Watagan Mountains range results in higher design rainfall depths when utilising the standard IFD procedures of AR&R (2001).

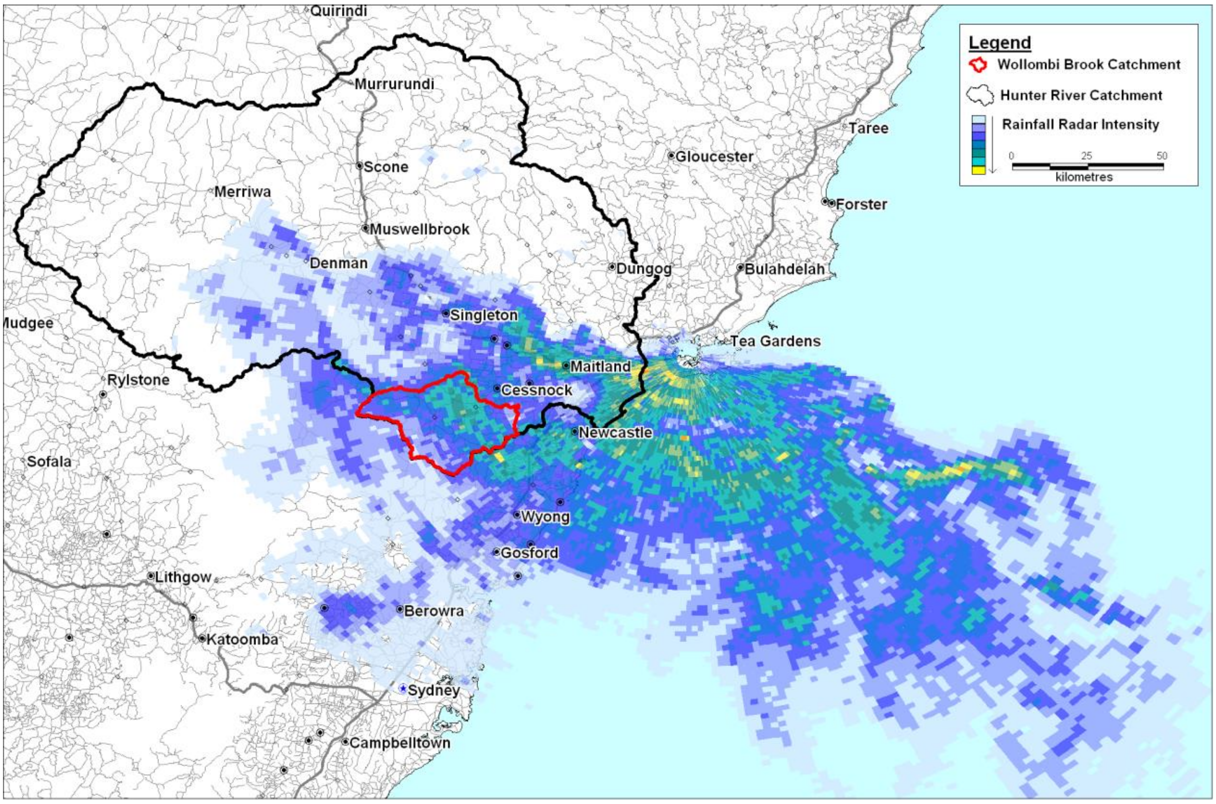


Figure 7-8 Sample Rainfall Radar Distribution

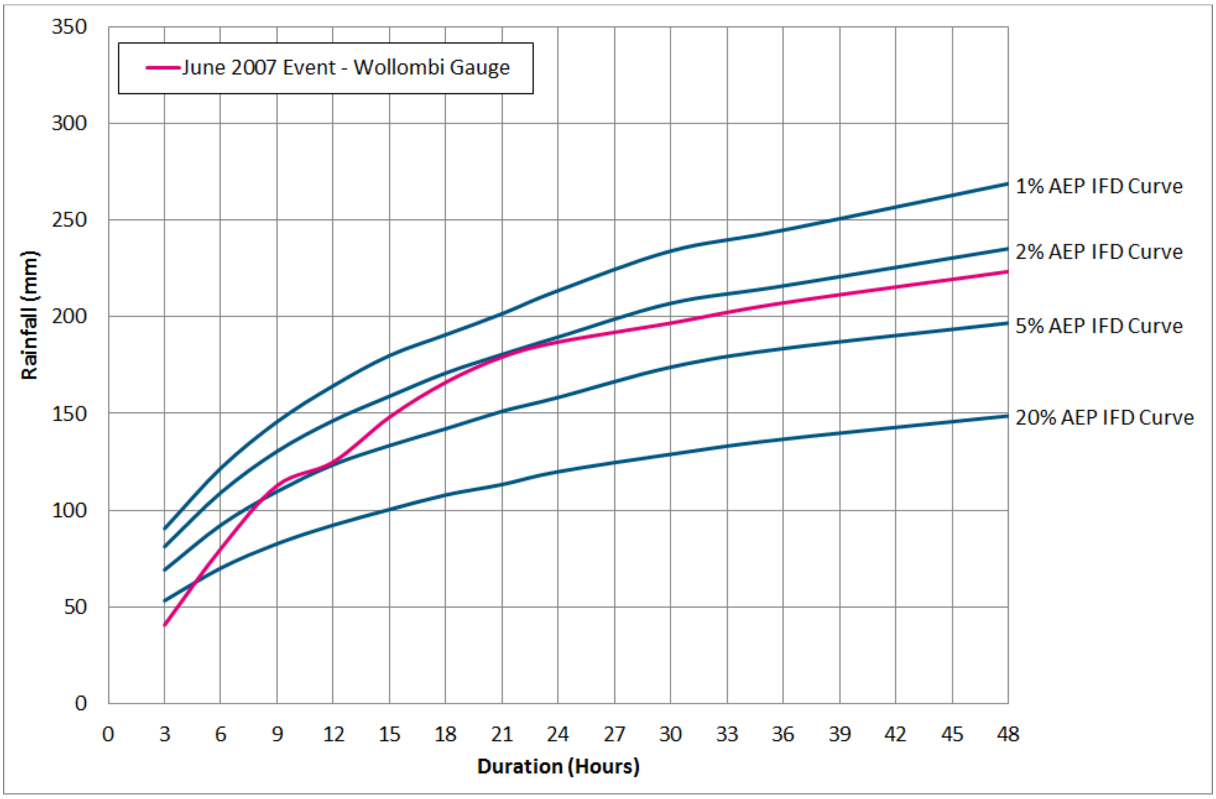


Figure 7-9 Comparison of Recorded Rainfall with IFD Relationships – Wollombi (St Johns Church) Gauge

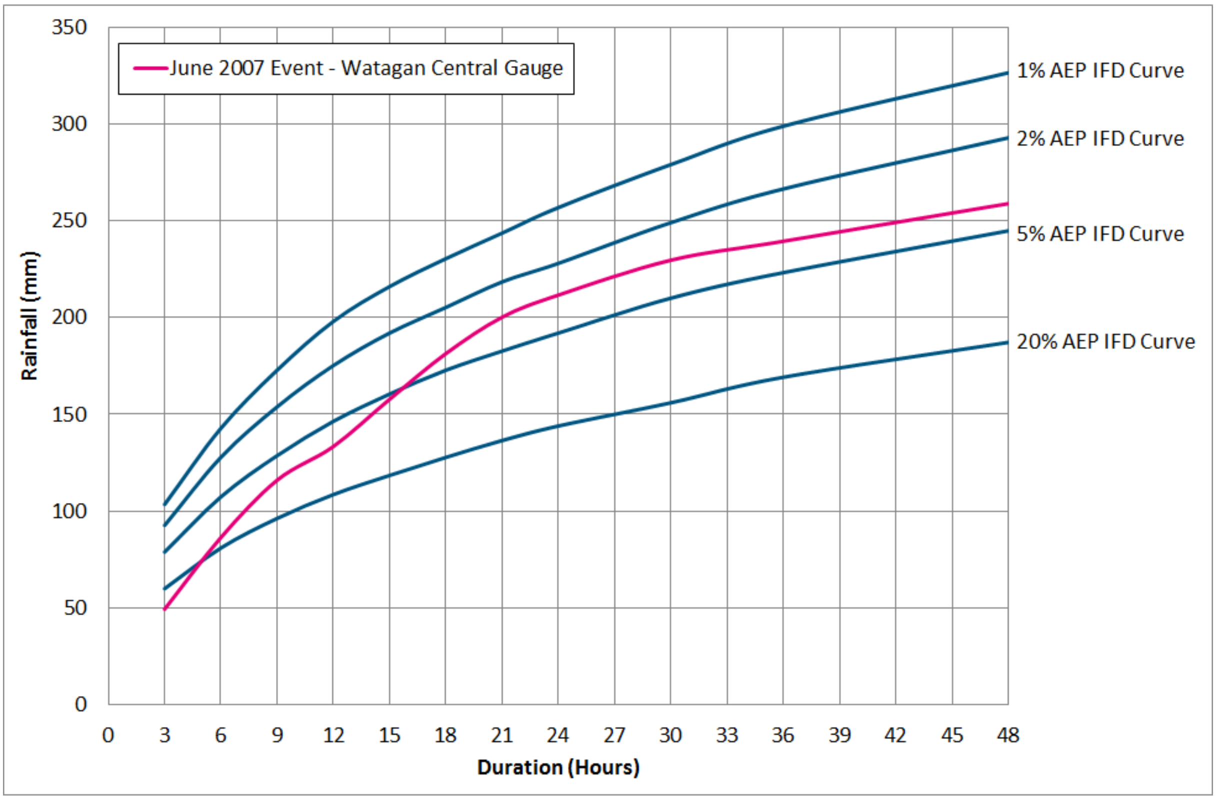


Figure 7-10 Comparison of Recorded Rainfall with IFD Relationships – Watagan Central Gauge

7.3.1.2 Streamflow Gauge Data

As discussed in Section 2.2.3, there are three active streamflow gauges located on Wollombi Brook, operated by the NSW Office of Water. The stations include D/S Brickmans Bridge (#210135), Bulga (#210028) and Warkworth (#210004).

Unfortunately, during the June 2007 flood the D/S Brickmans Bridge gauging station failed, with no water level timeseries recorded at this site. The Bulga and Warkworth gauges remained in operation. However, the NSW Office of Water identified and subsequently surveyed a high water mark (debris line) surveyed after the flood event high water mark (debris line) at the D/S Brickmans Bridge gauge location.

A comparison between the recorded and simulated water level time series and the corresponding converted and simulated streamflows at the gauge locations is presented in Section 7.3.5.

7.3.1.3 Flood Level Data

As previously presented in Section 4.2, eight historical flood marks were identified from the community questionnaire responses for the June 2007 event. These marks generally comprise recorded marks (scratches, lines drawn with marker on a wall, photographic evidence or points reconstructed from the memory of community members). The locations of the eight historical flood marks surveyed are presented in Table 7-6 and shown in Figure 4-1.

The recorded flood levels provide the basis for the water level calibration of the hydraulic model. A comparison of the observed and simulated water level profiles along the Wollombi Brook for the June 2007 is presented in Section 7.3.5.

Table 7-6 June 2007 Historical Flood Levels from Community Consultation

ID	Location	Flood Level (m AHD)
FM2	Cochrane Street, Broke	75.2
FM4	Butlers Road, Broke	75.1
FM5	185 Fordwich Road, Fordwich	71.7
FM6	80 Stockyard Creek Road, Paynes Crossing	90.8
FM7	80 Stockyard Creek Road, Paynes Crossing	90.8
FM8	1249 Broke Road, Broke	74.8
FM9	'Charlton' 154 Cobcroft Road, Broke	68.4
FM10	'Charlton' 154 Cobcroft Road, Broke	68.5

7.3.1.4 *Photographic Record*

Numerous photographs were taken during and after the June 2007 event by residents, Council and BMT WBM staff. The photographs have been compiled for Council records.

The photographs have proved a useful resource in developing and calibrating the hydraulic model, providing confirmation of inundation extents and flood levels at various locations within the catchment. A review of aerial photography taken by BMT WBM staff shortly after the June 2007 event provided an additional ten historical flood marks. These flood marks are presented in Table 7-7.

Table 7-7 June 2007 Historical Flood Levels from Aerial Photography

ID	Flood Level (m AHD)
P1	69.3
P2	71.8
P3	73.0
P4	74.8
P5	79.2
P6	79.2
P7	80.0
P8	82.0
P9	84.2
P10	86.0
P11	90.2

7.3.2 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. The initial loss-continuing loss model has been adopted in the XP-RAFTS hydrological model developed for the Wollombi Brook 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 7-11 shows the monthly rainfall at the Broke (Harrowby) gauge for 2007. Whilst some slightly above average monthly rainfall was experienced in March 2007, the two months preceding the flood events were characterised by below average rainfall.

The main rainfall burst that occurred over June 8th and 9th 2007 was preceded by approximately 10-20mm of rainfall across the catchment on June 7th. In considering the catchment wetness condition at the start of the June 2007 event, an initial loss value of 10mm was adopted. Given the duration of the event and the large rainfall depths, the initial loss parameter does not have a major influence on the simulated flow conditions.

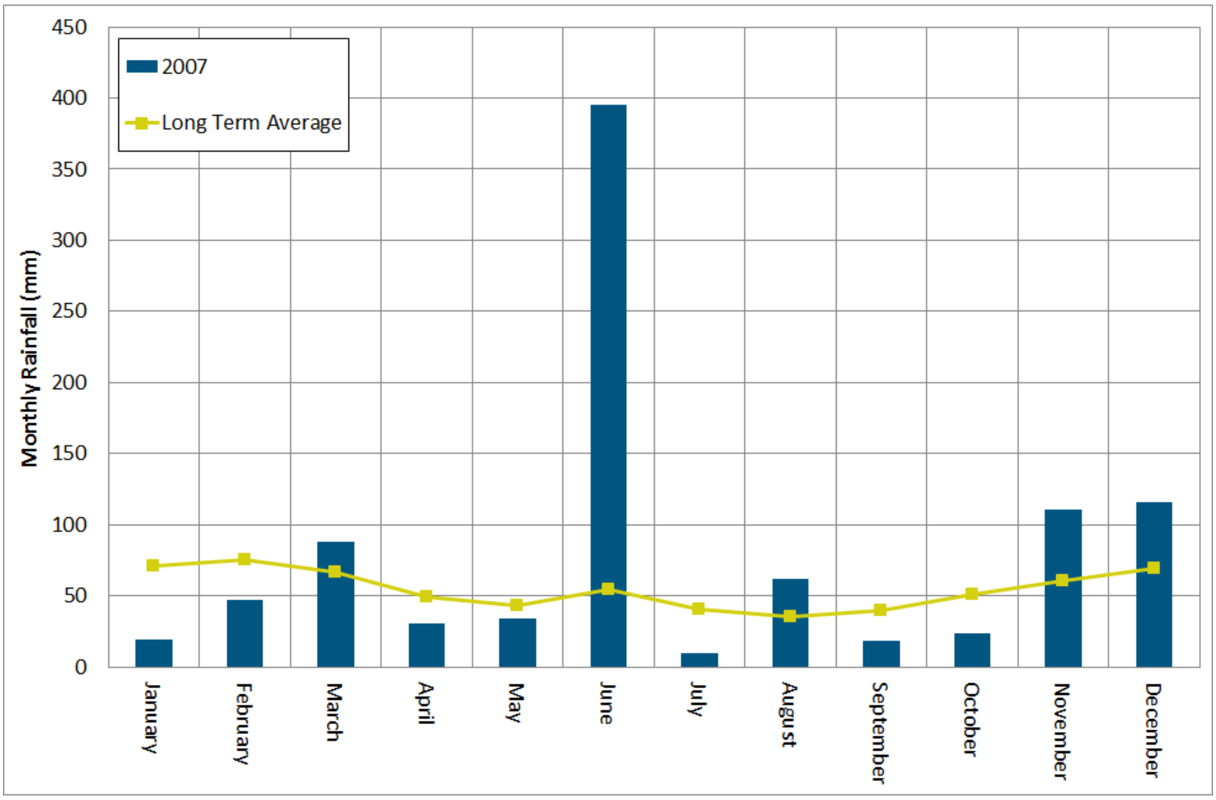


Figure 7-11 Broke (Harrowby) Monthly Rainfall Preceding June 2007 Event

7.3.3 Rainfall Losses

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 any rainfall that fell prior to the modelled storm burst. AR&R have also recently undertaken a series of revision projects including Project 6 Loss Models for Catchment Simulation – Rural Catchments (October 2014). This revision project involved the analysis of data for a large number of catchments and rainfall events across Australia to identify, among a number of outcomes, the distribution of loss values across Australia. The project found that continuing loss values in the GSAM Coastal Zone (within which the Wollombi Brook catchment is located) ranged from 0-8mm/hr with median continual loss values ranging from 0.5-3.9mm/hour.

An initial loss of 10mm and continuing loss of 5mm/hr were found to provide a reasonable fit to the observed hydrological behaviour in the Wollombi Brook catchment for the June 2007 event. These values are considered to be consistent with the AR&R guidelines and findings for loss values in the GSAM Coastal region.

7.3.4 Adopted Model Parameters

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

The final parameter values adopted, as shown in Table 7-8 were found to give a good result in representing the hydrological and hydraulic behaviour in the Wollombi Brook catchment for the June 2007 event. The 'current condition' in-channel Manning's distribution discussed in Section 7.2 was adopted for the June 2007 event model calibration.

Table 7-8 June 2007 Model Calibration Parameters

Parameter	Value	Comment
Initial Loss (mm)	10mm	Refer Section 7.3.3
Continuing Loss (mm/hr)	5mm	
Storage coefficient factor Bx	1.0	This routing parameter had the most significant influence on the shape of the simulated hydrograph. The adopted value was applied globally for the catchment and provided the best fit of catchment response in terms of flow magnitude and timing.
PERN (roughness value for hydrological model)	0.06 -0.12	The PERN factors are used to adjust the catchment routing factor to allow for catchment roughness. Catchment average values were estimated based on percentage of cleared floodplain and forested areas.
Manning's 'n' roughness value for hydraulic model (channel)	0.04 -0.11	Variable adjusted locally (within reasonable bounds) to provide best fit for peak water level profiles. Variability largely reflects degree of vegetation within main channel section.

Parameter	Value	Comment
Manning's 'n' roughness value for hydraulic model (floodplain)	0.05 – 0.12	Variable adjusted locally (within reasonable bounds) to provide best fit for peak water level profiles. Variability largely reflects degree of vegetation and land use on the floodplain (cleared and forested)

7.3.5 Observed and Simulated Flood Behaviour June 2007

As discussed in Section 2.2.3, there are three active streamflow gauges located on Wollombi Brook, operated by the NSW Office of Water. The stations include D/S Brickmans Bridge (#210135), Bulga (#210028) and Warkworth (#210004).

The gauging station at Warkworth can be influenced by backwater flows from the Hunter River and as such would not be entirely representative of the levels in the Wollombi Brook. As such, the model calibration for the June 2007 event is focused on the Bulga and D/S Brickmans Bridge gauges which are considered to provide for a more accurate representation of the flood behaviour within the Wollombi Brook.

The effectiveness of the model representation of the catchment response to the adopted rainfall inflows can be assessed through comparison of the recorded and modelled hydrographs at the Bulga and D/S Brickmans Bridge gauging stations. Given the uncertainty surrounding appropriate rating curves at the gauges, this comparison has been undertaken using water levels.

The Brickman's Bridge gauge failed during the June 2007 event such that the water level timeseries for this gauge site is only an estimate based on a recorded peak water level and the downstream Bulga water level timeseries. However, it is still considered to be a useful comparison against the simulated model result.

The effectiveness of the model representation of the adopted rainfall inflows can also be assessed by comparing the simulated flow against the flow estimated at the Bulga gauge using the model derived 'current' condition rating curve discussed in Section 7.2. The comparison of the recorded and modelled water level timeseries at the Bulga and D/S Brickmans Bridge gauging stations are presented in Figure 7-12 and Figure 7-13 respectively. The simulated peak flows, water levels and corresponding peak flow estimate based on the model derived rating curve is presented in Table 7-9.

Table 7-9 June 2007 Observed and Simulated Peak Flood Levels and Flows

Location	Observed Water Level (m AHD)	Simulated Water Level (m AHD)	Estimated Peak Flow (m^3/s)	Simulated Peak Flow (m^3/s)
Warkworth	56.3	56.1 (-0.2)	1,084	957
Bulga	64.1	64.1 (0.0)	950	963
D/S Brickmans Bridge	88.8	88.7 (-0.1)	944	939

Note: Bracketed value is difference in peak flood level between observed and simulated

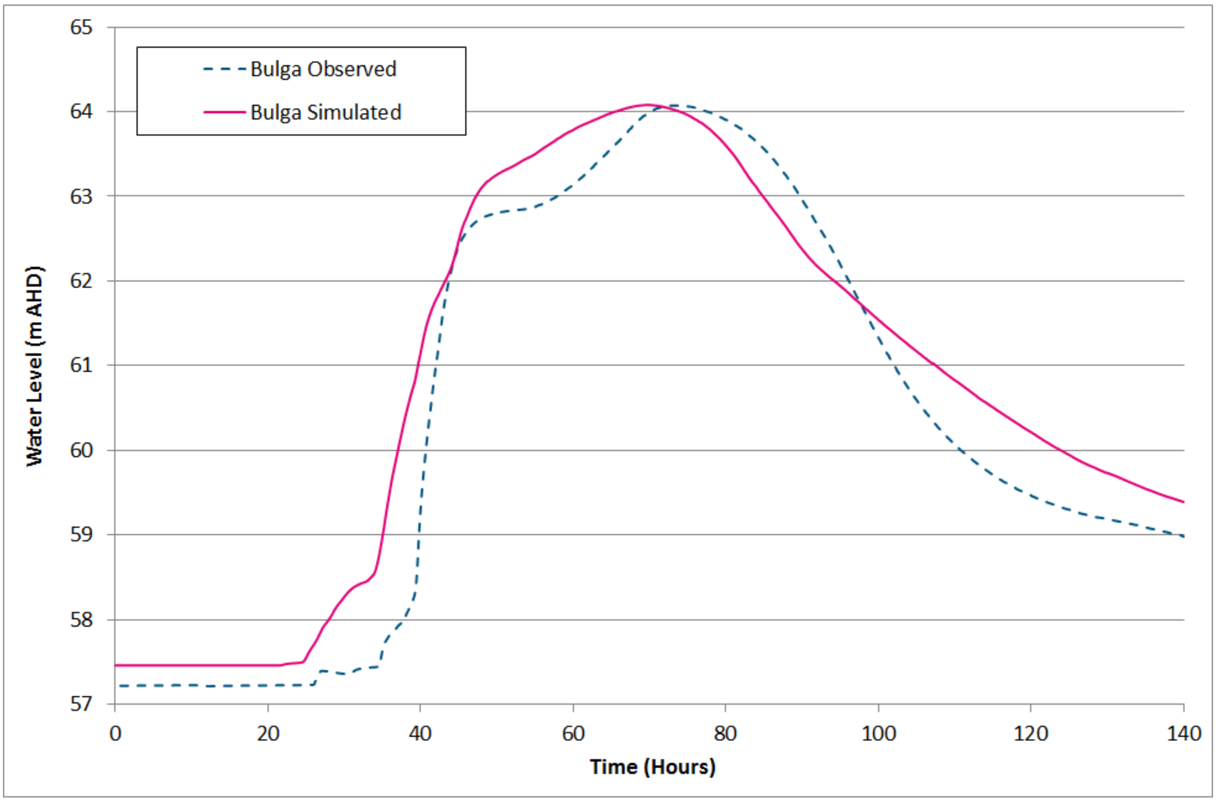


Figure 7-12 June 2007 Observed and Simulated Hydrograph at Bulga

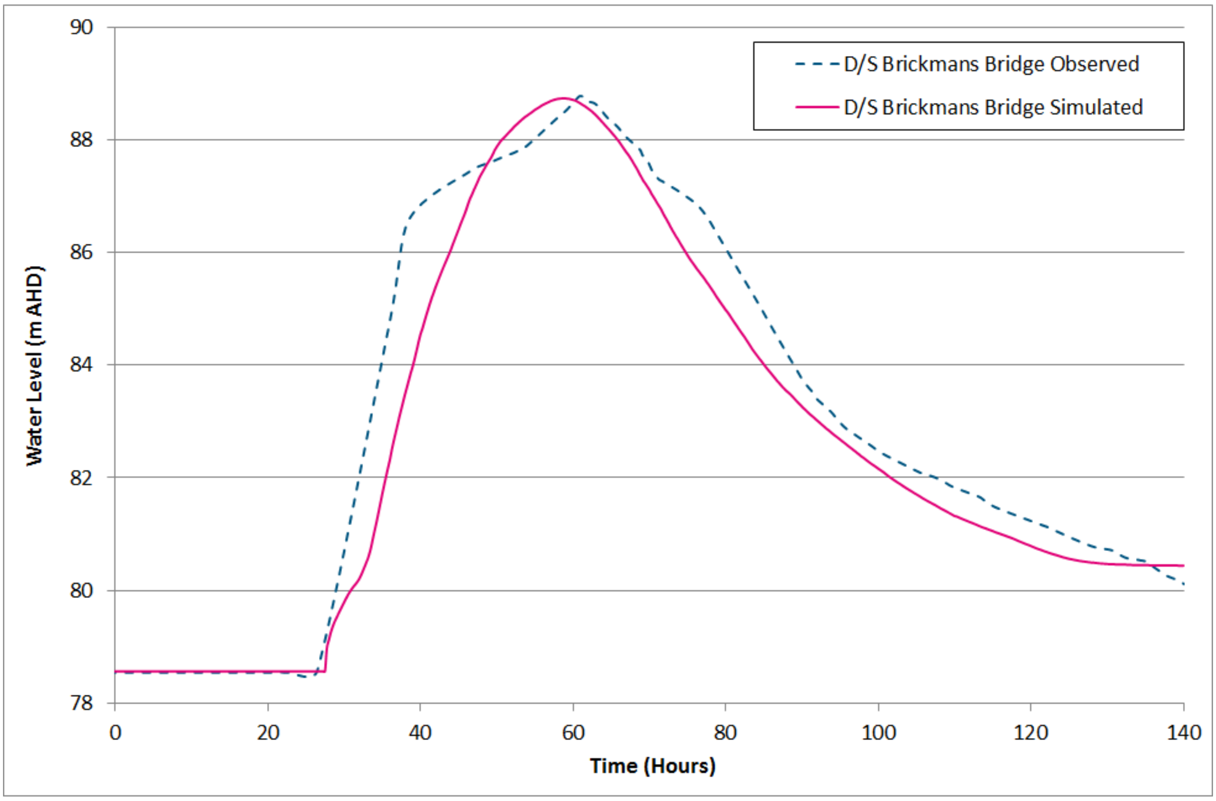


Figure 7-13 June 2007 Observed and Simulated Hydrograph at D/S Brickman's Bridge

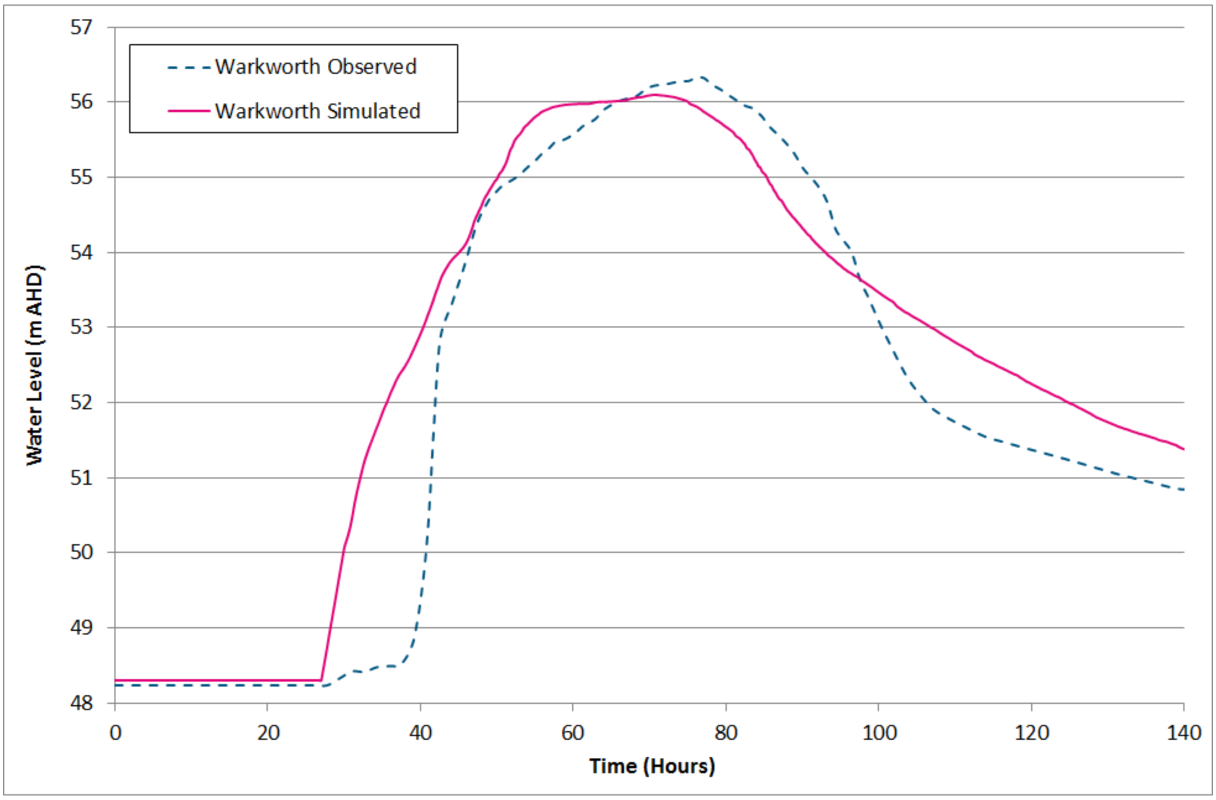


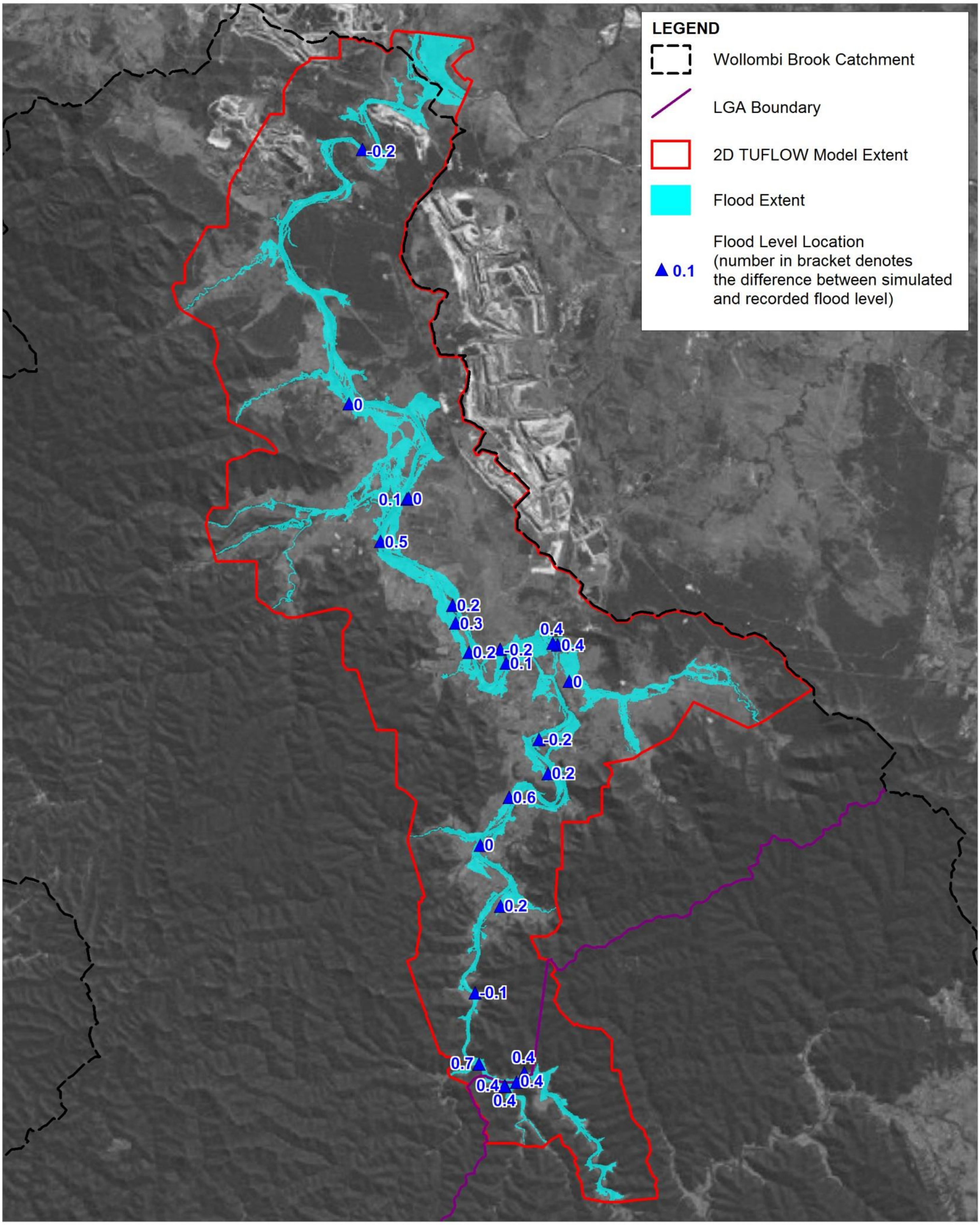
Figure 7-14 June 2007 Observed and Simulated Hydrograph at Warkworth

It is evident that model provides for a good correlation with the recorded peak flood levels with the simulated peak flood levels at the Bulga and D/S Brickmans Bridge gauges within 0.1m of the recorded level and within 0.2m at Warkworth. The overall shape of the water level timeseries is also well represented at each gauge location in terms of rate and timing of the rise and retreat of floodwaters.

It is also evident that the simulated peak flow for the June 2007 event from the hydraulic model at the Bulga gauge is 963m^3/s compares well with the estimated peak flow at Bulga from the gauging analysis described in Section 7.2 of 950m^3/s (difference +1%).

As previously discussed, in addition to the gauge data, eight historical flood marks were identified from the community questionnaire responses for the June 2007 event. An additional ten historical flood marks were also identified following a review of aerial photography taken by BMT WBM staff shortly after the June 2007 event. These historical flood marks provide flood levels along the length of the modelled reaches of Wollombi Brook and its tributaries.

A comparison of simulated and observed peak flood levels for the June 2007 event are shown in Figure 7-15 and Figure 7-16 and presented in Table 7-10.



Title:

June 2007 Calibration Event
Peak Flood Extent

Figure: **7-15**

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Approx. Scale

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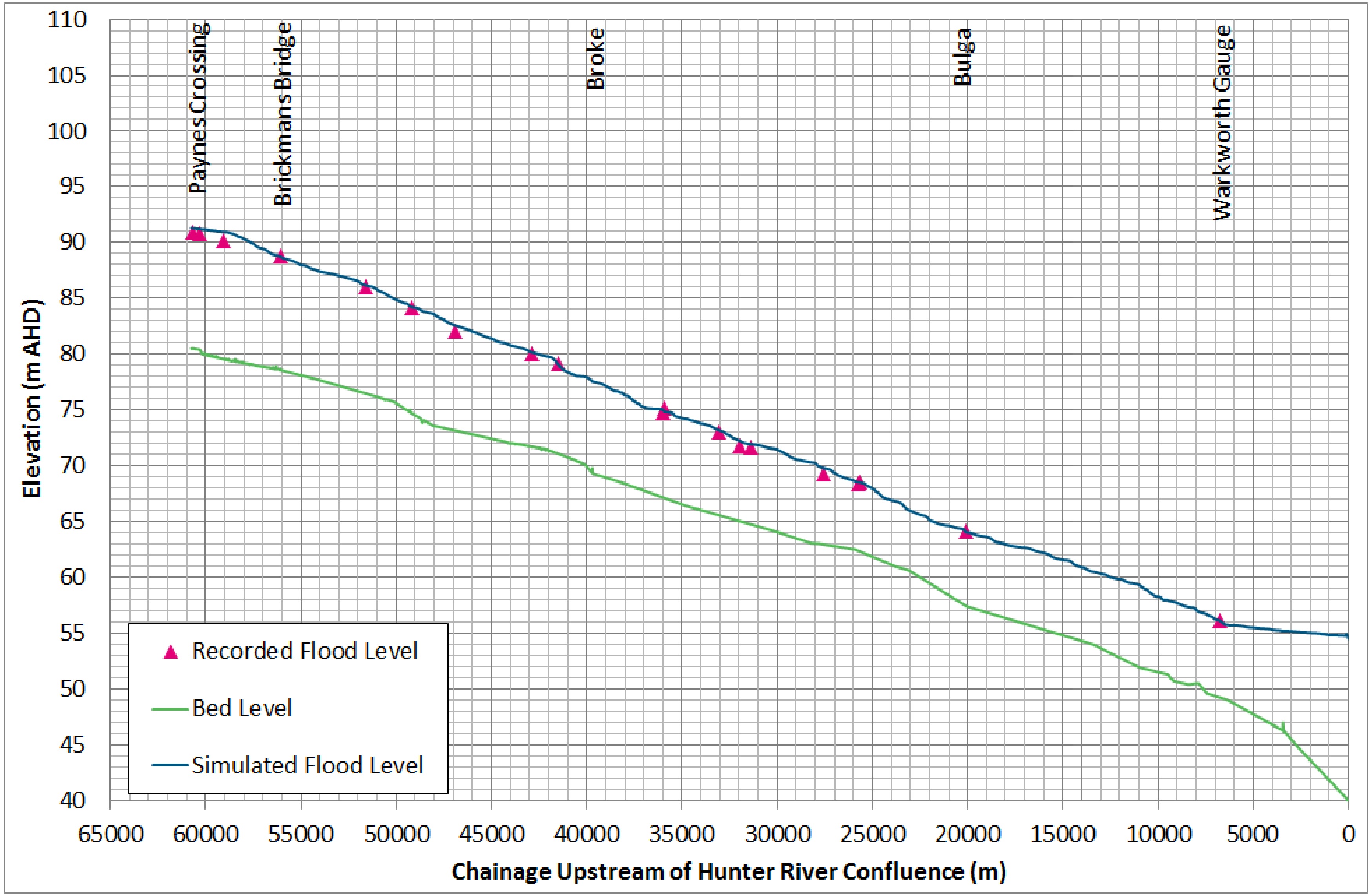


Figure 7-16 June 2007 Peak Water Level Calibration Long Section

Table 7-10 June 2007 Observed and Simulated Flood Levels (m AHD)

Location	Observed	Simulated	Difference
Warkworth Gauge	56.3	56.1	-0.2
Bulga Bridge Gauge	64.1	64.1	0.0
‘Charlton’ 154 Cobcroft Road, Broke	68.4	68.5	0.1
‘Charlton’ 154 Cobcroft Road, Broke	68.5	68.5	0.0
Estimated from Aerial Photography *	69.3	69.8	0.5
185 Fordwich Road, Fordwich	71.7	71.9	0.2
Estimated from Aerial Photography *	71.8	72.1	0.3
Estimated from Aerial Photography *	73.0	73.2	0.2
Estimated from Aerial Photography *	74.8	74.9	0.1
Estimated from Aerial Photography *	74.8	75.2	0.4
1249 Broke Road, Broke	74.8	75.2	0.4
Butlers Road, Broke	75.1	74.9	-0.2
Cochrane Street, Broke	75.2	75.2	0.0
Estimated from Aerial Photography *	79.2	79.0	-0.2
Estimated from Aerial Photography *	80.0	80.2	0.2
Estimated from Aerial Photography *	82.0	82.6	0.6
Estimated from Aerial Photography *	84.2	84.2	0.0
Estimated from Aerial Photography *	86.0	86.2	0.2
D/S Brickmans Bridge Gauge	88.8	88.7	0.1
Estimated from Aerial Photography *	90.2	90.9	0.7
80 Stockyard Creek Road, Paynes Crossing	90.8	91.2	0.4
80 Stockyard Creek Road, Paynes Crossing	90.8	91.2	0.4
Paynes Crossing Gauge Location	90.9	91.3	0.4
Estimated from Aerial Photography *	91.0	91.4	0.4

* - Peak flood levels estimated from aerial photography taken shortly after the June 2007 event (refer Appendix F)

The comparison of the observed and simulated peak flood levels indicates a good agreement for the June 2007 event with the majority of simulated levels being within 0.3m of the observed flood levels. It should be noted that the historical flood marks are often constructed from the memories of residents and estimated from photographs taken following the flood event and as such can often be slightly incorrect or unreliable. However, the historical flood levels still provide a useful source of calibration data and in the most part indicate that the simulated flood levels are in agreeance with observed levels.

It is evident that area of discrepancy between the simulated and recorded flood levels is the reach of Wollombi Brook between Paynes Crossing and Brickmans Bridge. It was found that in order to match the flood levels along the Wollombi Brook between Brickmans Bridge and Broke, a high in-channel Manning’s ‘n’ roughness value was required as outlined in Section 7.2. Whilst the comparison between the simulated and observed flood levels within this reach indicates a good match, this increased Manning's 'n; value results in a backwater effect that effectively reduces the flood slope upstream of Brickmans Bridge which subsequently results in elevated water levels upstream along the Wollombi Brook as far as Paynes Crossing. Whilst the resulting water levels are higher than the observed, the simulated flood behaviour is still considered to provide for a reasonable representation of the June 2007 flood event in terms of the peak flood extent.

It is also evident in Table 7-10 that there is some discrepancy between the simulated flood levels and the flood levels estimated from the aerial photography taken shortly after the June 2007 flood event. The observed levels where estimated by identifying the peak flood extent from the aerial photography and using the LiDAR data to ascertain the corresponding ground level at this location. It should be noted that there is a level of interpretation required to estimate these levels and that there is also some uncertainty around the accuracy of the LiDAR data. In some instances difference between the estimated and simulated flood levels were in excess of 0.5m but it is important to note however that the simulated peak flood extents at these locations correlate well with the observed flood extents from the aerial photography. Overall, the historical flood levels approximated from the aerial photography where considered to be a useful source of calibration data and in the most part indicate that the simulated flood levels are in agreeance with estimated levels as well as providing a good correlation to the observed peak flood extents.

7.4 1949 Model Validation

The objective of the model validation was to test the appropriateness of the adopted calibration parameters for a different historical event. Based on available data, the June 1949 flood event was selected for this purpose.

It should be noted that the 1949 flood event is believed to have been responsible for initiating significant channel change within the Wollombi Brook resulting from scouring of the river bed and banks under the action of floodwaters. As outlined in *The Way of the River: Environmental Perspectives on the Wollombi* (1994) the June 1949 flood resulted in significant damage in the Wollombi Brook catchment including inundation of houses, roads and bridges, extensive river bank erosion, destruction of bridges and gauging stations, substantial sand deposition in the river bed and on the floodplain and widespread destruction of riparian vegetation. The extensive bank erosion reportedly resulted in substantial channel enlargement with the Wollombi Brook channel at Bulga widened by some twelve metres.

The model development and calibration for the 2007 event utilised topographical data representative of the current channel bathymetry of Wollombi Brook. However, there is little topographical data available describing the channel bathymetry prior to the 1949 flood event, thus limiting the opportunity to change the model to reflect the actual 1949 conditions. Accordingly, the 1949 event has been simulated utilising the current channel bathymetry.

As previously discussed, there have also been considerable changes to the in-stream vegetation in the years since the 1949 event with significantly more in-stream vegetation located within the Wollombi Brook channel today then in 1949. As such, some modifications have been made to the in-stream Manning's 'n' roughness values in hydraulic model to be more representative of the in-stream vegetation in 1949 as discussed in Section 7.2.

Despite the lack of real bathymetry data, the simulation undertaken for the 1949 event is still considered useful modelling scenario as at a minimum it provides the estimated inundation pattern that could be expected for present conditions under a rainfall event of similar magnitude to that experienced in 1949.

7.4.1 Calibration Data

7.4.1.1 Rainfall Data

Similar to the June 2007 calibration event, the June 1949 flood event occurred as a result of sustained rainfall over a period of around two days. Up to 500m of rainfall fell over a two-day period at the top of the Wollombi Brook catchment around the Letter A, gradually decreasing down through the valley with some 280mm at Wollombi and 180mm at Bulga.

The spatial variation of rainfall depth for the June 1949 event across the catchment was estimated using the distribution defined in Figure 7-17 by the 1949 event rainfall isohyets from Bernard (1950).

The available rainfall data for the 1949 event consists only of daily read gauge totals. No continuous rainfall gauge (pluviometers) data is available, and accordingly the temporal pattern of the rainfall event is unknown.

In the absence of any temporal data, standard design temporal patterns as defined in AR&R (2001) have been applied to the 1949 event. The main rainfall occurred over a two-day period. Two validation runs were undertaken assuming a total storm duration of 36 hours and 48 hours.

7.4.1.2 Streamflow Gauge Data

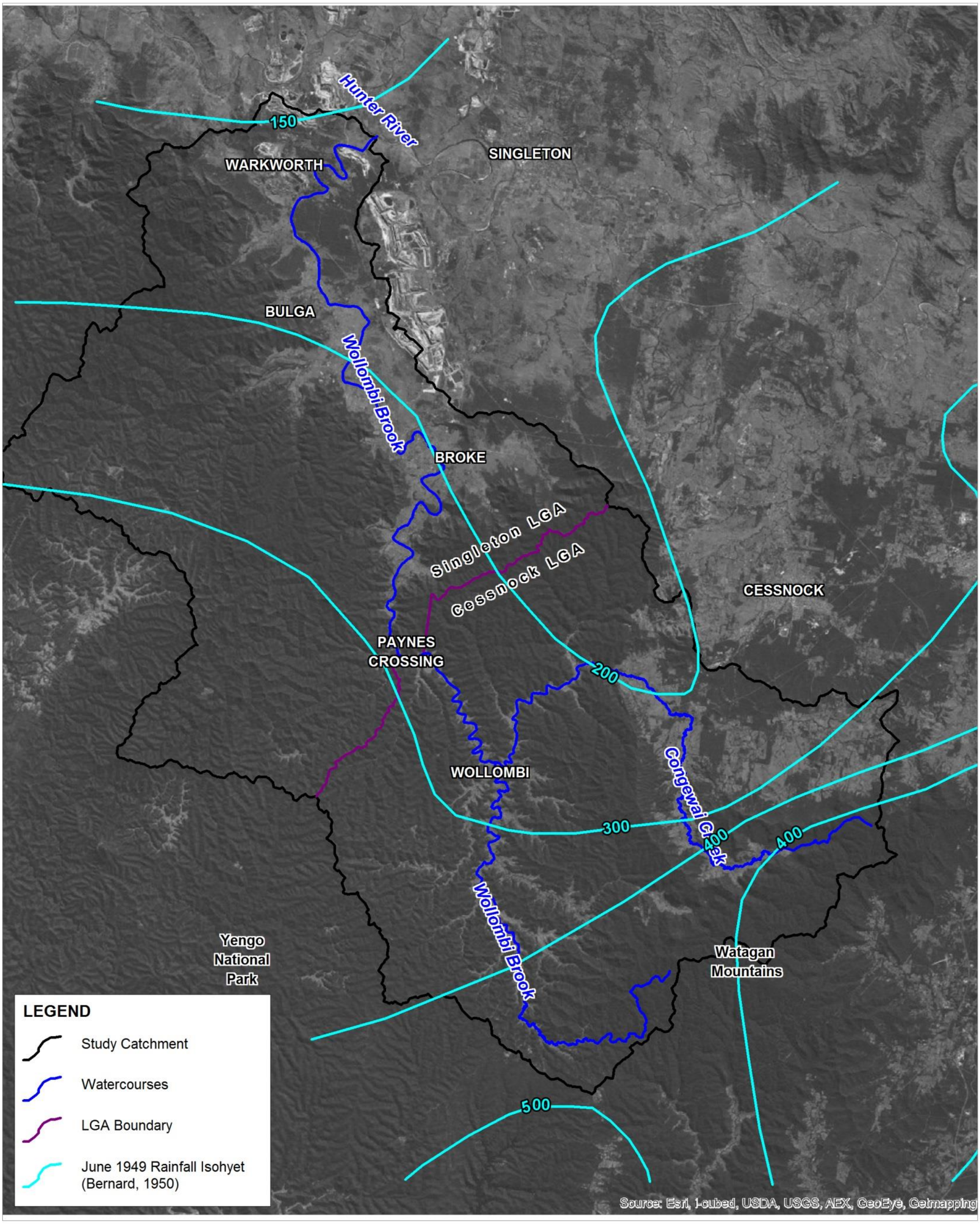
As discussed in Section 2.2.3, there are three active streamflow gauges located on Wollombi Brook, operated by the NSW Office of Water. The stations include D/S Brickmans Bridge (#210135), Bulga (#210028) and Warkworth (#210004). There is also a discontinued gauge located at Paynes Crossing (#210048).

Unfortunately, the D/S Brickmans Bridge and Bulga gauging stations were not installed in June 1949, and the Paynes Crossing gauge did not remain operational. There is also insufficient data available for the Warkworth gauge for the June 1949 event, which as previously discussed is considered unreliable given the likely backwater influence in any case. However, a peak water level was recorded at both the Bulga and Paynes Crossing gauges for the June 1949 event.

A comparison between the recorded and simulated water level time series and the corresponding converted and simulated streamflows at the gauge locations is presented in Section 7.4.4.

7.4.1.3 Flood Level Data

As previously presented in Section 4.2, three historical flood marks were identified from the community questionnaire responses for the June 1949 event. An additional three flood historical flood marks were taken from the Wollombi Flood Study (BMT WBM, 2010). These marks generally comprise recorded marks (scratches, lines drawn with marker on a wall, photographic evidence or points reconstructed from the memory of community members). The locations of the six historical flood marks surveyed are presented in Table 7-11 and shown in Figure 7-20.



Title:
June 1949 Rainfall Distribution

Figure: 7-17

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The recorded flood levels provide the basis for the water level calibration of the hydraulic model. A comparison of the observed and simulated water level profiles along the Wollombi Brook for the June 1949 is presented in Section 7.4.4.

Table 7-11 June 1949 Historical Flood Levels

ID	Location	Flood Level (m AHD)
FM1	Broke Fire Station, Wollombi Road, Broke	79.9*
FM3	Butlers Road, Broke	77.0
FM11	'Charlton' 154 Cobcroft Road, Broke	69.6
-	Werong Creek Confluence	92.3
-	Paynes crossing	93.2
-	Paynes Crossing	93.3

* There is some conjecture surrounding the peak flood level at the Broke Fire Station for the 1949 flood event. The level presented above and discussed in the report was based on a point indicated by a local resident during the community consultation process. This point was subsequently surveyed as part of the additional survey works discussed in Section 4.

In addition to the above historical flood levels, as part of the Wollombi Flood Study (BMT WBM, 2010), the NSW Office of Environment and Heritage (OEH) provided a file of historical notes on flooding in the Wollombi Brook. This data file included a peak 1949 flood level profile along Wollombi Brook from Paynes Crossing to Warkworth which has also been used for water level calibration for the 1949 event. This flood level profile is based on recorded peak flood levels at Warkworth, Bulga, Broke and Paynes Crossing. With the exception of the peak flood level at Bulga (known to be upstream of Bulga Bridge) the exact location of the remaining three peak flood levels was unknown and as such could not be used for model validation. However, the peak flood level at Warkworth has been compared to the simulated levels to provide some indication of model performance in the downstream reaches of the catchment as discussed in Section 7.4.4.

7.4.2 Rainfall Losses

As previously discussed, the initial loss for historical events is indicative of the catchment wetness and prior rainfall to the modelled storm burst. Figure 7-18 shows the monthly rainfall at the Broke (Harrowby) gauge for 1949. Whilst some above average monthly rainfall was experienced at the start of the year, the two months preceding the flood events were characterised by below average rainfall. In considering the catchment wetness condition at the start of the June 1949 event, an initial loss value of 10mm was adopted similar to the June 2007 event.

In combination with an initial loss of 10mm, a continuing loss of 5mm/hr was found to provide a reasonable fit to the observed hydrological behaviour in the Wollombi Brook catchment for the June 1949 event. A continual loss of 4mm/hr was also tested as discussed in Section 7.4.4 below. These values are considered to be consistent with the AR&R guidelines and findings for loss values in the GSAM Coastal region as discussed in Section 7.3.3.

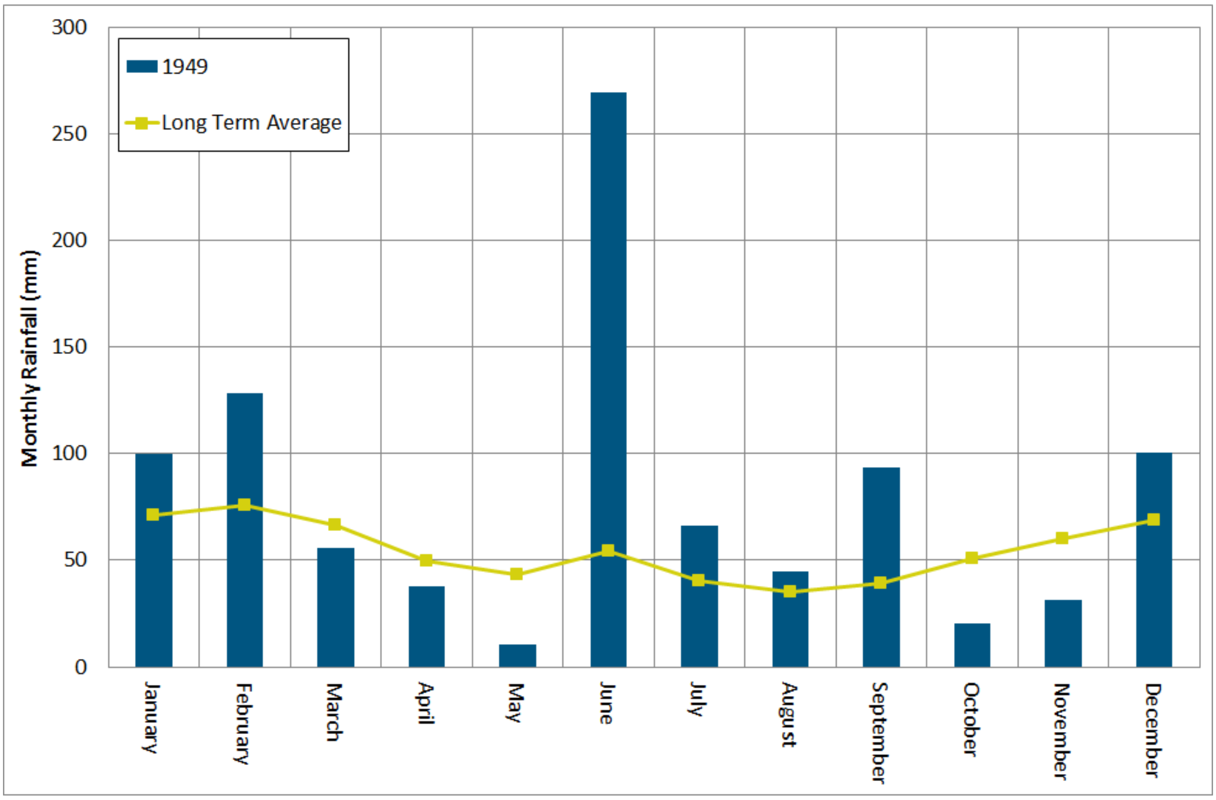


Figure 7-18 Broke (Harrowby) Monthly Rainfall Preceding June 1949 Flood

7.4.3 Adopted Model Parameters

All model parameters developed for the June 2007 model calibration event where adopted for the June 1949 model validation event with the exception of the in-channel Manning's 'n' roughness distribution. The 'historic condition' in-channel Manning's distribution discussed in Section 7.2 was adopted for the June 1949 model validation.

7.4.4 Observed and Simulated Flood Behaviour June 1949

For the 1949 flood event there is no recorded water level timeseries available for comparison with simulated water level timeseries. Nevertheless, a peak flood level was identified at the Bulga gauge and subsequently converted to an estimated peak flow using the model derived 'historical condition' rating curve discussed in Section 7.2. As there is no direct historical water level time series or corresponding hydrograph available, the relative timing of the flood through the catchment cannot be confirmed. The only test of appropriateness of the model simulation can be made in comparing the observed and simulated peak water levels and estimated and simulated peak flows at the Bulga gauge.

The comparison of the recorded peak water level and the modelled water level timeseries at the Bulga gauging station is presented in Figure 7-19. The simulated peak flows, water levels and corresponding peak flow estimate based on the model derived rating curve is presented in Table 7-12 for an adopted continual loss of 4mm/hr and 5mm/hr.

Table 7-12 June 1949 Observed and Simulated Peak Flood Levels and Flows

Location	Observed Water Level (m AHD)	Simulated Water Level (m AHD)	Estimated Peak Flow (m^3/s)	Simulated Peak Flow (m^3/s)
Bulga (5mm/hr continual loss)	64.8	64.7 (-0.1)	1,870	1,791
Bulga (4mm/hr continual loss)	64.8	65.0 (+0.2)	1,870	2,058

Note: Bracketed value is difference in peak flood level between observed and simulated

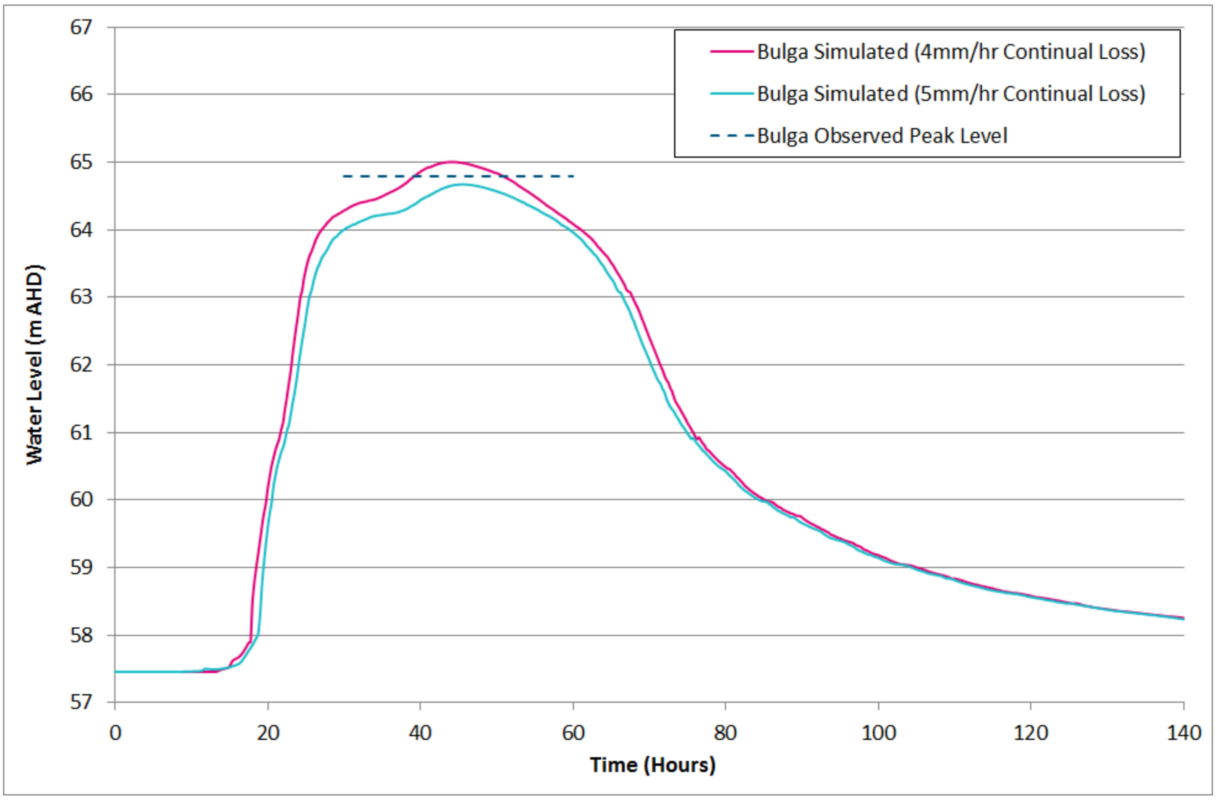


Figure 7-19 June 1949 Estimated and Simulated Water Levels at Bulga Gauge

The model provides for a good correlation with the recorded peak flood levels at the Bulga gauge with the simulated peak level adopting a 5mm/hr continual loss being 0.1m below the recorded peak level and the simulated peak level adopting a 4mm/hr continual loss being 0.2m above the recorded peak level.

The limited number of historical data points limits the opportunity to compare the simulated flood water level profile along the entire modelled reach. A comparison of simulated and observed peak flood levels along the modelled reach of Wollombi Brook for the June 1949 event is shown in Figure 7-20 and Figure 7-21 and tabulated in Table 7-13. As previously discussed, historical flood marks are often constructed from the memories of residents and estimated from photographs taken following the flood event and as such can often be slightly incorrect or unreliable. However, the historical flood levels still provide a useful source of calibration data.

Table 7-13 June 1949 Observed and Simulated Flood Levels

Location	Observed	Simulated (4mm/hr CL)	Simulated (5mm/hr CL)
Warkworth [1]	58.3	57.7 (-0.6)	57.2 (-1.1)
Bulga Bridge [2]	64.8	65.0 (+0.2)	64.7 (-0.1)
Charlton' 154 Cobcroft Road, Broke	69.6	69.0 (-0.6)	68.9 (-0.7)
Butlers Road, Broke	77.0	75.8 (-1.2)	75.5 (-1.5)
Broke Fire Station, Wollombi Road, Broke	79.9	79.3 (-0.6)	79.0 (-0.9)
Werong Creek Confluence [3]	92.3	92.9 (+0.6)	92.4 (+0.1)
Paynes Crossing Gauge	93.3	93.5 (+0.2)	92.9 (-0.4)
Paynes Crossing [3]	93.2	93.6 (+0.4)	93.0 (-0.3)
Paynes Crossing [3]	93.3	93.6 (+0.3)	93.0 (-0.3)

1 - Peak flood level taken from NSW Office of Environment and Heritage (OEH) historical flood profile (exact location of point unknown)

2 - Peak flood level taken from NSW Office of Environment and Heritage (OEH) historical flood profile (location known)

3 - Peak flood levels taken from the Wollombi Flood Study (BMT WBM, 2010)

4. As previously discussed there is some conjecture surrounding the peak flood level at Broke Fire Station for the 1949 flood event

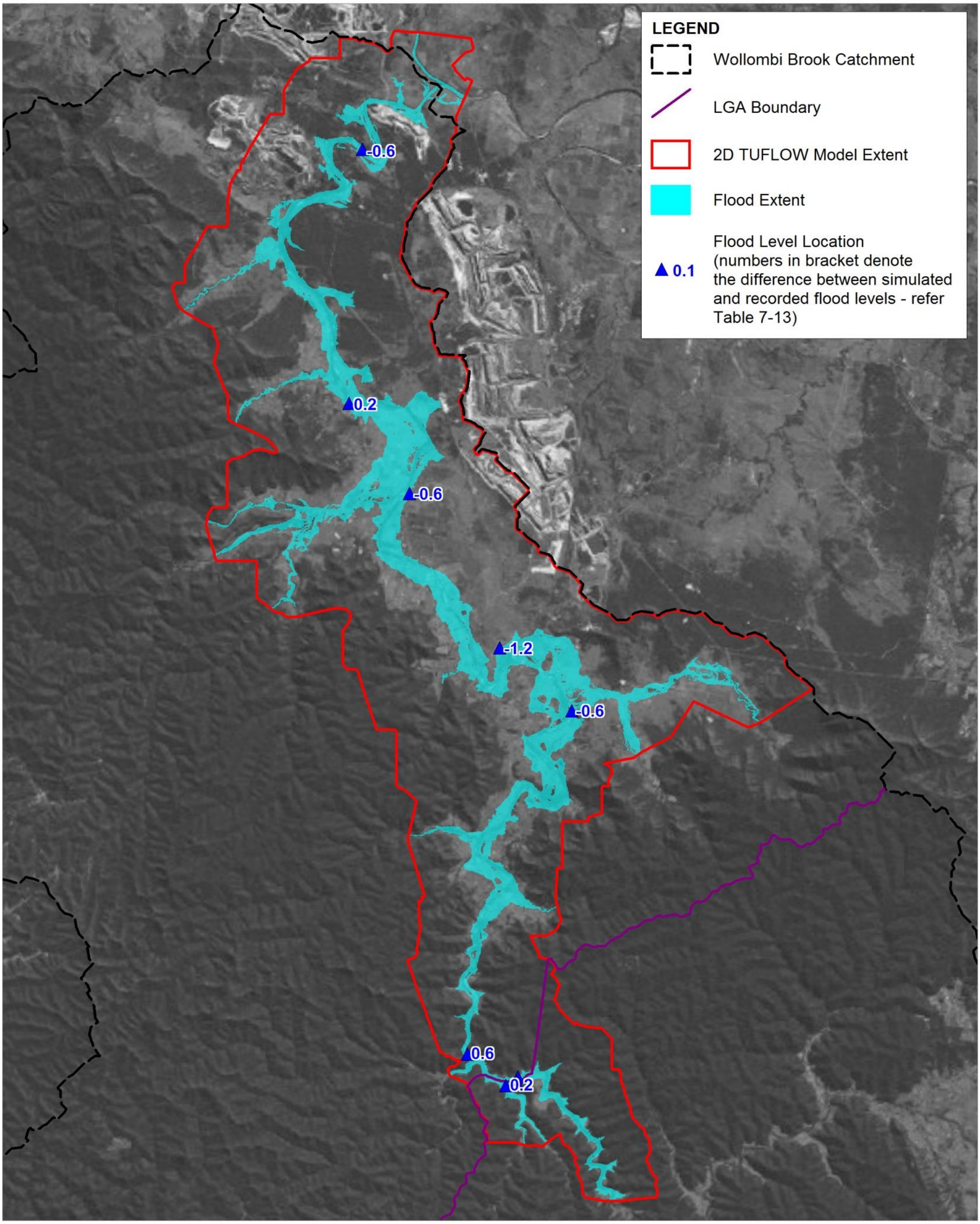
A good agreement is indicated between observed and simulated peak flood heights at Paynes Crossing and Bulga. However, there are some significant (i.e. >0.5m) discrepancies between the observed and simulated peak flood levels between these two locations. There are a number of factors which may contribute to this discrepancy including:

- Changes in in-channel and floodplain vegetation;
- Topographical changes in the Wollombi Brook (such as changes in the bed level, cross sectional width and alignment of the Brook as a result of the 1949 flood); and
- Inherent inaccuracies in historical flood levels estimated from historical photography and memories of residents (particularly for an event dating back to 1949).

As previously discussed, the extensive bank erosion that occurred during the 1949 flood event resulted in substantial channel enlargement and destruction of bridges structures throughout the catchment. This change in channel width dimensions and blockage and damage to bridge structures was not included in the simulated model due to the lack of data available to reflect the actual 1949 conditions. It would be expected that these factors if incorporated into the hydraulic model would result in an increase in the simulated flood levels.

It should be noted however, that although there are some discrepancies in the peak flood levels reached (particularly in regard to the flood levels at 'Charlton' 154 Cobcroft Road, Broke, Butlers Road, Broke and Broke Fire Station), the simulated flood extents in these areas show a good agreement to the observed historical flood extent for the June 1949 event.

The simulated peak levels at Warkworth are significantly lower than the observed flood level. The exact location of the observed water level record is not known. Nevertheless, the under prediction of the model simulation is a function of the adopted coincident condition in the Hunter River. As noted, the Warkworth gauge is significantly influenced by Hunter River water levels. The local Hunter River flood conditions for the 1949 event are unknown. Accordingly, a nominal tailwater condition approximating a 20% AEP design flow in the Hunter River was adopted in the model for the 1949 event. It is likely that this condition is an underestimate of actual conditions, thereby providing the underestimate of peak flood level at Warkworth through a lower backwater influence.



Title:

June 1949 Calibration Event Peak Flood Extent

Figure: **7-20**

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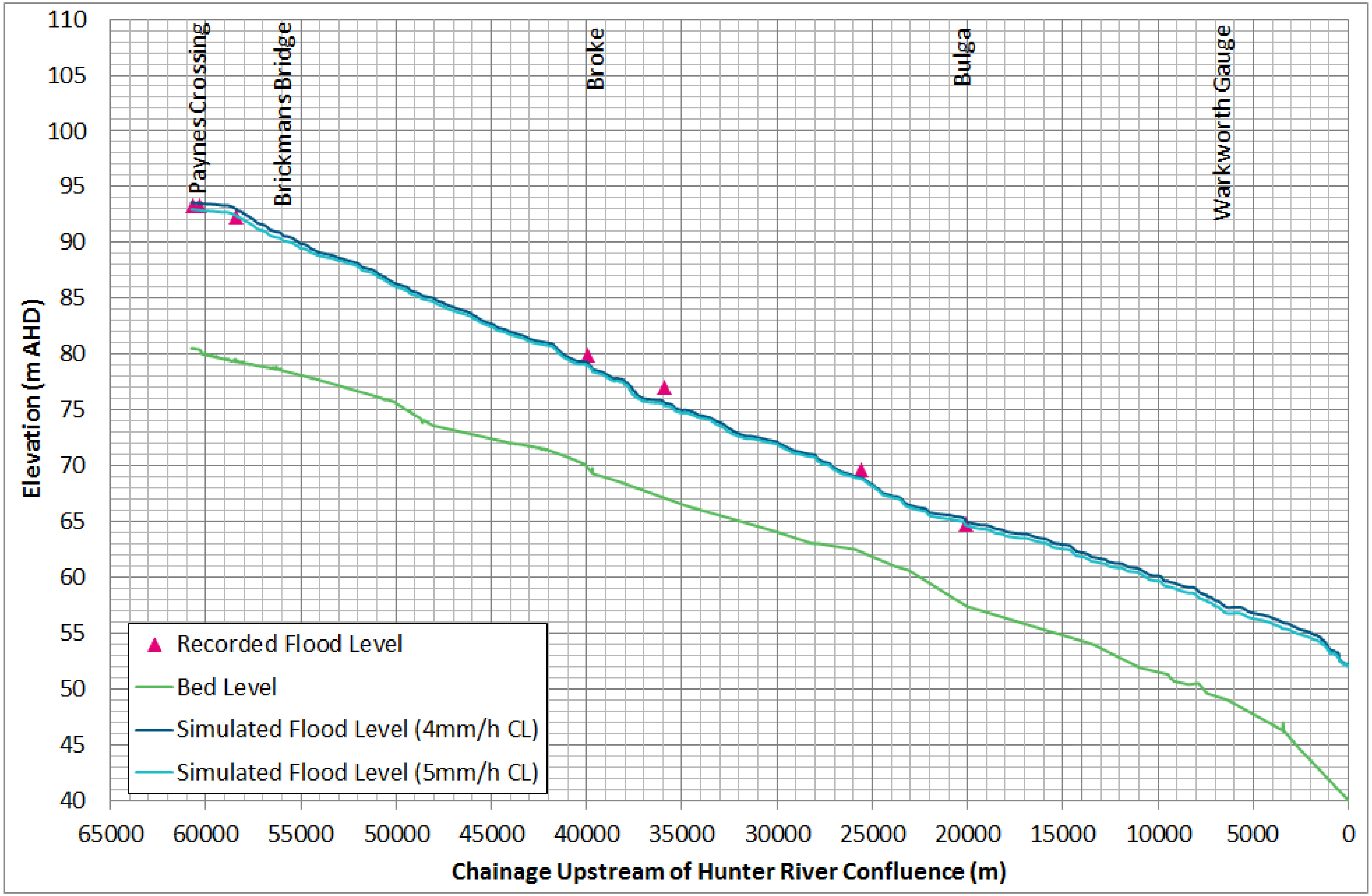


Figure 7-21 June 1949 Peak Water Level Validation Long Section

7.5 April 2015 Model Validation

7.5.1 Calibration Data

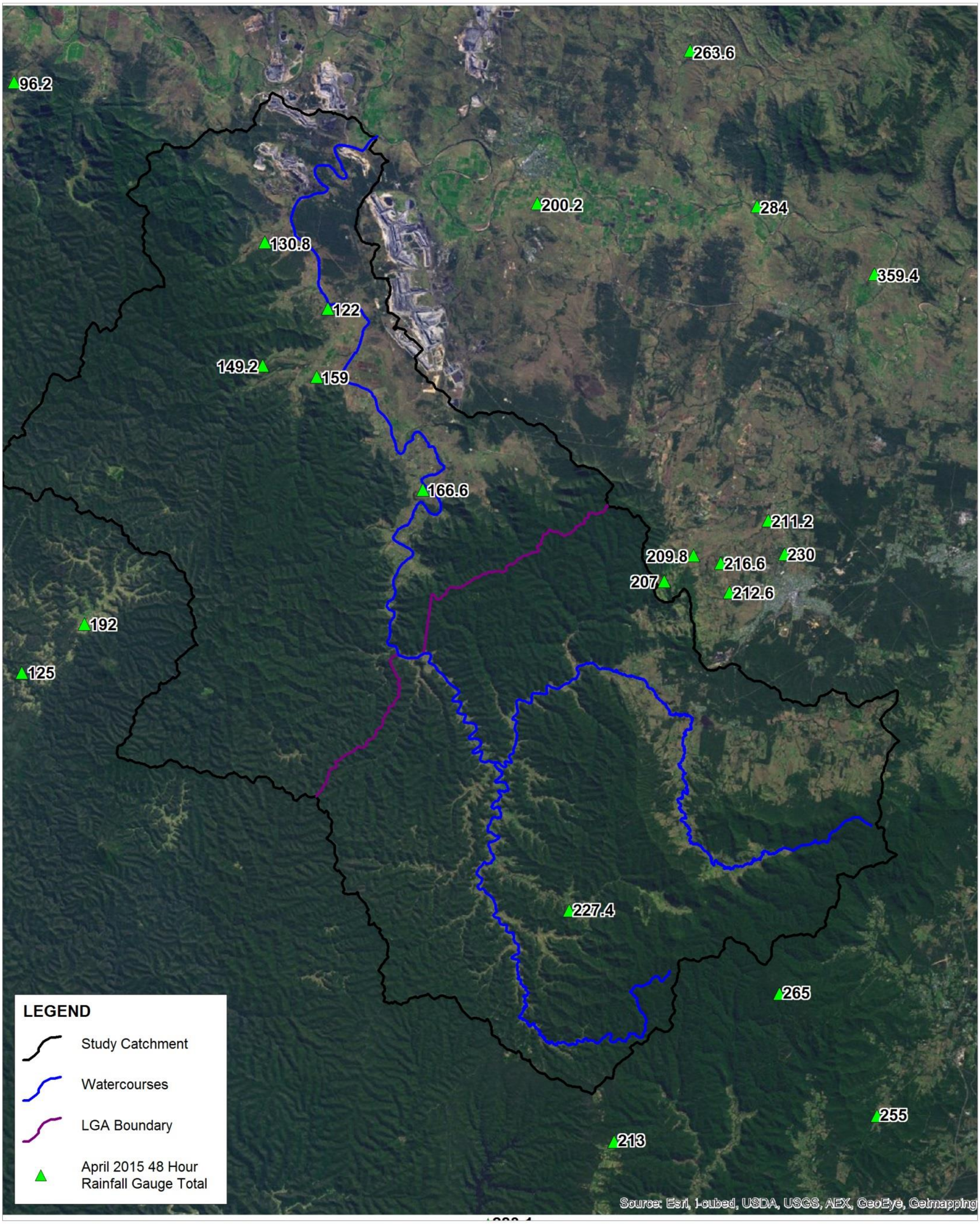
7.5.1.1 Rainfall Data

Similar to the June 2007 and June 1949 flood events, the April 2015 event occurred as a result of sustained rainfall over a period of around two days. Up to 260m of rainfall fell over a two-day period at the top of the Wollombi Brook catchment decreasing down through the valley to around 130mm at Warkworth.

The recorded daily totals (for the 24 hours to 9am) for the 21st-22nd April 2015 for rainfall gauges in the vicinity of the Wollombi Brook catchment are summarised in Table 7-14. Of the 24 rainfall gauges listed, four are continuous read rainfall gauges Milbrodale School, Wyong (Olney Forest), Watagan Central and Broke (Harrowby)) and the remaining twenty gauges are daily read gauges. The distribution of the rainfall gauges is shown in Figure 7-22 displaying 48-hour totals to 9am 22nd April 2015.

Table 7-14 Recorded Daily Rainfall Totals to 9am for April 2015 Event

Station No.	Station Name	21st April	22nd April	48-Hour Total
61014	Branxton (Dalwood Vineyard)	160	199.4	**359.4**
61050	Sedgefield (Bun dajon)	207.2	56.4	**263.6**
61110	Howes Valley Repeater	42	83	**125**
61130	Doyles Creek (Wood Park)	56.2	40	**96.2**
61143	Bulga (Down Town)	53	69	**122**
61162	Howes Valley (Putty Road)	78	114	**192**
61191	Bulga (South Wambo)	55.4	75.4	**130.8**
61201	Watagan Central	107.4	120	**227.4**
61238	Pokolbin (Somerset)	66.2	150.4	**216.6**
61242	Cessnock (Nulkaba)	92	138	**230**
61260	Cessnock Airport AWS	84.6	126.6	**211.2**
61298	Pokolbin (Bellevue)	64	145.8	**209.8**
61309	Milbrodale (Hillsdale)	55	94.2	**149.2**
61422	Milbrodale School	56	103	**159**
61327	Pokolbin (Myrtledale)	75	132	**207**
61329	Pokolbin (Jacksons Hill)	64.8	147.8	**212.6**
61357	Mandalong (Mandalong Rd)	115	140	**255**
61382	Wyong (Kulnura Jeavons)	113	100	**213**
61385	Wyong (Olney Forest)	134	131	**265**
61394	Kulnura (Mangrove Creek Dam)	130.5	152.6	**283.1**
61100	Broke (Harrowby)	56.6	110	**166.6**
61397	Singleton STP	129.4	70.8	**200.2**
61092	Edlerslie (Elderslie Farm)	175	109	**284**



Title:

April 2015 Rainfall Distribution - 21st-22nd April

Figure: **7-22**

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Approx. Scale

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The recorded hyetographs at the Milbrodale School, Wyong (Olney Forest), Watagan Central and Broke (Harrowby)) continuous rainfall gauges are shown in Figure 7-23. The hyetograph period shown is from 9am 20th April to 9am 22nd April 2015, corresponding to the period of the main rainfall in the Wollombi Brook catchment. It would appear that the Watagan Central and Broke (Harrowby) gauges both failed during the vent given the abrupt end of the recorded event rainfall at both locations. There was also an additional two continuous rainfall gauges within or in close vicinity to the Wollombi Brook catchment (namely Wollombi (St Johns Church) and Pokolbin) that were found to have failed during the rainfall event. It is evident that the April 2015 event was characterised by a period of sustained rainfall over the two day period with a series of intermittent bursts throughout the event.

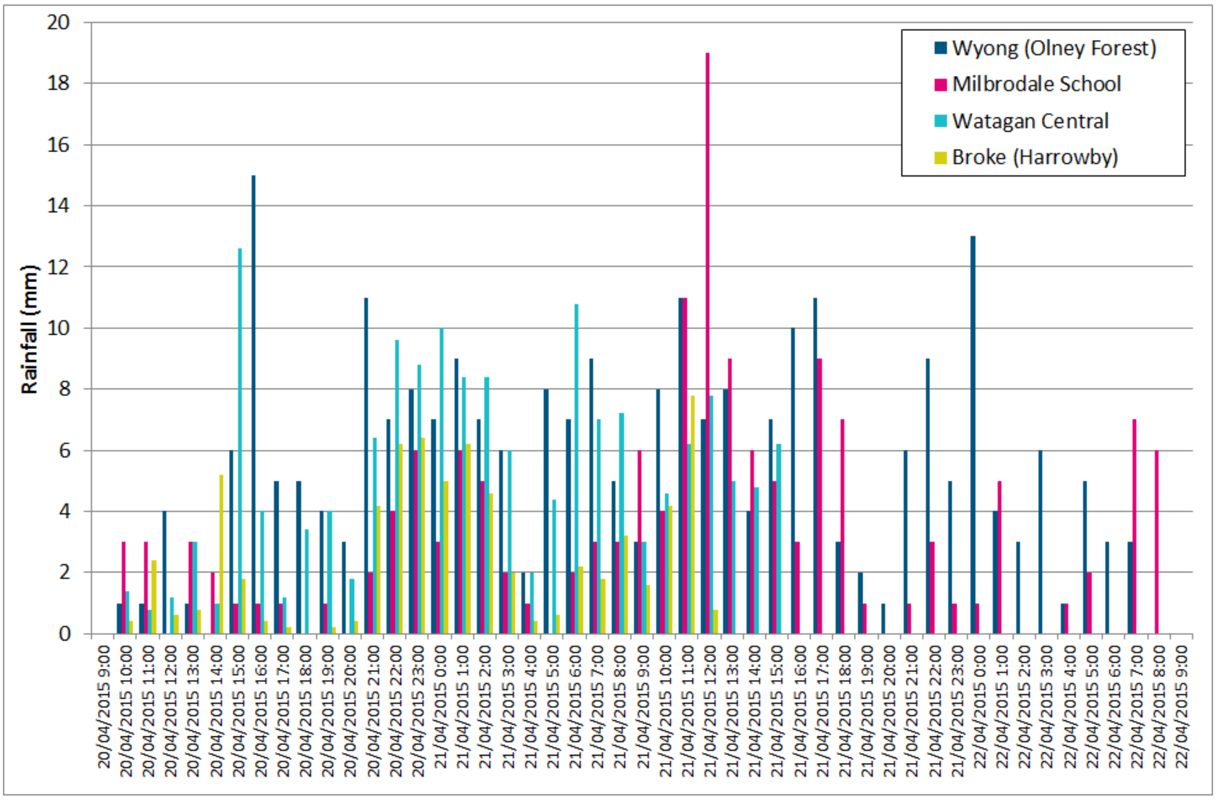


Figure 7-23 Recorded Rainfall Hyetographs April 2015

Given the number and location of daily read rainfall gauges shown in Figure 7-22, a reasonable representation of the daily total rainfall distribution across the catchment is available. As previously there is a significant spatial variation in total rainfall across the catchment with up to 260m recorded over the two-day period at the top of the Wollombi Brook catchment decreasing down through the valley to around 130mm at Warkworth.

In addition to the spatial variation across the catchment, there is also the temporal variation in rainfall to consider in defining rainfall inputs to the hydrological model. It is evident in Figure 7-23 that there are some significant differences between the four recorded hyetographs. There are some similarities, particularly between the mid catchment gauges at Broke (Harrowby) and Milbrodale School up to the point of failure for the Broke (Harrowby) gauge but clear differences when these two gauges are compared to the gauges in the upper catchment at Watagan Central and Wyong Olney. It is noted that the adoption of a single temporal pattern across the study area catchments may not be representative of the actual April 2015 storm conditions across the catchment. However, for the purpose of a model validation event, the Milbrodale School gauge was adopted for the catchment in its entirety.

Utilising on-ground rainfall gauge data, a daily rainfall distribution was developed for the daily totals to 9am on the 21st and 22nd April 2015. The daily rainfall distributions were then used to define a daily rainfall depth for each of the XP-RAFTS sub-catchments. The Milbrodale School recorded temporal pattern was then applied to the defined daily rainfall depths for each sub-catchment.

To gain an appreciation of the relative intensity of the June 2007 event, the recorded rainfall depths at the Milbrodale School continuous read rainfall gauges for various storm durations were compared with the design IFD data for the same locations as shown in Figure 7-24.

The Milbrodale School gauge recorded a total of 144mm for the 36 hours 8:00pm 20th April to 8:00am 22nd April 2015. With reference to the IFD relationships at each site, this corresponds to approximately a 10% AEP rainfall for Milbrodale School.

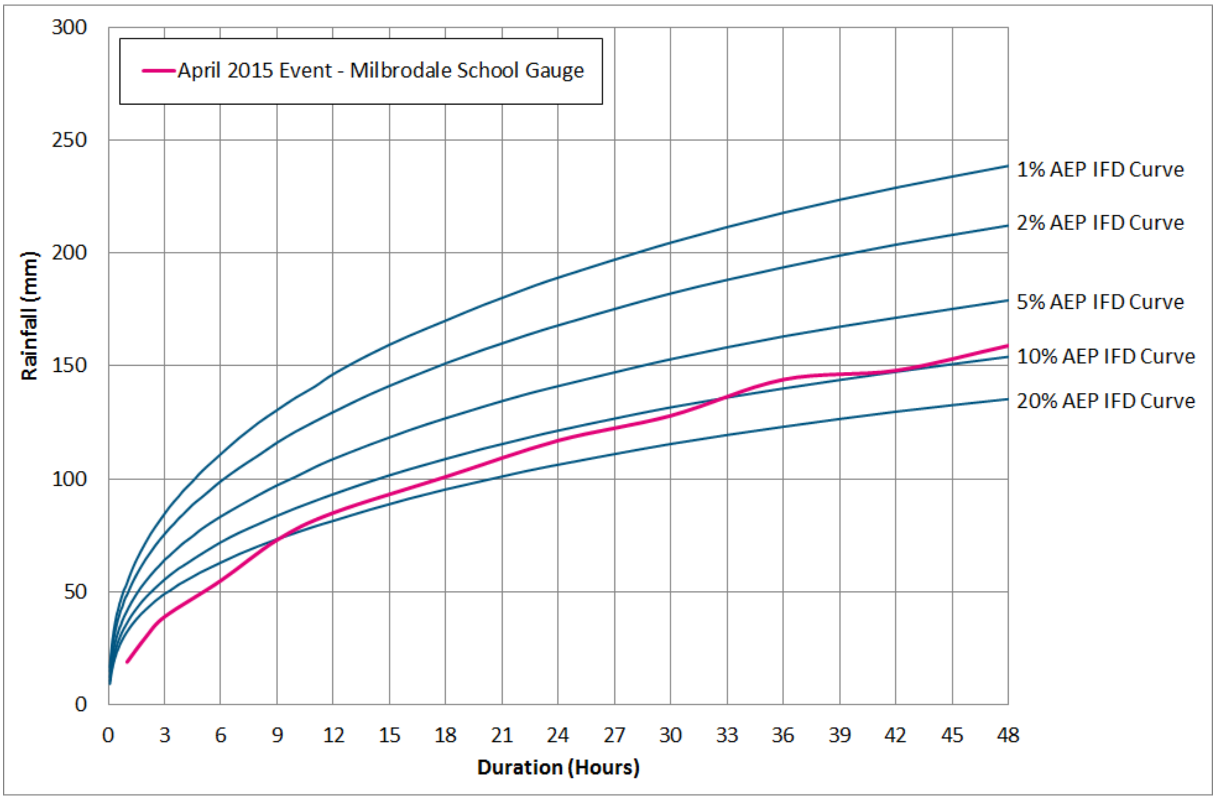


Figure 7-24 Comparison of Recorded Rainfall with IFD Relationships – Milbrodale School Gauge

7.5.1.2 Streamflow Gauge Data

Similar to the June 2007 event, there were three active streamflow gauges located on Wollombi Brook during the April 2015 event (D/S Brickmans Bridge (#210135), Bulga (#210028) and Warkworth (#210004)).

A comparison between the recorded and simulated water level time series and the corresponding converted and simulated streamflows at the gauge locations is presented in Section 7.3.5.

7.5.2 Rainfall Losses

As previously discussed, the initial loss for historical events is indicative of the catchment wetness and prior rainfall to the modelled storm burst. Figure 7-25 shows the monthly rainfall at the Milbrodale (Hillsdale) gauge for 2015. Whilst some above average monthly rainfall was experienced in the month of January 2015, the two months preceding the flood events were characterised by below average rainfall. In considering the catchment wetness condition at the start of the April 2015 event, an initial loss value of 10mm was adopted similar to the June 2007 and June 1949 events.

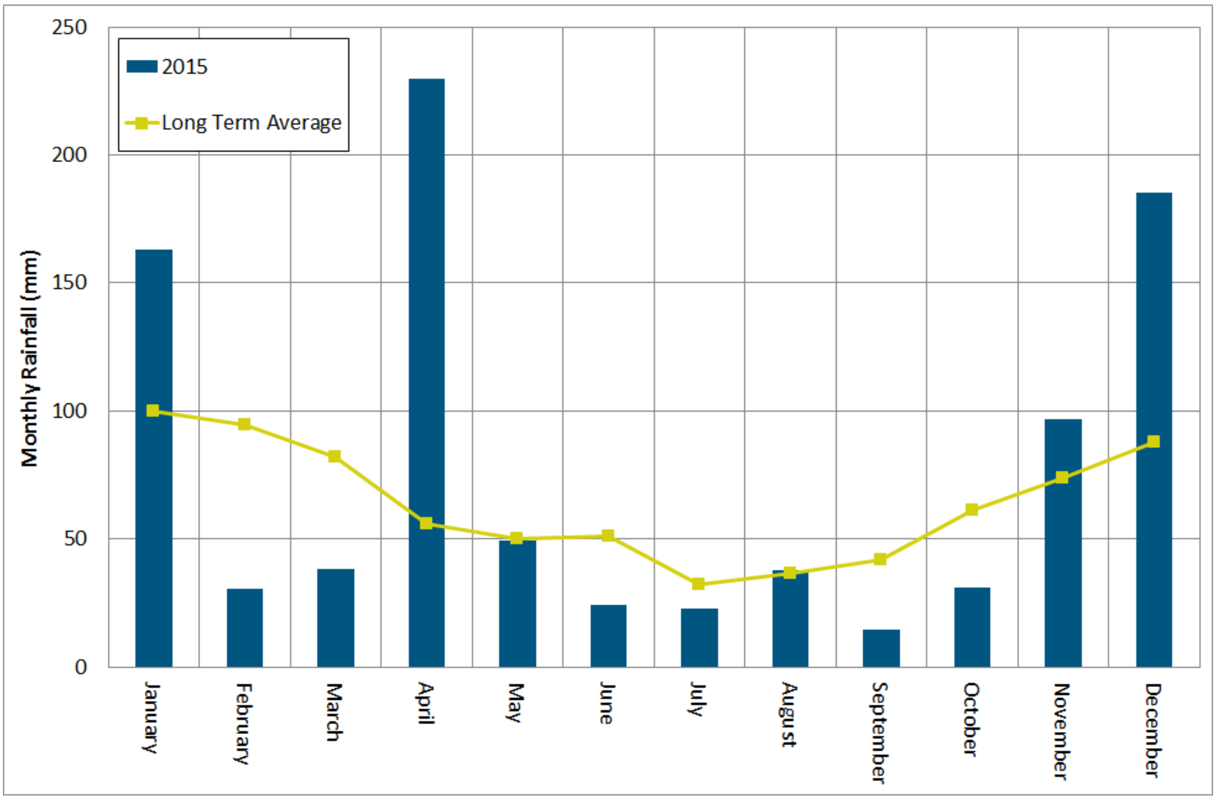


Figure 7-25 Milbrodale (Hillsdale) Monthly Rainfall Preceding April 2015 Flood

In combination with an initial loss of 10mm, a continuing loss of 4mm/hr was found to provide a reasonable fit to the observed hydrological behaviour in the Wollombi Brook catchment for the April 2015 event. These values are considered to be consistent with the AR&R guidelines and findings for loss values in the GSAM Coastal region as discussed in Section 7.3.3.

7.5.3 Adopted Model Parameters

All model parameters developed for the June 2007 model calibration event where adopted for the April 2015 model validation event with the exception of the continual rainfall loss as discussed above in Section 7.5.2.

7.5.4 Observed and Simulated Flood Behaviour April 2015

Similar to the June 2007 event, the effectiveness of the model representation of the catchment response to the adopted rainfall inflows can be assessed through comparison of the recorded and modelled water level timeseries at the Bulga and D/S Brickmans Bridge gauging stations and comparing the simulated flow against the flow estimated at the Bulga gauge using the model derived ‘current’ condition rating curve discussed in Section 7.2

The comparison of the recorded and modelled water level timeseries at the Bulga and D/S Brickmans Bridge gauging stations are presented in Figure 7-26 and Figure 7-27 respectively. The simulated peak flows, water levels and corresponding peak flow estimate based on the model derived rating curve is presented in Table 7-15.

Table 7-15 April 2015 Observed and Simulated Peak Flood Levels and Flows

Location	Observed Water Level (m AHD)	Simulated Water Level (m AHD)	Estimated Peak Flow (m^3/s)	Simulated Peak Flow (m^3/s)
Warkworth Gauge	55.4	55.6 (+0.2)	782	852
Bulga	63.7	63.9 (+0.2)	800	852
D/S Brickmans Bridge	87.6	87.9 (+0.3)	714	765

Note: Bracketed value is difference in peak flood level between observed and simulated

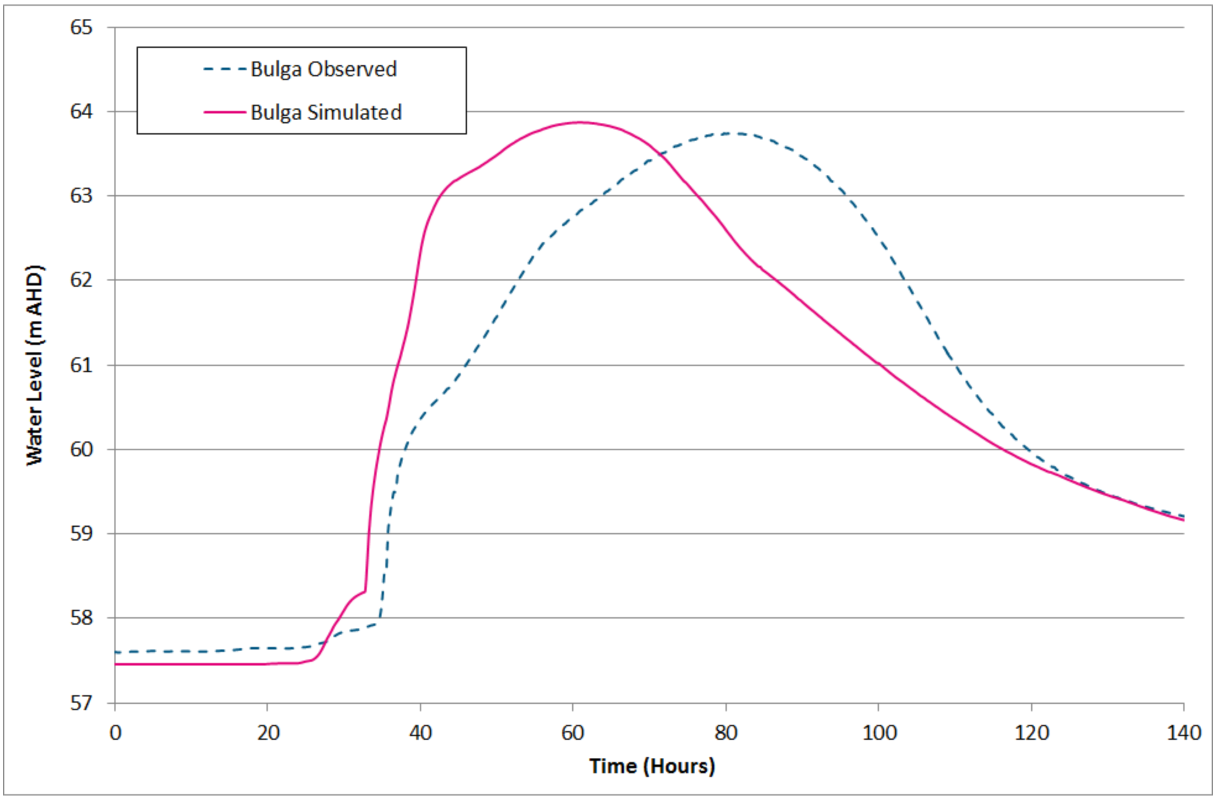


Figure 7-26 April 2015 Observed and Simulated Hydrograph at Bulga

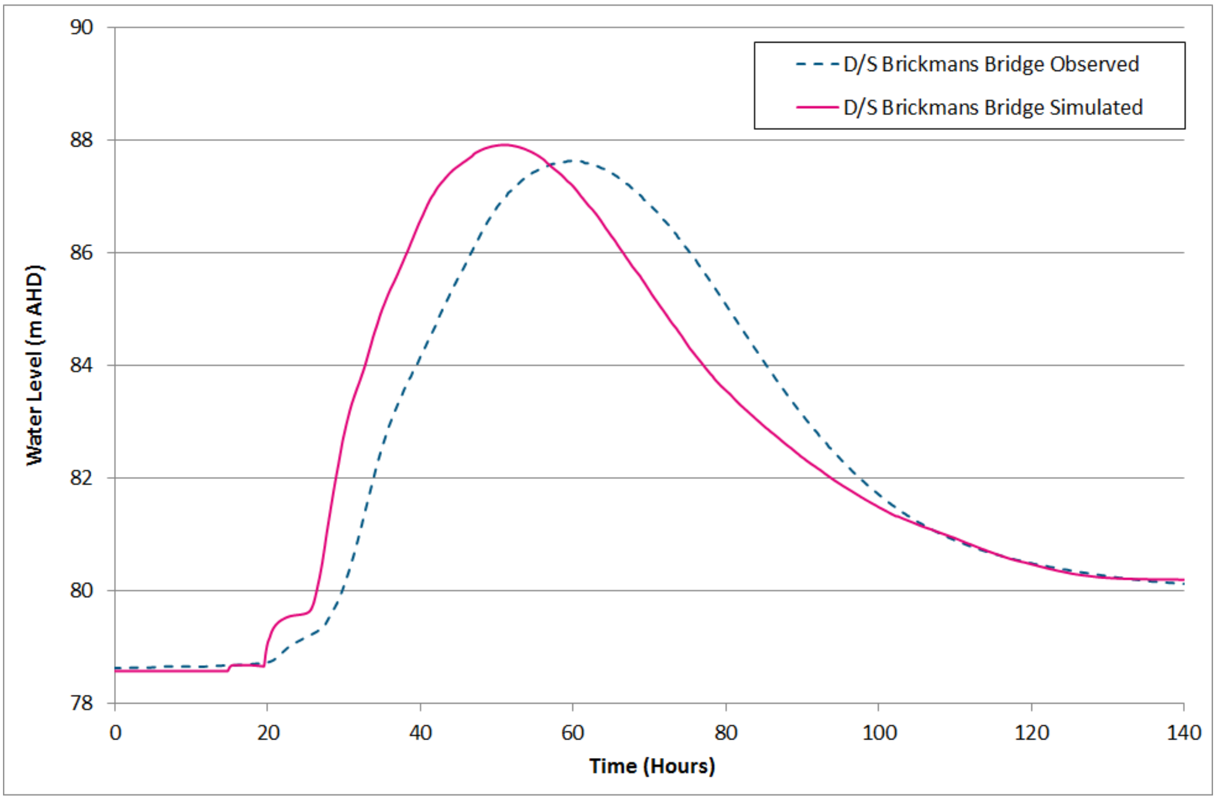


Figure 7-27 April 2015 Observed and Simulated Hydrograph at D/S Brickman's Bridge

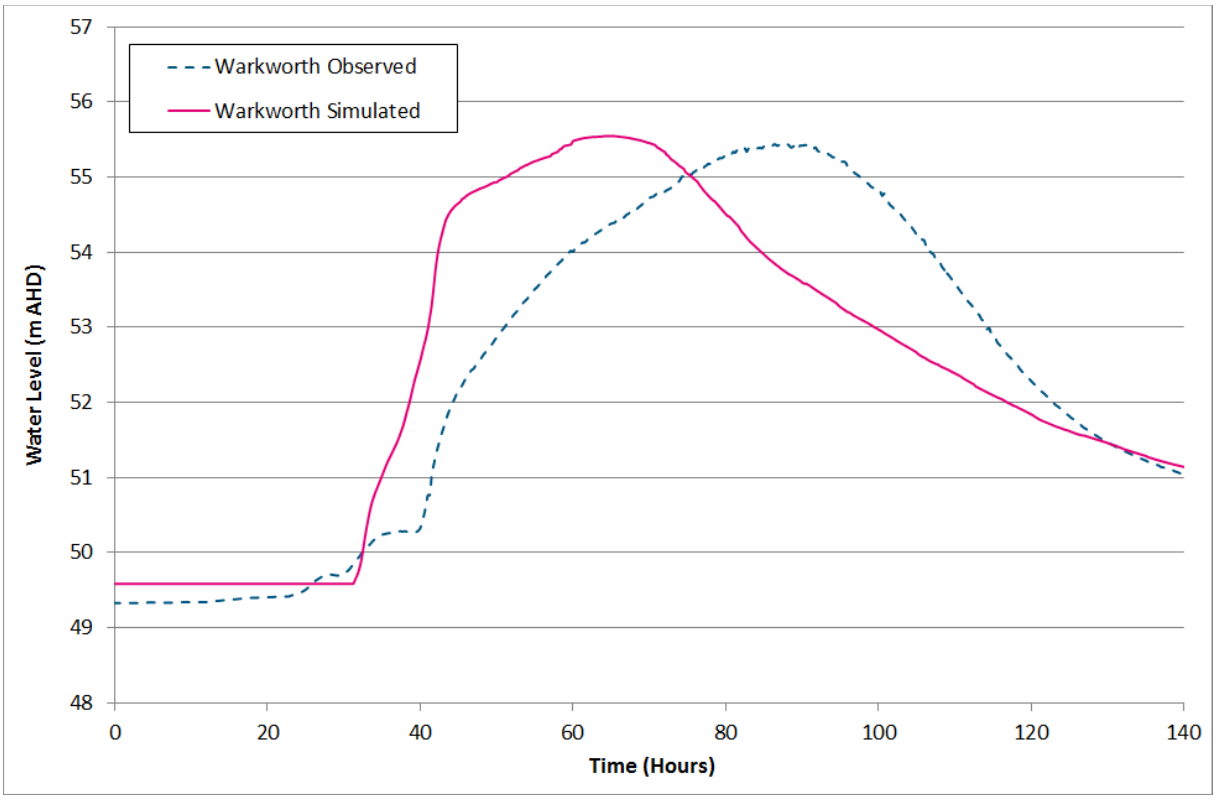
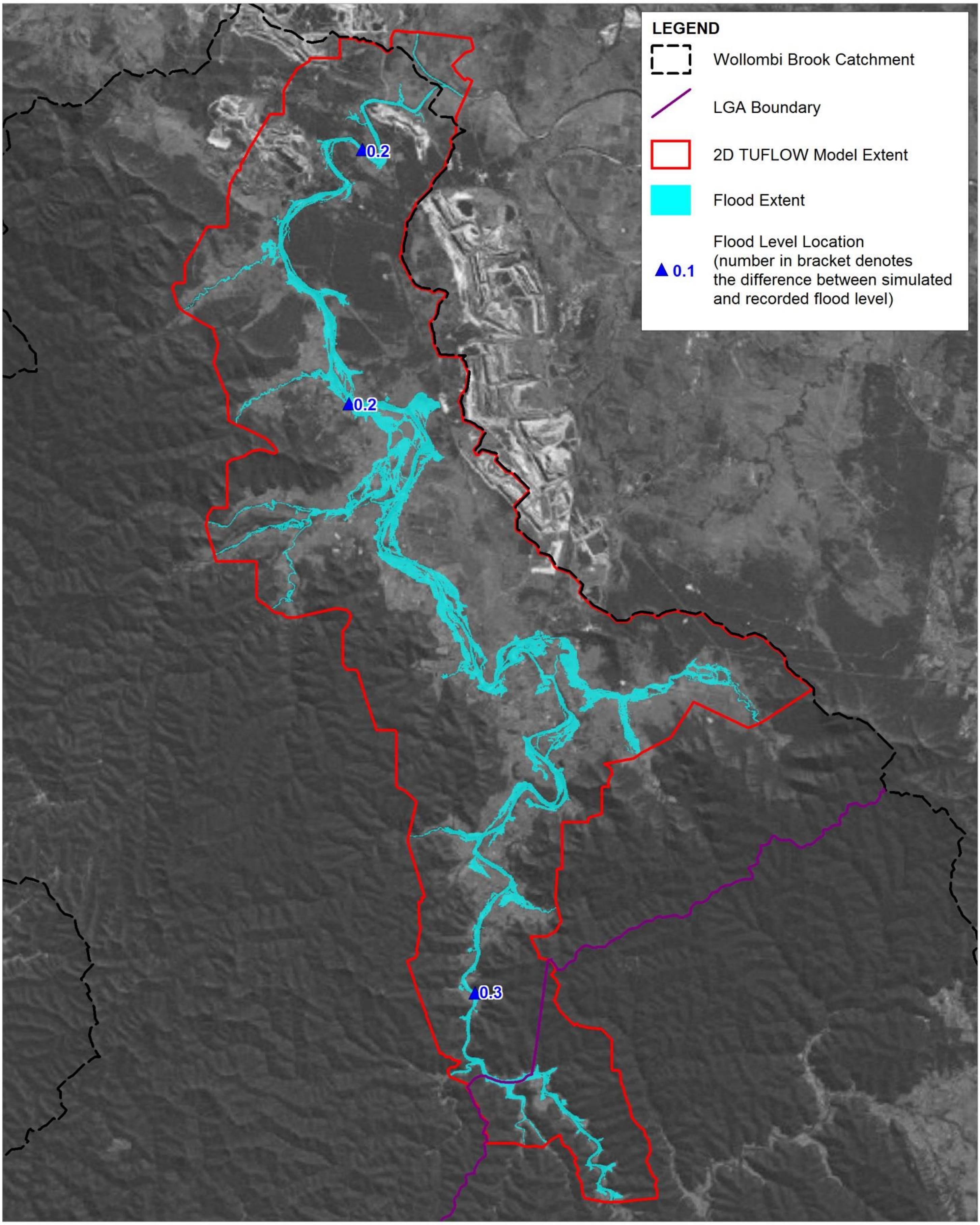


Figure 7-28 April 2015 Observed and Simulated Hydrograph at Warkworth

It is evident that model provides for a good correlation with the recorded peak flood levels each of the three gauge locations with the simulated peaks at both Bulga and Warkworth being within 0.2m and D/S Brickmans Bridge being within 0.3m of the recorded levels. The overall shape of the water level timeseries is also reasonably well represented each gauge location in terms of the rate of rise and rate of retreat of the floodwaters although there are clear differences in the timing of the peak as the floodwaters progress from Paynes Crossing down to Warkworth.

The difference in timing may be attributed to the uncertainty around the spatial distribution and temporal pattern of the applied rainfall. There are some significant differences between the four recorded hyetographs for the April 2015 event. It was found that applying the Milbrodale School temporal pattern results in a good match to the peak flood level and rate of rise and fall of the floodwaters but a difference in timing (as shown in Figure 7-26 to Figure 7-28). Applying the Wyong Olney temporal pattern resulted in an improvement in the correlation between the observed and simulated timing of the peak but also a reduction in the simulated peak flood levels due to the wider distribution of rainfall (i.e. fewer intense bursts). It can be inferred that a reasonable match to the observed flood behaviour could be achieved via a combination of the two temporal patterns and variations of the total rainfall distribution across the catchment. However, as the focus of the model validation was to confirm the appropriateness of the adopted model parameters in the hydraulic model, the application of the Milbrodale school temporal pattern was considered to apply a reasonable match to the observed flood behaviour (albeit with some discrepancies in the timing of the peaks).

Unfortunately for the April 2015 event no other surveyed peak flood marks were available to compare with the simulated flood behaviour throughout other parts of the catchment. Nonetheless, the simulated peak flood extent and peak flood levels for the April 2015 event are shown in Figure 7-29 and Figure 7-30 respectively.



Title:

April 2015 Validation Event
Peak Flood Extent

Figure: **7-29**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

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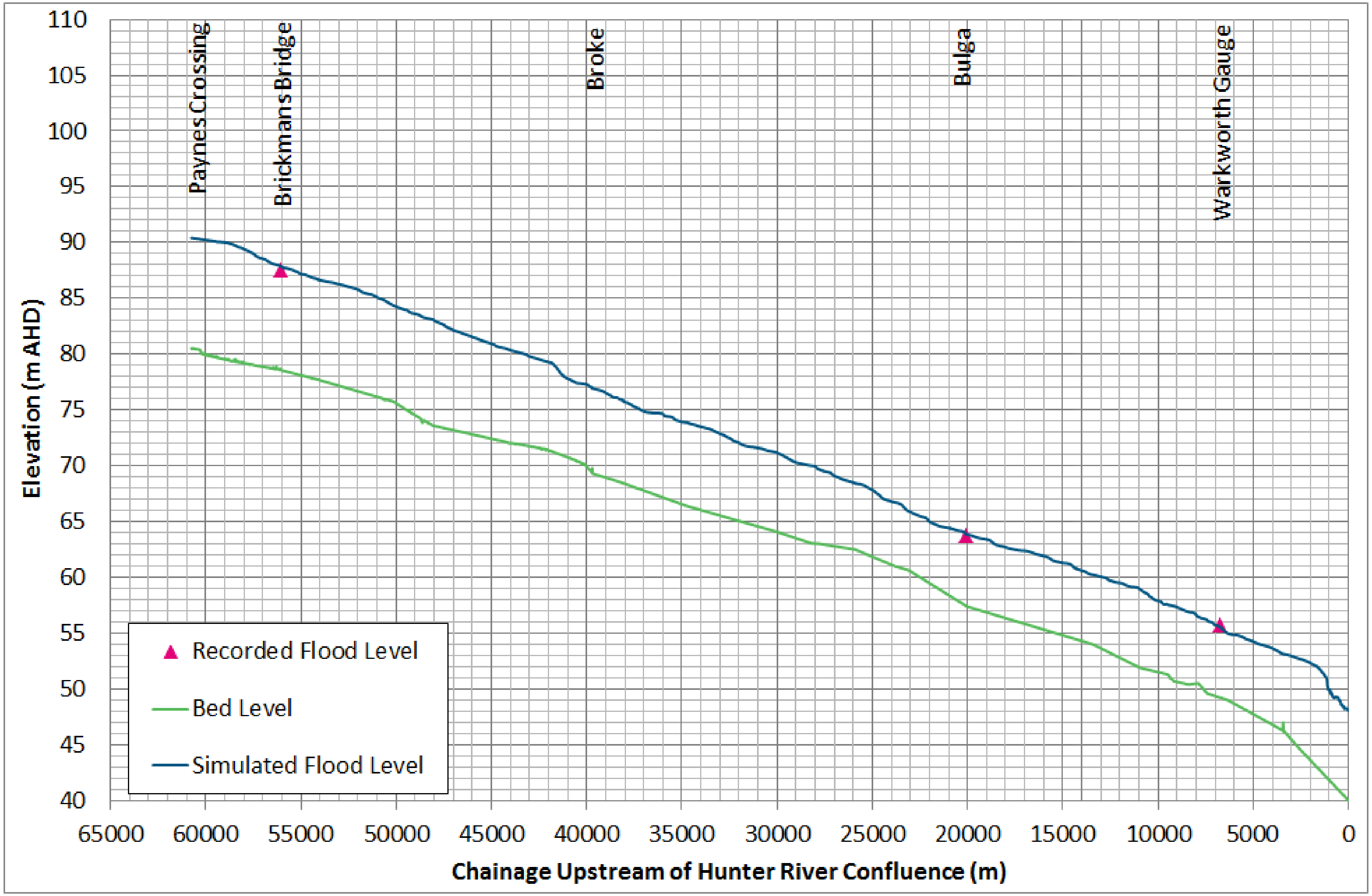


Figure 7-30 April 2015 Peak Water Level Validation Long Section

7.6 Determination of Design Model Parameters

In calibrating the model, emphasis was placed on reaching agreement between recorded and simulated flood conditions with respect to:

- Peak flood water levels;
- Peak magnitude of flow; and
- Timing and shape of the water level timeseries.

The model calibration achieved good agreement to the estimated peak flows using the model derived rating curves discussed in Section 7.2, peak flood water levels and the shape of the hydrographs and reasonable agreement with the timing of the hydrographs. The model calibration centred around the adjustment of the rainfall losses, the sub-catchment PERN values, routing adjustment parameter (BX value) and the Manning n values for the floodplain and in-channel reaches.

The parameters developed for the 'current' channel and catchment conditions have been maintained for design event simulation. Given that the calibration and validation events included the relatively recent June 2007 and April 2015 events, the developed models are assumed to be representative of existing catchment conditions. The values design event simulation are summarised in Table 7-16

Consideration of the impact of potential climate change may warrant adjustment to some of the model parameters for future scenario analysis. However in most instances these scenarios will only necessitate changes in the model input (e.g. design rainfall intensities).

Table 7-16 Design Event Model Parameters

Parameter	Value	Comment
Initial Loss (mm)	10mm	Refer Section 8.3.3
Continuing Loss (mm/hr)	4mm	
Storage coefficient factor Bx	1.0	As used for the 2007 calibration event and 1949 and 2015 validation events.
PERN (roughness value for hydrological model)	0.06 -0.12	As used for the 2007 calibration event and 1949 and 2015 validation events.
Manning's 'n' roughness value for hydraulic model (channel)	0.04 -0.11	The 'current condition' in-channel Manning's distribution discussed in Section 7.2 as adopted for the June 2007 event model calibration and April 2015 event model validation.
Manning's 'n' roughness value for hydraulic model (floodplain)	0.05 – 0.12	As used for the June 2007 event model calibration and June 1949 and April 2015 model validation events.

8 Design Flood Conditions

Design floods are hypothetical floods used for floodplain risk management. 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 8-1 for a definition of AEP and the ARI equivalent.

Table 8-1 Design Flood Terminology

AEP[1]	ARI[2]	Comments
Extreme Flood		A hypothetical flood or combination of floods which represent an extreme scenario (for this study the extreme flood event was taken to be 3 times the 1% AEP event).
0.5%	200 years	A hypothetical flood or combination of floods likely to occur on average once every 200 years or with a 0.5% probability of occurring in any given year
1%	100 years	As for the 0.5% AEP flood but with a 1% probability or 100 year return period.
2%	50 years	As for the 0.5% AEP flood but with a 2% probability or 50 year return period.
5%	20 years	As for the 0.5% AEP flood but with a 5% probability or 20 year return period.
10%	10 years	As for the 0.5% AEP flood but with a 10% probability or 10 year return period.
20%	Approx. 5 years	As for the 0.5% AEP flood but with a 20% probability or 5 year return period.

1 Annual Exceedance Probability (%)

2 Average Recurrence Interval (years)

The design events simulated include the Extreme Flood event, 0.5%, 1%, 2%, 5%, 10%, and 20% AEP events. The 1% AEP flood is generally used as the standard flood for land use planning and control.

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, the critical duration of the Wollombi Brook catchment may potentially be significantly shorter than for the larger Hunter River catchment); and
- The relative timing and magnitude of flooding in the Hunter River in relation to the Wollombi Brook catchment flooding.

8.1 Coincident Hunter River Flooding

The Wollombi Brook is a tributary of the Hunter River with the confluence located at Warkworth. The peak flood levels for the Hunter River contribute to the critical flooding condition for the lower Wollombi Brook catchment. The peak flood levels along the lower reaches of the Wollombi Brook will also be influenced by the water level in the Hunter River. Adopting a fixed flow boundary for the Hunter River will not provide representative flood conditions for the Lower Wollombi Brook and surrounds and so an appropriate coincident flood condition needs to be considered.

Given the differences in scale of the Wollombi Brook and Hunter River 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 Wollombi Brook and Hunter River catchments.

In order to assign a downstream Hunter River boundary condition for the design flood events, a flood frequency analysis was undertaken for the Mason Dieu streamflow gauge (#210128) included in the NSW Office of Water PINEENA database. The Mason Dieu gauge is located on the Hunter River approximately 1.8 kilometres upstream of the Wollombi Brook confluence and commenced operation in 1993.

As previously discussed, BMT WBM has previously completed a significant amount of analysis on streamflow gauges located within the Hunter River system and identified significant shifts in the derived stage discharge relationship (i.e. rating curve) information for a number of gauging stations. Taking in to consideration the uncertainty in the derived streamflows, particularly for major flood events, the flood frequency analysis was based on the annual maxima recorded water levels rather than the derived streamflows.

The annual maximum water level series used for the frequency analysis has been derived from the gauging station records in the PINEENA database for the period 1993-2015. The flood frequency distribution was calculated using the Gumbel distribution approach and is presented in Figure 8-1 and Table 8-2.

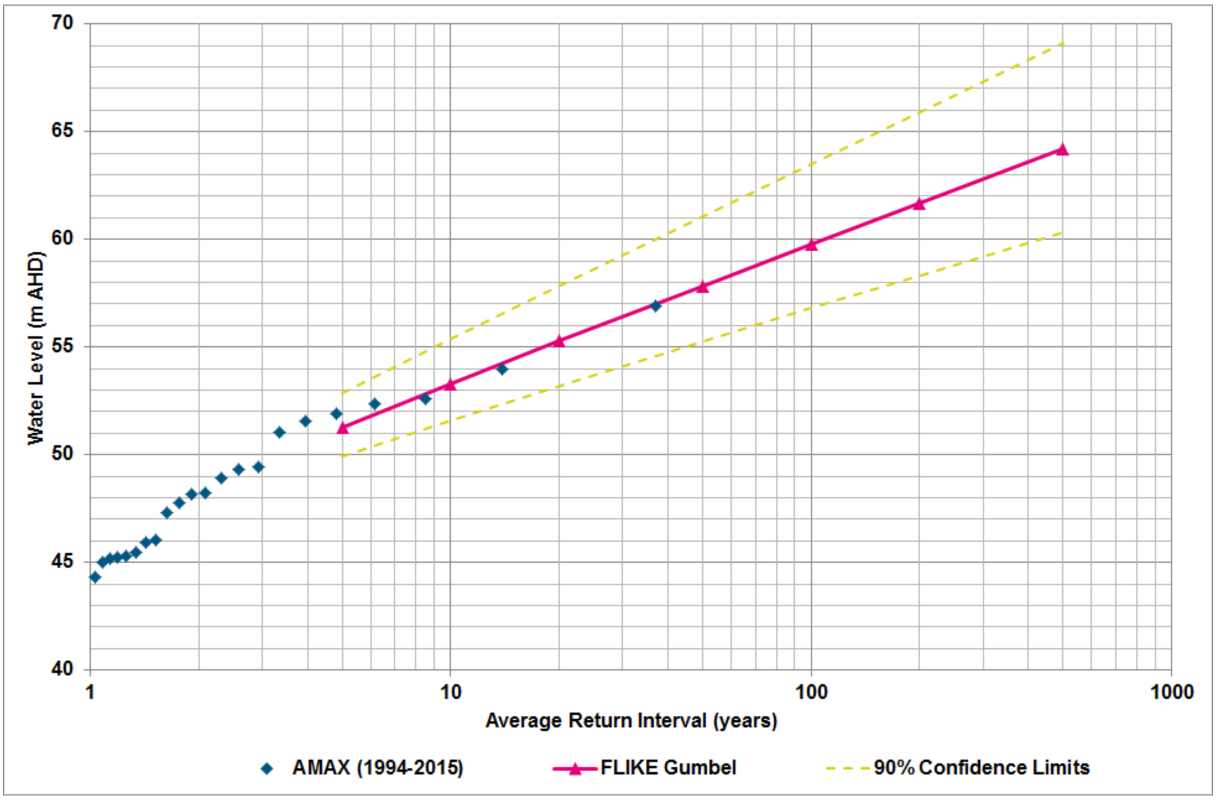


Figure 8-1 Mason Dieu Gumbel Distribution Chart

Table 8-2 Mason Dieu Gumbel Distribution Values

AEP	Water Level (m AHD)
2yr ARI	48.2
20%	51.3
10%	53.3
5%	55.3
2%	57.8
1%	59.8

The recorded June 2007 water level time series was considered to provide a representative water level response for the Hunter River. As such, the recorded June 2007 water level time series was scaled using the design water levels in Table 8-2 to create design water level timeseries for the Hunter River as presented in Figure 8-2. It should be noted that the first minor peak in the 2007 water level timeseries has been removed to provide for a gradual increase in water level up to the estimated peak design flow.

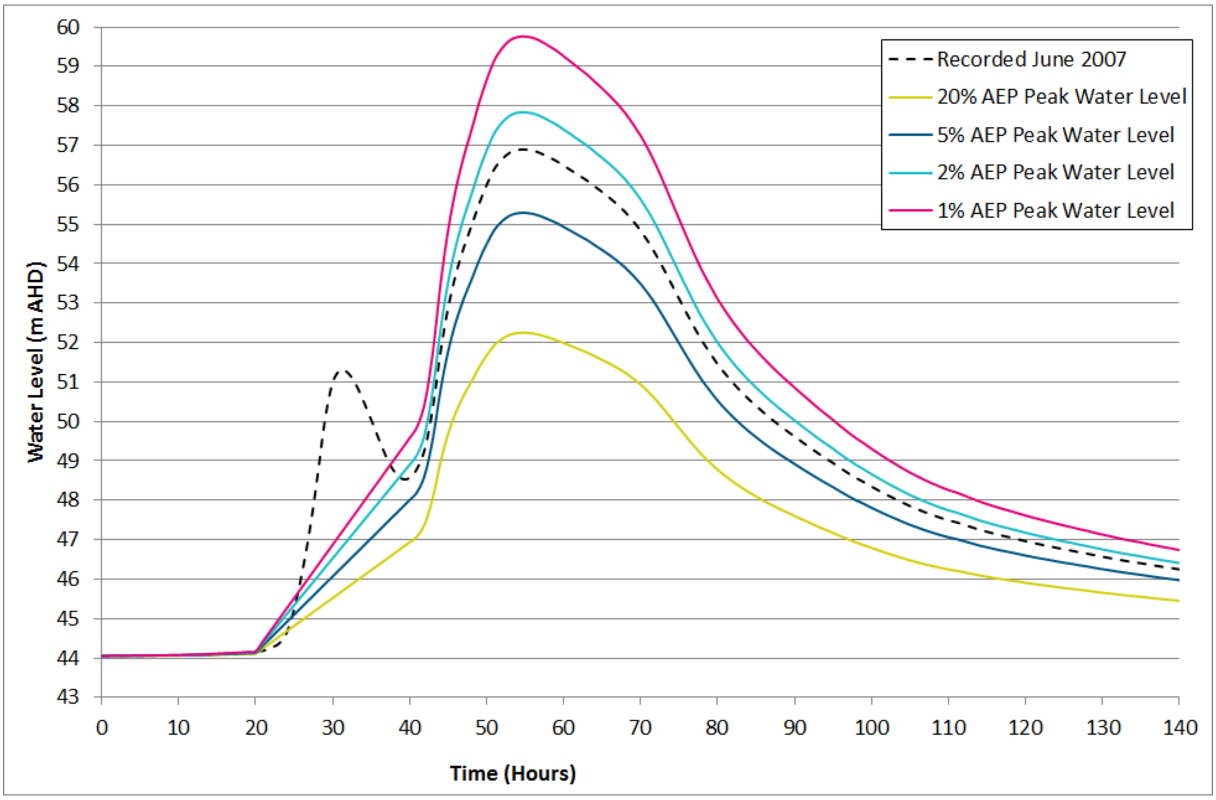


Figure 8-2 Design Hunter River Water Level Timeseries

As previously discussed, it is unlikely that a 1% AEP event would occur simultaneously in the Wollombi Brook and Hunter River. As such, the design flood magnitude combinations presented in Table 8-3 have been adopted for this study. The Hunter River design water level time series were also adjusted so that the peak water levels in the Hunter River coincided with the peak flow in the Wollombi Brook at the Hunter River confluence in order to ascertain the peak design flood levels for each design event.

Table 8-3 Coincident Flood Event Combinations

Wollombi Brook AEP (design catchment rainfall inflows)	Hunter River AEP (design downstream water level timeseries)
20%	2yr ARI
10%	2yr ARI
5%	20%
2%	10%
1%	5%
0.5%	2%
Extreme Flood (3 x 1%)	1%

8.2 Flood Frequency Analysis

Having established a reasonable set of model roughness values and estimates of peak flow rates for the June 2007, April 2015 and June 1949 events, the available historic peak flood level records at the streamflow gauge sites were assessed in terms of suitability to derive a flood frequency analysis (FFA).

Of the three active streamflow gauges located in the Wollombi Brook, only two (Bulga and Warkworth) have a long enough period of record to enable a reasonable FFA to be derived. The gauge at Warkworth provides the longest term and most complete record. However, at high flood stages, the site is affected by backwater form the Hunter River. Therefore the Bulga gauge is considered as the most reliable gauge location at which to undertake a FFA.

However, it was found that there were significant uncertainties surrounding the derivation of a reliable FFA at Bulga. These uncertainties included:

- The lack of information regarding potential changes to channel and floodplain topography over the period of record;
- The lack of information regarding the variation in riparian vegetation over the period of record;
- The substantial shift in rating curves over the period of record as a result of changes in the riparian vegetation and the difficulty in identifying exactly when the shift in the simulated rating curves should occur;
- The limitation of only having 61 years of recorded gauge data on which to undertake the FFA; and
- Whether the re-vegetated channel will be stripped clean during the next major flood event.

A series of probability models and data combinations were investigated but it was found that the level of uncertainty and range of resulting flood frequency distributions were too unreliable to take forward into the design event modelling.

8.3 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 Wollombi Brook catchment is presented below.

8.3.1 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.

IFD data derived for the Wollombi Brook catchment is included in Appendix D.

Of note is the spatial variation in rainfall intensity over the whole catchment that shows higher rainfall in the upper catchment on the slopes of the Watagan Ranges. This is generally consistent with the major flood events experienced in the catchment, in particular the 1949 and 2007 calibration events.

This spatial variation in design rainfall is illustrated in Figure 8-3. This shows the 1% AEP 48-hour rainfall depth (mm) for the Wollombi Brook catchment from the Watagan Ranges down to the confluence with the Hunter River at Warkworth. There is a marked difference in design rainfall across the catchment from some 390mm in the Watagan Ranges to some 220mm at Warkworth. The most notable reduction in design rainfall occurs in the downstream reaches of the catchment around Broke and Bulga, which corresponds to the change in the landform from steep mountainous terrain to a more gentle topography as the Wollombi Brook floodplain widens. Conversely, the highest design rainfall at the top of the catchment is representative of the orographic rainfall effects provided by the Watagan Ranges.

In order to incorporate the spatial distribution within the hydrological model, IFD parameters were assigned to 23 points across the catchment as shown in Figure 8-3. A gridded rainfall surface for each storm event was then created based on the values at each of the 23 IFD locations. An average design rainfall depth for each sub-catchment within the model was then estimated based on the gridded rainfall surface. Table 8-4 shows the average design rainfall intensities based on AR&R adopted for each IFD location.

8.3.1.1 Areal Reduction Factor

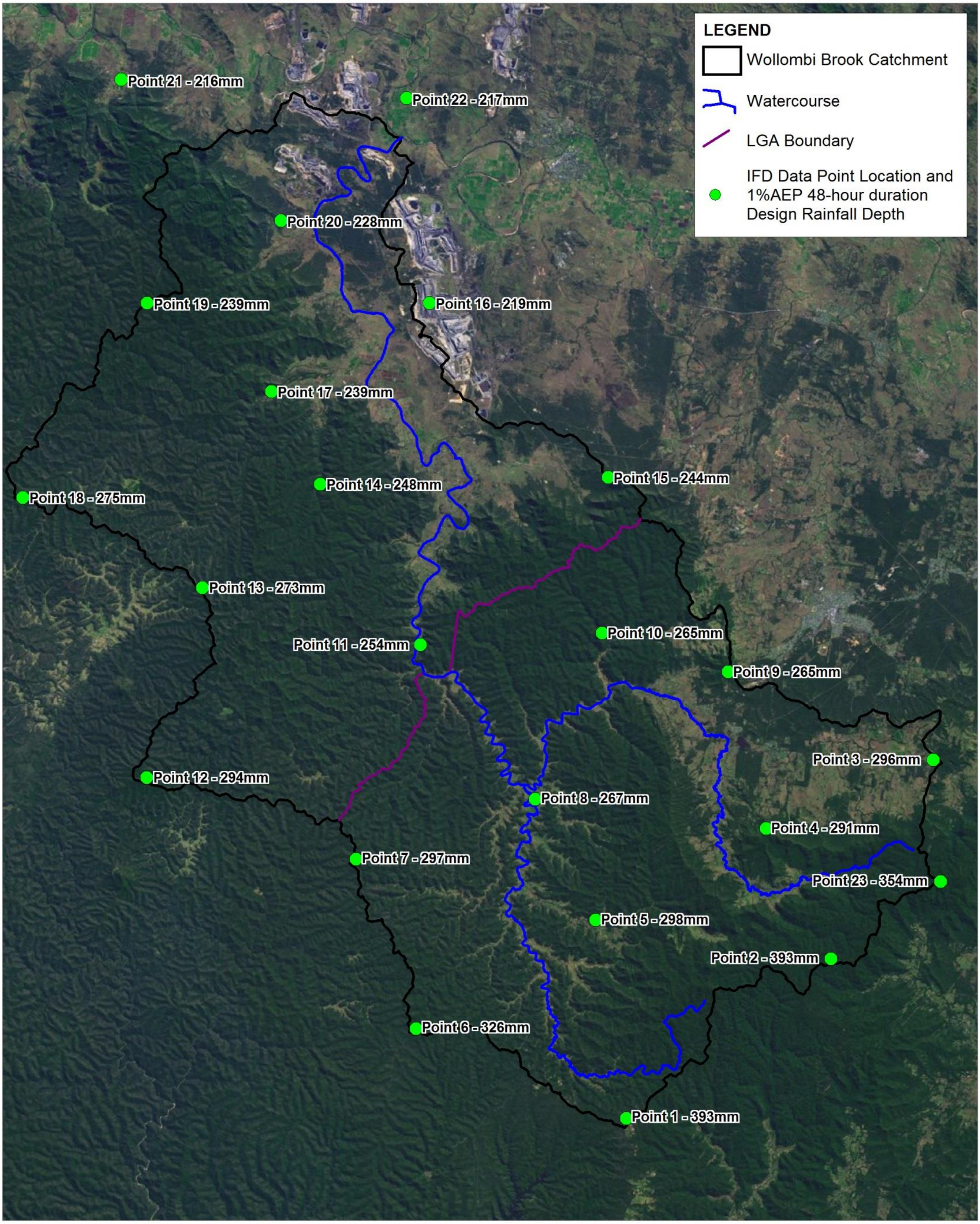
Hydrologic model runs were also carried out with the application of an areal reduction factor. The areal reduction factor takes into account the unlikelihood that larger catchments will experience rainfall of the same design intensity (eg 1% AEP) over the entire area. The selection of the factors has been based on that provided in AR&R (2001), for a catchment area of 1,290km^2 (the total catchment area of upstream of Broke).

8.3.2 Temporal Patterns

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 12-hour, 18-hour, 24-hour, 36-hour, 48-hour and 72-hour durations.

The IFD data presented in Section 8.3.1 provides for the total depth (or average intensity) 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 can be determined for historical events, as was considered for the June 2007 calibration event. However, from a design perspective the same pattern across the catchment is generally adopted.



Title:

Spatial Variation in IFD Design Rainfall Points
1% AEP 48-hour Design Rainfall Event

Figure: 8-3

Rev: A

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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Table 8-4 Average Rainfall Intensities (mm/hr) 48 hour Duration

Point ID	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Point 1	5.3	6.1	7.2	8.6	9.8
Point 2	5.3	6.1	7.2	8.6	9.8
Point 3	4.3	4.8	5.6	6.7	7.5
Point 4	4.2	4.8	5.6	6.6	7.4
Point 5	4.3	4.9	5.7	6.8	7.7
Point 6	4.3	5.0	5.9	7.2	8.2
Point 7	4.1	4.7	5.5	6.6	7.5
Point 8	3.8	4.3	5.1	6.0	6.8
Point 9	3.8	4.3	5.0	6.0	6.7
Point 10	3.7	4.2	5.0	5.9	6.7
Point 11	3.6	4.1	4.8	5.7	6.5
Point 12	3.9	4.6	5.4	6.5	7.3
Point 13	3.7	4.3	5.0	6.0	6.8
Point 14	3.5	4.0	4.7	5.6	6.3
Point 15	3.5	4.0	4.7	5.5	6.2
Point 16	3.2	3.7	4.2	5.0	5.6
Point 17	3.4	3.9	4.5	5.4	6.1
Point 18	3.8	4.4	5.1	6.1	6.9
Point 19	3.4	3.9	4.5	5.4	6.1
Point 20	3.2	3.7	4.3	5.1	5.8
Point 21	3.0	3.5	4.0	4.8	5.4
Point 22	3.1	3.5	4.1	4.9	5.5
Point 23	5.0	5.7	6.7	7.9	8.8

8.3.3 Rainfall Losses

The rainfall loss parameters adopted for the design floods were similar to those used in the hydraulic model calibration and validation. For the initial and continuing rainfall losses, values of 10mm and 4mm/h have been used. These values are considered to be consistent with the AR&R guidelines and findings for loss values in the GSAM Coastal region as discussed in Section 7.3.3.

The selection of the 4mm continual loss was found to provide for the best correlation between the design flows and the historical event IFD data (with aerial reduction factor applied) and simulated peak flows for the calibration and validation events as presented in Table 8-5.

Table 8-5 Simulated Design Event Peak Flows at Bulga

AEP Event	Simulated Peak Flow Rate (m^3/s)
20%	403
10%	526
5%	696
2%	894
1%	1,128
0.5%	1,473
April 2015 (~5% AEP rainfall event)	852
June 2007 (between a 2%-1% AEP rainfall event)	962
June 1949 (>1% AEP rainfall event)	1,791

8.3.4 Critical Duration

A range of design event durations were simulated to determine the critical duration for flooding in the Wollombi Brook catchment including the 12-hour, 18-hour, 24-hour, 36-hour, 48-hour and 72-hour durations. It is likely that the critical duration of flooding for some of the tributaries will be different, however, given the focus of the study being flooding emanating from the main channel of the Wollombi Brook, design event simulations were focused on critical flood conditions for the wider Wollombi Brook catchment.

The model simulations indicated the peak flood levels in the Wollombi Brook corresponded to the 36 hour duration. As such, the design results presented in the remainder of the report are for the 36-hour duration event.

9 Design Flood Results

A range of design flood conditions were modelled, the results of which are presented and discussed below. The simulated design events included the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and Extreme Flood events. A series of design flood maps for selected events are provided in a separate Mapping Compendium.

It is reiterated that the objective of this flood study was to define the critical mainstream flood condition of the Wollombi Brook which corresponds to a critical event duration of 36-hours. As such, the simulated flood behaviour along the smaller tributary alignments may not be representative of the critical flood condition as this would likely be associated which a much shorter critical event duration. Further investigations would be required to define the critical flood condition along the major tributary alignments, including Yellow Rock Creek (Broke township) and Parsons Creek (Milbrodale), in subsequent floodplain management activities.

9.1 Flood Behaviour

The catchment area upstream of Paynes Crossing is typically steep sided and forested with a cleared, relatively narrow floodplain on the valley floors. The combination of these features results in a ‘flashy’ catchment that converts rainfall rapidly into relatively large flow rates and elevated flood levels. The modelled water level time series for the 1% AEP event at Paynes Crossing is presented in Figure 9-1. During the 1% AEP event, inundation of the floodplain at Paynes Crossing begins around 24 hours after the onset of rainfall with the peak level reached at around 36 hours. For the 1% AEP design event, the floodwaters rise rapidly at rates of up to around 1.3m/h, reaching depths of up to around 4.3m in the floodplain and 11.2m in the Wollombi Brook.

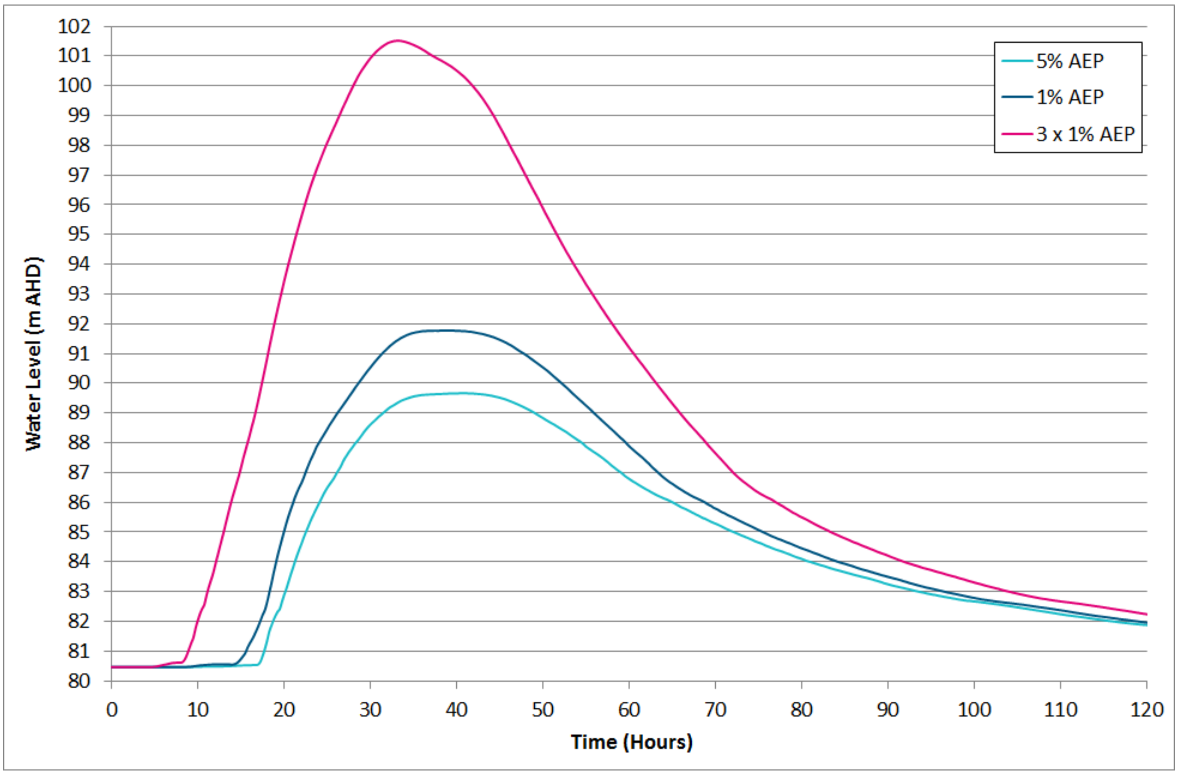


Figure 9-1 Modelled Design Event Water Level Timeseries at Paynes Crossing

Downstream of Paynes Crossing, Wollombi Brook remains a highly incised channel with a narrow floodplain until approximately 13.5km upstream of Broke (approximately 3.5km downstream of Brickmans Bridge). At this point the floodplain widens progressively for the remaining 42km to the confluence with the Hunter River passing through the townships of Broke, Fordwich, Bulga and Warkworth.

Flooding in Broke and the surrounding floodplain emanates from both the Wollombi Brook and Yellow Rock Creek. Floodwaters overtop the banks of the Wollombi Brook and begin inundating areas of the Broke township in events greater than the 1% AEP design event (the 1% AEP event is generally contained within the Wollombi Brook with some out of bank flooding and inundation of the floodplain along the western bank and along Yellow Rock Creek to the north of the township). The modelled water level time series for the 1% AEP event immediately upstream of the Milbrodale Road Bridge at Broke is presented in Figure 9-2. It is evident that the floodwaters rise at rates of up to 1.3m/h, reaching depths of up to around 8.7m in the Wollombi Brook with peak flood level reached at approximately 44 hours after the onset of rainfall. For the 1% AEP there is significant inundation of the floodplain immediately downstream of the Broke township around the confluence of the Wollombi Brook and Yellow Rock Creek. This is largely due to a backwater influence from the Wollombi Brook forcing elevated peak water levels upstream into Yellow Rock Creek resulting in the inundation of low lying floodplain areas on both sides of the Wollombi Brook and the development of a significant flood runner adjacent to Butlers Rd.

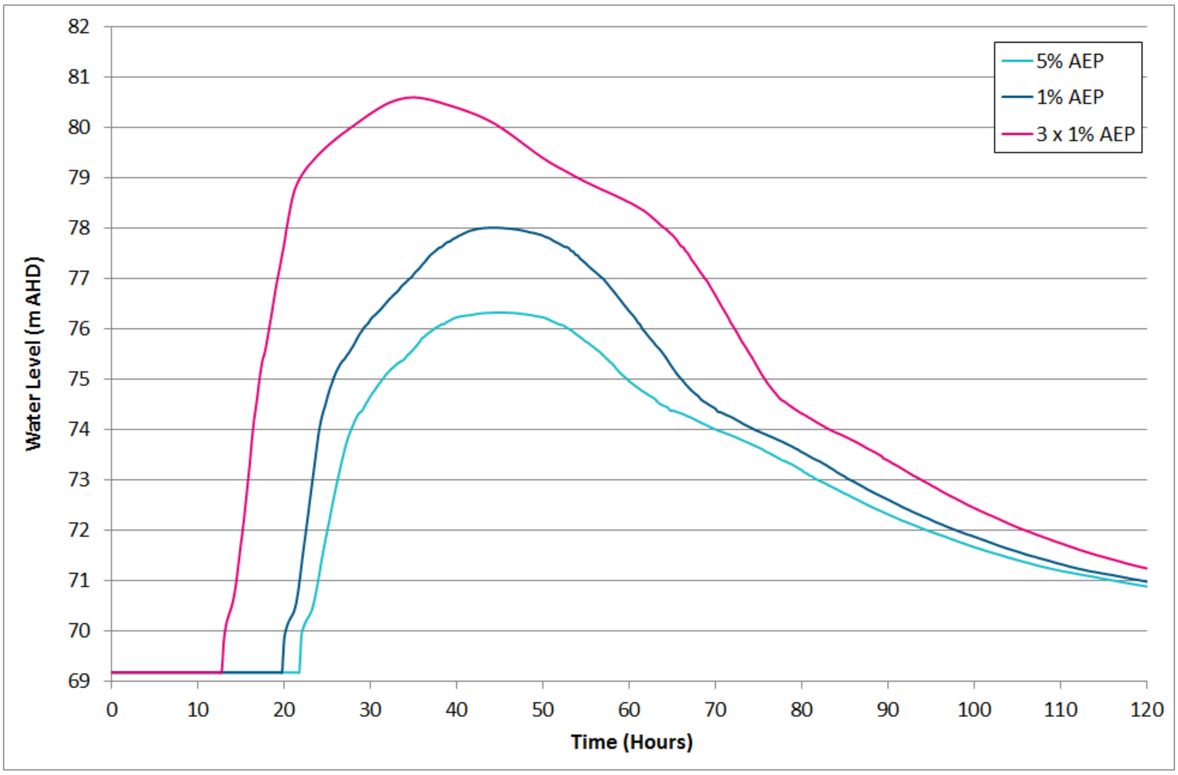


Figure 9-2 Modelled Design Event Water Level Timeseries at Broke

Between Broke and Bulga, the floodplain continues to widen with some significant out of bank flooding occurring on both sides of the Wollombi Brook (particularly in the floodplain area in the vicinity of the Parsons Creek / Wollombi Brook confluence) as a results of the formation of temporary flood runners and backwater flooding inundating areas of the floodplain as temporary storage.

Flooding in Bulga occurs when floodwaters overtop the banks of the Wollombi Brook. The modelled water level time series for the 1% AEP event at Bulga is presented in Figure 9-3. It is evident that the floodwaters rise at rates of up to 1.3m/h, reaching depths of up to around 6.9m in the Wollombi Brook with peak flood level reached at approximately 50 hours after the onset of rainfall.

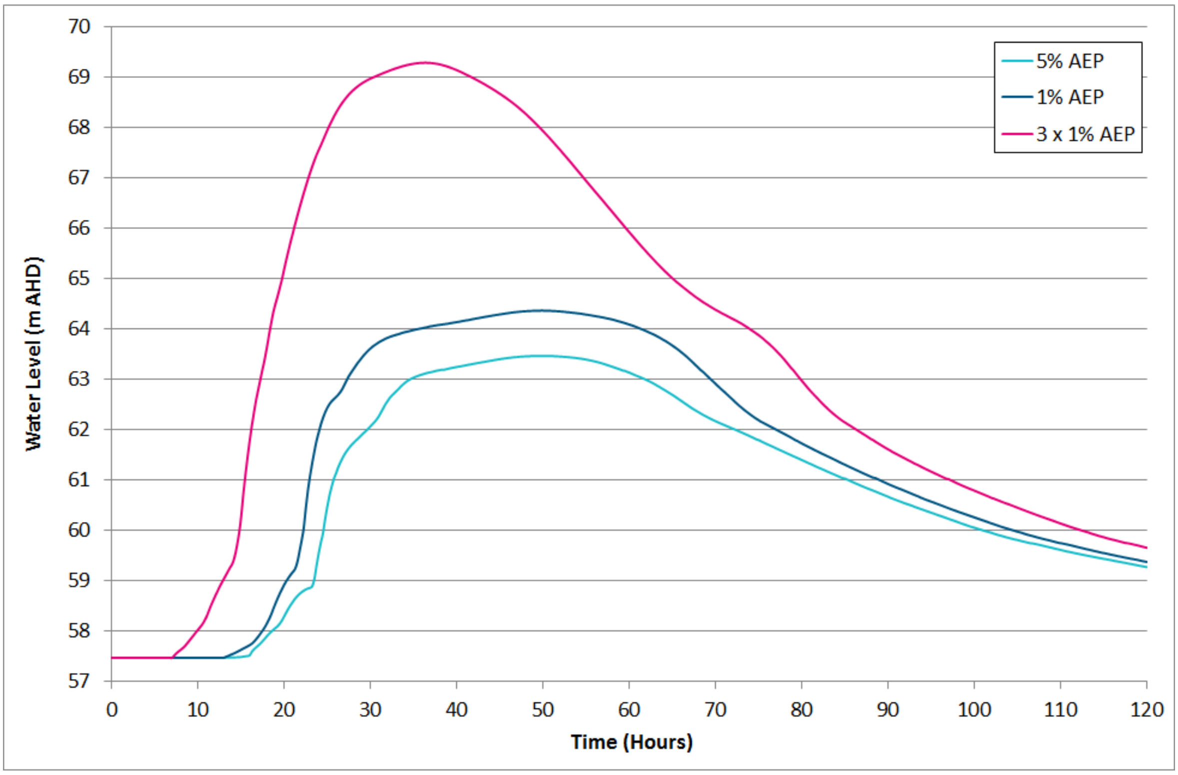


Figure 9-3 Modelled Design Event Water Level Timeseries at Bulga

Flooding downstream of Bulga (including the township of Warkworth) occurs as a result of floodwaters emanating from Wollombi Brook as well as backwater flooding emanating from the Hunter River with the 1% AEP flood level in Warkworth reached approximately 54 hours after the onset of rainfall as shown in Figure 9-4.

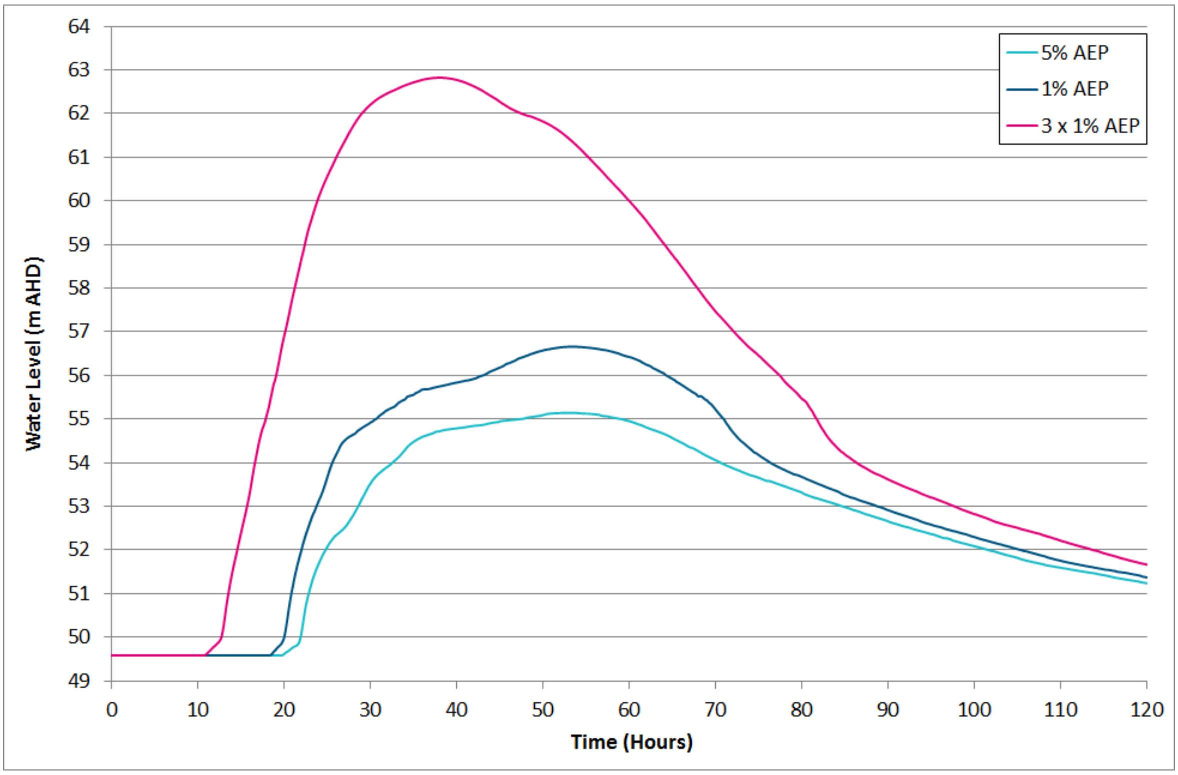


Figure 9-4 Modelled Design Event Water Level Timeseries at Warkworth

As previously discussed, the Wollombi Brook downstream of Payne's Crossing is fed by a number of tributaries draining areas of the Yengo and Pokolbin State Forests and Yengo National Park as shown on Figure 2-2. Whilst flooding emanating from Wollombi Brook does present the most significant flood hazard in the catchment, flooding along the tributaries also presents a flood hazard particularly due to the fact that a number of properties are situated along the tributary alignments (but out of the main Wollombi Brook flood extent). The flood behaviour along these tributary alignments is also significantly different to that of the greater Wollombi Brook with peak flood levels likely to be reached in a much shorter timeframe and also dissipate much quicker (especially in the upper reaches of the tributary alignments).

9.2 Peak Flood Conditions

The design flood results are presented in a separate mapping compendium. For the simulated design events including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and Extreme Flood events, a map of peak flood level, depth and velocity is presented covering the modelled area.

Modelled peak flood levels at selected locations (as presented in Figure 9-5) are presented in Table 9-1, for the full range of design flood events considered. Longitudinal profiles showing modelled peak flood levels for the Wollombi Brook are shown in Figure 9-6, with the channel bed profile also shown for reference. Deck and obvert levels of the bridge structures are also shown in Figure 9-6 with the deck levels and modelled peak flood levels at the major bridge structures over the Wollombi Brook also presented in Table 9-2. It can be seen that three of the structures (including the series of culverts on Mine Rd, the access bridge to the Wambo Coal site upstream of Warkworth and the bridge at Paynes Crossing) are overtopped during the 20% AEP flood event.

The Milbrodale Road Bridge is then overtopped during the 0.5% AEP event, with all other structures only overtopped during the Extreme Flood event. Note that property access was not granted to Carman Surveyors by Wambo Coal to undertake the survey of the access bridge structure so deck levels for the bridge were inferred from available LiDAR data.

Table 9-1 Modelled Peak Flood Levels

ID	Location	Modelled Peak Flood Level (m AHD)						
		20%	10%	5%	2%	1%	0.5%	Extreme Flood
1	Warkworth Gauge	54.2	54.6	55.2	55.9	56.7	57.9	62.8
2	Bulga Bridge Gauge	62.6	62.9	63.4	64.0	64.3	64.8	69.3
3	U/S Wollombi Brook/Parsons Creek Confluence	67.6	68.0	68.4	68.7	69.0	69.3	71.6
4	U/S Milbrodale Rd Bridge (Broke)	75.0	75.6	76.5	77.5	78.3	78.9	81.1
5	D/S Brickmans Bridge Gauge	85.0	86.0	87.2	88.3	89.3	90.2	96.4
6	Paynes Crossing	87.6	88.6	89.7	90.8	91.8	92.8	101.5

Table 9-2 Modelled Peak Flood Levels at Major Structure Locations

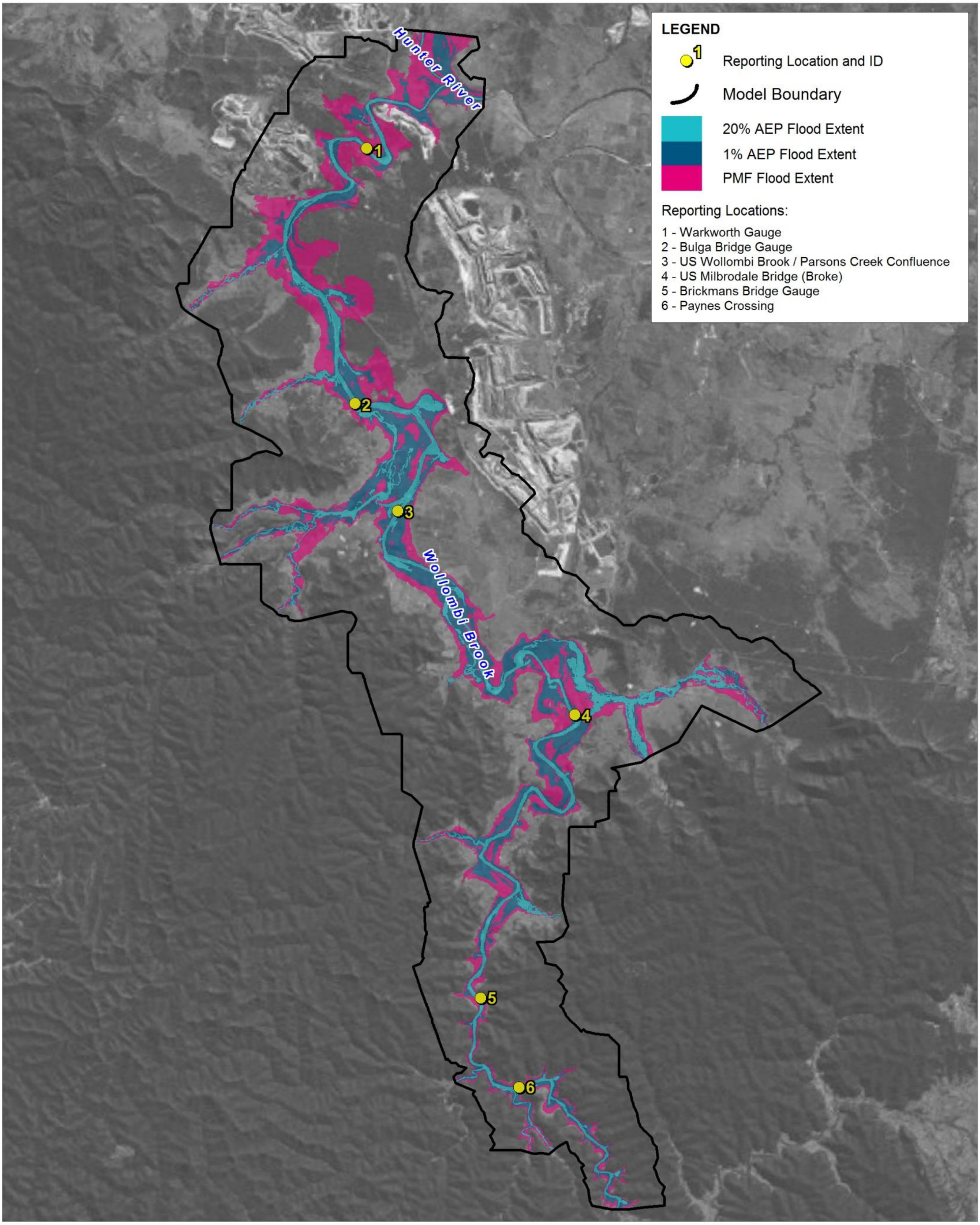
ID	Location	Watercourse	Deck Level (m AHD)	Modelled Peak Flood Level (m AHD)		
				5% AEP	1% AEP	Extreme Flood
S1	Paynes Crossing, Wollombi Road	Wollombi Brook	82.6	89.7	91.8	101.5
S13	Milbrodale Road, Broke	Wollombi Brook	78.5	76.4	78.1	80.7
S7	Putty Road (Bulga Bridge), Bulga	Wollombi Brook	66.9	63.5	64.4	69.3
S10	Golden Highway (Cockfighter Bridge), Warkworth	Wollombi Brook	61.5	55.8	57.2	63.0

Figure 9-5 shows the design flood inundation extents for the 20% AEP, 1% AEP and Extreme Flood events. The flood extents for the range of events are broadly similar within much of the catchment (particularly upstream of Brickmans Bridge). The floodplain upstream of the Brickmans Bridge is well-defined, with relatively steep sides. Although the flood depths increase significantly with event magnitude, there is little change in the flood extents across the valley floor. However, downstream of Brickmans Bridge where the floodplain begins to widen, the change in flood extents is more pronounced (especially the increase in flood extents associated with the Extreme Flood event). This includes floodplain areas near Broke, the confluence with Parsons Creek, Bulga and the lower catchment around Warkworth.

Figure 9-5 shows that the 20% AEP flood extent is generally contained within the Wollombi Brook with minimal out of bank flooding. The main area impacted by the 20% AEP event is the Yellow Rock Creek catchment area due to the limited conveyance capacity of Yellow Rock Creek. There is also a small flood runner that forms between Parsons Creek and Bulga that runs adjacent to the Wollombi Brook.

The increase in flood extent for the 1% AEP event (compared to the 20% AEP flood extent) is associated with the overtopping of the Wollombi Brook banks and inundation of low lying floodplain areas and small flood runners or ephemeral channels located adjacent the Wollombi Brook. However the flood extents are still generally well defined with limited out of bank flooding in the key developed areas of the catchment (including Broke and Bulga). The majority of out of bank flooding is a function of either the formation of a temporary flood runners adjacent to the Wollombi Brook that eventually re-joins the main waterway; or backwater flooding that inundates/fills temporary storages in the floodplain (often occurs along the bends in the Wollombi Brook where elevated peak water levels upstream of the bend (as shown in Figure 9-6) result in a backwater flooding effect). Similar to the 20% AEP event, there is some out of bank flooding and inundation of the floodplain along the Yellow Rock Creek running along the northern edge of the Broke township that occurs due to the limited conveyance capacity of Yellow Rock Creek.

The increase in flood extents between the 1% AEP and the Extreme Flood event is significant as the banks of the Wollombi Brook are overtopped throughout the catchment, resulting in the inundation of the floodplain including widespread property inundation in the townships of Broke and Bulga.



Title:

Design Flood Extents and Reporting Locations

Figure: 9-5

Rev: A

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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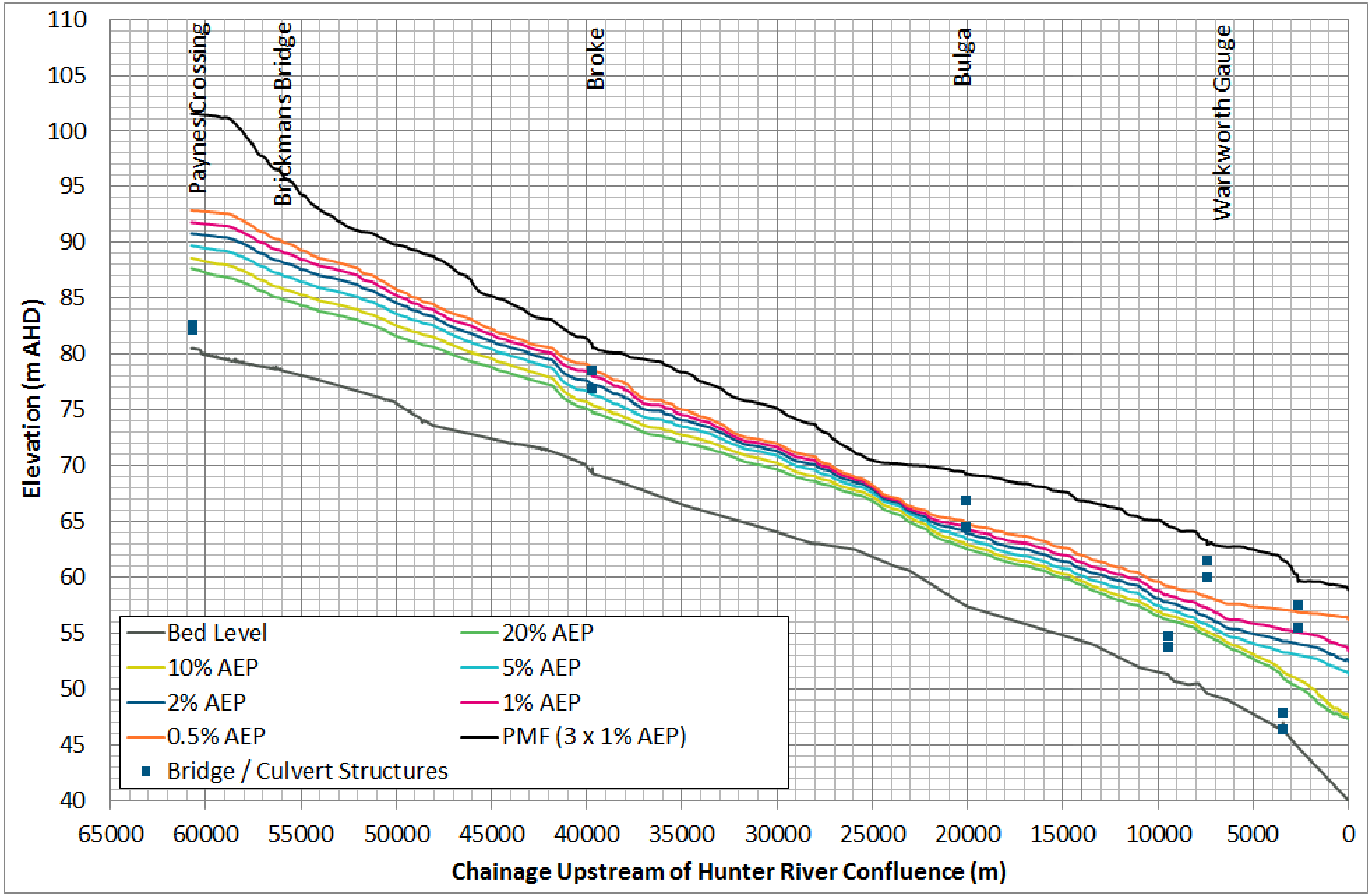


Figure 9-6 Design Flood Profiles Wollombi Brook

9.3 Design Flood Flow Hydrographs

Modelled peak flood flows at selected locations are presented in Table 9-3 for the full range of design flood events considered. The flood hydrographs at each of the selected locations reported in Table 9-3 are presented in Figure 9-7 for the 1% AEP event.

The flow hydrographs of the Wollombi Brook at each of the selected locations shown in Figure 9-7 show a similar shape, with a progressively later and higher flood peak when moving downstream through the catchment.

Table 9-3 Modelled Peak Flood Flows

Location	Modelled Peak Flood Flows (m^3/s)						
	20%	10%	5%	2%	1%	0.5%	Extreme Flood
Warkworth Gauge	426	553	717	910	1,142	1,453	7,146[1]
Bulga Gauge	420	546	714	910	1,147	1,483	7,068[2]
Milbrodale Rd Bridge (Broke)	362	485	652	852	1,071	1,366[3]	6,253[3]
D/S Brickmans Bridge Gauge	349	469	637	842	1,057	1,342	6,106
Paynes Crossing	310	417	564	742	932	1,163	5,259

[1] Peak flow approximately 2.8km upstream of Warkworth gauge

[2] Peak flow approximately 1.3km upstream of Bulga Bridge

[3] Peak flow approximately 1.3km upstream of Milbrodale Rd Bridge

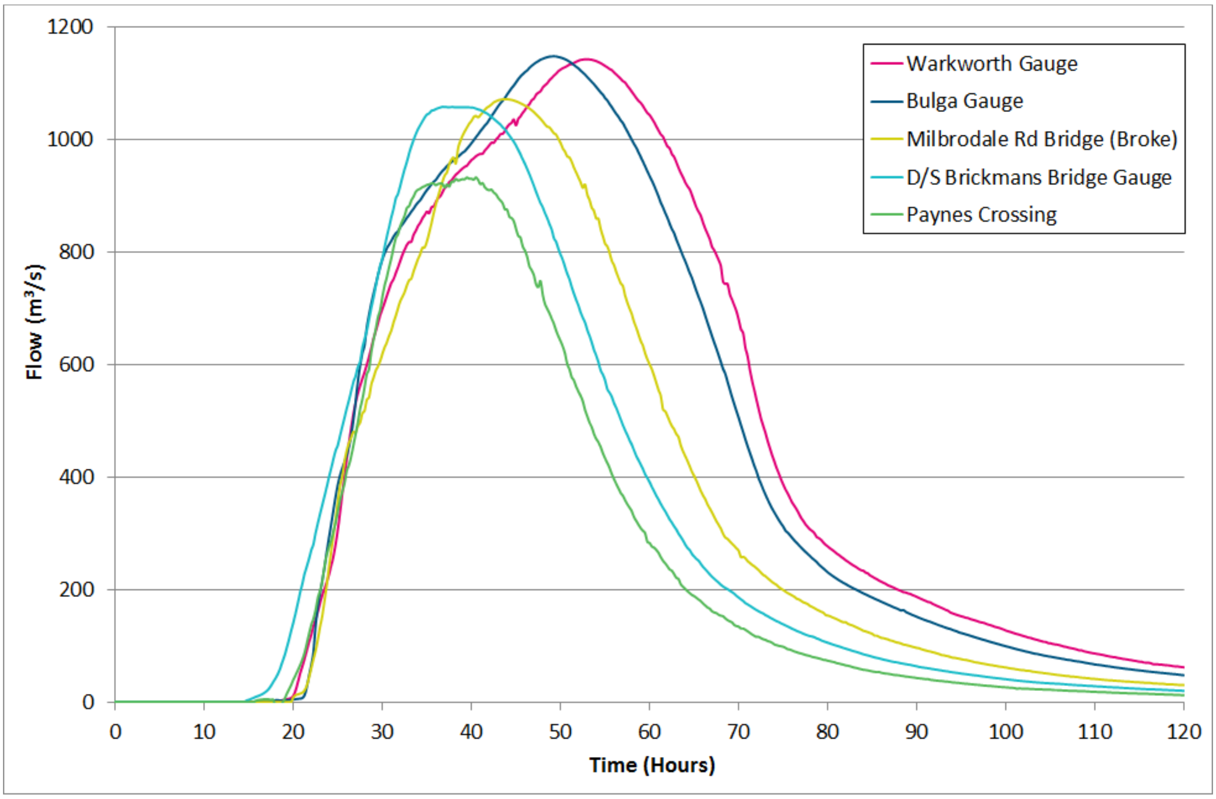


Figure 9-7 Modelled 1% AEP Event Hydrographs at Selected Locations

9.4 Hydraulic Classification

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 (NSW Government, 2005) 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 effect on the flood pattern or flood levels.

A number of approaches were considered when attempting to define flood impact categories across the study catchment. The approach that was adopted derived a preliminary floodway extent from the velocity * depth product (sometimes referred to as unit discharge). The floodway extent was then locally adjusted where appropriate, in order to produce a cleaner and more contiguous extent. The peak flood depth was used to define flood storage areas. The adopted hydraulic categorisation is defined in Table 9-4.

Table 9-4 Hydraulic Categories

Floodway	Velocity * Depth > 0.3	Areas and flowpaths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 0.3 and Depth > 0.3 metres	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Velocity * Depth < 0.3 and Depth < 0.3 metres	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

Hydraulic category mapping for the 1% AEP and Extreme Flood design events is included in a separate mapping compendium.

For the 1% AEP event, the floodway is extensive for the Wollombi Brook upstream of Brickman's Bridge. Deep flooding extends to the steep valley sides and most of the floodplain is classed as floodway, albeit with some isolated fringe areas of less severe flooding. Downstream of Brickman's Bridge the floodway extent continues to cover much of the design flood extent including several flood runners and tributary alignments. The occurrence of areas of flood storage and flood fringe increase moving downstream of Brickman's Bridge particularly adjacent to bending sections of the Wollombi Brook. Significant areas of flood storage and flood fringe occur along the alignments of Monkey Place Creek and Yellow Rock Creek and at the confluence of Parsons Creek and Wollombi Brook.

For the Extreme Flood event, the floodway is extensive for the entire modelled Wollombi Brook catchment (particularly upstream of Bulga). The Extreme Flood event is characterised by deep floodwaters extending to the valley sides resulting in the majority of the flood extent being classified as floodway, albeit with some isolated areas of flood storage and flood fringe (particularly in the lower catchment downstream of Bulga).

It is also noted that mapping associated with the flood hydraulic categories may be amended in the future (e.g. a change from floodway to flood storage), at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts to upstream, downstream or adjacent properties. From the definitions provided in the Floodplain Development Manual, it should be noted that filling would generally only be permissible in flood fringe areas. Filling would generally not be permitted in Floodways or Flood Storage Areas.

9.5 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 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 classification within flood liable land. These figures are reproduced in Figure 9-8.

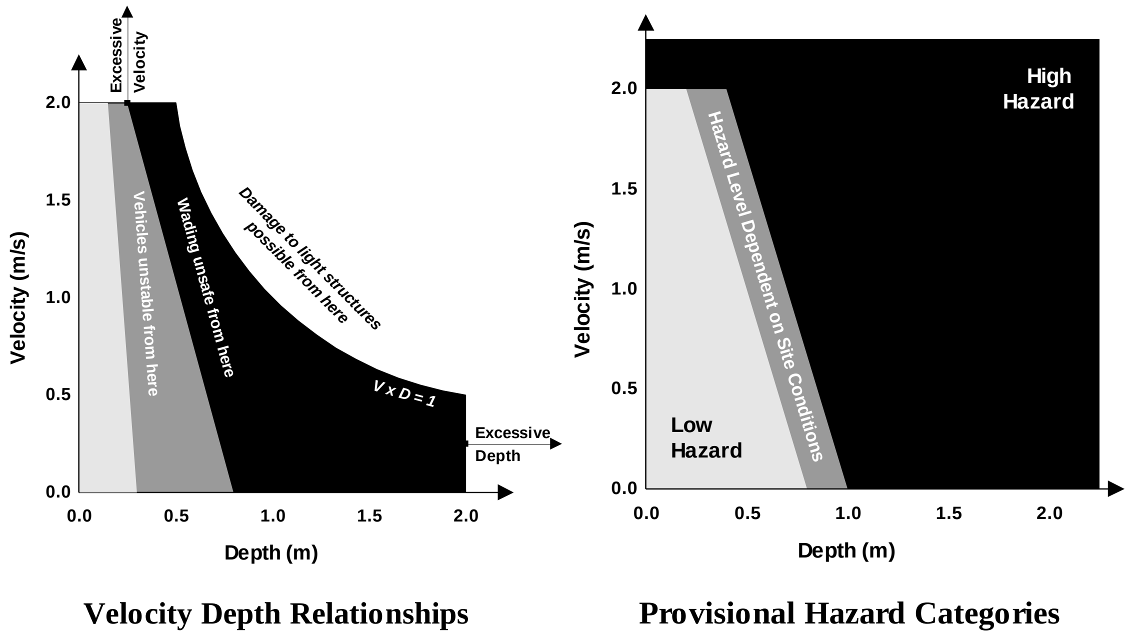


Figure 9-8 Provisional Flood Hazard Categorisation

The hydraulic hazard mapping for the 1% AEP and Extreme Flood events is included in a separate mapping compendium.

9.6 Sensitivity Tests

A number of sensitivity tests have been undertaken on the modelled flood behaviour in the Wollombi Brook catchment. 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:

- design continual / infiltration loss;
- hydraulic roughness;
- structure blockage;
- downstream Hunter River boundary; and
- 2013 Intensity–Frequency–Duration (IFD) Design Rainfall.

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 (36-hour duration) is also presented in Appendix B as a series of peak water level afflux diagrams.

9.6.1 Rainfall Losses

The hydrological model parameters adopted for the design floods were similar to those used in the hydrological model calibration and validation. For the initial and continuing rainfall losses, values of 10mm and 4mm/hr were adopted across the catchment. Rainfall losses are to some degree dependent on antecedent catchment conditions which vary between dry and wet conditions. Given the critical duration for the Wollombi Brook catchment is 36 hours, altering the initial rainfall loss would provide for negligible change in the peak flows and water levels. However, given that the 1% AEP 36-hour design storm results in an average rainfall intensity of ~7.0mm/hour across the catchment, altering the continuing loss (also known as infiltration loss) has the potential to influence the peak flows and water levels across the catchment. As such, sensitivity tests on the adopted continual / infiltration loss have been undertaken for the 1% AEP catchment rainfall event (36 hour duration). These sensitivity tests undertaken included a continual loss of 3mm and 5mm (the initial loss was maintained at 10mm). The change in peak water levels associated with the simulated continual loss is summarised in Table 9-5.

Table 9-5 Peak 1% AEP Flood Levels for Rainfall Losses Sensitivity Tests

Location	Peak Design Flood Level (m AHD)		
	Base (4mm/hr)	Increased Losses (5mm/hr)	Decreased Losses (3mm/hr)
Warkworth Gauge	56.7	56.1 (-0.6)	57.2 (+0.5)
Bulga Gauge	64.3	64.0 (-0.3)	64.7 (+0.4)
US Wollombi Brook/Parsons Creek Confluence	69.0	68.8 (-0.2)	69.2 (+0.2)
US Milbrodale Rd Bridge (Broke)	78.3	77.6 (-0.7)	78.8 (+0.5)
D/S Brickmans Bridge Gauge	89.3	88.5 (-0.8)	90.0 (+0.7)
US Paynes Crossing	91.8	91.0 (-0.8)	92.6 (+0.8)

Note: Bracketed value is change in peak flood level from base design conditions

As shown in Table 9-5 and the afflux mapping in Appendix B, the assumed design continual loss has a significant influence on the peak design flood levels with localised changes in peak flood levels of up to 0.9m occurring throughout the catchment. The change in peak design flood levels are more prominent upstream of Broke (±~0.8m) where the flooding is confined within the steep sided and relatively narrow floodplain. Downstream of Broke, the change in peak design flood levels is less pronounced with changes in peak flood level generally around ±0.4m. It should be noted that the changes in peak design flood levels is generally limited to the Wollombi Brook and adjacent floodplain areas with minimal changes in peak flood levels occurring along the tributary alignments (including Yellow Rock Creek).

9.6.2 Hydraulic Roughness

Sensitivity tests on the hydraulic roughness (Manning's 'n') were undertaken by applying a 25% decrease and a 25% increase in the adopted values for the baseline design conditions. Whilst a calibration process has been undertaken with respect to available data, and adopted design parameters are within typical ranges, the inherent variability/uncertainty in hydraulic roughness warrants consideration of the relative impact on adopted design flood conditions. It should be noted that in order to maintain model stability in the lower catchment the in-channel Manning's 'n' value for the Hunter River channel was maintained at 0.03.

The sensitivity tests have been undertaken for the 1% AEP catchment rainfall event (36 hour duration). The results of the sensitivity tests on hydraulic roughness for the 1% AEP design event are summarised in Table 9-6. The change in peak flood level conditions from the adopted design base case is also shown as afflux diagrams in Appendix B.

Table 9-6 Peak 1% AEP Flood Levels for Hydraulic Roughness Sensitivity Tests

Location	Peak Design Flood Level (m AHD)		
	Base	25% Decrease	25% Increase
Warkworth Gauge	56.7	56.2 (-0.5)	57.0 (+0.3)
Bulga Gauge	64.3	64.0 (-0.3)	64.6 (+0.3)
US Wollombi Brook/Parsons Creek Confluence	69.0	68.8 (-0.2)	69.2 (+0.2)
US Milbrodale Rd Bridge (Broke)	78.3	77.6 (-0.7)	78.7 (+0.4)
D/S Brickmans Bridge Gauge	89.3	88.3 (-1.0)	90.0 (+0.7)
US Paynes Crossing	91.8	90.8 (-1.0)	92.6 (+0.8)

Note: Bracketed value is change in peak flood level from base design conditions

The model simulation results show minor to moderate reductions in peak flood level (up to -0.5m) for reduced hydraulic roughness in the lower catchment downstream of Broke. However, upstream of Broke where the floodplain is confined within the steep sided and relatively narrow floodplain the simulated results show more significant reductions (up to -1.0m) in peak flood level.

Similarly, minor to moderate increases in peak flood level in the lower catchment downstream of Broke (up to -0.4m) are simulated for the increased hydraulic roughness conditions applied in the sensitivity test. Again however, for the catchment area upstream of Broke the results show more significant increases (~0.8m) in peak flood levels.

Whilst the increase/decrease in hydraulic roughness conditions does result in some changes to the modelled peak water levels, it has minimal influence on inundation extents in overbank areas.

9.6.3 Structure Blockage

Sensitivity of peak flood levels to potential structure blockages were undertaken by applying a 25% and 50% blockage factor to both the bridge structures and culvert structures across the catchment (refer to Table 6-2 for a description of the structures included in the hydraulic model).

AR&R have also recently released a national guideline document titled 'A Guide to Flood Estimation' (Ball et al, 2016) that includes some guidance around the assessment procedure to estimate blockage levels of structure inlet blockages to be used for design flood event modelling (refer Book 6: Flood Hydraulics – Chapter 6. Blockage of Hydraulic Structures).

The AR&R assessment procedure includes the assessment and classification of the following parameters/mechanisms:

- Debris type and dimensions (including identification of the average length of the longest 10% of the debris that could arrive at the site (termed as L_{10});
- Debris availability in the study area;
- Debris mobility; and
- Debris transportability.

A classification is applied to each of the above components and the combination of these classifications provides a debris potential classification as presented in Table 9-7.

Table 9-7 Blockage Classification

Component	Value / Classification
L_{10}	15m
Debris Availability	Medium
Debris Mobility	Medium
Debris Transportability	High
Debris Potential	Medium (MMH Combination)

Based on the debris potential classification the guideline provides an estimate of the 'most likely' inlet blockage level for a given structure inlet size as presented in Table 9-8.

Table 9-8 AR&R Most Likely Blockage Levels – Medium Debris Potential

Control Dimension Inlet Clear Width (W) (m)	(1% AEP) Medium Debris Potential at Structure
$W < L_{10}$	50%
$L_{10} \leq W \leq 3 \times L_{10}$	10%
$W > 3 \times L_{10}$	0%

Based on the estimated blockage levels presented in Table 9-8, a blockage was applied to each of the culvert and bridge structures included in the hydraulic model as presented in Table 9-9 (refer to Table 6-2 for additional structure details and Figure 6-2 for structure locations).

The change in peak water levels with the assumed blockage conditions is summarised at key locations (generally corresponding to the structure locations) in Table 9-10. Mapping of the extents of the simulated afflux is included in Appendix B for the 1% AEP catchment rainfall event (36 hour duration). Table 9-10 shows the simulated peak flood level with no structure blockage, along with the change from the assumed structure blockage flood conditions shown in brackets.

Table 9-9 Applied Blockage Factors based on AR&R Guidelines

ID	Location	Watercourse	Blockage %
S1	Paynes Crossing, Wollombi Road	Wollombi Brook	50%
S2	Broke-Cessnock Road, Broke	Yellow Rock Creek	50%
S3	Wollombi Road (near Charlton Rd intersection)	Yellow Rock Creek	10%
S4	Milbrodale Road	Watts Creek	50%
S5	Putty Road, Milbrodale	Bulga Creek	50%
S6	Putty Road, Milbrodale	Parsons Creek	10%
S7	Putty Road (Bulga Bridge), Bulga	Wollombi Brook	10%
S8	Wambo Road	Hayes Creek	50%
S9	Mine Access Road (off Golden Highway)	Wollombi Brook	50%
S10	Golden Highway (Cockfighter Bridge), Warkworth	Wollombi Brook	10%
S11	Mine Access Road (off Comleroi Road), Warkworth	Wollombi Brook	50%
S12	Mine Access Road (off/parallel to Comleroi Road), Warkworth	Wollombi Brook	10%
S13	Milbrodale Road, Broke	Wollombi Brook	10%

Table 9-10 Peak 1% AEP Flood Levels for Structure Blockage Sensitivity Tests

Location	Peak Design Flood Level (m AHD)			
	Base	25% Blockage	50% Blockage	AR&R Blockage Guideline
US Golden Highway Bridge (Warkworth)	57.3	57.4 (+0.1)	57.9 (+0.6)	57.3 (0.0)
Bulga Bridge	64.6	64.6 (0.0)	64.9 (+0.3)	64.6 (0.0)
US Putty Road Bridge (Parsons Creek)	73.5	73.5 (0.0)	73.8 (+0.3)	73.5 (0.0)
US Milbrodale Road Culvert (Watts Creek)	78.6	79.1 (+0.5)	79.3 (+0.7)	79.3 (+0.7)
US Milbrodale Road Bridge (Broke)	78.2	78.4 (+0.2)	78.7 (+0.5)	78.3 (+0.1)
US Paynes Crossing	91.8	91.8 (0.0)	91.8 (0.0)	91.8 (0.0)

Note: Bracketed value is change in peak flood level from base design conditions

As shown in Table 9-10 and the afflux mapping in Appendix B, the 25% blockage condition has minimal impact on flood conditions in the catchment with the only notable impact being immediately upstream of the Milbrodale Road Bridge at Broke. However, the 50% blockage condition resulted in some notable increases in simulated flood levels (typically 0.3-0.6m) with the area of influence extending upstream of a number of structures (particularly the Milbrodale Rd Bridge, Bulga Bridge and the series of structures in the lower catchment around Warkworth).

It is evident that the AR&R Blockage scenario also had minimal impact on flood conditions along the Wollombi Brook, but it did have some impact along the smaller tributary alignments such as Watts Creek where a 50% blockage was applied.

It is evident in Table 9-10 that the adopted blockage conditions had minimal impact on flood levels at Paynes Crossing. This is due to the fact that the Paynes Crossing Bridge structure has a significant depth of overtopping during the 1% AEP design event and as such applying a blockage factor would not significantly reduce the conveyance of the Wollombi Brook channel and result in an increase in peak flood levels.

9.6.4 Downstream Water Level

As previously discussed, the peak flood levels along the lower reaches of the Wollombi Brook will be influenced by the water level in the Hunter River. Taking in to consideration the low likelihood that a 1% AEP event would occur simultaneously in the Wollombi Brook and Hunter River, a series of design flood magnitude combinations were adopted as presented in Table 8-3. As shown in Table 8-3, the 1% AEP design rainfall event in the Wollombi Brook catchment was combined with the 5% AEP Hunter River water level timeseries. In order to assess the sensitivity of the model to the downstream Hunter River water level timeseries the design flood magnitude combinations presented in Table 9-11 were simulated.

Table 9-11 Coincident Flood Event Combinations – Sensitivity Test

Wollombi Brook AEP (design catchment rainfall inflows)	Hunter River AEP (design downstream water level timeseries)
1%	50% (2 year ARI)
1%	1%

The change in peak water levels associated with the simulated coincident flood event combinations is summarised in Table 9-12. Longitudinal profiles showing the change modelled peak flood levels for the Wollombi Brook are shown in Figure 9-9. Mapping of the extents of the simulated afflux is included in Appendix B.

Table 9-12 Peak 1% AEP Flood Levels for Downstream Water Level Sensitivity Tests

Location	Peak Design Flood Level (m AHD)		
	Base	Increased DS Boundary	Decreased DS Boundary
Warkworth Gauge	56.7	59.3 (+2.6)	56.3 (-0.4)
Bulga Gauge	64.3	64.3 (0.0)	64.3 (0.0)
US Wollombi Brook/Parsons Creek Confluence	69.0	69.0 (0.0)	69.0 (0.0)
US Milbrodale Rd Bridge (Broke)	78.3	78.3 (0.0)	78.3 (0.0)
D/S Brickmans Bridge Gauge	89.3	89.3 (0.0)	89.3 (0.0)
US Paynes Crossing	91.8	91.8 (0.0)	91.8 (0.0)

Note: Bracketed value is change in peak flood level from base design conditions

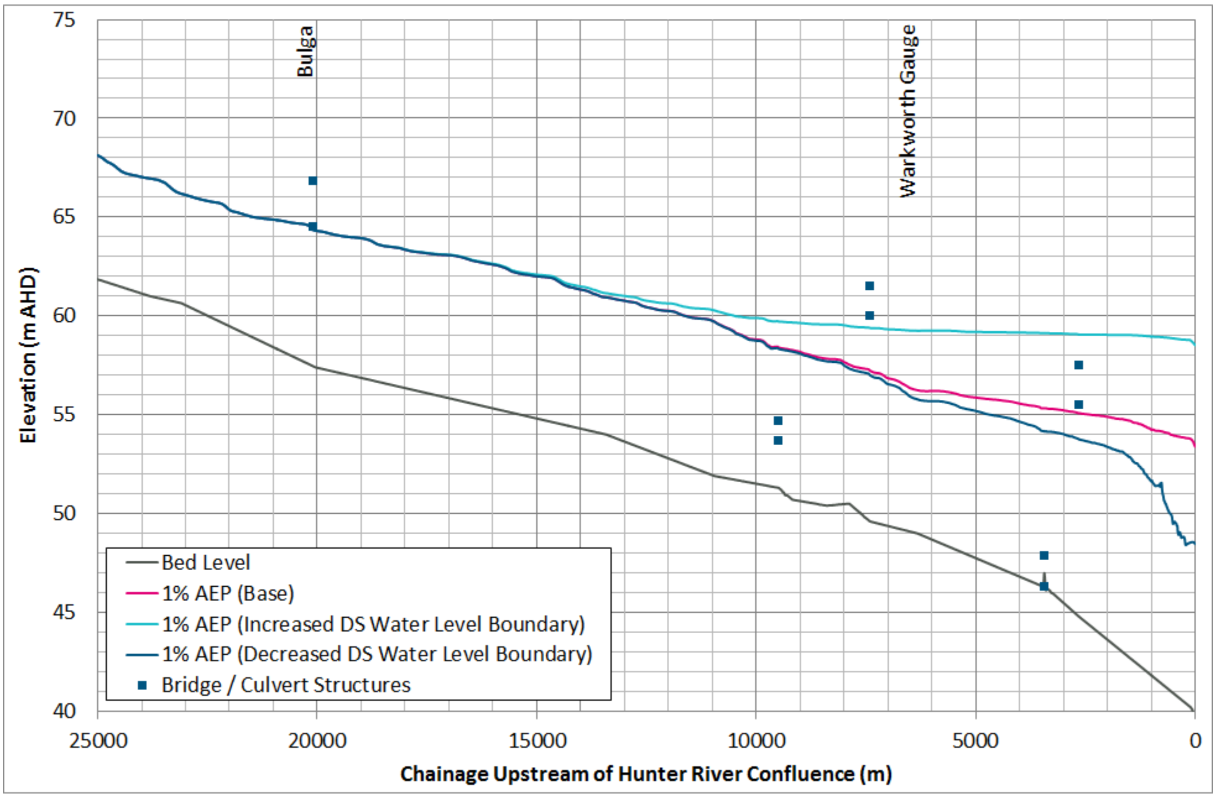


Figure 9-9 Design Flood Profiles Wollombi Brook – Downstream Water Level Sensitivity

As shown in Table 9-12, Figure 9-9 and the afflux mapping in Appendix B, the adopted downstream water level has a significant impact on peak flood levels in the lower catchment (including the township of Warkworth). However, the significant influence of the adopted downstream water level only extends approximately 14.3km upstream from the Hunter River confluence to the confluence of Wollombi Brook and Wambo Creek. No impact in simulated peak levels was observed at Bulga.

9.6.5 2013 Intensity–Frequency–Duration (IFD) Design Rainfall

The Bureau of Meteorology (BoM) released the 2013 Intensity–Frequency–Duration (IFD) design rainfalls as part of the revision of Engineers Australia's design handbook *Australian Rainfall and Runoff: A Guide to Flood Estimation*.

While the new IFDs are derived from a longer and more extensive dataset, careful consideration is needed before they are used with other existing inputs to design flood estimation techniques (i.e. temporal patterns, areal reduction factors and rainfall losses).

The BoM advises that you cannot assume that using the 2013 IFD design rainfalls with AR&R87 techniques and design parameters will deliver a more reliable estimate of the design flood. As such, BoM recommends that until such time at the entire suite of updated AR&R techniques and design parameters are available, it would be prudent to use the AR&R87 design parameters and conduct sensitivity testing with revised 2013 IFD design rainfalls. This will enable an assessment of the impact of updated information on design flood conditions.

As such, a sensitivity test has been undertaken combining the 2013 IFD design rainfalls with the AR&R87 design parameters (i.e. temporal patterns, areal reduction factors and rainfall losses).

The 1987 and 2013 AR&R design rainfall intensities for the 1% AEP 48-hour design event are shown in Table 9-13. This spatial variation in design rainfall points is shown in Figure 8-3.

Table 9-13 AR&R Rainfall Intensities (mm/hr) 1% AEP 48 hour Duration

Point ID	AR&R 1987	AR&R 2013	Point ID	AR&R 1987	AR&R 2013
Point 1	8.19	7.75 (-0.44)	Point 13	5.69	5.60 (-0.09)
Point 2	8.19	8.22 (+0.03)	Point 14	5.16	5.39 (+0.23)
Point 3	6.17	7.59 (+1.42)	Point 15	5.09	5.51 (+0.42)
Point 4	6.06	7.28 (+1.22)	Point 16	4.56	4.73 (+0.17)
Point 5	6.21	6.17 (-0.04)	Point 17	4.97	4.88 (-0.09)
Point 6	6.80	6.46 (-0.34)	Point 18	5.73	5.24 (-0.49)
Point 7	6.19	5.94 (-0.25)	Point 19	4.98	5.35 (+0.37)
Point 8	5.56	5.46 (-0.10)	Point 20	4.74	4.64 (-0.10)
Point 9	5.52	6.46 (+0.94)	Point 21	4.50	4.92 (+0.42)
Point 10	5.52	5.82 (+0.30)	Point 22	4.52	4.57 (+0.05)
Point 11	5.30	5.08 (-0.22)	Point 23	7.37	8.54 (+1.17)
Point 12	6.13	5.79 (-0.34)			

Note: Bracketed value is change in design rainfall intensity from the 1987 AR&R rainfall intensities (mm/hour)

As shown in Table 9-13, the changes in rainfall intensities vary across the catchment with both increases and decreases in rainfall intensities at point locations distributed across the catchment (refer Figure 8-3). However, on average, the adoption of the 2013 AR&R IFD data results in an increase in design rainfall intensity of ~0.2mm/hour.

The change in peak water levels associated with the application of the 2013 IFD design rainfall is summarised in Table 9-14. Mapping of the extents of the simulated afflux is included in Appendix B for the 1% AEP catchment rainfall event (48 hour duration).

Table 9-14Peak 1% AEP Flood Levels for AR&R IFD Design Rainfall Sensitivity Tests

Location	Peak Design Flood Level (m AHD)	
	Base (1987 AR&R IFD Data)	2013 AR&R IFD Data
Warkworth Gauge	56.7	56.8 (+0.2)
Bulga Gauge	64.3	64.4 (+0.1)
US Wollombi Brook/Parsons Creek Confluence	69.0	69.1 (+0.1)
US Milbrodale Rd Bridge (Broke)	78.3	78.6 (+0.3)
D/SBrickmans Bridge Gauge	89.3	89.6 (+0.4)
US Paynes Crossing	91.8	92.1 (+0.4)

Note: Bracketed value is change in peak flood level from base design conditions

As shown in Table 9-14 and the afflux mapping in Appendix B, the adoption of the 2013 AR&R IFD data generally results in minor to moderate (0.1 - 0.4m) increases in peak design flood levels. It is important to note however that similar to the changes in adopted rainfall intensities shown in Table 9-13, the changes in peak design flood levels vary across the catchment. Figure B-9 in Appendix B shows the variability of the change in peak flood levels associated with adoption of the 2013 AR&R data with peak flood levels generally increasing upstream of Broke by 0.2-0.4m. Downstream of Broke the change in peak flood levels is variable with the majority of areas showing minor increases of less than 0.1m with some localised areas showing increases up to ~0.2m.

10 Climate Change Analysis

Regional climate change studies (e.g. CSIRO, 2004) indicate that there may be an increase in the maximum intensity of extreme rainfall events. This may include increased frequency, duration and height of flooding and consequently increased number of emergency evacuations and associated property and infrastructure damage.

The NSW Floodplain Development Manual (2005) requires consideration of climate change in the preparation of Floodplain Risk Management Studies and Plans, with further guidance provided in Floodplain Risk Management Guideline – Practical Consideration of Climate Change (DECC, 2007).

An assessment of the potential impact of future climate change on future flooding conditions in the Wollombi Brook catchment has been undertaken for consideration in the ongoing floodplain risk management process.

10.1 Climate Change Model Conditions

Current research predicts that a likely outcome of future climatic change will be an increase in flood producing rainfall intensities. The NSW Government released a guideline (DECC, 2007) for Practical Consideration of Climate Change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. In line with this guidance note, additional tests incorporating 10%, 20% and 30% increases in design rainfall have been undertaken.

10.2 Climate Change Results

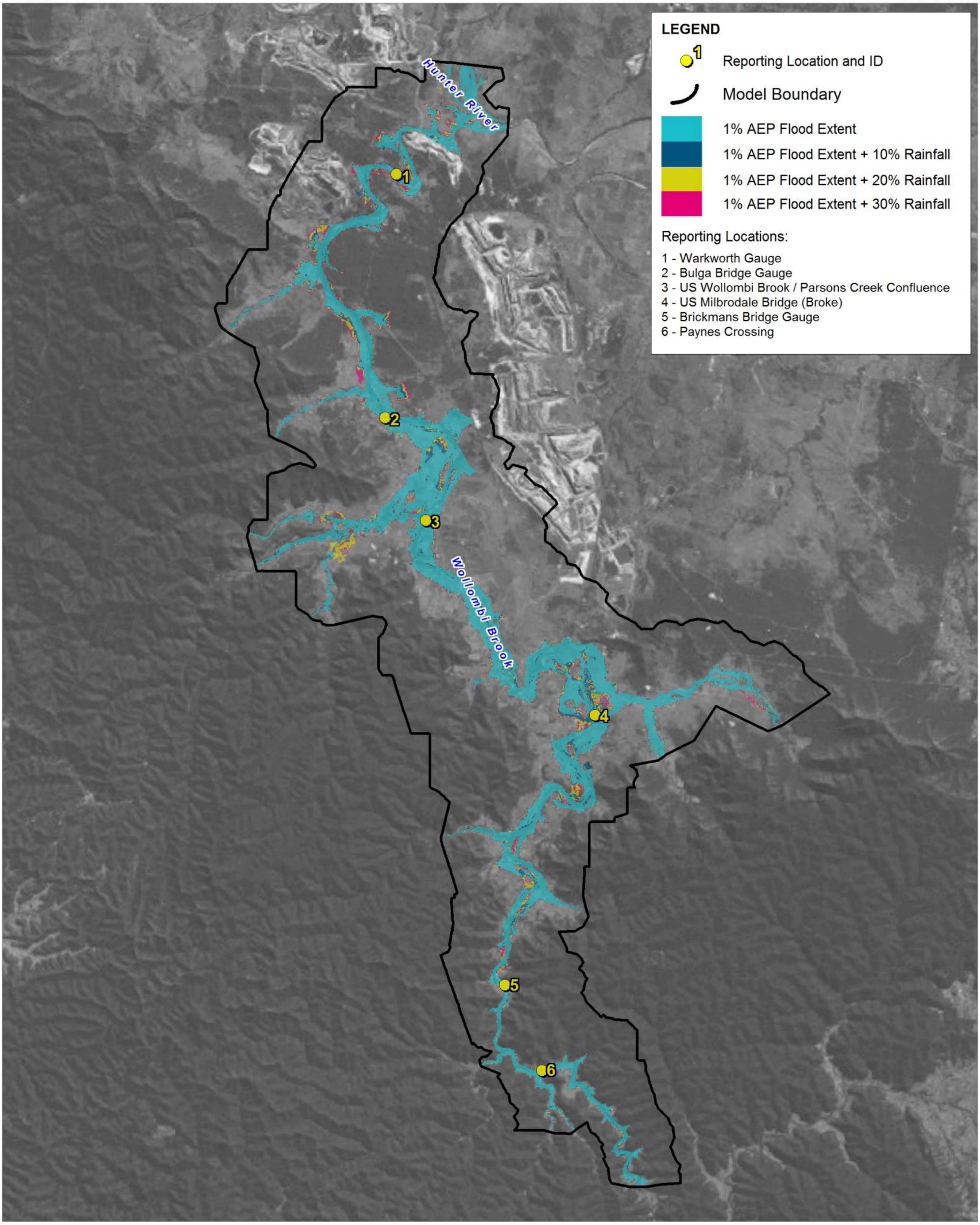
The change in peak water levels associated with the 10%, 20% and 30% increases in design rainfall is summarised in Table 10-1. The simulated flooding extents for each of the climate change scenarios are shown in Figure 10-1.

Table 10-1Peak 1% AEP Flood Levels for Climate Change Scenarios

Location	Peak Design Flood Level (m AHD)			
	Base	+10%	+20%	+30%
Warkworth Gauge	56.7	57.2 (+0.5)	57.7 (+1.0)	58.1 (+1.4)
Bulga Gauge	64.3	64.7 (+0.4)	65.0 (+0.7)	65.4 (+1.1)
US Wollombi Brook/Parsons Creek Confluence	69.0	69.2 (+0.2)	69.4 (+0.4)	69.5 (+0.5)
US Milbrodale Rd Bridge (Broke)	78.3	78.8 (+0.5)	79.1 (+0.8)	79.3 (+1.0)
D/S Brickmans Bridge Gauge	89.3	90.0 (+0.7)	90.6 (+1.3)	91.2 (+1.9)
US Paynes Crossing	91.8	92.6 (+0.8)	93.4 (+1.6)	94.0 (+2.2)

Note: Bracketed value is change in peak flood level from base design conditions

Figure 10-1 and Table 10-1 show that although the simulated increases in design rainfall result in significant increases in simulated flood levels and that the change in peak flood level varies across the catchment, there is limited change to the design flood extents. However, one key location where an increase in flood extents occurs as a result of a percentage increase is design rainfall is around the township of Broke. The increases in design rainfall of >10% result in additional property inundation in Broke as a result of the significant increase in peak design flood levels.



Title:

Wollombi Brook Flood Study - Design Flood Extents Climate Change Scenarios

Figure: **10-1**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

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11 Conclusions and Recommendations

The main objective of the Flood Study has been to undertake a detailed flooding assessment of the Wollombi Brook catchment. Central to this has been the development of appropriate hydrological and hydraulic models.

In completing the flood study, the following activities have been undertaken:

- 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 that included the identification of local flooding concerns, collection of information on historical flood behaviour and engagement of the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrological and hydraulic models;
- Determination of design flood conditions for a range of design events including the Extreme Flood (3 x 1% AEP), 0.5%, 1%, 2%, 5%, 10% and 20% AEP events; and
- Assessment of the potential impact of climate change using the latest guidelines.

The key study outputs include a full suite of design flood mapping incorporating peak flood inundation extent, flood depth, flood velocity and flood hazard. This report and the key mapping outputs help to define the mainstream flood behaviour in the Wollombi Brook catchment and establish the basis for subsequent floodplain management activities.

Provided below is a summary of the key findings of the Flood Study, in particular some of the important considerations for future floodplain risk management in the catchment:

- The model simulations indicated the peak flood levels in the Wollombi Brook corresponded to the 36 hour duration with peak flood levels reached in the key locations of Paynes Crossing, Broke and Bulga at approximately 39 hours, 44 hours and 50 hours after the onset of rainfall respectively.
- Flooding in Broke and the surrounding floodplain emanates from both the Wollombi Brook and Yellow Rock Creek. Floodwaters overtop the banks of the Wollombi Brook and begin inundating areas of the Broke township in events greater than the 1% AEP design event (the 1% AEP event is generally contained within the Wollombi Brook with some out of bank flooding and inundation of the floodplain along the western bank and along Yellow Rock Creek to the north of the township).
- The design flood inundation extents for the 20% AEP, 1% AEP and Extreme Flood events are broadly similar within much of the catchment (particularly upstream of Brickmans Bridge). The floodplain upstream of the Brickmans Bridge is well-defined, with relatively steep sides. Although the flood depths increase significantly with event magnitude, there is little change in the flood extents across the valley floor. However, downstream of Brickmans Bridge where the floodplain begins to widen, the change in flood extents is more pronounced (especially the increase in flood extents associated with the Extreme Flood event). This includes floodplain areas near Broke, the confluence with Parsons Creek, Bulga and the lower catchment around Warkworth.

- It is reiterated that the defined flood extents and reported flood behaviour relates to mainstream flooding emanating from the Wollombi Brook with the critical flood conditions corresponding to a 36-hour duration storm event. It is expected that the critical flood conditions along the tributary alignments would correspond to storms of a much shorter duration. As such it is recommended that further investigations be undertaken to define the existing flood behaviour along the major tributary alignments, particularly Yellow Rock Creek and Parsons Creek, to be included in subsequent floodplain management activities.
- The model sensitivity testing showed that the model is particularly sensitive to the adopted continual rainfall loss parameter and hydraulic roughness (Manning's 'n') values (particularly in the upper catchment upstream of Brickman's Bridge).
- It should be noted that the model sensitivity is not an artefact of the adopted hydraulic modelling approach but rather a representation of the actual sensitivity of the catchment to changes in the type and distribution of in-channel and floodplain vegetation; changes to channel dimensions as a result of bank erosion or deposition of sediment; antecedent rainfall conditions and the volume and temporal distribution of rainfall across the catchment; and the level of blockage at major structures (each of these characteristics can vary between different flood events).
- The climate change analysis showed that although the simulated increases in design rainfall result in significant increases in simulated flood levels, there is limited change to the design flood extents.
- Based on the sensitivity of the simulated flood levels to structure blockage levels, it is recommended that the 1% AEP design event incorporating the blockage levels based on the recently released AR&R guidelines be adopted for use in flood planning.
- Furthermore, based on the sensitivity of the model and the significant increase in simulated peak flood levels between the 1% AEP and 0.5% AEP design event (up to 1.0m in some parts of the study area), it is recommended that consideration be given to an increased freeboard from the standard 0.5m to a more conservative 1.0m in establishing the Flood Planning Area (FPA) and associated Flood Planning Levels (FPLs).

12 References

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Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2004) *Climate Change in New South Wales Part 2: Projected changes in climate extremes.*

Department of Infrastructure, Planning and Natural Resources (DIPNR) (2005) *Floodplain Development Manual.*

Department of Environment, Climate Change and Water (DECCW) (2007) *Floodplain Risk Management Guideline: Practical Consideration of Climate Change.*

Patterson Britton & Partners (PBP) (2005). *Wollombi Valley Flood Study*. Prepared for Cessnock Council.

The Institute of Engineers Australia (1998) *Australian Rainfall and Runoff, Volume One and Volume Two*

Wollombi Valley Landcare Group (1994). *The Way of the River – Environmental Perspectives of the Wollombi*. Edited by Denis Mahoney and Joe Whitehead.

Appendix A Community Consultation Material

What is the study about?

The main objective of the study is to characterise the flooding behaviour in the catchment describing in detail the potential flood inundation extents, peak water levels, depths and velocities across the floodplain for a range of flood magnitudes.

Detailed computer models are developed specifically for the catchment to simulate flood behaviour. Historical flood information such as rainfall depths, peak water levels, flooded property details etc, are used to ensure the computer models are representative of the real catchment behaviour.

Flood maps across the catchment will be produced using the model results which will show the predicted extent of flooding.

The flood study results will be used to provide more effective flood planning in the catchment and will assist Councils in:

- Setting appropriate levels for future development control;
- Identifying potential works to reduce existing flooding; and
- Improving flood emergency response and recovery.

This project was supported by Singleton Council and the NSW Government's Flood Management Program.

NSW GOVERNMENT | Office of Environment & Heritage

Want more information?

For further information about the Wollombi Brook Flood Study, or to provide any information you feel is relevant to the study, please contact:

Singleton COUNCIL

Mr Ajith De Alwis
Singleton Council
PO Box 314
Singleton NSW 2330
Ph (02) 6578 7229
e: *adealwis@singleton.nsw.gov.au*

Mr Darren Lyons (Project Manager)
BMT WBM (Consultant)
Ph 4940 8882
e: *Darren.Lyons@bmtwbm.com.au*

We need your help!

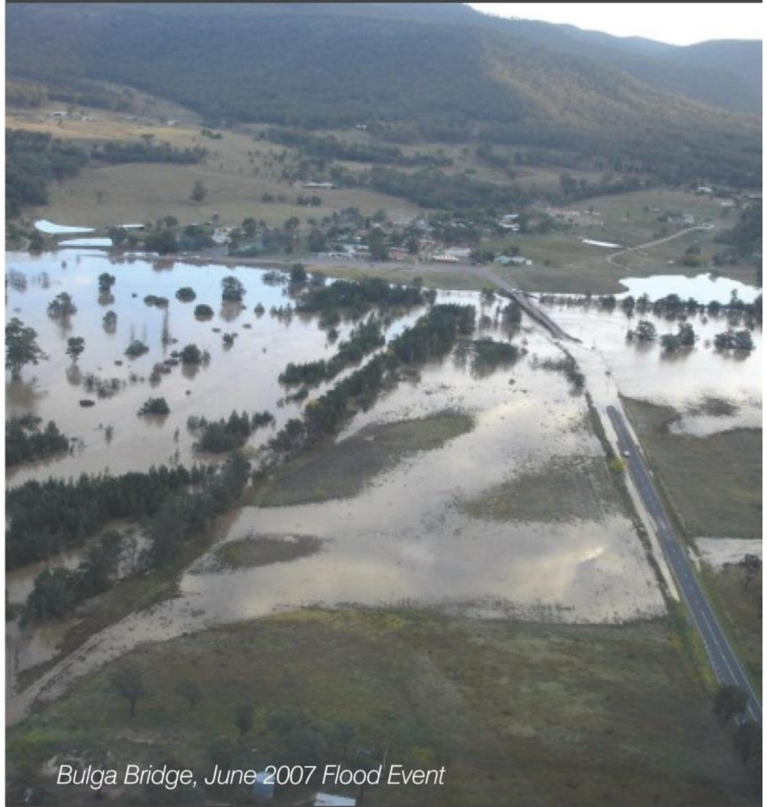
Your information about previous flooding, including photographs and video, is highly valuable in understanding flooding behaviour and potential flood risk to residents.

You can help us by passing on information about flooding you may have experienced by completing the questionnaire enclosed with this brochure.

Please take a minute to fill in the questionnaire and return with any other information you feel relevant by 8th November 2013.

Wollombi Brook Flood Study

Community Information Brochure



Bulga Bridge, June 2007 Flood Event

Singleton COUNCIL

BMT WBM

Introduction

Singleton Council is carrying out a flood study to understand flood risks in the Wollombi Brook catchment. This includes the section of Wollombi Brook extending from Paynes Crossing to the confluence with the Hunter River at Warkworth which includes the villages of Broke, Fordwich and Bulga.

Singleton Council Floodplain Risk Management Committee will oversee the study, providing regular input and feedback on key outcomes. The Committee has a broad representation including Councillors, Council Staff, State Govt. representatives, stakeholder groups and community representatives.

BMT WBM, an independent company specialising in flooding and floodplain risk management, will undertake the study.

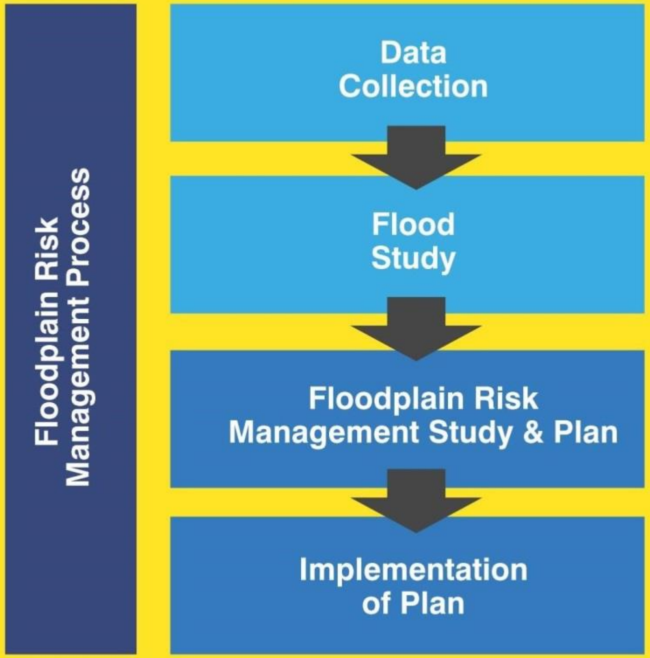
Bulga Bridge

Why do we need a study?

The Wollombi Brook catchment has a history of major flooding, including the June 2007 event experienced within many catchments in the Hunter/Greater Newcastle area.

In order to appropriately plan for future flood events and reduce the potential impacts of flooding on the community, we need to determine the nature and extent of the existing flooding problem across the catchment.

The study will identify existing flood risk within flood prone areas of the catchment including the main areas of existing development and help in Council's planning for the future.



The next stage of the floodplain risk management process is the assessment of a range options to manage these flood risks for existing and future development.

Community input and involvement

Community involvement in managing flood risks is essential to improve the decision making process, to identify local concerns and values, and to inform the community about the consequences of flooding and potential management options. The success of the flood planning in the Wollombi Brook catchment hinges on the community's input and acceptance of the proposals.

There are a number of ways you can be involved in the study:

Please take a few minutes of your time to complete and return the questionnaire. This will greatly assist in collating people's knowledge and experience about previous flooding history and existing flood problem areas.

A community information session is planned at a later stage following completion of the modelling assessments to present study results and provide further opportunity for feedback from the community.

Thank you for taking the time to complete this questionnaire!

The questionnaire can be returned without a postage stamp or scanned and emailled to Darren.Lyons@bmtwbm.com.au. Flood photos and videos can also be sent to this email address. "Hard copies" of photos or VHS tapes can be posted to:

Darren Lyons
BMT WBM
126 Belford Street
Broadmeadow New South Wales 2292

BMT WBM will analyse the community responses and report back to Council. If you would like to have items returned please note this and the items will be returned at the conclusion of the study.

Fold Here

How to send back this questionnaire...

Please fold this questionnaire using the 'Fold Here' lines as a guide to form a business sized evelope with the address on the front and this text box on the back. Seal the folded pages with a piece of tape to help maintain privacy (but not so much tape that we can't open it) and then post it back.

Fold Here

Delivery Address:
PO Box 266
BROADMEADOW NSW 2292

No stamp required
if posted in Australia

BMT WBM Pty Ltd
Reply Paid 266
BROADMEADOW NSW 2292

Wollombi Brook Flood Study

Wollombi Brook Flood Study

Community Questionnaire

Singleton Council is completing a flood study for the Wollombi Brook catchment.
The flood study is the first step in assisting council to better understand, plan and manage the risk of flooding across the catchment.

The information that you provide in the following questionnaire will prove invaluable in the calibration of computer models that are being developed as part of the flood study. It will also provide Council with an understanding of existing flooding problems and areas where flood damage reduction measures should be investigated in the future.

The following questionnaire should only take around 10 minutes to complete. Try to answer as many questions as possible and give as much detail as possible (attach additional pages if necessary). Once complete, please return the questionnaires via email or mail (no postage stamp required) by 8th November 2013 .

If you have any questions, require any further information or would like to contribute additional information to the study, please contact:

BMT WBM
"Where will our knowledge take you?"

Darren Lyons
BMT WBM
126 Belford Street
Broadmeadow NSW 2292
(02) 4940 8882
Darren.Lyons@bmtwbm.com.au

Mr Ajith De Alwis
Singleton Council
PO Box 314
Singleton NSW 2330
Ph (02) 6578 7229
e: adealwis@singleton.nsw.gov.au

QUESTION 1 (OPTIONAL)

Can you please provide the following contact details in case we need to contact you for additional information?

Note that your personal information will remain confidential at all times and will not be published unless you give us permission to do so (refer to following question).

Name: ____________________ Phone Number: ____________________

Address: ____________________ email: ____________________

____

Do you give permission for your contact details to be published as part of the flood study?

☐ Yes ☐ No

BMT WBM
"Where will our knowledge take you?"

QUESTION 2

How long have you lived and/or worked in the area?

At current address: ________________ Years __________ Months __________

In the general area: ________________ Years __________ Months __________

QUESTION 3

Have you been affected by flooding in the past?

☐ Yes ☐ No

If 'Yes', how have you been affected?

☐ Traffic was disrupted (please provide a description below if possible)

☐ My back/front yard was flooded (please provide a description below if possible)

☐ My house/business and its contents were flooded (please provide a description below if possible)

☐ Sewer or water was turned off at my property (please provide a description below if possible)

☐ Other (please provide a description below if possible)

Description: ____

QUESTION 4

Can you provide specific details of how high floodwaters reached?

☐ Yes ☐ No

If 'Yes', please give as much detail as possible (e.g., location, dates, times, description of water movement, depth of water, flood mark location, high water mark on building, level on flood depth indicator).

QUESTION 5

What do you think may have been the main source/cause of the flooding (e.g., creek banks overtopping, blockage of bridges)?

QUESTION 6

Did you keep any rainfall records during any past storm events, or do you know someone locally that does?

☐ Yes ☐ No

If 'Yes', can you please include a copy of the records or provide a description of the records below?

QUESTION 7

Are you concerned that your property could be flooded in the future?

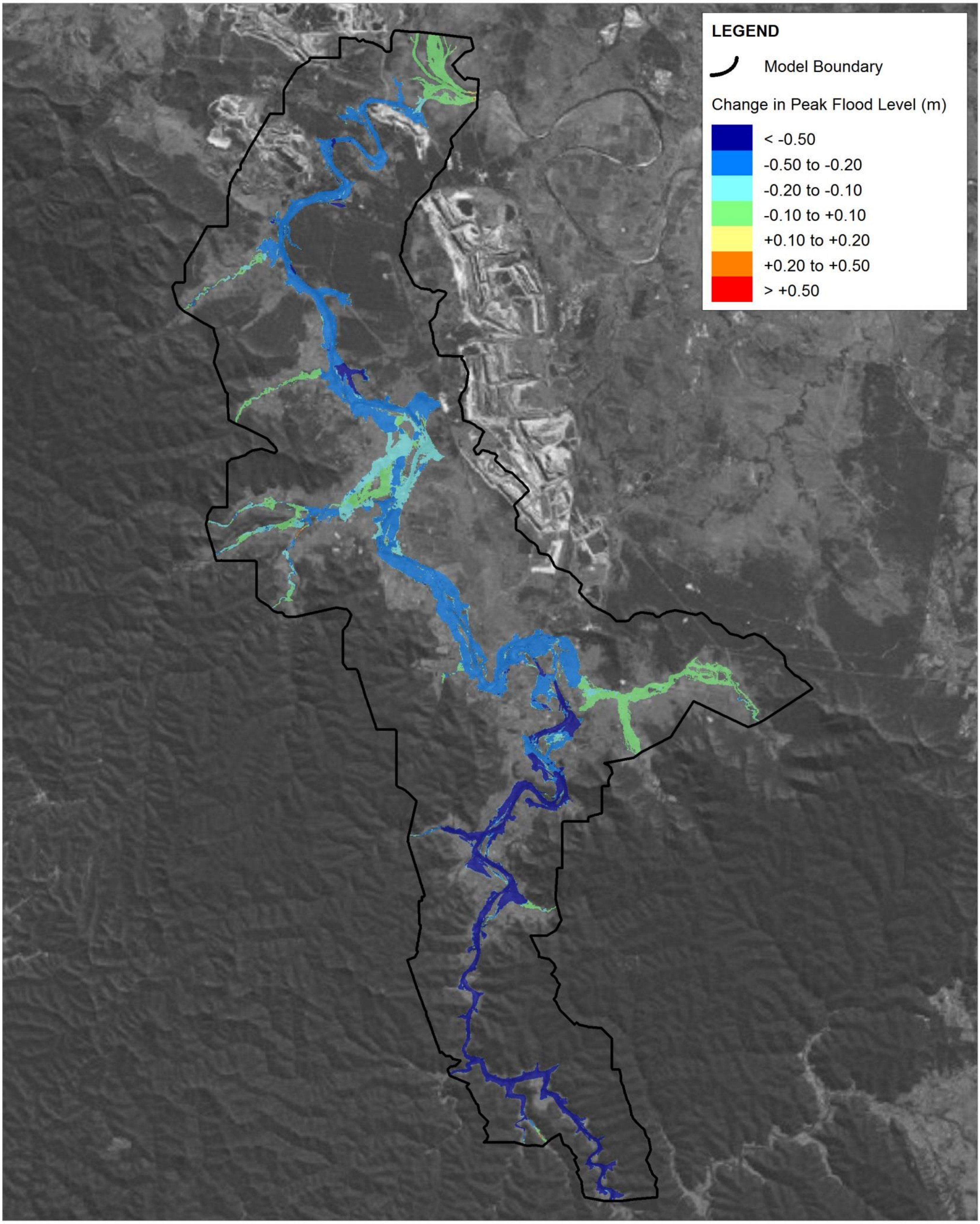
☐ Yes ☐ No

If 'Yes', what makes you concerned?

QUESTION 8

Do you have any other comments or information that you think would be useful for this investigation?

Appendix B Flood Afflux Mapping



Title:

Wollombi Brook Flood Study - Change in Peak Flood Level 25% Decrease in Hydraulic Roughness (1% AEP Design Event)

Figure: **B-1**

Rev: **A**

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Approx. Scale

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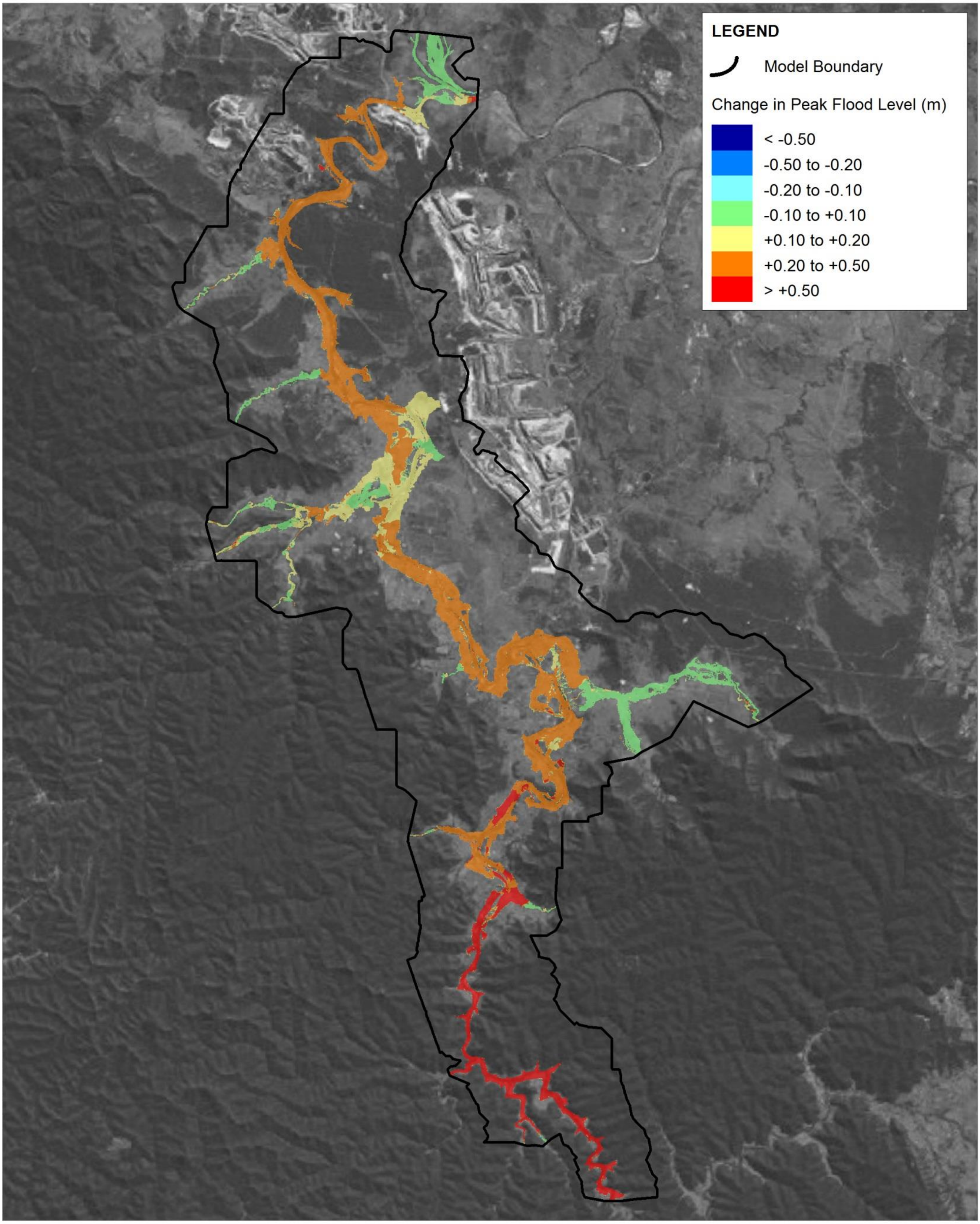

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Wollombi Brook Flood Study - Change in Peak Flood Level 25% Increase in Hydraulic Roughness (1% AEP Design Event)

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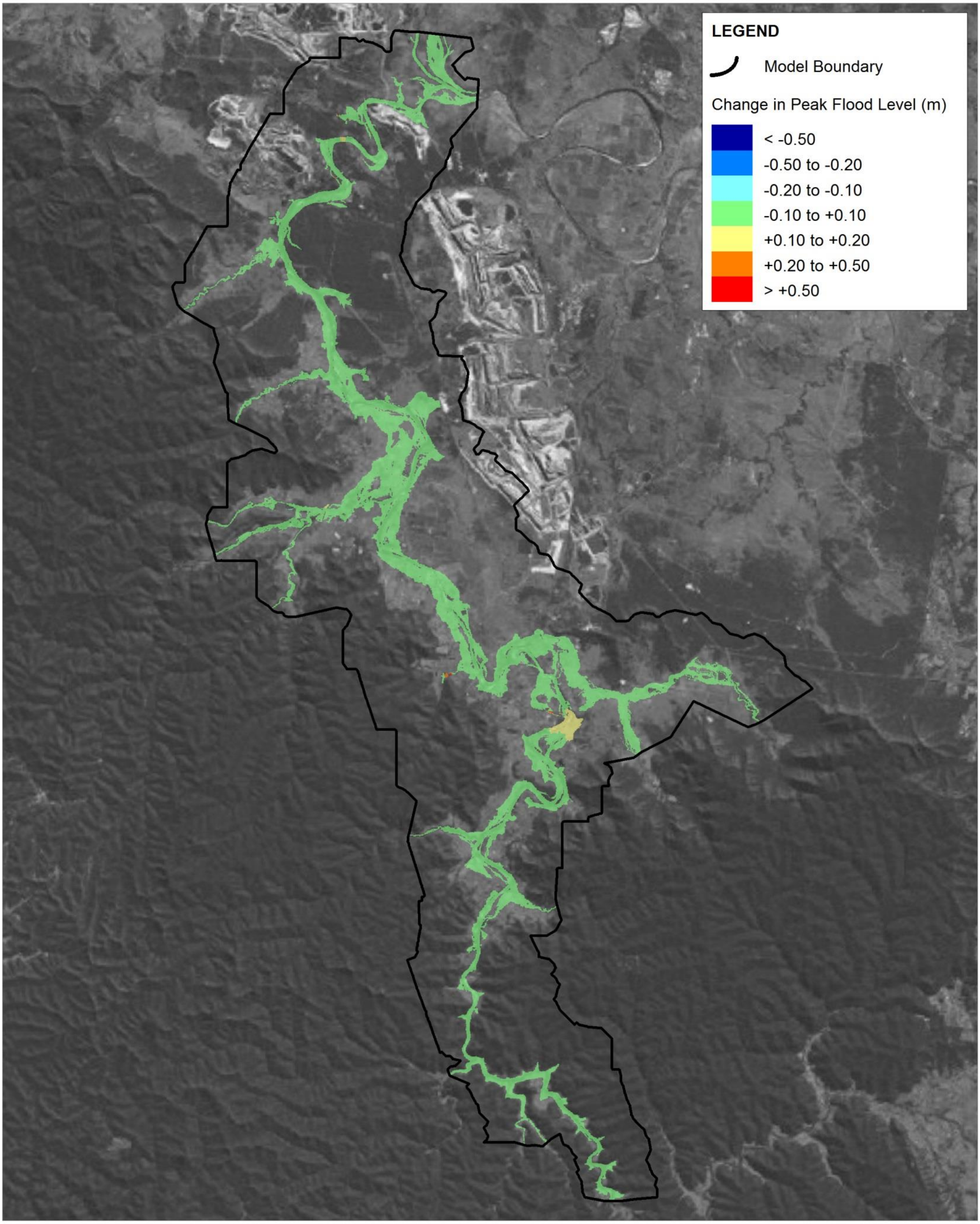

Title:

Wollombi Brook Flood Study - Change in Peak Flood Level 25% Structure Blockage (1% AEP Design Event)

Figure: **B-3**

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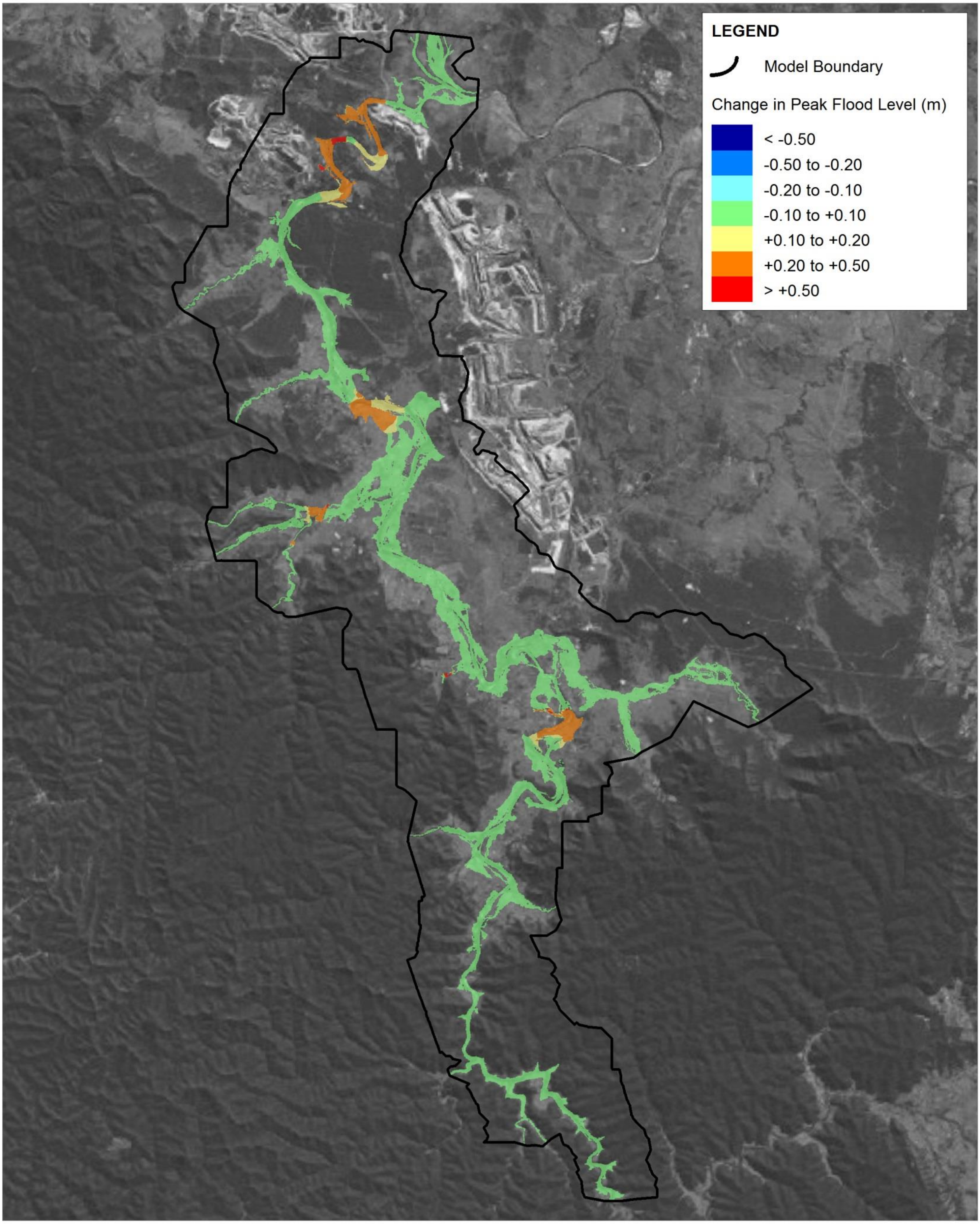

Title:

Wollombi Brook Flood Study - Change in Peak Flood Level 50% Structure Blockage (1% AEP Design Event)

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Approx. Scale

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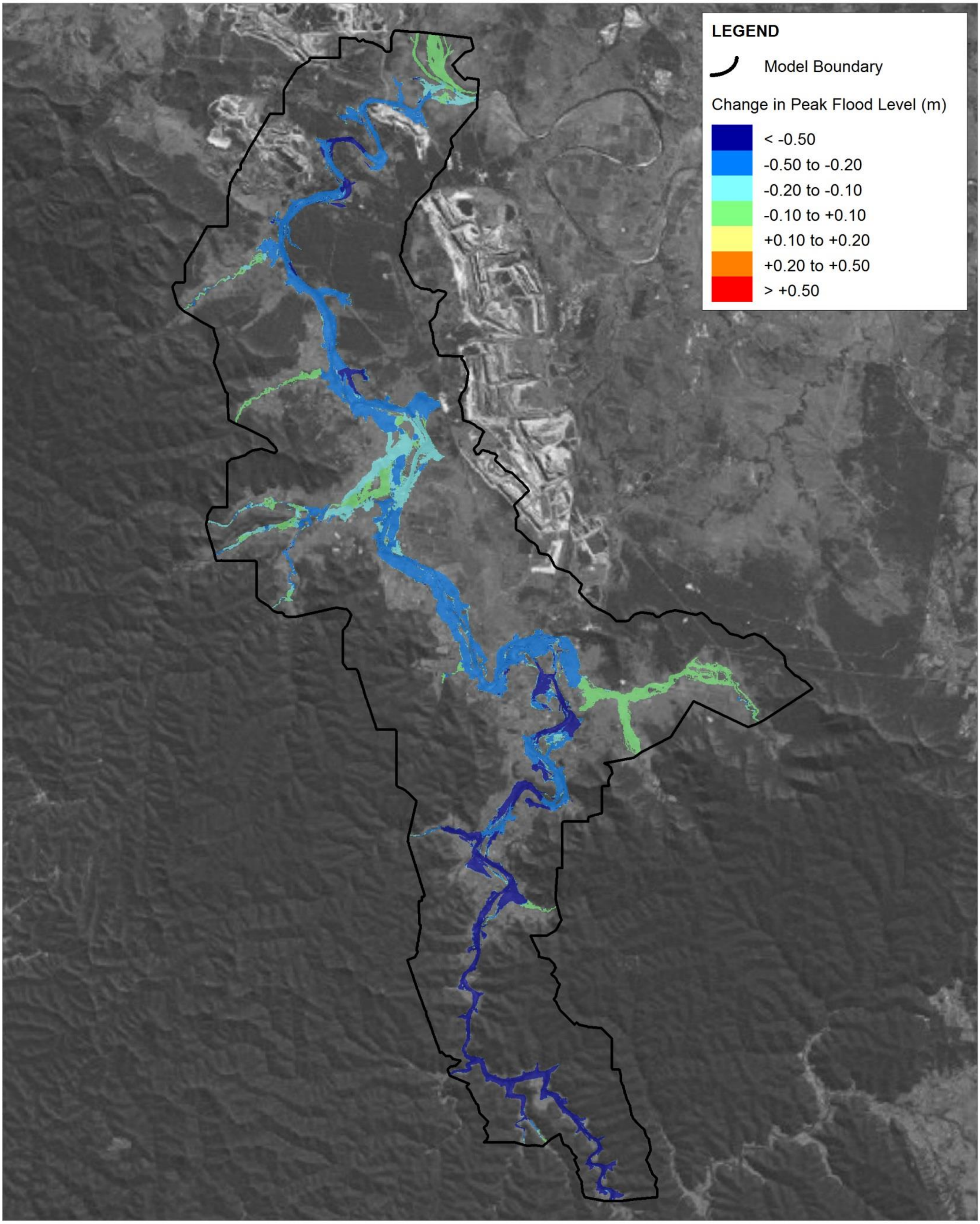

Title:
Wollombi Brook Flood Study - Change in Peak Flood Level Increased Continual Rainfall Loss (1% AEP Design Event)

Figure: **B-5**

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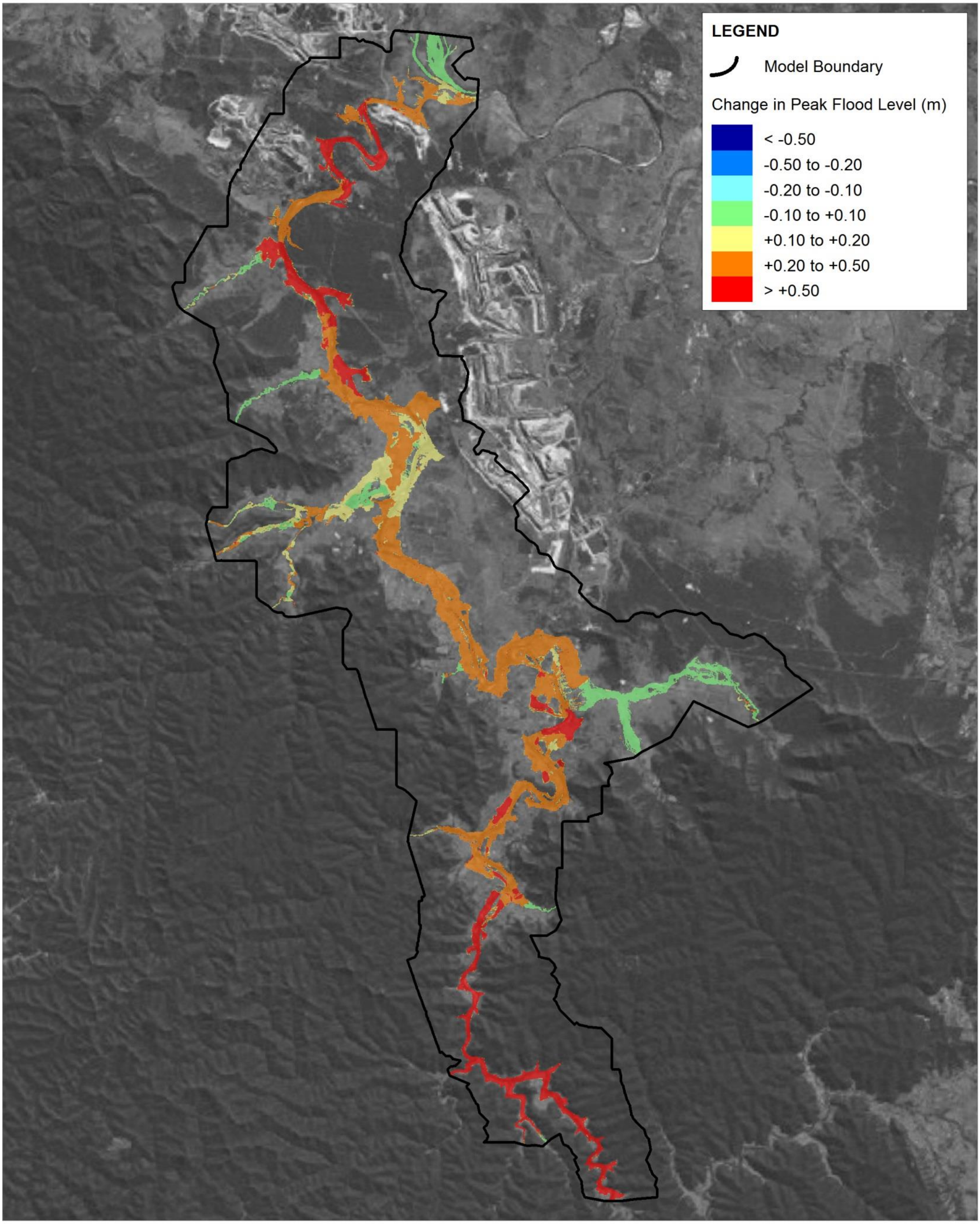

Title:

Wollombi Brook Flood Study - Change in Peak Flood Level Decreased Continual Rainfall Loss (1% AEP Design Event)

Figure: **B-6**

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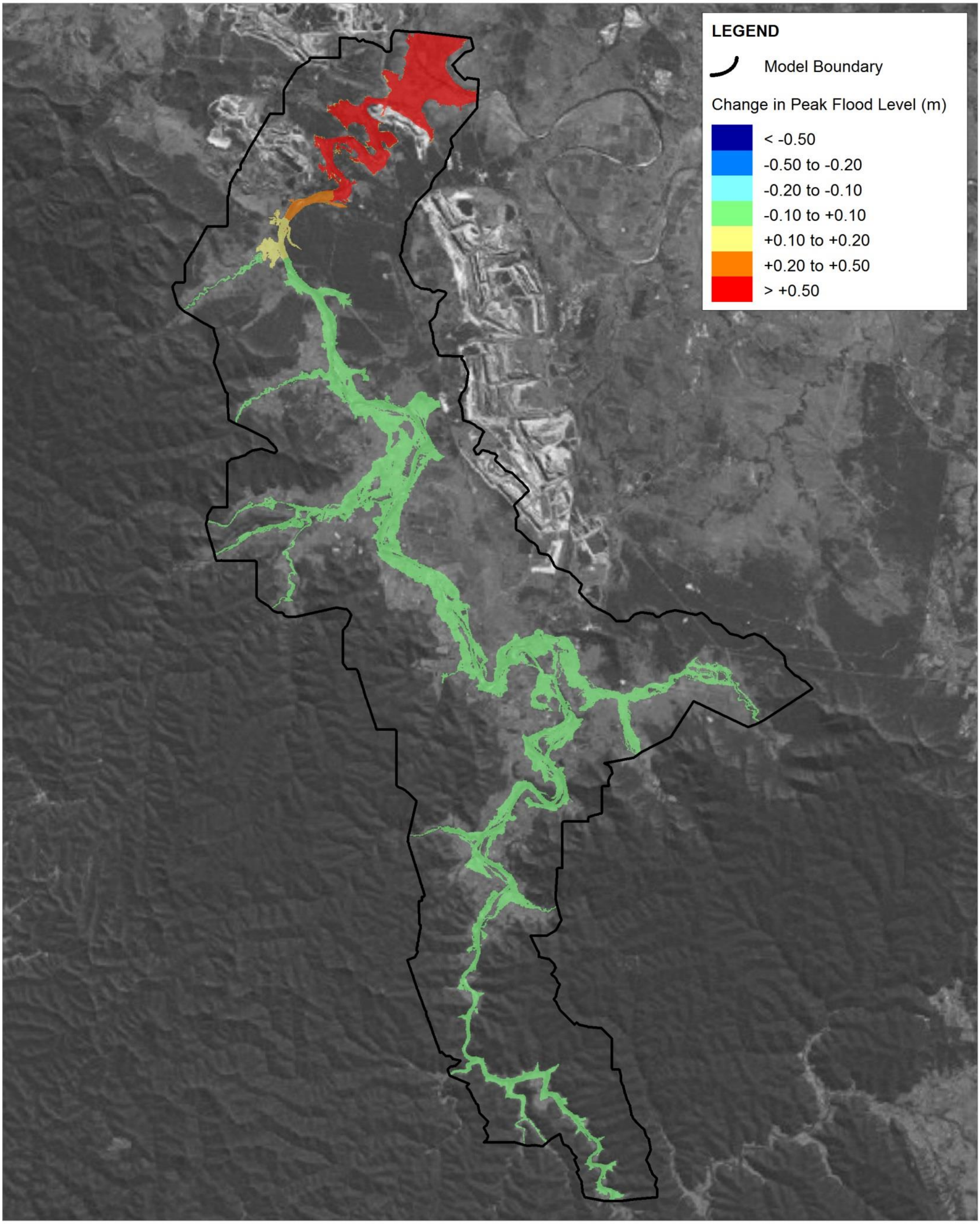

Title:

Wollombi Brook Flood Study - Change in Peak Flood Level Increased Downstream Water Level (1% AEP Design Event)

Figure: **B-7**

Rev: **A**

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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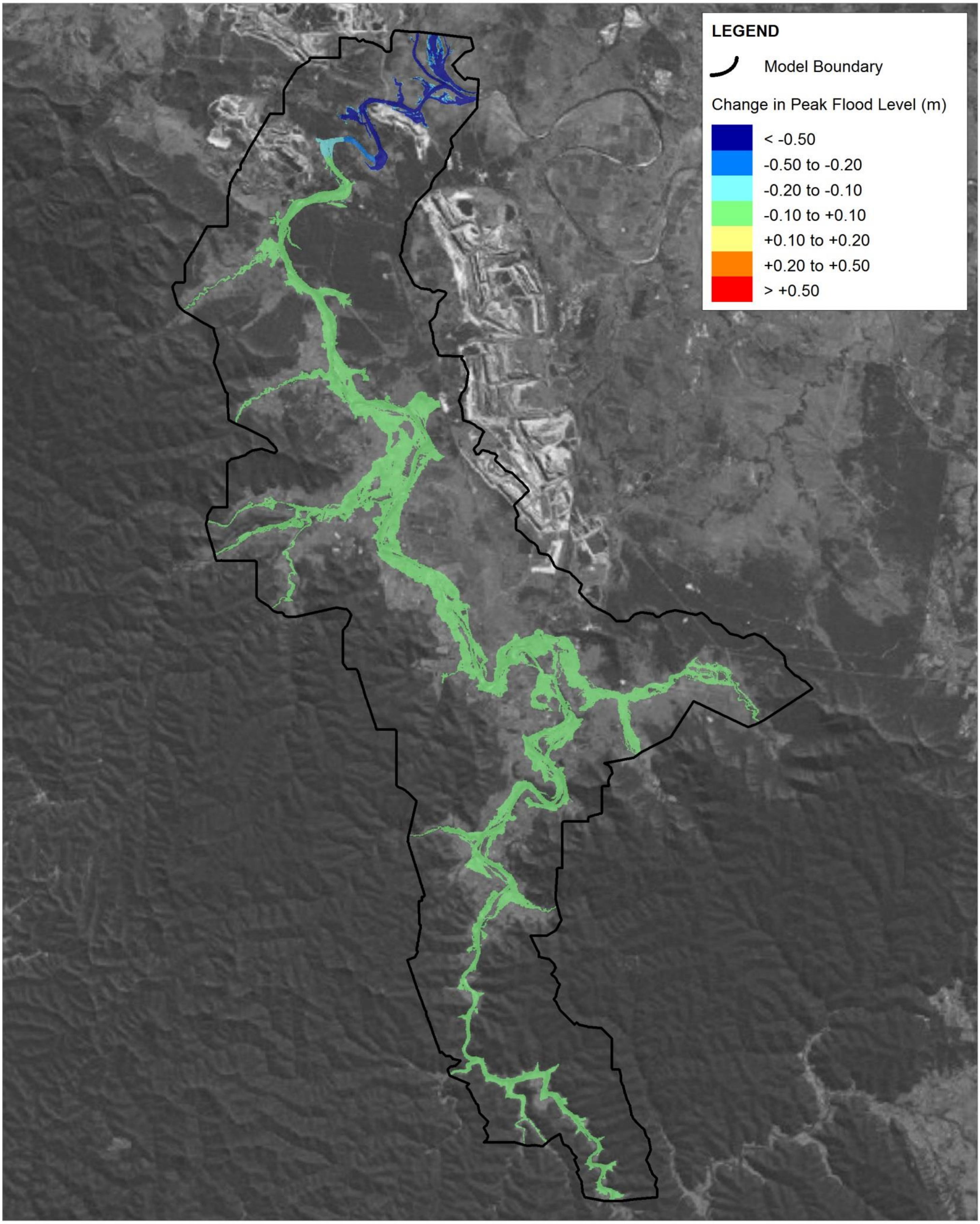

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Wollombi Brook Flood Study - Change in Peak Flood Level Decreased Downstream Water Level (1% AEP Design Event)

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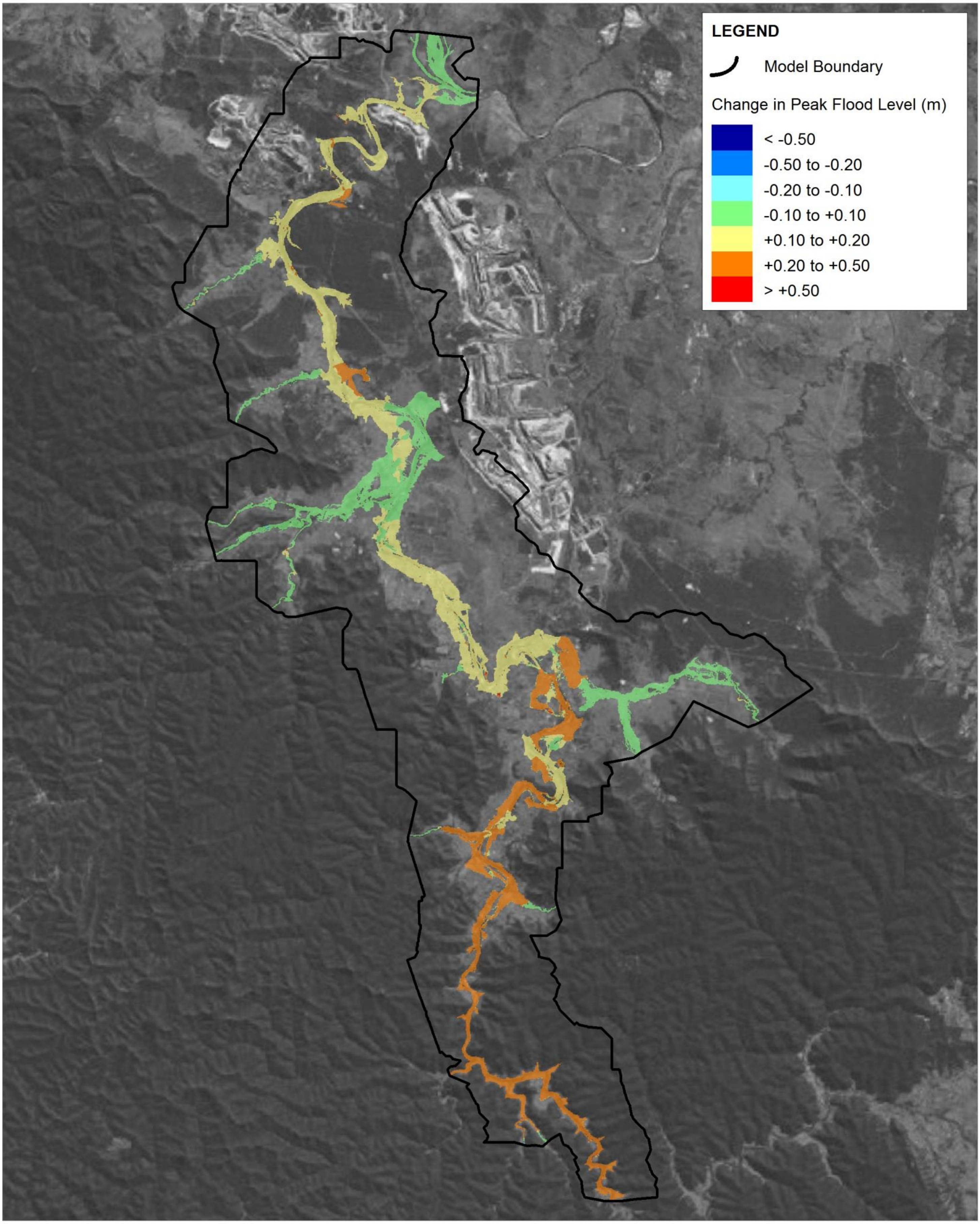

Title:

Wollombi Brook Flood Study - Change in Peak Flood Level 2013 AR&R IFD Data (1% AEP Design Event)

Figure: **B-9**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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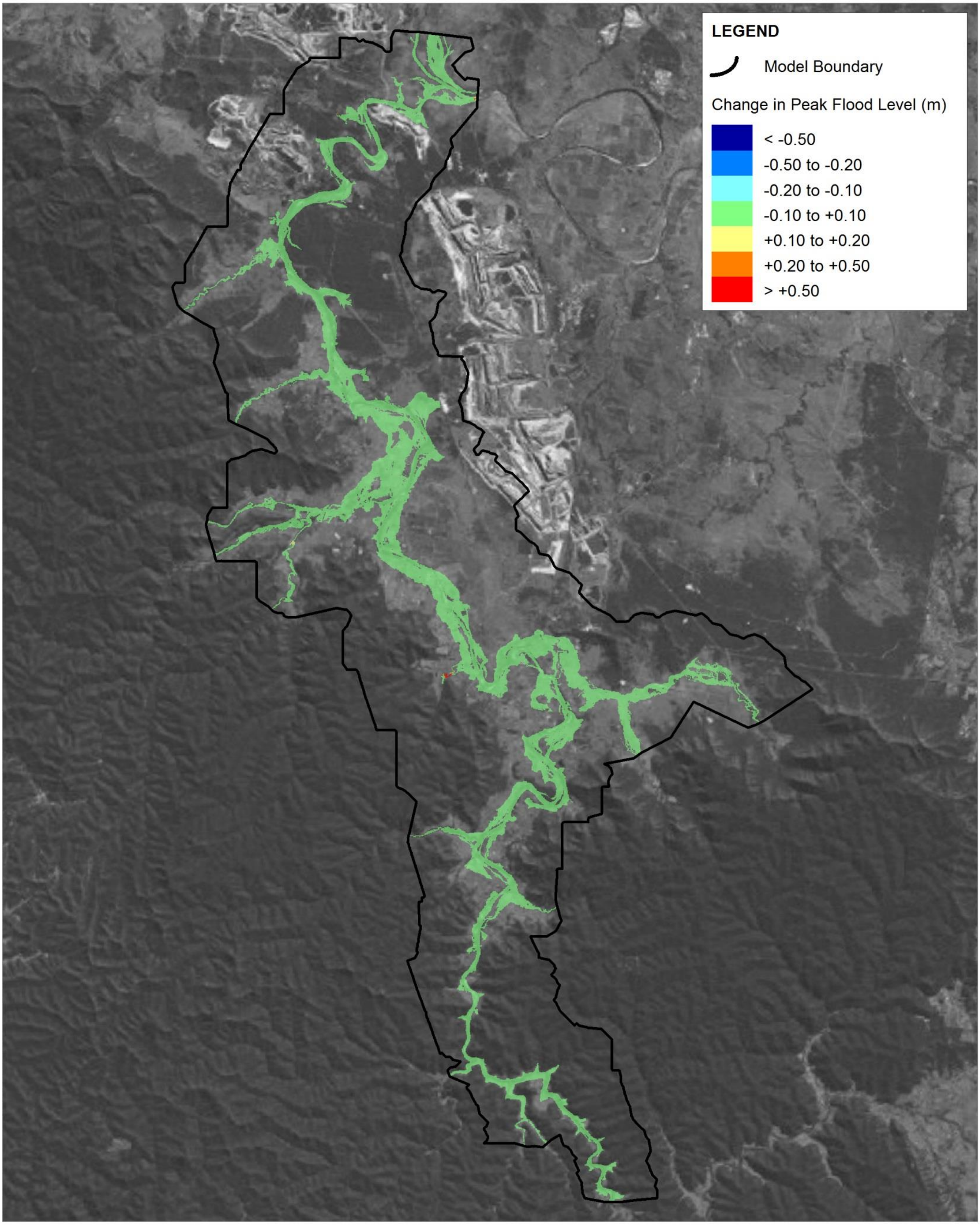

Title:

Wollombi Brook Flood Study - Change in Peak Flood Level AR&R Guideline Structure Blockage (1% AEP Design Event)

Figure: **B-10**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

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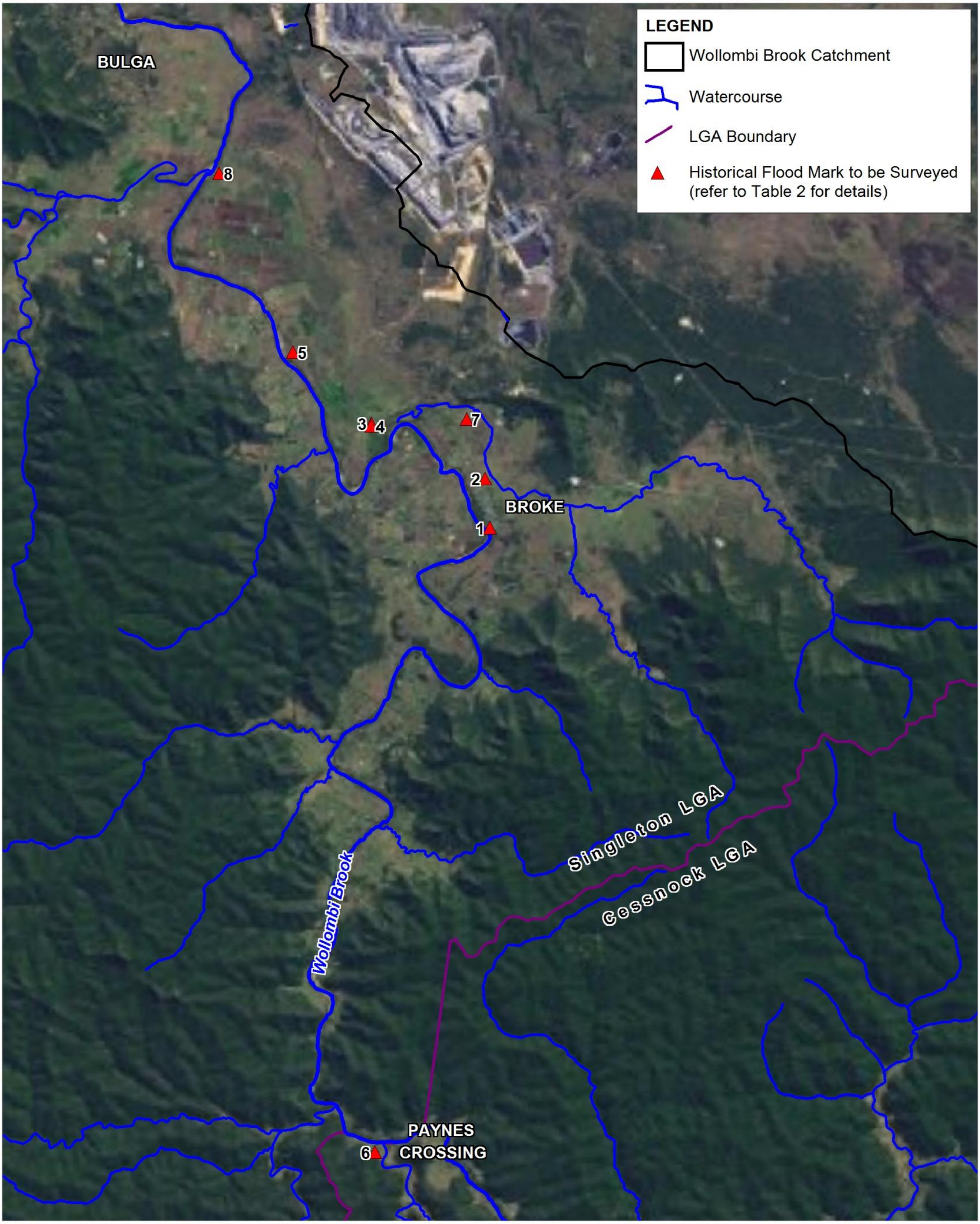
Appendix C Historical Flood Levels

Details of historical flood marks were collated from the community questionnaire. These marks generally comprised recorded marks (scratches, lines drawn with marker on a wall, photographic evidence or points reconstructed from the memory of community members) and the level which these marks represent provided valuable information for the calibration and validation of the hydraulic model.

Historical Flood Mark Descriptions

ID	Location	Description
1	Broke Fire Station, Paynes Crossing Road, Broke*	June 1949 flood level – top of step at side door to fire station (see Figure 3)
2	Cochrane Street, Broke	June 2007 flood level – top of step at rear entrance to house
3	Butlers Road, Broke	June 1949 flood level – base of strainer post in front yard (see Figure 5 and Figure 6)
4	Butlers Road, Broke	June 2007 flood level – base of mulberry tree in front yard (see Figure 5 and Figure 6)
5	185 Fordwich Road, Fordwich	June 2007 flood mark on deck support pillar of clubhouse (see Figure 7)
6	80 Stockyard Creek Road, Paynes Crossing	June 2007 flood mark on outdoor toilet (see Figure 8)
7	1249 Broke Road, Broke	June 2007 flood mark – base of post in backyard (see Figure 9).
8	'Charlton' 154 Cobcroft Road, Broke	June 2007 flood marks in field

* There is some conjecture surrounding the peak flood level at the Broke Fire Station for the 1949 flood event. The level presented above and discussed in the report was based on a point indicated by a local resident during the community consultation process. This point was subsequently surveyed as part of the additional survey works discussed in Section 4.



Title:

Location of Historical Flood Marks to be Surveyed

Figure: C-1

Rev: A

N

0 2 4km

Approx. Scale

BMT WBM

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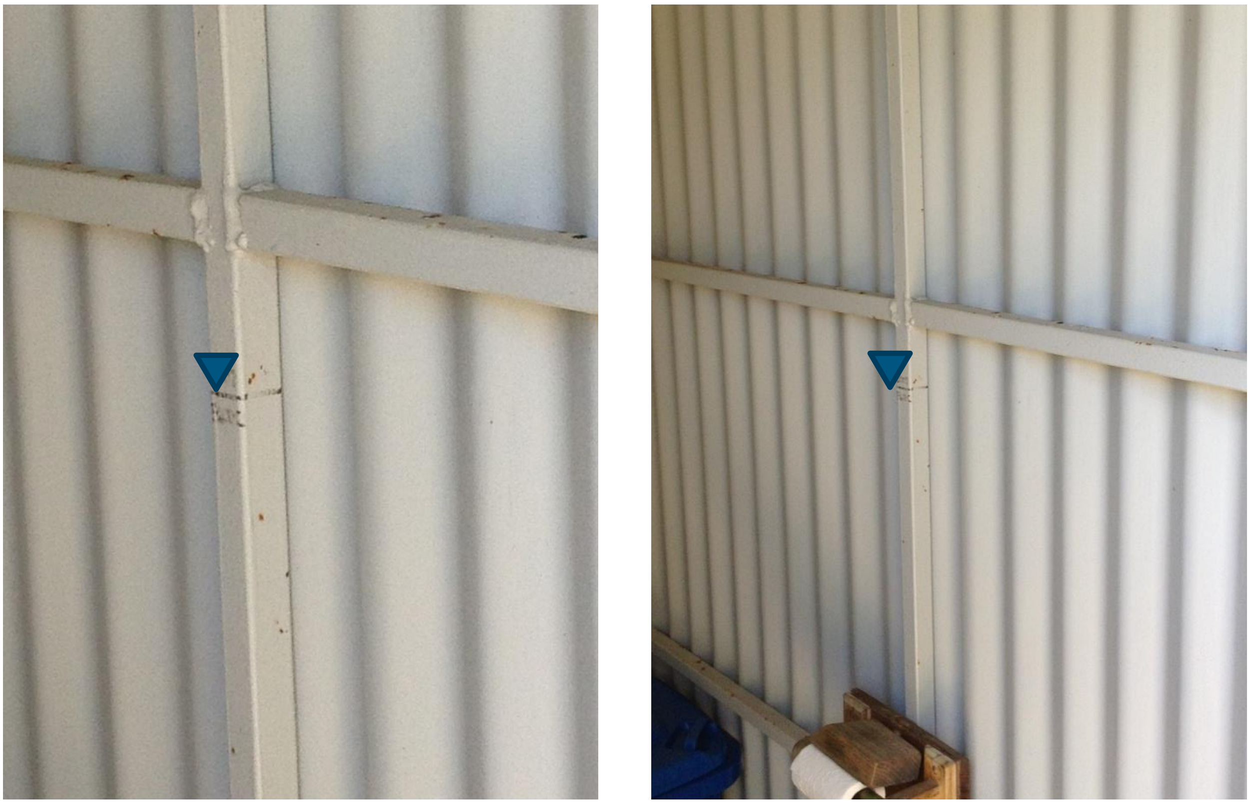
Filepath : K:\N2390_Wollombi_Brook_Flood_Study\MapInfo\Workspaces\Report_Figures\DWG_006_FloodMark_Locations_Survey.WOR

Historical Flood Mark #1 – Broke Fire Station

Historical Flood Mark #3 and #4 – Butlers Road, Broke

Historical Flood Mark #3 and #4 – Butlers Road, Broke

Historical Flood Mark #5 – 185 Fordwich Road, Fordwich



Historical Flood Mark #6 – 80 Stockyard Creek Road, Paynes Crossing

Historical Flood Mark #7 – 1249 Broke Road, Broke

Appendix D IFD Tables for the Wollombi Brook 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). These curves provide rainfall depths for various design magnitudes (up to the 1% AEP) and for durations from 5 minutes to 72 hours.

In order to incorporate the spatial distribution within the hydrological model, IFD parameters were assigned to 23 points across the catchment as shown in Figure 8-3. The IFD design rainfall intensities for the range of 1% AEP durations are provided below. Also shown are the 36-hour design duration rainfall intensities for the full range of design events simulated.

ID_Number	Lat	Long	IFD Design Rainfall Intensity (mm/hr)							
			100y6h	100y9h	100y12h	100y18h	100y24h	100y36h	100y48h	100y72h
Point 1	-33.1329	151.204	26.10	21.10	18.20	14.50	12.30	9.76	8.19	6.29
Point 2	-33.0404	151.35	26.10	21.10	18.20	14.50	12.30	9.76	8.19	6.29
Point 3	-32.9233	151.424	22.10	17.40	14.70	11.50	9.63	7.46	6.17	4.64
Point 4	-32.9624	151.306	21.60	17.20	14.70	11.40	9.56	7.36	6.06	4.52
Point 5	-33.0151	151.185	23.10	18.70	16.10	12.30	10.10	7.65	6.21	4.54
Point 6	-33.0775	151.057	23.20	18.60	15.90	12.50	10.50	8.19	6.80	5.14
Point 7	-32.9763	151.017	21.70	17.40	14.80	11.60	9.70	7.50	6.19	4.64
Point 8	-32.9426	151.144	20.30	16.20	13.70	10.60	8.85	6.78	5.56	4.12
Point 9	-32.8693	151.281	19.90	15.80	13.40	10.40	8.71	6.70	5.52	4.11
Point 10	-32.8448	151.193	19.50	15.50	13.10	10.30	8.61	6.67	5.52	4.14
Point 11	-32.8499	151.065	19.60	15.50	13.20	10.20	8.46	6.47	5.30	3.93
Point 12	-32.9257	150.871	20.50	16.30	13.80	11.00	9.30	7.32	6.13	4.69
Point 13	-32.8136	150.913	19.30	15.30	12.90	10.20	8.67	6.81	5.69	4.33
Point 14	-32.7537	150.997	19.00	15.00	12.70	9.84	8.19	6.28	5.16	3.83
Point 15	-32.7527	151.199	18.90	14.90	12.60	9.74	8.10	6.21	5.09	3.77
Point 16	-32.6474	151.076	18.10	14.20	11.90	9.08	7.47	5.62	4.56	3.32
Point 17	-32.6981	150.964	18.50	14.50	12.20	9.45	7.88	6.05	4.97	3.69
Point 18	-32.7581	150.788	19.90	15.80	13.40	10.50	8.86	6.90	5.73	4.33
Point 19	-32.6443	150.878	18.50	14.50	12.20	9.48	7.90	6.06	4.98	3.70
Point 20	-32.5969	150.973	17.80	13.90	11.70	9.04	7.52	5.77	4.74	3.52
Point 21	-32.5311	150.861	16.20	12.40	10.30	8.15	6.88	5.39	4.50	3.42
Point 22	-32.5255	151.062	17.20	13.40	11.20	8.64	7.19	5.51	4.52	3.35
Point 23	-32.9954	151.427	24.80	19.80	16.90	13.30	11.30	8.83	7.37	5.60

ID_Number	Lat	Long	IFD Design Rainfall Intensity (mm/hr)					
			5y36h	10y36h	20y36h	50y36h	100y36h	200y36h
Point 1	-33.1329	151.204	5.3	6.1	7.2	8.6	9.8	11.04
Point 2	-33.0404	151.35	5.3	6.1	7.2	8.6	9.8	11.04
Point 3	-32.9233	151.424	4.3	4.8	5.6	6.7	7.5	8.38
Point 4	-32.9624	151.306	4.2	4.8	5.6	6.6	7.4	8.26
Point 5	-33.0151	151.185	4.3	4.9	5.7	6.8	7.7	8.68
Point 6	-33.0775	151.057	4.3	5.0	5.9	7.2	8.2	9.42
Point 7	-32.9763	151.017	4.1	4.7	5.5	6.6	7.5	8.61
Point 8	-32.9426	151.144	3.8	4.3	5.1	6.0	6.8	7.70
Point 9	-32.8693	151.281	3.8	4.3	5.0	6.0	6.7	7.62
Point 10	-32.8448	151.193	3.7	4.2	5.0	5.9	6.7	7.64
Point 11	-32.8499	151.065	3.6	4.1	4.8	5.7	6.5	7.43
Point 12	-32.9257	150.871	3.9	4.6	5.4	6.5	7.3	8.53
Point 13	-32.8136	150.913	3.7	4.3	5.0	6.0	6.8	7.90
Point 14	-32.7537	150.997	3.5	4.0	4.7	5.6	6.3	7.29
Point 15	-32.7527	151.199	3.5	4.0	4.7	5.5	6.2	7.11
Point 16	-32.6474	151.076	3.2	3.7	4.2	5.0	5.6	6.47
Point 17	-32.6981	150.964	3.4	3.9	4.5	5.4	6.1	7.01
Point 18	-32.7581	150.788	3.8	4.4	5.1	6.1	6.9	8.14
Point 19	-32.6443	150.878	3.4	3.9	4.5	5.4	6.1	7.09
Point 20	-32.5969	150.9729	3.2	3.7	4.3	5.1	5.8	6.76
Point 21	-32.5311	150.861	3.0	3.5	4.0	4.8	5.4	6.37
Point 22	-32.5255	151.0625	3.1	3.5	4.1	4.9	5.5	6.47
Point 23	-32.9954	151.427	5.0	5.7	6.7	7.9	8.8	9.87

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