“Where will our knowledge take you?”

Murrumbidgee River at Darlington Point and Environs Flood Study

Draft Report for Public Exhibition

August 2018

Murrumbidgee COUNCIL

Murrumbidgee River at Darlington Point and Environs Flood Study

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Synopsis: **Report for the Darlington Point Flood Study covering the review of available data, development and calibration of computer models and design flood modelling.**

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Executive Summary

Introduction

The Murrumbidgee River at Darlington Point and Environs Flood Study has been prepared for Murrumbidgee Council (Council) to define the existing flood behaviour in the catchment and establish the basis for subsequent floodplain management activities.

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

- Compilation and review of existing information pertinent to the study;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and Extreme flood event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

Catchment Description

The Murrumbidgee River catchment area of upstream of Darlington Point is over 32 000 km^2. The Murrumbidgee River is a tributary of the Murray River and forms part of the broader Murray-Darling catchment.

The upper catchment, which forms part of the western slopes of the Great Dividing Range is steep, with elevations peaking at around 2000 m AHD in the Snowy Mountains. Downstream to Narrandera, the catchment is well-defined, elevated between 200 and 500 m AHD, and has a relatively confined floodplain. Downstream of Narrandera the floodplain becomes broad and flat, with numerous anabranches and flood runners.

Over time, the catchment has been largely cleared for farming purposes. The other dominant land use is remnant vegetation, including the river red gum forests which are native to Australia and exist along inland waterways and floodplain areas. Only a small portion of the catchment is occupied by urban areas, with the major town centres of Narrandera, Wagga Wagga, Gundagai, Yass and Canberra located in the catchment.

There are a number of major transport routes traversing the catchment. The most significant to the study area are the Kidman Way and the Sturt Highway, between them connecting Darlington Point to Griffith, Narrandera and Hay and onto all other major urban centres in the region.

Historical Flooding

The Darlington Point township experiences mainstream flooding emanating from the Murrumbidgee River. The Murrumbidgee River has experienced a number of major historical flood events including in the years of 1891, 1900, 1925, 1931, 1956, 1974, 1975, 1989, 2010, 2012 and most recently in 2016.

Historically, flooding in the catchment was known to cause extensive damage and disruption. During the 1956 flood event, which was the largest on record at the time, construction of a levee to protect the town was initiated. Construction of the levee was completed in 1965, which has offered flood protection to the southern part of Darlington Point for all historical events since.

Due to the large size of the catchment upstream of Darlington Point, flood events are of long duration and can last weeks or even months.

Community Consultation

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

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

- Questionnaire available to be completed by landowners, residents and businesses within the study area,
- A community information session to present information on the progress and objectives of the flood study and obtain feedback on historical events in the catchment and other flooding issues, and
- Public exhibition of the draft Flood Study.

Model Development

Development of hydrologic and hydraulic models has been undertaken to simulate flood conditions in the catchment.

The hydraulic model, simulating flood depths, extents and velocities utilises the TUFLOW two-dimensional (2D) software developed by BMT, one of the leading flood models currently in use across the globe. The 2D modelling approach is suited to model the complex interaction between channels and floodplains and converging and diverging of flows through structures and urban environments.

A TUFLOW HPC model was developed to provide a two-dimensional (2D) representation of the channel and floodplain of the Murrumbidgee River floodplain at Darlington Point. A model resolution of 10 m was adopted. The floodplain topography is defined using a digital elevation model (DEM) derived from aerial survey data. Available channel cross section survey was utilised to inform and reinforce channel capacity of the Murrumbidgee River.

With consideration to the available LiDAR survey information and local topographical and hydraulic controls, a 2D model was developed extending 17.3 km upstream of the township and 28.5 km downstream, covering just under 46 km length of the Murrumbidgee River. The hydraulic model extends between 6 to 10 km laterally across the floodplain, the extent of which was limited by availability of high resolution topographic survey (LiDAR data). The area modelled within the 2D domain comprises a total area of some 204 km^2 of the Murrumbidgee River and floodplain.

A separate TUFLOW HPC model of the Darlington Point township was also developed to simulate local overland flow behind the levee. This model is a linked 1D / 2D model and covers an area of around 2.1 km^2.

The hydrological rainfall-runoff model is only required to provide local inflows into the model domain behind the levee. A hydrological model was developed using the XP-RAFTS software.

Model Calibration and Validation

The selection of suitable historical events for calibration of computer models is largely dependent on available historical flood information. The calibration data available for the study area comprises principally the record at the Darlington Point streamflow gauge. The gauge has been in operation since 1939, with continuous time series records available from 1970. The 1956, 1974, 2010, 2012 and 2016 events were utilised for model calibration.

Due to the long period of record and high flow spot gaugings available at the gauge site, the TUFLOW HPC model parameters were adjusted so the modelled rating curve matched the spot gaugings at the gauge site. The calibration process firstly involved calibrating the modelled channel bed elevation and roughness to low, in-channel flows, before calibrating the floodplain roughness to higher, out-of-bank flows.

If the TUFLOW HPC model rating is reliable then the modelled peak flows at the Darlington Point gauge should be representative of the actual peak flow conditions during each flood event. The TUFLOW derived rating curve was used to adjust historical peak flows estimated from the gauge site rating curve. These updated historical flows were used to complete a Flood Frequency Analysis at the site. A summary of historical flow rates estimated from the site rating curve compared to flow rates derived from the TUFLOW modelled rating curve is presented in Table 1.

Table 1 Modelled Peak Flood Conditions for Calibration Events

Flood Event	Site Rating Flow (m^3/s)	Modelled Rating Flow (m^3/s)
July 1956	1014	1190
September 1974	1368	1420
December 2010	820	775
March 2012	1311	1360
September 2016	838	791

Design Event Modelling and Output

The developed models have been applied to derive design flood conditions within the Murrumbidgee River catchment. Mainstream inflows into the model domain were determined from a Flood Frequency Analysis completed at the Darlington Point Bridge gauge location.

The design events considered in this study include the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and Extreme flood events. Peak flow rates for the range of design events considered are contained in Table 2.

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, peak flood water levels and depths and peak flood velocities.

The results suggest that the Darlington Point levee may have a lower level of freeboard than previously understood, being around 0.85 m above the 1% AEP along the eastern side. For the 0.5% AEP and 0.2% AEP events, the levee will offer around 0.75 m and 0.65 m freeboard, respectively, if it remains structurally sound.

Additionally, flood function mapping (or hydraulic categorisation i.e. floodway, flood storage and flood fringe) and provisional flood hazard mapping (in accordance AIDR, 2017) has been produced.

Table 2 Design Peak Flood Flows

Design Event	This Study (m^3/s)	2009 Study (m^3/s)
20% AEP	500	510
10% AEP	690	670
5% AEP	880	850
2% AEP	1160	1140
1% AEP	1390	1410
0.5% AEP	1620	1730
0.2% AEP	1950	2280

Sensitivity Testing

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

- The influence of adopted hydraulic model roughness;
- Uncertainty surrounding peak flow estimation from a Flood Frequency Analysis; and
- Increases in rainfall intensities to assess the impact of predicted climate change.

Floodplain Risk Management Considerations

An increasingly important requirement of a Flood Study is to consider and investigate flood planning and flood risk management issues within the study area. This study has derived an interim Flood Planning Area (Section 8.1) and completed a baseline flood damages assessment.

A flood damages database was developed to identify potentially flood affected properties and to quantify the extent of damages in economic terms for existing flood conditions. The total number of properties included in the database is 463. Property flood levels have been estimated using the same assumptions used by Worley Parsons (2009b). A flood damages assessment was undertaken with the total tangible flood damages for residential properties, commercial properties and the public sector calculated. From this data, the combined AAD was calculated as being $157,000, comprised as follows:

- $118,000 from residential properties;

- $3,000 from commercial properties; and
- $36,000 from infrastructure and public sector.

Conclusions

The objective of the study was to undertake a detailed flood study of the Murrumbidgee River at Darlington Point and to establish models as necessary for design flood level prediction.

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

- Collation of historical and recent flood information for the study area;
- Development of computer models to simulate hydrology and flood behaviour in the catchment;
- Calibration of the developed models using the available flood data, including the recent events of 2010, 2012 and 2016 and the historic events of 1956 and 1974; and
- Prediction of design flood conditions in the catchment and production of design flood mapping series.

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Glossary

annual exceedance probability (AEP)	AEP (measured as a percentage) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 1% AEP flood is a flood that has a 1% chance of occurring, or being exceeded, in any one year. It is also referred to as the '100 year ARI flood' or '1 in 100 year flood'. The term 100 year ARI flood has been used in this study. See also average recurrence interval (ARI).
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
attenuation	Weakening in force or intensity
average recurrence interval (ARI)	ARI (measured in years) is a term used to describe flood size. It is the long-term average number of years between floods of a certain magnitude. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years. The term 100 year ARI flood has been used in this study. See also annual exceedance probability (AEP).
average annual damage (AAD)	Average damage in dollars per year that would occur in a pereticular area from flooding over a very long period of time.
catchment	The catchment at a particular point is the area of land that drains to that point.
digital elevation model (DEM)	A 3D representation of a terrians surface greated from elevation data.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flood	A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
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 for damage to property or risk to persons during a flood. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.The degree of flood hazard varies with circumstances across the full range of floods.
flood level	The height of the flood described either as a depth of water above a particular location (eg. 1m above a floor, yard or road) or as a depth of water related to a standard level such as Australian Height Datum (eg the flood level was 7.8 mAHD). Terms also used include flood stage and water level.
flood liable land	See flood prone land.
floodplain	Land susceptible to flooding up to the probable maximum flood (PMF). Also called flood prone land. Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level.
floodplain risk management study	Studies carried out in accordance with the Floodplain Development Manual (NSW Government, 2005) that assesses options for minimising the danger to life and property during floods. These measures, referred to as 'floodplain risk management measures / options', aim to achieve an equitable balance between environmental, social, economic, financial and engineering considerations. The outcome of a Floodplain Risk Management Study is a Floodplain Risk Management Plan.
floodplain risk management plan	The outcome of a Floodplain Risk Management Study.
flood planning area (FPA)	The area of land up to the flood planning level that is subject to Council flood planning controls.
flood planning levels (FPL)	The combination of flood levels and freeboards selected for planning purposes, as determined in Floodplain Risk Management Studies and incorporated in Floodplain Risk Management Plans. The concept of flood planning levels supersedes the designated flood or the flood standard used in earlier studies..
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood stage	See flood level.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
flood study	A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood sizes.

floodway	Those areas of the floodplain where a significant discharge of water occurs during floods. Floodways are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
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.
high flood hazard	For a particular size flood, there would be a possible danger to personal safety, able-bodied adults would have difficulty wading to safety, evacuation by trucks would be difficult and there would be a potential for significant structural damage to buildings.
hydraulics	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
low flood hazard	For a particular size flood, able-bodied adults would generally have little difficulty wading and trucks could be used to evacuate people and their possessions should it be necessary.
m AHD	Metres Australian Height Datum (AHD).
m/s	Metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second or 'cumecs'. A unit of measurement for creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
overland flow path	The path that floodwaters can follow if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters travelling along overland flow paths, often referred to as 'overland flows', may or may not re-enter the main channel from which they left; they may be diverted to another water course.
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
probable maximum flood (PMF)	The largest flood likely to ever occur. The PMF defines the extent of flood prone land or flood liable land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event are addressed in the current study.
probability	A statistical measure of the likely frequency or occurrence of flooding.

risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
topography	The shape of the surface features of land
TUFLOW HPC	TUFLOW is a powerful computational engine that provides one-dimensional (1D) and two-dimensional (2D) solutions of the free-surface flow equations to simulate flood and tidal wave propagation. TUFLOW HPC (Heavily Parallelised Compute) utilises the substantial power of parallel computing.
velocity	The term used to describe speed of floodwaters, usually in m/s.
water level	See flood level.

Acknowledgements

Murrumbidgee Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage (OEH).

We would like to acknowledge the input of the Murrumbidgee Floodplain Risk Management Committee, which has provided valuable input to the Flood Study. Without their local knowledge and expertise, the Study would not have been as comprehensive.

1 Introduction

The Darlington Point Flood Study has been prepared for Murrumbidgee Council (Council) to define the existing flood behaviour in the catchment and establish the basis for subsequent floodplain management activities.

This study was commissioned by Council and has received financial support from the Office of Environment and Heritage (OEH) as part of the NSW Floodplain Management Program.

1.1 Study Location

The township of Darlington Point is located in the Murrumbidgee LGA in south-western NSW and has a population of 1,016 (2011 census). The town is situated in the floodplain of the Murrumbidgee River, approximately 36 km to the south of Griffith. The general study area locality and major waterway alignments are shown in Figure 1-1. Downstream of Narrandera, the Murrumbidgee River floodplain becomes broad and flat, whereby it is difficult to accurately delineate a catchment boundary. Further detail around the catchment topography is provided in Section 2.1.1.

The study area is around 440 km^2 and is focussed on the Murrumbidgee River floodplain in the vicinity of Darlington Point. Following project initiation, it was decided through consultation with Council and OEH that the study area would be limited to the extent of available high-resolution survey data. The resulting study area covers some 204 km^2, extending around 2 km south of the Sturt Highway and up to 4 km north of Murrumbidgee River Road and Whitton Darlington Point Road.

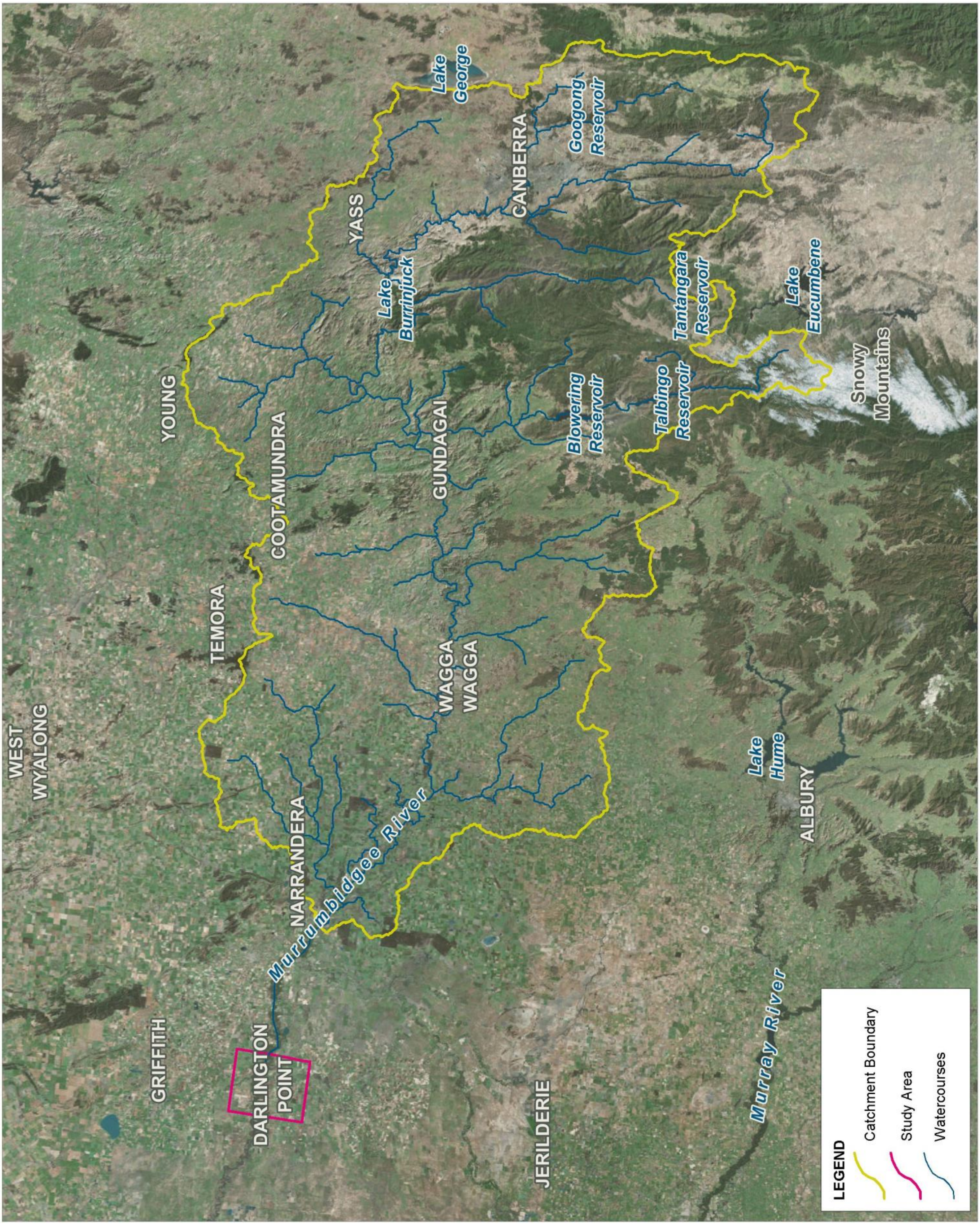
The Darlington Point town centre is situated on the southern floodplain of the Murrumbidgee River and is protected from mainstream flooding by a levee. The smaller population of North Darlington Point is not protected by a levee and is exposed to considerable flood risk, as was experienced in March 2012.

1.2 Study Background

The flood of July 1956 was the largest flood on record since records began some 130 years ago. Prior to this, the catchment had experienced frequent flooding with significant events known to have occurred in 1931, 1950, 1952 and 1955. During the onset of the 1956 flood, a levee was partly constructed around the township as an emergency mitigation measure. Construction of the levee was officially completed in 1965, with the levee crest set to the peak level of the 1956 flood.

In September 1974, a flood event occurred with the peak flood level recorded at the Darlington Point stream flow gauge some 0.2 m higher than what was recorded in 1956. During this event, there was anecdotal evidence that the levee appeared unstable, indicating that it may have been close to failure. A third large flood then occurred in November 1975.

Following from the 1974 and 1975 flood events, a number of investigations into the flood behaviour within the study area, with the primary focus on the expected levee immunity were initiated. Most recently, the *Darlington Point Levee Sensitivity Analysis* and *Darlington Point Levee Rehabilitation Project - Phase A: Geotechnical Investigations and Options Assessment* were completed by WorleyParsons in 2009. The general consensus was that the levee may be structurally inadequate and as the crest elevation is quite variable, the levee required upgrade works.



Title:

Study Locality

Figure: **1-1**

Rev: **A**

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Since the 1970's numerous significant flood events have occurred in the catchment. Notably, the events of April 1987, July 1991, December 2010, March 2012 and October 2016 all fall within the largest ten floods on record. The March 2012 event was larger than the 1974 event and caused wide spread flooding issues, particularly at North Darlington Point. Further detail surrounding the March 2012 event can be found in Section 2.1.2.

This Darlington Point Levee Renewal Project is running concurrently with this study. To date, around half of the levee upgrade works (constituting the eastern portion of the levee) have been completed. The outcomes of this study will be compared to the previous work by WorleyParsons (2009) to assess the revised design flood immunity of the upgraded levee system.

1.3 The Floodplain Risk Management Process

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

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

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

Table 1-1 Stages of Floodplain Risk Management

Stage	Task	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 risk management for the floodplain.
6	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stage 3 of the above process and aims to provide an understanding of flood behaviour at Darlington Point.

1.4 Study Objectives

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

- Compilation and review of existing information pertinent to the study;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design event including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5%, AEP 0.2% AEP and an Extreme Flood event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

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

1.5 About this Report

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

Section 1 introduces the study.

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

Section 3 outlines the community consultation program undertaken.

Section 4 details the development of the computer models.

Section 5 details the model calibration and validation process including sensitivity tests.

Section 6 presents the adopted design flood inputs and boundary conditions.

Section 7 presents design flood simulation results and the associated flood mapping.

Section 8 investigates preliminary floodplain risk management considerations such as flood planning areas, classification of flood communities and a baseline flood damages assessment.

2 Study Approach

2.1 The Study Area

2.1.1 Catchment Description

The Murrumbidgee River catchment area of upstream of Darlington Point is over 32,000 km^2. The topography of the Murrumbidgee River catchment is shown in Figure 2-1. The Murrumbidgee River is a tributary of the Murray River and forms part of the broader Murray-Darling catchment.

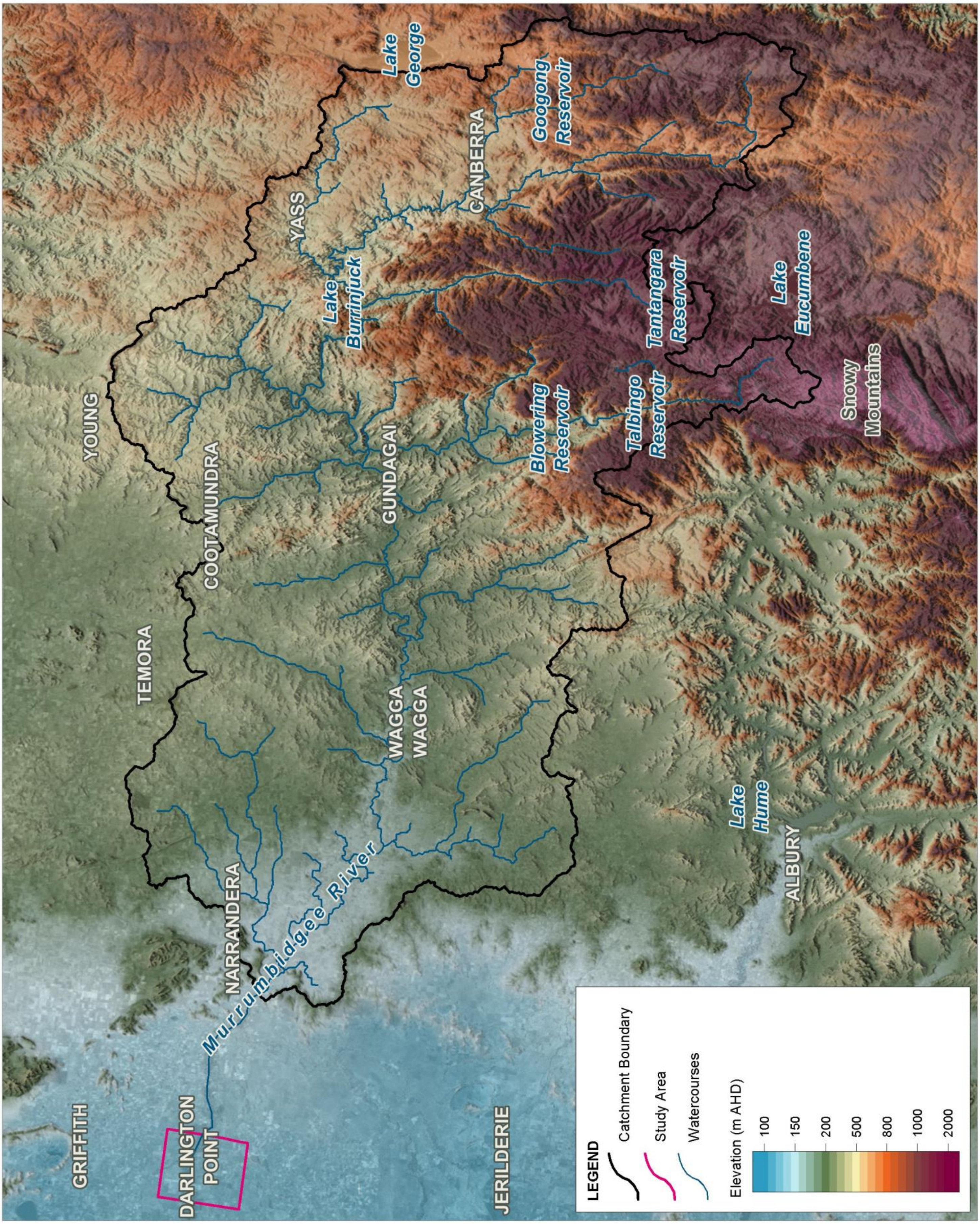
The upper catchment, which forms the western slopes of the Great Dividing Range is steep, with elevations peaking at around 2000 m AHD at the Snowy Mountains. To Narrandera, the catchment is well defied (as outlined on Figure 2-1), elevated between 200 and 500 m AHD and has a relatively confined floodplain area. This is the catchment from which floods at Darlington Point are generated. Downstream of Narrandera, the floodplain becomes broad and flat, with numerous anabranches and flood runners. Darlington Point is situated in the Riverina region of the catchment, which is characteristic of flat plains and semi-arid climate. Elevations in the order 110 to 140 m AHD of are typical.

Multiple dams have been constructed in the upper catchment over the last century. The two largest of these are:

- Burrinjuck Dam (capacity 1,026,000 ML), located on the Murrumbidgee River near Yass. Construction commenced 1907 and was completed 1928. The dam wall was upgraded in 1957 and again in 1994.
- Blowering Dam (capacity 1,628,000 ML), located on the Tumut River upstream of Gundagai. Construction commenced in 1964 and completed in 1968. The dam wall was upgraded in 2010.

Both dams were built for water supply, flood mitigation and agriculture supply purposes. As such, they have the potential to significantly alter the natural flow regime of large flood events through attenuation of floodwater, reduced peak flows and flow release regimes. The location of these can be seen on Figure 2-1.

Following the commission of Burrinjuck Dam, the NSW Government initiated plans for the development of the Murrumbidgee Irrigation Area (MIA) – the agricultural region extending from Narrandera to the confluence of Mirrool Creek with the Lachlan River (around 60 km north-west of Hay). WaterNSW controls releases from Burrinjuck and Blowering Dams into the Murrumbidgee River for water supply. Similarly, the Coleambally Irrigation District (CID) operates between Darlington Point and Jerilderie. The main supply offtake for the CID is located around 50 km upstream from Darlington Point at Gogeldrie Weir. Although offtakes located on the Murrumbidgee River upstream of Darlington Point supply water to the MIA and CID through an artificial network of irrigation water and drainage services, this daily practice will not influence flood behaviour downstream.



Title:
Murrumbidgee River Catchment Topography

Figure:
2-1

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Only a small portion of the catchment is occupied by urban areas, with the major town centres of Narrandera, Wagga Wagga, Gundagai, Yass and Canberra located in the catchment.

There are a number of major transport routes traversing the catchment. The most significant to the study area are the Kidman Way and the Sturt Highway, between them connecting Darlington Point to Griffith, Narrandera and Hay and onto all other major urban centres in the region.

2.1.2 History of Flooding

The Darlington Point township experiences mainstream flooding from the Murrumbidgee River. The Murrumbidgee River has experienced a number of major historical flood events including in the years of 1891, 1900, 1925, 1931, 1956, 1974, 1975, 1989, 2010, 2012 and most recently in 2016.

Historically, flooding in the catchment was known to cause extensive damage and disruption. During the 1956 flood event, which was the largest on record at the time, construction of a levee to protect the town was initiated. Construction of the levee was completed in 1965, which has offered flood protection to the southern part of Darlington Point for all historical events since.

Due to the large size of the catchment upstream of Darlington Point, flood events are of long duration and can last weeks or even months. The 1956 was the largest on record in terms of volume, with the Bridge Street road embankment being inundated by flood waters for up to five days and other areas of the floodplain remaining inundated for five months (WorleyParsons, 2009a). The recent event of March 2012 resulted in the highest peak flood level on record at the Bridge Street, Darlington Point, streamflow gauge.

Figure 2-2 Murrumbidgee River Bridge Crossing at Bridge Street, Darlington Point during the March 2012 Flood Event

Figure 2-3 Darlington Point Town Centre during the March 2012 Flood Event

Figure 2-4 North Darlington Point during the March 2012 Flood Event

There is also potential for local runoff to become trapped behind the levee, particularly in periods of high tailwater conditions.

2.2 Compilation and Review of Available Data

2.2.1 Previous Studies

A number of investigations into the flooding characteristics of the study area have been undertaken over the last 20 years. Various studies have looked at the design flood conditions along the Murrumbidgee River, largely with the focus on specific townships. Previous investigations at Darlington Point has centred around assessment of the levee performance.

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

2.2.1.1 Darlington Point Levee Gradient Sensitivity Analysis (WorleyParsons, 2009a)

The Darlington Point Levee Gradient Sensitivity Analysis was prepared for Murrumbidgee Shire Council (now Murrumbidgee Council) by WorleyParsons (formerly Patterson Britton and Partners) in parallel with a floodplain risk management study for the area *(Darlington Point Levee Rehabilitation Project Phase A – Geotechnical Investigations and Options Assessment*).

A flood frequency analysis was completed from an annual maxima series determined at the Darlington Point streamflow gauge data. The data set was supplemented with adjacent station gauge records between the years 1885-1913 (the Darlington Point streamflow gauge was established in 1914) and 1923-1924 (recorded data at Darlington Point was unavailable). Adjacent gauges used in the analysis to extend and fill the record include Wagga Wagga, Hay, Narrandera and the Yanco Creek offtake.

A RMA-2 hydraulic model was developed and calibrated to the 1956 and 1974 events. The aim of the study was to investigate the effect of hydrograph shape (rate of rise and total volume) on peak flood level gradients at Darlington Point. The study concluded that there is minimal variation in the flood gradient around the levee regardless of the hydrograph shape or relative magnitude of peak discharge adopted.

The study determined that the existing levee would overtop when Murrumbidgee River flows reached around 1730 m^3/s – approximately equal to a 0.5% AEP design flood event.

2.2.1.2 Darlington Point Levee Rehabilitation Project Phase A – Geotechnical Investigations and Options Assessment (WorleyParsons, 2009b)

Levee audits completed by NSW Public Works Department in 1991 and the Department of Commerce in 2007 recommended works to upgrade the existing earthen levee at Darlington Point. Murrumbidgee Council commissioned WorleyParsons (formerly Patterson Britton & Partners) to conduct a preliminary assessment of options to upgrade the existing levee and the potential of a new levee alignment to protect North Darlington Point. Specifically, the report included geotechnical investigation to confirm the existing condition of the levee and flood modelling to determine the existing design immunity of the levee. The flood modelling portion of the assessment is largely contained in the *Darlington Point Levee Gradient Sensitivity Analysis* report.

The report found that the existing levee was generally in poor condition and could therefore potentially be breached in the 20% AEP design event. A flood damages assessment was completed for Darlington Point under this assumption.

The preferred options for upgrading the existing levee were determined from a cost-benefit analysis. The report recommended that the levee be upgraded to the 1% AEP design event plus freeboard, with the freeboard requirement varying from between 750 mm on the western and southern side of town to 1000 mm on the northern and eastern side of town.

2.2.1.3 Narrandera Flood Study Review and Levee Options Assessment Volume 1 (Lyall & Associates, 2015)

This study, commissioned by Narrandera Shire, provides a detailed summary in Appendix D of Flood Frequency Analysis investigations previously completed at the Narrandera and Wagga Wagga gauge locations. At both sites, the main uncertainty is the estimation of the magnitude of historical peak flows for four large flood events that are known to have occurred in the catchment in the 1800s (that is, 1852, 1853, 1870 and 1891) and their inclusion (or not) as historical ungauged flows above user specified flow thresholds. The construction and impact of Burrinjuck Dam is also considered in the more recent investigations.

The study also identified that different roughness parameters were required to be adopted within the hydraulic model for calibration to the 1974 and 2012 historic events. This method was required to achieve a good hydraulic model calibration for other studies within the Murrumbidgee River catchment and has been attributed to changed land use practices within riparian corridors such as grazing controls and native vegetation protection / enhancement.

2.2.1.4 MR 321 Darlington Point Bridge and Road Upgrades Flood Impact Assessment Revision 2 (WorleyParsons, 2014)

The study assesses any post-construction flood impacts that may have resulted from road and bridge works. Details surrounding the reconstruction of Kidman Way to the south of the town in the mid-1980s and works as executed (WAE) drawings for both historic and present day bridge crossings are provided in the Appendices, and are of use for development of the hydraulic model.

2.2.2 Water Level Data

A continuous water level gauge site is located at on the downstream side of Bridge Street. This gauge site was established in 1914. Historical peak flood levels recorded at Bridge Street, Darlington Point are summarised in Table 2-1.

2.2.3 Historical Flood Marks

Care must be taken when assessing flood marks recorded during historic events, as changes within the catchment over the years (clearing of catchment vegetation, topographic changes associated with urban development, construction of arterial roads, bank stability works etc.) may mean that the flow rates producing these levels cannot be directly compared.

There are 24 surveyed peak flood levels in town available for the 1956 event, as detailed in WorleyParsons (2009b). Nineteen of these are located against the levee bank. A memorial plaque resides on a tree stump outside the Darlington Point Swimming Pool (corner of Carrington Street and Curphey Place, as depicted in Figure 2-5).

No surveyed flood levels are available for the other events.

2.2.4 Additional Data

A number of datasets were provided by either Council of NSW Public Works for use in the study. These included previous flood investigation reports within the catchment, levee design and audit reports, survey data sets, bridge and road design drawings, SES documents and flood photographs of the 2012 event.

Table 2-1 Historic Peak Flood Levels at Bridge Street, Darlington Point

Rank	Year	Flood Level (m AHD)
1	March 2012	125.61
2	September 1974	125.55
3	July 1956	125.33
4	November 1975	125.09
5	October 2016	125.04
6	April 1989	125.03
7	December 2010	125.01
8	October 1970	124.89
9	October 1960	-
10	July 1991	124.76
11	1955	-
12	1978	124.60

Figure 2-5 July 1956 Flood Level

2.3 Site Inspections

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 including the levee, road bridges and associated embankments.
- General nature of the Murrumbidgee River, the secondary channels and associated floodplains 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 the levee and other topographic features identified from the survey datasets.

2.4 Survey Requirements

Murrumbidgee River cross section survey data is available in the vicinity of Darlington Point and was provided by NSW Public Works from the following two sources:

- Polkington, Harrision & Longhurst surveyed 31 river cross sections within the study area in 2004.
- Brian Mitsch and Associates surveyed 22 river cross sections between Narrandera and Maude in 2011. Four of these cross sections are located within the study area and are of use to this study.

The calibration process indicated that the road crest of Kidman Way to the south of town is a critical topographic feature contributing to the flood behaviour observed during the recent March 2012 event. It was therefore decided to obtain additional survey of key floodplain features. A number of road crests were surveyed. In addition to using this information to reinforce these key features into the hydraulic model, the spot heights were utilised to confirm the accuracy of the LiDAR dataset in its entirety. Further information is provided in Section 4.2.1.

Additionally, a property floor level database for the study area was required to complete the flood damages assessment. As requested in Councils brief, the property database established by WorleyParsons (2009b) was used as the basis for this. For this study, properties located on the southern floodplain, outside of the levee extent that were not included in the previous study have had their flood levels surveyed. This work was undertaken by Docherty Surveying.

2.5 Community Consultation

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

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

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

- Public exhibition of Draft Report and community information session.

These elements are discussed in further detail in Section 3.

2.6 Development of Computer Models

2.6.1 Hydrological Model

For the purpose of the Flood Study, a hydrologic model (discussed in Section 4.1) was developed to simulate the rate of local storm runoff behind the levee. A hydrological model predicts the amount of runoff from rainfall and the attenuation of the flood wave as it travels down the catchment. This process is dependent on:

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

The output from the hydrologic model is a series of flow hydrographs at selected locations such as at the boundaries of the hydrodynamic model or as local "source" inflows. These hydrographs are used by a hydrodynamic model to simulate the passage of a flood through the study area.

2.6.2 Hydraulic Models

Hydraulic models are developed to examine the flow of water across a surface and can therefore be used to predict flood behaviour. They can be used to determine flood levels, velocities and depths across the study area for historical and design events. Two hydraulic models were developed for this study:

- A TUFLOW HPC model was developed to provide a two-dimensional (2D) representation of the channel and floodplain of the Murrumbidgee River. The model domain extends some 600 m upstream and almost 5 km downstream of the study area, covering a total area of around 200 km^2.
- A TUFLOW HPC model of the Darlington Point township was developed to simulate local catchment runoff behind the levee. This model is a linked 1D / 2D model and covers an area of around 2.1 km^2.

Hydraulic model development is described further in Section 4.2.

2.7 Calibration and Sensitivity Testing of Models

The hydrologic and hydraulic models were calibrated and verified to available historical flood event data, to establish the values of key model parameters and confirm that the models were capable of adequately simulating 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 major historical flood events of July 1956, September 1974, March 2012 and September 2016 were identified as suitable events for calibration/validation of the developed models. Assessment of the model performance also incorporated a range of sensitivity tests of key variables/model assumptions, including:

- The influence of adopted hydraulic model roughness;
- Uncertainty surrounding peak flow estimation from a Flood Frequency Analysis; and
- Increases in rainfall intensities to assess the impact of predicted climate change.

Sensitivity testing was undertaken for the design flood events and has been reported in Section 7.4.

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 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 study area, design floods were based on a combination of flood frequency and design rainfall estimates, in accordance with the procedures Australian Rainfall and Runoff (ARR) (Ball et. al, 2016). In accordance with Council's brief, the simulated design events include the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and Extreme Flood event.

The design flood conditions form the basis for floodplain management in the catchment and in particular design planning levels for future development controls. The adopted design flood conditions are presented in Section 6.

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 for each of the design events. The maps present the peak value of each parameter. Flood function (hydraulic categories) and provisional flood hazard categories and are derived from the hydraulic model results and are also mapped. The mapping outputs are described in Section 7 and presented in the accompanying flood mapping compendium.

3 Community Consultation

3.1 The Community Consultation Process

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

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

- Questionnaire available to be completed by landowners, residents and businesses within the study area;
- Public exhibition of the draft Flood Study.

These elements are discussed in detail below. The community information brochure and questionnaire are also provided in Appendix A.

3.2 Community Questionnaire

An information brochure and accompanying questionnaire was delivered to the residents of Darlington Point. The questionnaire sought to collect information on previous flood experience and flooding issues. The focus of the questionnaire was historical flooding information that may be useful for correlating with predicted flooding behaviour from the modelling.

In total 12 questionnaire returns were received. Included in the responses were some historic flood photographs and local rainfall records.

Other key messages from the responses included:

- All respondents are concerned about more severe flooding occurring in the future,
- 11 of the 12 respondents had experienced flooding on their property in the past,
- There is a general understanding / acknowledgement that road infrastructure and local levee works (i.e. unauthorised construction on private property) can influence flood behaviour, and
- There is a sense of feeling “safe” due to the presence of the levee.

3.3 Public Exhibition

The Draft Flood Study Report was placed on public exhibition for a four-week period between XX and XX. The exhibition sought public comments and feedback on the study. XX comments were received during the public exhibition period.

4 Model Development

4.1 Hydrological Model

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

- The catchment slope, area, vegetation and other characteristics;
- Variations in the distribution, intensity and amount of rainfall; and
- The antecedent conditions (dryness/wetness) of the catchment.

These factors are represented in the model by:

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

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

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

4.1.1 Flow Path Mapping and Catchment Delineation

The Murrumbidgee River catchment area of upstream of Darlington Point is over 32,000 km^2. The floodplain is relatively confined downstream to Narrandera, with a well-defined catchment boundary. Downstream of Narrandera the floodplain becomes broad and flat. The catchment topography is shown in Figure 2-1.

Due to the long history of stream gauge records along the Murrumbidgee River upstream of Darlington Point, mainstream inflows into the model domain will not be defined from hydrological modelling; rather the following approach will be adopted:

- For calibration events, historic streamflow data recorded at the Darlington Point gauge will be used to inform inflows applied to the upstream model boundary. Further information is contained in Section 5.2.3.

- For design events, a Flood Frequency Analysis will be used to determine peak flow rates. Further information is contained in Section 6.2.

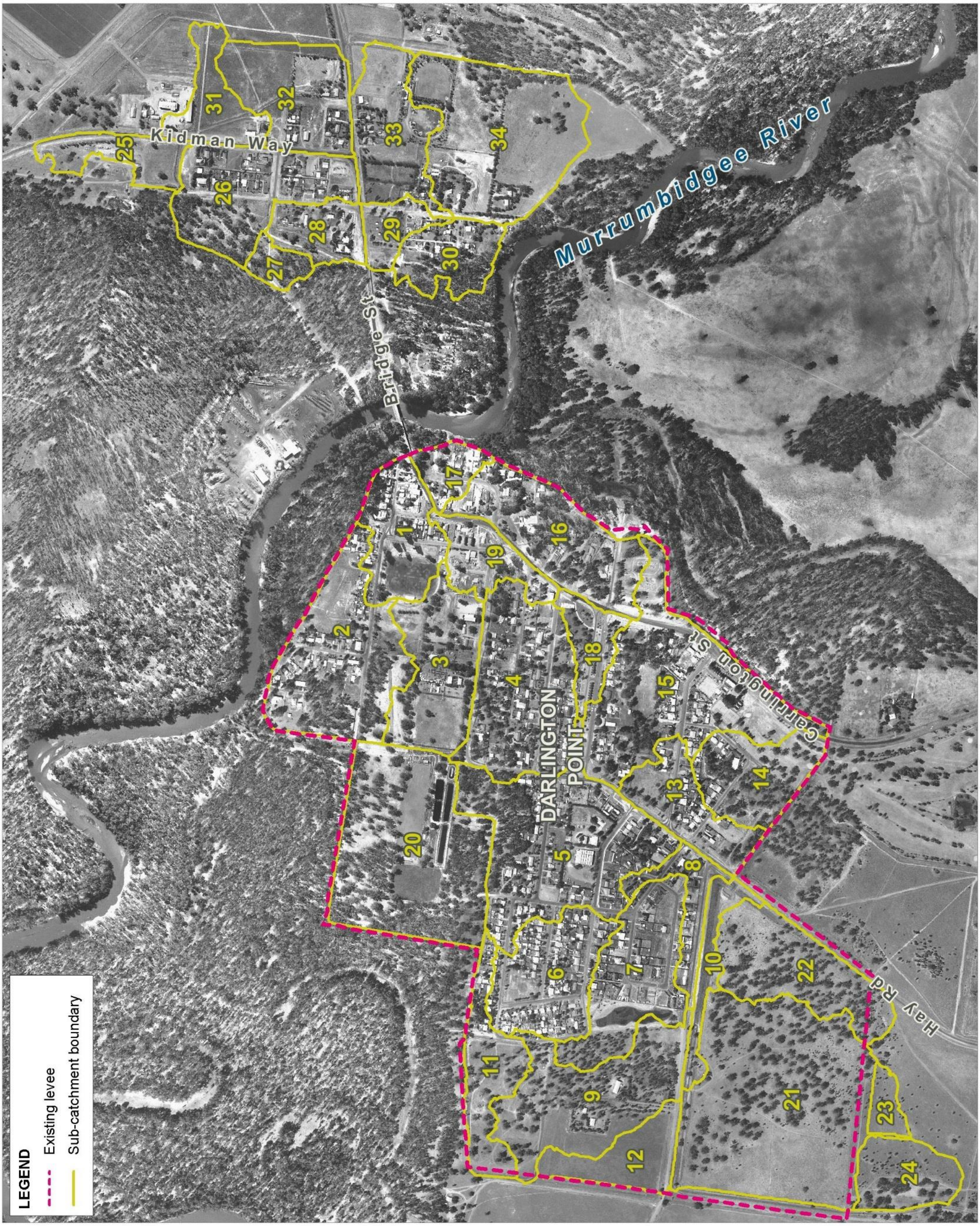
The hydrological model is therefore only required to provide local inflows into the model domain behind the levee. Given the lack of historic flood level data behind the levee, no value was to be added to the model calibration process by simulating local runoff for historic events. Therefore, local model inflows will be generated for simulation of design flood events only.

In order to accurately represent the rate and volume of runoff generated behind the levee to be fed into the local hydraulic model, it was important to delineate the catchments appropriately. An XP-RAFTS hydrological model was developed for the study, comprising some 23 local sub-catchments at Darlington Point and a further 10 sub-catchments at North Darlington Point, as presented Figure 4-1. Only the 19 hydrological sub-catchments located within the existing levee extent have been applied to the TUFLOW model. However, the additional sub-catchments have been incorporated into the hydrological model to enable future assessments of the potential levee extension at Darlington Point and a levee construction at North Darlington Point.

Table 4-1 summarises the key catchment parameters adopted in the XP-RAFTS model, including catchment area, vectored slope and PERN (roughness). A PERN value of 0.06 was adopted for all sub-catchments. It was assumed that around 25% of each sub-catchment was comprised of impervious surfaces (roads, roofs etc.) based on analysis of a sample of aerial photography of the town.

Table 4-1 XP-RAFTS Sub-catchment Properties

ID	Area (ha)		Slope (%)	ID	Area (ha)		Slope (%)
	Pervious	Impervious			Pervious	Impervious	
C1	4.91	1.64	0.06	C12	3.41	1.14	0.18
C2	10.0	3.34	0.02	C13	4.31	1.44	0.03
C3	6.76	2.25	0.2	C14	4.95	1.65	0.03
C4	9.55	3.18	0.55	C15	12.8	4.27	0.13
C5	13.2	4.38	0.2	C16	7.64	2.55	0.41
C6	6.38	2.13	0.12	C17	1.73	0.58	0.2
C7	7.22	2.41	0.48	C18	2.35	0.78	0.41
C8	2.56	0.85	0.06	C19	3.13	1.04	0.2
C9	9.29	3.10	0.23	C20	16.7	1.85	0.2
C10	2.18	0.73	0.1	C21	25.0	0	0.08
C11	4.43	1.48	0.1	C22	9.24	0	0.08



Title:

Hydrologic Model - XP-RAFTS Sub-catchment Layout

Figure: 4-1

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0 250 500m

Approx. Scale

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4.1.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrological model, which simulates the catchments response in generating surface runoff. 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/h); and
- Temporal pattern – describes the distribution of rainfall depth at a certain time interval over the duration of the rainfall event.

Both of these properties may vary spatially across the catchment.

The procedure for defining these properties is different for historical and design events. For historical events, the recorded hyetographs at continuous rainfall gauges provide the observed rainfall depth and temporal pattern. Where only daily read gauges are available within a catchment, assumptions regarding the temporal pattern may need to be made. For design events, rainfall depths are most commonly determined by the estimation of intensity-frequency-duration (IFD) design rainfall curves for the catchment. Standard procedures for derivation of these curves are defined in the ARR guidelines. Similarly, ARR also defines temporal patterns and rainfall losses for use in design flood estimation.

Further detail is provided in Section 6.3.

4.2 Hydraulic Model

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

Two TUFLOW HPC models were developed for this study:

- A fully 2D representation of the channel and floodplain of the Murrumbidgee River. The model domain extends some 600 m upstream and almost 5 km downstream of the study area, covering a total area of around 200 km^2.
- A linked 1D / 2D model of the Darlington Point township. This model covers an area of around 2.1 km^2.

4.2.1 Topography and River Cross Section Survey

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 this study, a 5 m by 5 m gridded DEM was derived from the NSW LPI LiDAR survey datasets, originally sourced by OEH.

River cross section survey data is available for the Murrumbidgee River in the vicinity of Darlington Point and was provided by NSW Public Works from the following two sources:

- Polkington, Harrision & Longhurst surveyed 31 river cross sections within the study area in 2004.
- Brian Mitsch and Associates surveyed 22 river cross sections between Narrandera and Maude in 2011. Four of these cross sections are located within the study area and are of use to this study.

The study area topography and location of surveyed river cross-sections is shown in Figure 4-2.

Docherty Surveying was engaged to undertake a road crest elevation survey for this study. In addition to using this information to reinforce these key features into the hydraulic model, the spot heights were utilised to confirm the accuracy of the 2009 LiDAR dataset in its entirety. Comparison between the two datasets indicated that the LiDAR data was suitable for use.

4.2.2 Murrumbidgee River Hydraulic Model

4.2.2.1 Extents and Layout

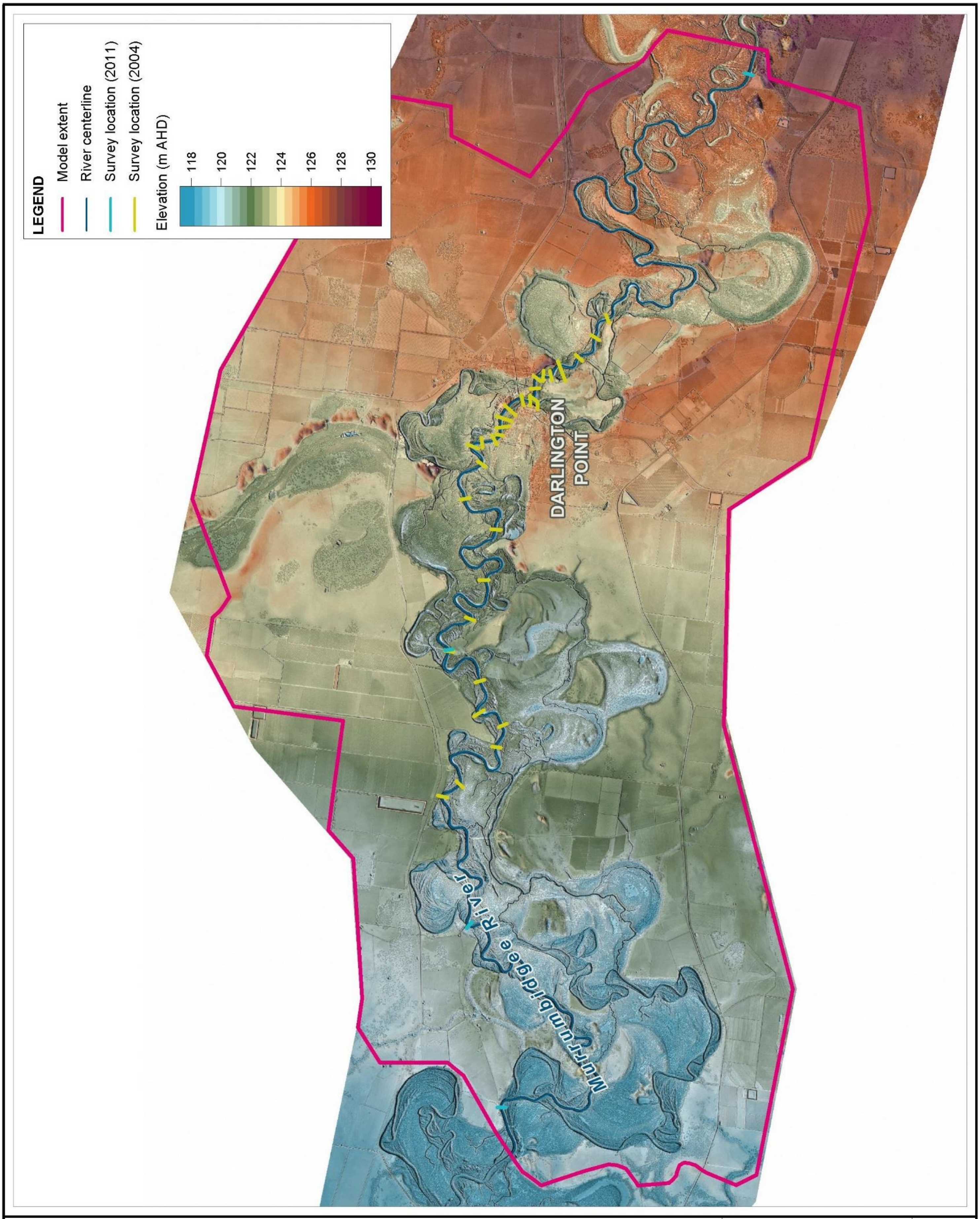
Consideration needs to be given to the following elements in constructing the model:

- Topographical data coverage and resolution;
- Location of recorded data (e.g. levels/flows for calibration);
- Location of controlling features (e.g. dams, levees, bridges);
- Desired accuracy to meet the study's objectives; and
- Computational limitations.

With consideration to the available LiDAR survey information and local topographical and hydraulic controls, a 2D model was developed extending 17.3 km upstream of the township and 28.5 km downstream, covering just under 46 km length of the Murrumbidgee River. The hydraulic model extends between 6 to 10 km laterally across the floodplain, the extent of which was limited by availability of high resolution topographic survey (LiDAR data). The area modelled within the 2D domain comprises a total area of some 204 km^2. The extent of the hydraulic model is shown in Figure 4-3.

A TUFLOW 2D domain model horizontal grid resolution of 10 m was adopted for study area. TUFLOW HPC samples elevation points at the cell centres and sides so a 10 m cell size results in DEM elevations being sampled every 5 m. This resolution was selected to give necessary detail required for accurate representation of floodplain and channel topography and its influence on flood flows. It also considers the need to largely restrict modelled depths as being less than the cell width and to achieve model simulations within a reasonable run time.

A 10 m grid model resolution may not pick up topographical features at a finer scale than 5 m. There are numerous topographic controls such as the crest of a roadway, levee or field embankment throughout the model domain. These features have been reinforced into the 2d model with "z-shapes" (3D topographical breaklines). Topographic features across the study area with the potential to act as hydraulic controls were identified and centrelines digitised for the crest alignments. The topographic controls included in the model are shown on Figure 4-2. GIS spatial analysis techniques were then used to capture the crest elevations along these alignments from a 2 m horizontal grid resolution LiDAR DEM.



Title:
Study Area Topography and Surveyed River Cross Section Coverage

Figure: 4-2

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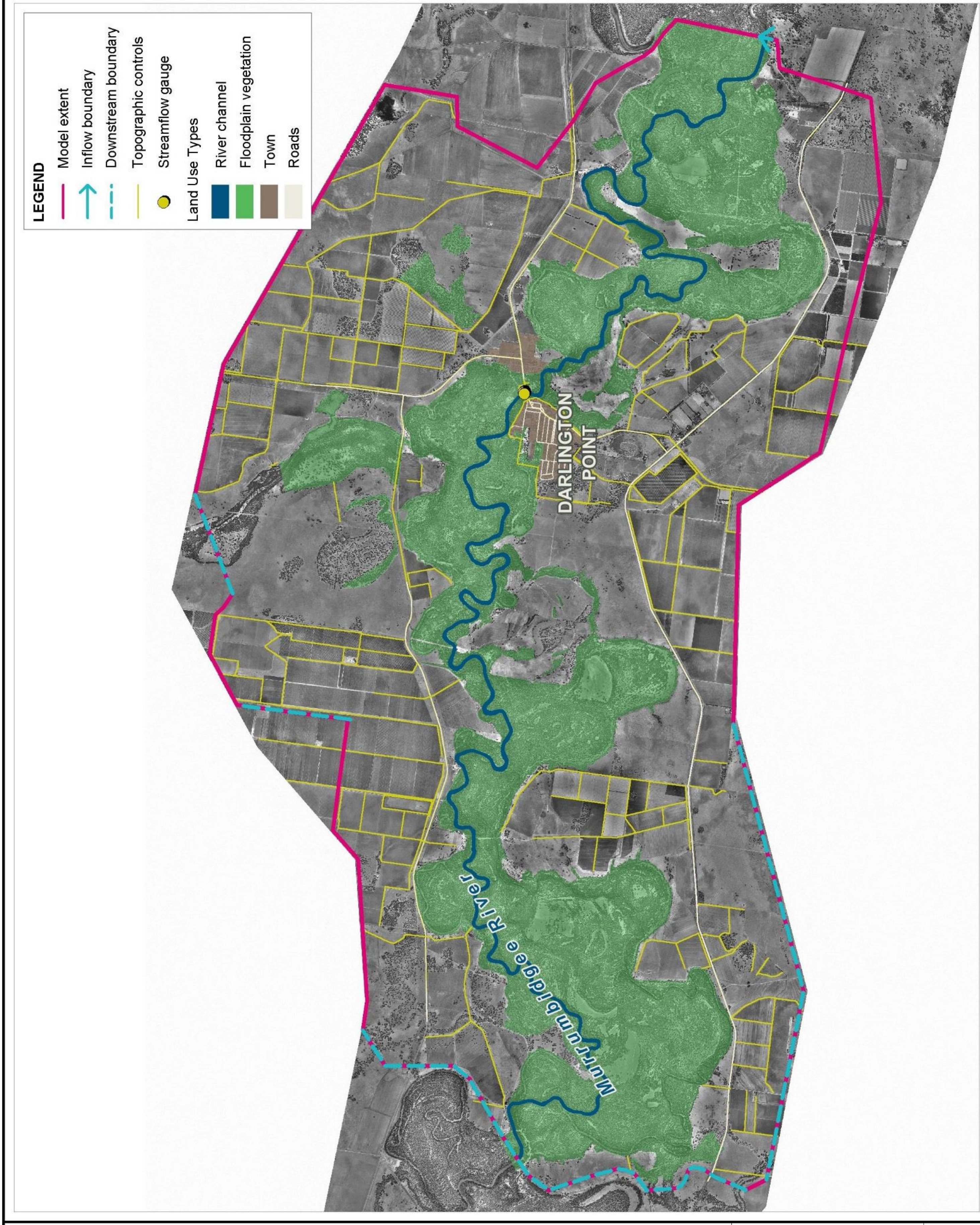

Title:
Murrumbidgee River Hydraulic Model Layout

Figure: **4-3**

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4.2.2.2 Hydraulic Roughness

The development of the TUFLOW model requires the assignment of different hydraulic roughness zones. These zones are delineated from aerial photography and cadastral data identifying different land-uses (e.g. forest, cleared land, roads, urban areas, etc.) for modelling the variation in flow resistance. The different land use types identified for each hydraulic roughness zone is shown of Figure 4-2.

The hydraulic roughness is one of the principal calibration parameters within the hydraulic model and has a major influence on flow routing and flood levels. The roughness values adopted from the calibration process is discussed in Section 5.

4.2.2.3 Channel Network

River cross section survey was available for the Murrumbidgee River within the study area, as detailed in Section 4.2.1. Figure 4-3 presents the coverage of the available river survey sections.

As LiDAR cannot penetrate water, representation of an appropriate channel capacity within the model was required. A river centreline 50 m wide was reinforced into the 2D model with the bed elevation along the channel reach informed by the survey datasets. It was found that adopting bed elevations similar to those surveyed at a channel width of 20 m (combined with a 50 m wide centreline) provided the best fit to measured low-flows at the Darlington Point gauge location. Further information around the calibration of adopted bed elevations is contained in Section 5.2.1.

Surveyed cross sections at location XS10 and XS11 (Polkinghorne, Harrison and Longhurst, 2004) have been plotted against the 2011 LiDAR dataset in Figure 4-4. The adopted model DEM is also presented for comparison. For reference, these cross sections are located around 190 m and 30 m upstream of the bridge crossing at Bridge Street, Darlington Point, respectively.

4.2.2.4 Structures

4.2.2.4.1 Bridge

The bridge crossing at Bridge St, Darlington Point, is a significant structure within the model extent. Incorporation of hydraulic bridge structures in the model provides for simulation of the hydraulic losses and their influence on peak water levels within the study area. The bridge crossing has been modelled utilising the layered flow constriction option available in TUFLOW, which represents the bridge superstructure and associated losses. Obvert levels, road crests and hand rail obstruction details are entered along with additional form losses.

The original bridge structure at Darlington Point was replaced in 1978. Details of the old and new structures were available as appendices to the MR 321 Darlington Point Bridge and Road Upgrades Flood Impact Assessment (WorleyParsons, 2014). The drawings for the new structure use elevations that are to the local Griffith datum, which is some 0.63 m above AHD. The drawings for the old bridge structure have elevations in feet with a reference to the local bridge benchmark. This was used to convert the elevations into m AHD. The old bridge structure details have been used for simulations of the 1956 and 1974 flood events, with the new bridge structure details being used for the more recent flood events and the design flood events.

The flow constrictions properties representing the old and new bridge structures in the TUFLOW model are summarised in Table 4-2.

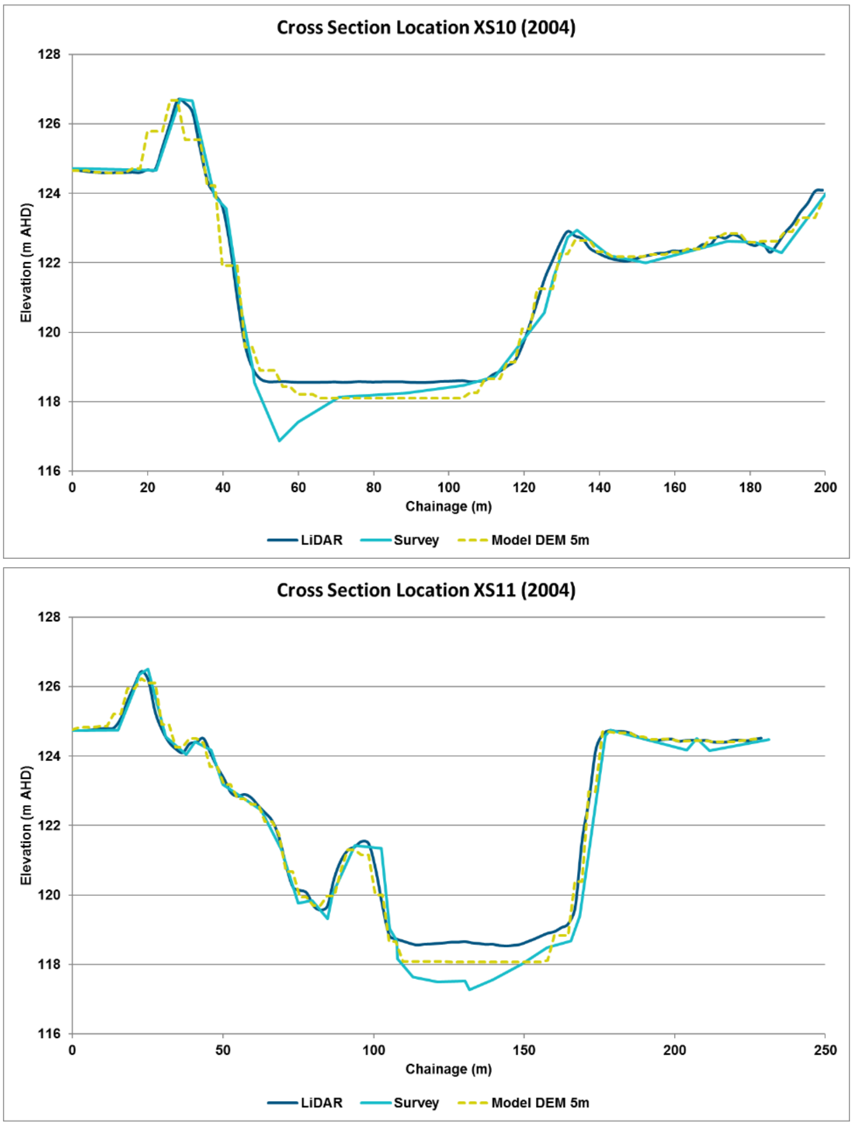


Figure 4-4 Comparison of Surveyed and Modelled River Cross Sections at Location XS10 and XS11

4.2.2.4.2 Levee

Construction of the Darlington Point levee began during the major flood of 1956 and was officially completed in 1965, with the levee crest set to the peak level of the 1956 flood. Geotechnical investigation of the levee indicated that the existing levee was generally in poor condition, with slope instability, low permeability, poor compaction and potential for piping failure (WorleyParsons, 2009b). As such, it was recommended the levee be upgraded with the design crest level equal to the 1% AEP design event plus freeboard, with the freeboard requirement varying from between 750 mm on the western and southern side of town to 1000 mm on the northern and eastern side of town.

Table 4-2 Modelled Bridge Structure Properties

Layer	Obvert (m AHD)	Depth (m)	Blockage (%)	Form Loss
Old Bridge (Main Channel)				
L1 (Waterway)	124.91 – 126.31	-	5 - 8	0.10 – 0.16
L2 (Supports)	-	0.43 – 1.20	10 – 50	0.2 – 1.0
L3 (Deck)	-	0.53	100	1.56
Old Bridge (Eastern Channels)				
L1 (Waterway)	125.29	-	5	0.10
L2 (Deck)	-	0.54	100	1.56
L3 (Barriers)	-	1.00	40	0.80
New Bridge (Main Channel)				
L1 (Waterway)	125.65 – 126.26	-	5	0.15
L2 (Deck)	-	1.46	100	1.56
L3 (Barriers)	-	1.00	20	0.40
New Bridge (Eastern Channel)				
L1 (Waterway)	125.90	-	5	0.10
L2 (Deck)	-	0.85	100	1.56
L3 (Barriers)	-	1.00	20	0.40

Upgrade works to the Darlington Point levee were carried out concurrently with this current study. At the time of writing, completed upgrade works included:

- Area 1 – the northern portion of levee adjacent to Murrumbidgee River channel, including construction of a sheet pile wall for 180 m just north of Kidman Way / Bridge Street.
- Area 3 – eastern levee section adjacent to Carrington Street, including east-west spanning alignment between Hay Road and Carrington Street.
- Area 4 – the re-aligned section of levee to the north of town, located around the existing water treatment plant.

Upgrade works for the remaining levee around the eastern and western perimeter for the town centre (Area 5 and Area 6) and work to extend the levee south of town were yet to be completed.

All design events will be simulated with the proposed design levee crest in-place. Accordingly, either work-as-executed (WAE) plans (SMEC (2013), Polkinghorne, Harrison and Longhurst Surveyors, (2015) and T.J. Hinchcliffe & Associates (2017)) or design drawings (NSW Public Works (2015a, 2015b, 2006)) and were used to inform the levee crest height for incorporation into the TUFLOW hydraulic model.

For modelling purposes, a 200 m long spillway has been assumed to be located adjacent to Carrington Street just south of the Darlington Point Sports Club. The purpose of the spillway is to allow for controlled filling inside the perimeter of the levee, prior to levee failure, should mainstream flood levels exceed the design crest level. Further information regarding the spillway is provided in Section 6.4.

All cross-drainage structures through the levee are (or will be upgraded to) culverts with floodgates at the outlet. As such, they are not required for inclusion in the Murrumbidgee River hydraulic model for assessment of mainstream flooding events.

4.2.2.5 Boundary Conditions

For the Murrumbidgee River floodplain model, the upstream boundary corresponds to input flow hydrographs on the Murrumbidgee River.

The downstream model boundary has been represented as water level-discharge relationship, where discharge estimates for a range of water levels are determined based on the channel cross-section and geometry. The downstream model limit is located sufficiently far downstream from the study area of interest such that is should not influence flood behaviour in the vicinity of the town. Additionally, similar boundary conditions have been set at select locations along the longitudinal model boundaries to simulate floodwater spilling onto the broader floodplain beyond the model extent. The location of the upstream and downstream model boundaries is shown on Figure 4-2.

4.2.3 Local Catchment Hydraulic Model

4.2.3.1 Extents and Layout

For the Darlington point township TUFLOW model, a grid cell size of 4 m was adopted. This provides adequate resolution to define local topographical controls such as road crests and local drainage paths. The extent of the design levee forms the boundary of the local hydraulic model, as shown in Figure 4-5. The Digital Elevation Model (DEM) and location of modelled drainage structures are also shown for reference.

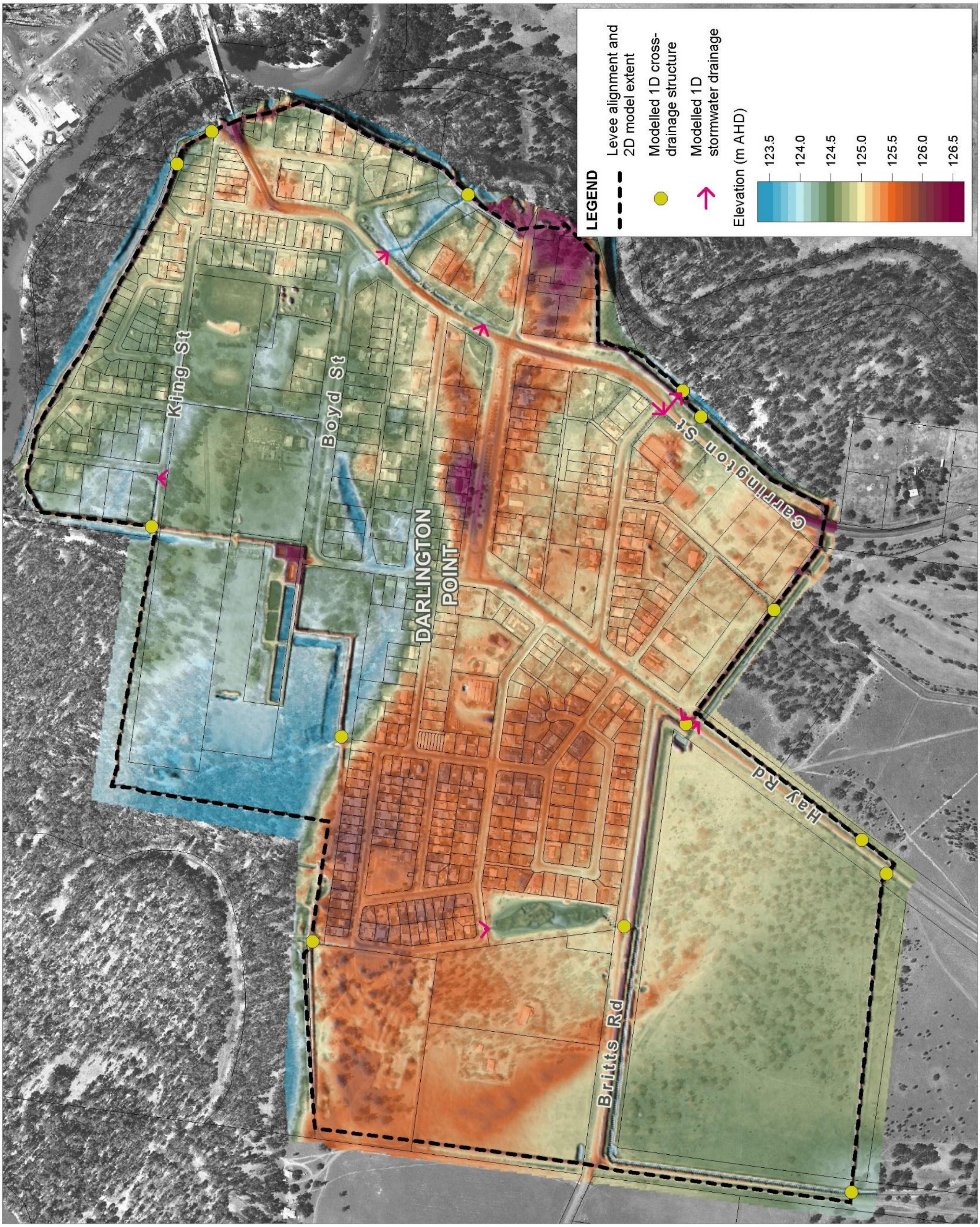
4.2.3.2 Hydraulic Roughness

As for the Murrumbidgee River hydraulic model, the development of the TUFLOW model requires the assignment of different hydraulic roughness zones. The different land use types identified for each hydraulic roughness zone can be seen on Figure 4-2. The roughness values adopted from the calibration process is discussed in Section 5.

4.2.3.3 Structures

There are a number of smaller culverts allowing for cross-drainage through the levee, roads and field embankments. To allow for both overland flow within the town centre and for filling of storages behind embankments, these minor flow connections have been incorporated into the 1D network which is dynamically linked into the 2D domain.

Levee cross-drainage structure dimensions were obtained from WAE or design drawings were appropriate. Invert levels were estimated from the available LiDAR dataset. The location and details of these are presented on Figure 4-6. All cross-drainage structures through the levee are (or will be upgraded to) culverts with floodgates at the outlet and as such have been modelled as “unidirectional” structures in TUFLOW.



Title:

Local Hydraulic Model Layout and DEM

Figure: 4-5

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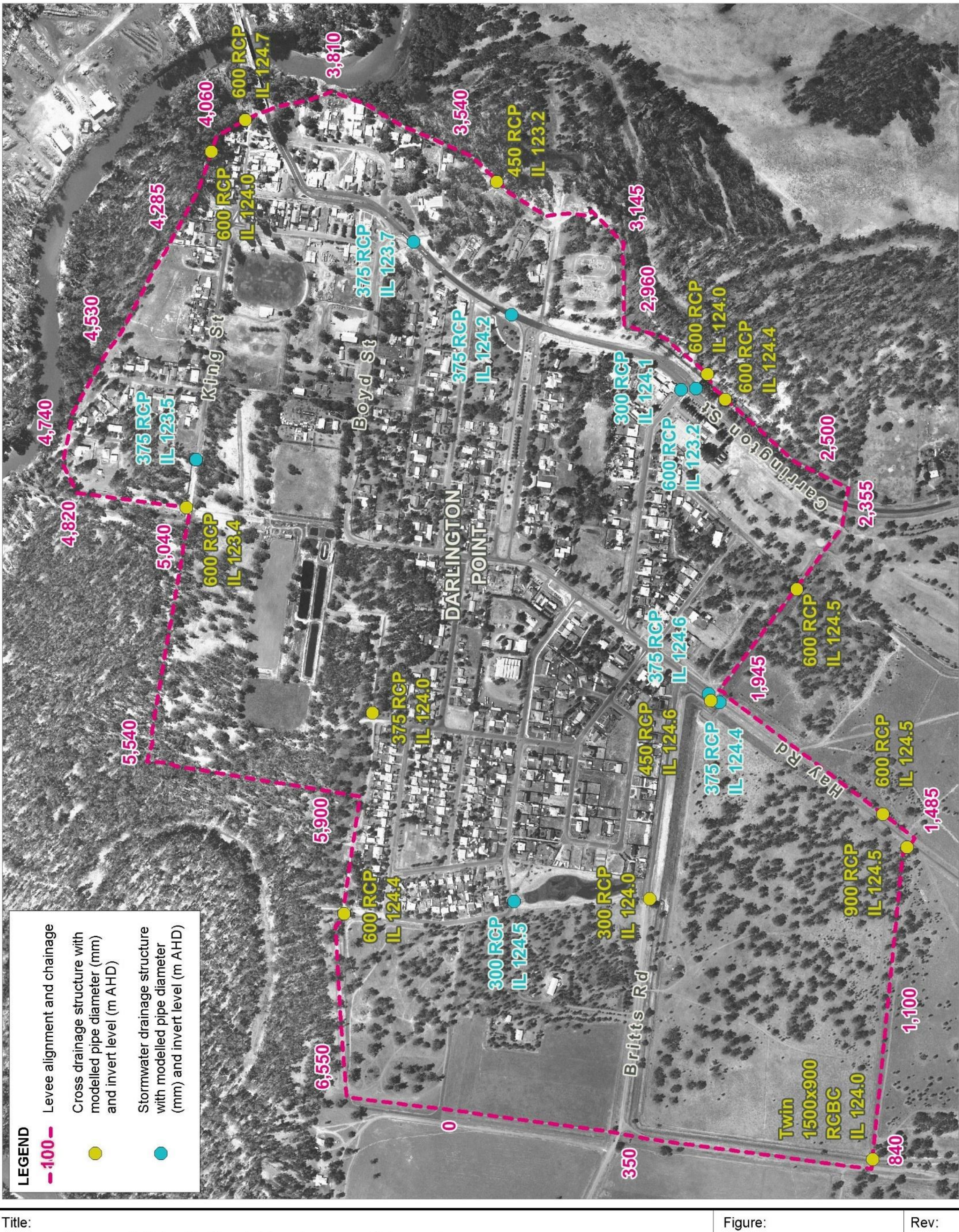

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Location of Modelled Drainage Structures

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There is no cross-drainage provided through the Area 4 levee section. It is understood that a pumping system will be utilised to discharge local runoff from behind the levee onto the floodplain at this location. Design conditions have been simulated without an operational pumping system.

The location and structure details (i.e. dimension and inverts) of stormwater drainage has been assumed from ground truthing and inspection of aerial / street-view photography and the LiDAR DEM. Assumed structure type, dimension and downstream invert levels are summarised on Figure 4-6.

4.2.3.4 Boundary Conditions

Local catchment runoff in the Darlington Point township model is determined through the hydrological model and is applied to the TUFLOW model as flow vs. time inputs. These are applied at appropriate locations within the town to model overland flow. All levee drainage outlets are elevated above typical Murrumbidgee River levels. However, when determining appropriate design conditions for runoff behind the levee, the likelihood of critical local rainfall conditions occurring coincidently with a Murrumbidgee River flood event was considered. Table 4-3 summarises the upstream (U/S) and downstream (D/S) invert levels of each of the cross-drainage structures on the eastern side of the levee against the peak Murrumbidgee River design flood levels at the outlet. Four of the five outlet structures would be inundated at the 20% AEP and 10% AEP design event. The other outlet would be inundated during a 5% AEP Murrumbidgee River flood event.

For simulation of local flood conditions behind the levee, a coincident 10% AEP Murrumbidgee River flood event has been assumed. At each of the identified inundated cross-drainage outlet structures, the downstream model boundary has been represented as a 1D water level equivalent to the 10% AEP Murrumbidgee River flood level. For outlets not inundated at the 10% AEP event, the boundary condition has been represented as a low 1D water level, allowing free discharge of floodwater onto the floodplain.

Higher river tailwater conditions can influence the critical duration of local rainfall behind the levee. When stormwater cannot freely discharge onto the floodplain, the critical conditions may be driven by a longer duration storm event with a greater total volume of rainfall. To assess the sensitivity of this, a 24-hour duration storm was simulated coincident with the equivalent Murrumbidgee River condition for each design event (e.g. a 24-hour duration 10% AEP local catchment rainfall event was simulated coincidently with a 10% AEP Murrumbidgee River flood event and a 1% AEP local catchment rainfall event was simulated coincidently with a 1% AEP Murrumbidgee River flood event etc.).

The results of this sensitivity analysis provided similar peak flood levels behind the levee (typically within 0.1 m). This coincident condition is regarded as being overly conservative due to the low likelihood of occurrence. However, it serves to confirm that the adopted design flood conditions do not significantly underestimate flood risk behind the levee.

Table 4-3 Cross Drainage Outlet and Design Murrumbidgee River Levels (m AHD)

ID	Pipe Size and Invert Level	Design Flood Event				
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1	RCP 600 U/S IL 124.4 D/S IL 124.0	124.5	125.1	125.5	126.0	126.2
2	RCP 600 U/S IL 124.0 D/S IL 123.4	124.5	125.1	125.5	126.0	126.2
3	RCP 450 U/S IL 123.2 D/S IL 123.0	124.5	125.0	125.5	125.9	126.1
4	RCP 600 U/S IL 124.75 D/S IL 124.7	124.3	124.7	125.1	125.4	125.5
5	RCP 600 U/S IL 124.0 D/S IL 123.5	124.2	124.6	125.0	125.3	125.4

5 Model Calibration

5.1 Selection of Calibration Events

The selection of suitable historical events for calibration of 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 suite of design events to be considered.

The calibration data available for the study area comprises principally the record at the Darlington Point water level gauge. The Darlington Point streamflow gauge has been in operation since 1939, with continuous time series records available from 1970. Due to the long period of record and high flow spot gaugings available at the gauge site, the model calibration process involved adjusting the TUFLOW HPC model configuration to match the modelled rating curve to the gauged flow records at the gauge site.

The streamflow gauge recorded major flood events in 1956, 1974 and 2012 as well as smaller events in 2010 and 2016. For the 1956 event, only a peak flood level at the gauge location was recorded. Multiple peak flood levels around town were also documented following this event.

There has been significant change to the Darlington Point floodplain over the years. Levee construction, urban development, road upgrades, replacement of the Murrumbidgee River bridge structure and other local topographic modifications will all influence local flood behaviour. The calibration process will be completed in light of the uncertainties surrounding exact catchment conditions at the time of each event. The 1956, 1974, 2010, 2012 and 2016 events will be utilised for model calibration.

5.2 Calibration Process

The focus of the model calibration process was to determine the most appropriate set of flow and roughness conditions for the model to be able to reasonably reproduce observed flood behaviour within the catchment.

As recorded flood levels are a function of both flows and roughness, there are a number of combinations of the two that will produce similar levels. Spot gaugings (measured combinations of flow rate and water level) recorded at streamflow gauge sites are a useful dataset for determining appropriate model roughness values. Spot gaugings recorded at the Darlington Point gauge site were obtained from the PINNEENA database released by the NSW Office of Water.

A rating curve defines the continuous relationship between flow rate and water level at a particular site. Within a 2D hydraulic model, the modelled rating curve for a given flow is a function of adopted roughness values and site geometry. Given the availability of LiDAR data to provide an accurate representation of the floodplain at this gauge site, the unknown parameters requiring calibration were channel capacity and roughness values.

The calibration process for this study firstly involved calibrating the modelled channel bed elevation and roughness to low, in-channel flows, before calibrating the floodplain roughness to higher, out-of-bank flows. This process is detailed in Section 5.2.1 and Section 5.2.2, respectively.

In addition to historic spot gauging records available from PINNEENA, continuous water level time series and flow hydrographs are available at the Darlington Point gauge site from 1970 onwards from the NSW Office of Water website. Once the hydraulic model configuration (i.e. channel/floodplain geometry and roughness) was confirmed, the flow hydrographs were applied as the upstream model inflow boundary to simulate each of the calibration events, as detailed in Section 5.2.3.

5.2.1 Channel Roughness and Bed Elevation

The shape of the modelled in-channel rating was calibrated by changing the adopted in-channel roughness and channel bed topography.

Figure 5-1 presents the recorded in-channel spot gaugings at the Darlington Point gauge and the corresponding modelled rating curve under a variety of adopted model configurations. There is a reasonable amount of “scatter” within the gauged flows which is influenced by whether water levels were rising or falling at the time of the gauging and the corresponding hysteresis effect. For each modelled scenario, there are two lines displayed on Figure 5-1 – the lower representing the rising limb of the hydrograph and the upper representing the falling limb i.e. the hysteresis effect.

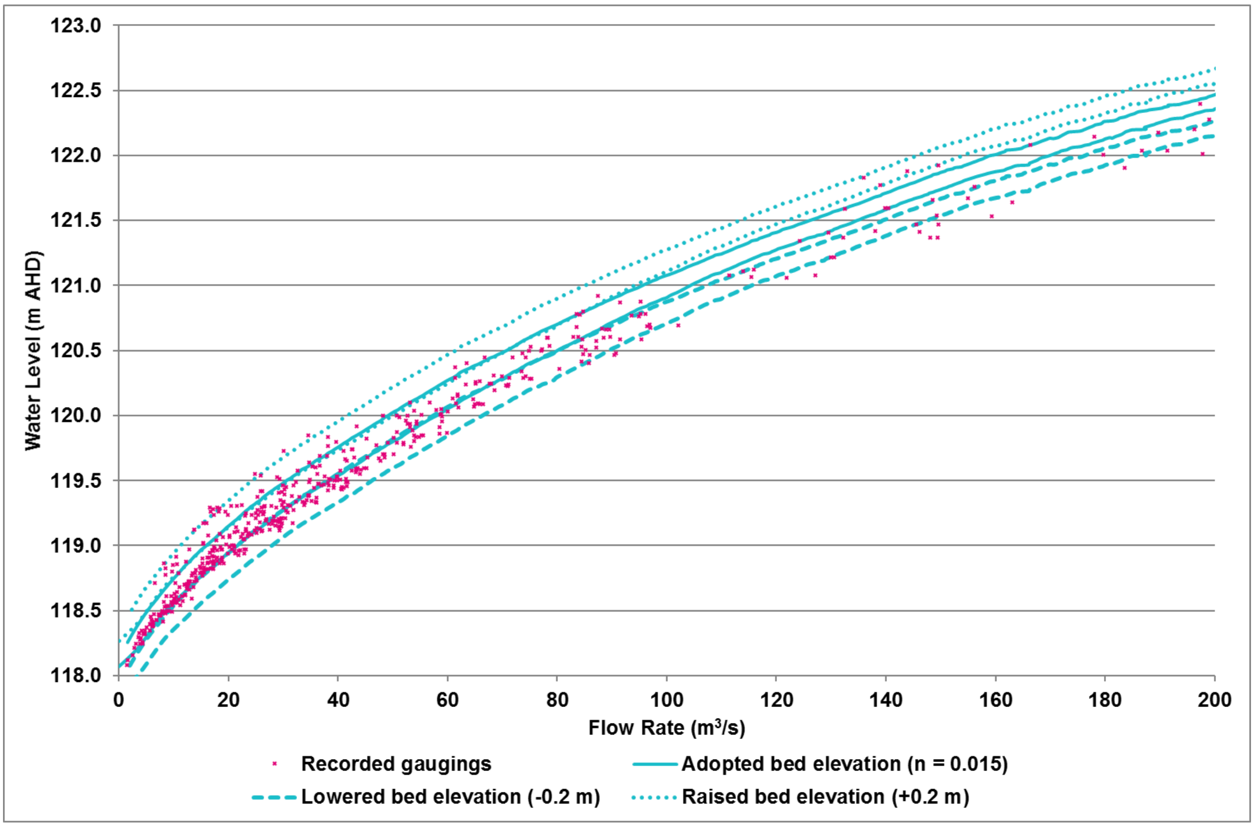


Figure 5-1 In-channel Model Calibration at the Darlington Point Gauge

The adopted channel bed level was based on the water surface level captured within the LiDAR data and was then adjusted to lower the bed level below the water surface. It was found that lowering the channel bed to 0.5 m below the water surface provided the best match to the recorded spot gaugings at the Darlington Point gauge. It can be seen from Figure 5-1 that raising or lowering the modelled bed level by 0.2 m from the adopted level results in modelled rating curves that do not align with the spot gaugings for the lowest recorded flow conditions. A modelled in-channel Manning's 'n' of 0.015 was found to provide the best match to the shape of the recorded in-channel sport gaugings. Raising or lowering the modelled in-channel Manning's 'n' results in the modelled rating curve deviating from spread of recorded spot gauging scatter.

The modelled channel bed profile is presented in Figure 5-2. The surveyed channel bed elevations typically demonstrate around a 1 m variation over relatively short distances. This is expected as river channels naturally develop an undulating bed comprising of shallower "riffles" and deeper "pools" situated between them. In terms of modelling the hydraulic conveyance capacity of the river channel, it is the bed levels of the higher riffles that act as the principal hydraulic controls. Also, there are often localised deeper spots within the channel sections, such as on the outside of river bends.

Figure 5-2 shows that the adopted channel bed profile is typically representative of the channel bed level within the riffle sections, where the channel width at that elevation is at or above 20 m. There are localised deep spots up to 2 m below the modelled channel bed that do not influence the hydraulic conveyance of the river channel, as demonstrated in Figure 5-2.

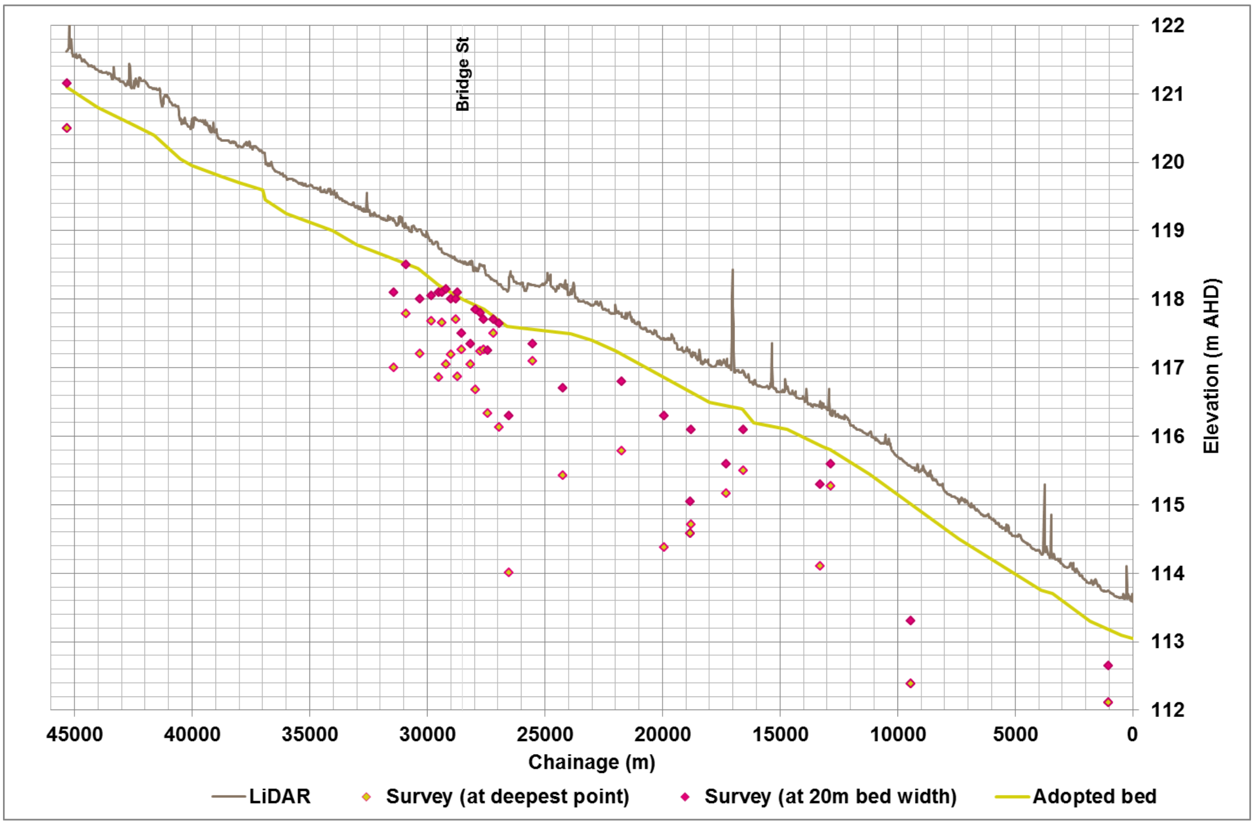


Figure 5-2 Modelled Channel Bed Profile

5.2.2 Floodplain Roughness

Calibrating a hydraulic model to high flows at a streamflow gauge can often be difficult, as high flow gaugings only exist when a flood has occurred within the catchment and a water level and flow has been recorded during the event. A large number of spot gaugings at high flow rates can provide a good rating curve (flow vs. level relationship), which can be matched within the model by selecting an appropriate roughness value. Fortunately, the Darlington Point gauge has a relatively good set of larger magnitude spot gaugings due to the occurrence of multiple flood events since its installation.

With the model parameters of the in-channel hydraulics calibrated, the calibration process progressed to analysis of the floodplain hydraulics. The floodplain topography and associated hydraulic controls are essentially fixed by the LiDAR elevations, with no justification for adjustment. This allows the calibration of appropriate floodplain Manning's 'n' roughness parameters, so that the hydraulic model continues to match the recorded spot gaugings throughout the out-of-bank flood flow range. This process resulted in a Manning's 'n' of 0.12 being adopted within the vegetated floodplain. A Manning's 'n' of 0.04 was adopted for the cleared floodplain areas.

Figure 5-3 presents the full set of recorded spot flow gaugings at Darlington Point, together with modelled rating curves for the 1974 and 2012 flood events. The two rating curves deviate for flows above around 800 m^3/s, which can be attributed to the changed bridge and approach road conditions. The modelled 1974 rating curve matches well to the flow gaugings measured during the event (three points above 800 m^3/s, recorded using a standard current meter). The flow gaugings measured during the 2012 event show a lower flow rate at the corresponding gauge level than the 1974 rating exhibits.

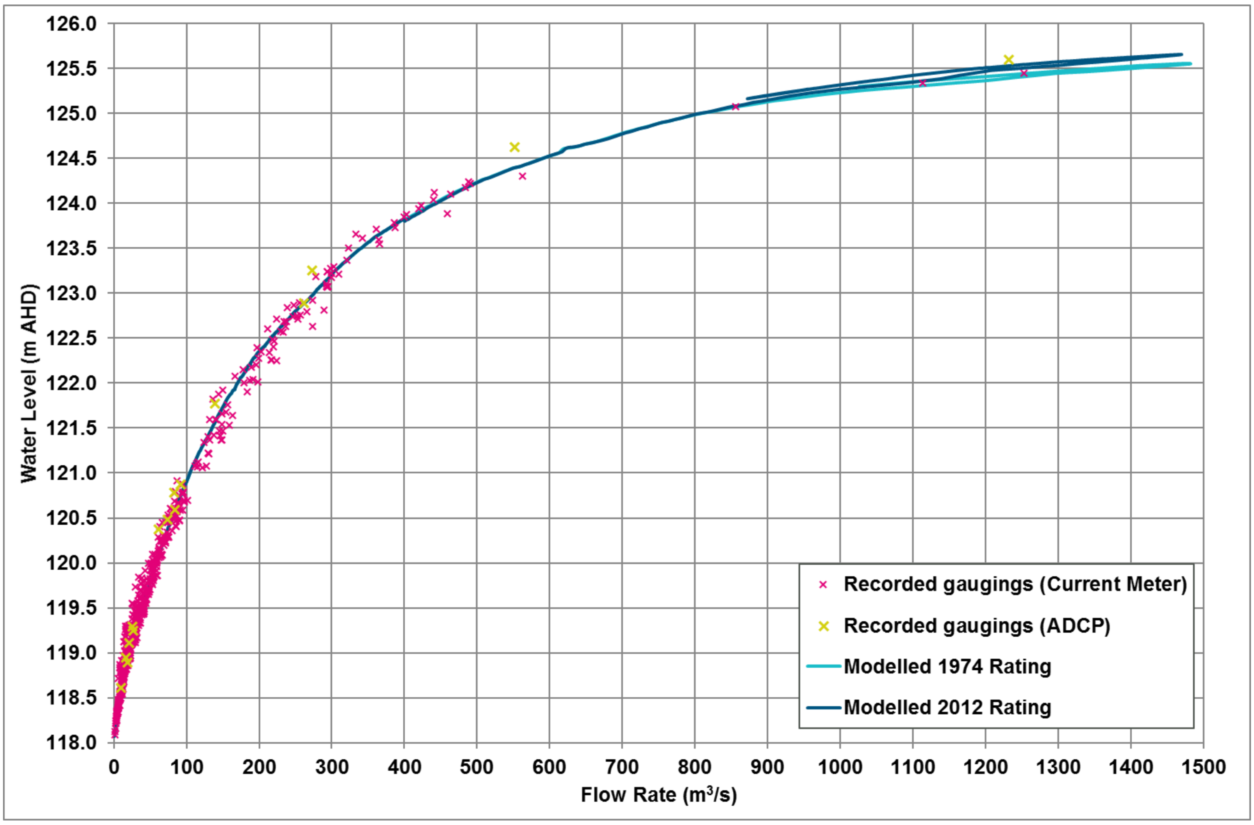


Figure 5-3 Out-of-bank Model Calibration at the Darlington Point Gauge

This apparent flow reduction is systematic within flow gaugings measured on the Murrumbidgee River using the newer ADCP (acoustic doppler) equipment than with the traditional propeller-based current meter equipment, as documented by Hayes et al (2012). The difference in measured flows is more pronounced during higher flow conditions and is likely the result of bed mobility during flood conditions. This potential under-estimation of flow may account for some or all of the observed difference between the 1974 rating. It is also noted that the spot gaugings measured during the 2012 flood event did not account for bypass flows spilling over the roads that traverse the floodplain and were limited to the main channel area between Darlington Point and North Darlington Point.

This theory differs from assumptions made in previous studies along the Murrumbidgee River, including at Narrandera (Lyall & Associates, 2015), where it was found that different representation of the density of floodplain vegetation through Manning's 'n' values was required to achieve good calibration to both the 1974 and 2012 historic events. This was justified though anecdotal evidence of changed farming and agricultural practices that prohibited gazing of riparian vegetation in recent years. Local residents suggested that this change in farming practice was not replicated in Darlington Point, supporting the assumptions made in this current study.

For flows below around 600 m^3/s, the rating curve was found to be highly sensitive to the shape of the adopted inflow hydrograph applied at the upstream model boundary. The modelled hysteresis effect (i.e. a "looped" rating curve that follows a different trajectory on the rising and falling limb of the flow hydrograph) at the site was found to be considerable when "steep" inflow hydrographs. Slower rising inflow hydrographs were found to give a rating curve at the gauge site that displayed less hysteresis. The general scatter of recorded spot gaugings at the site can be explained by this phenomenon.

The final roughness values adopted are shown in Table 5-1 and were found to give a good result in representing the recorded water levels at the Darlington Point streamflow gauge for the range of historic events considered.

Table 5-1 Adopted Model Roughness Parameters

Land use type	Value
Channel	0.015
Vegetated floodplain	0.12
Cleared floodplain	0.04
Urban	0.06
Sealed roads	0.03

5.2.3 Historical Model Inflows

Having established appropriate topographical and roughness parameters for the TUFLOW HPC model to replicate the recorded spot gaugings, recorded hydrographs from the Darlington Point gauge were input to the model to simulate the September 1974, December 2010, March 2012 and September 2016 flood events. The inflow hydrographs were scaled to provide the corresponding modelled peak flood level that matched the recorded data at the gauge. It was necessary to adjust the inflows some nine hours earlier to account for the travel time between the model inflow boundary (some 17 km upstream) and the gauge location. The July 1956 flood event was also simulated, although no recorded hydrograph was available. In lieu of recorded data, the March 2012 event hydrograph shape was adopted.

Table 5-2 presents the modelled peak flows and levels at the Darlington Point gauge site for the simulated calibration events.

Table 5-2 Modelled Peak Flood Conditions for Calibration Events

Flood Event	Peak Gauge Flow (m^3/s)	Peak Gauge Level (m AHD)
July 1956	1190	125.33
September 1974	1420	125.55
December 2010	775	125.01
March 2012	1360	125.61
September 2016	791	125.04

It should be noted that the model inflow hydrograph has been scaled to match the recorded peak gauge level. The flow required to match the recorded peak level is a function of the model rating curve at the gauge site. The modelled water level against the recorded data for the March 2012 event at the Bridge Street gauge location is presented in Figure 5-4.

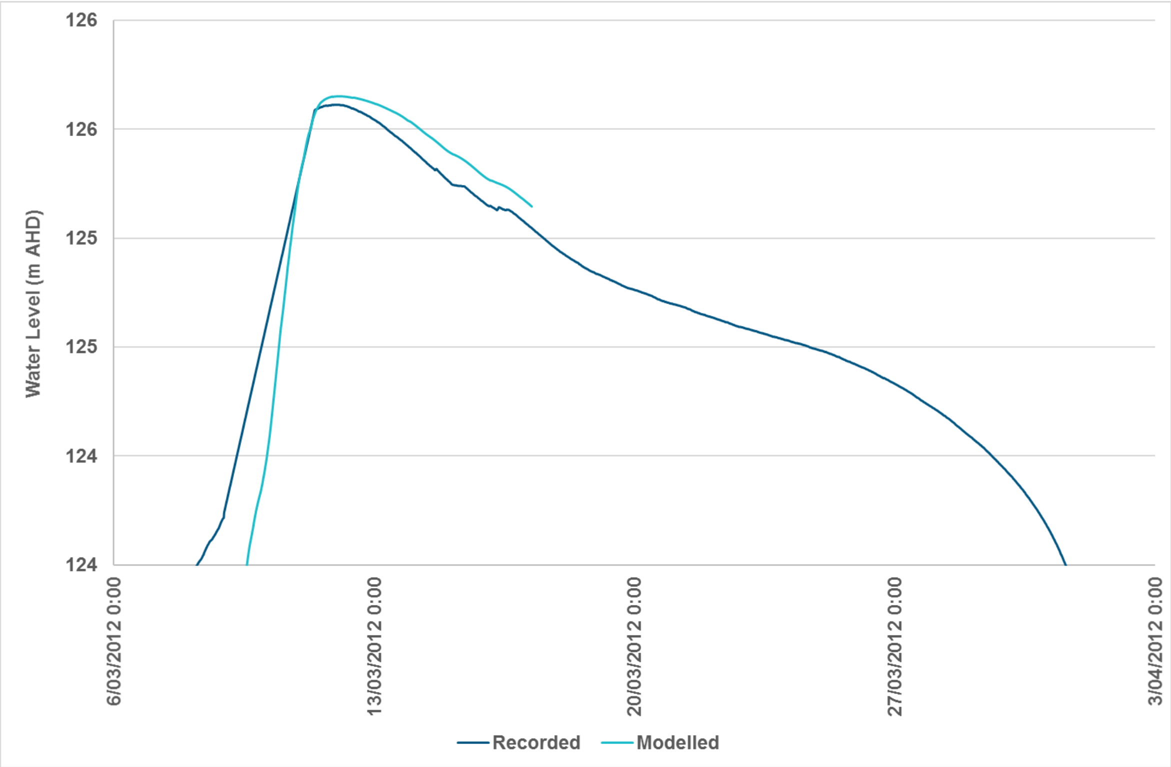


Figure 5-4 Comparison of Recorded and Modelled Water Levels at the Bridge Street Gauge for the March 2012 Event

Modelled peak flood levels along the Murrumbidgee River centreline for each of the calibration events considered is shown in Figure 5-5. Chainages extend from the upstream model limit (chainage. 0 km) to the downstream model limit (ch. 45.8 km).

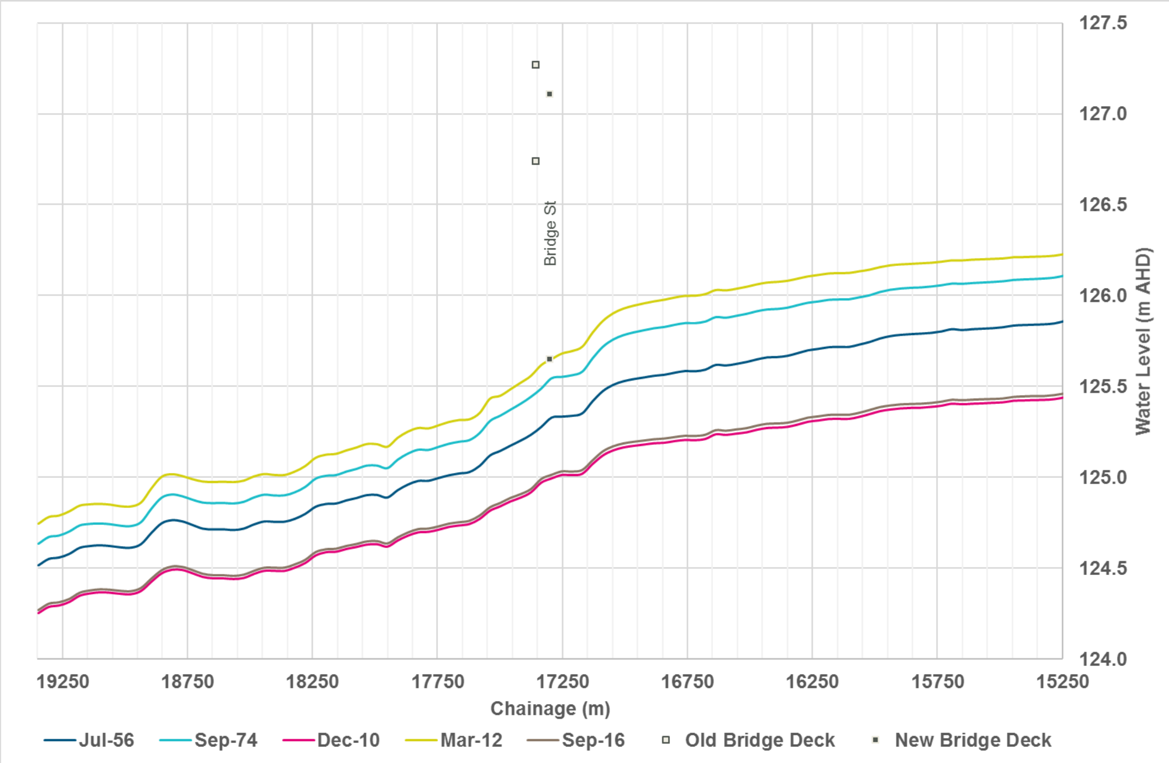
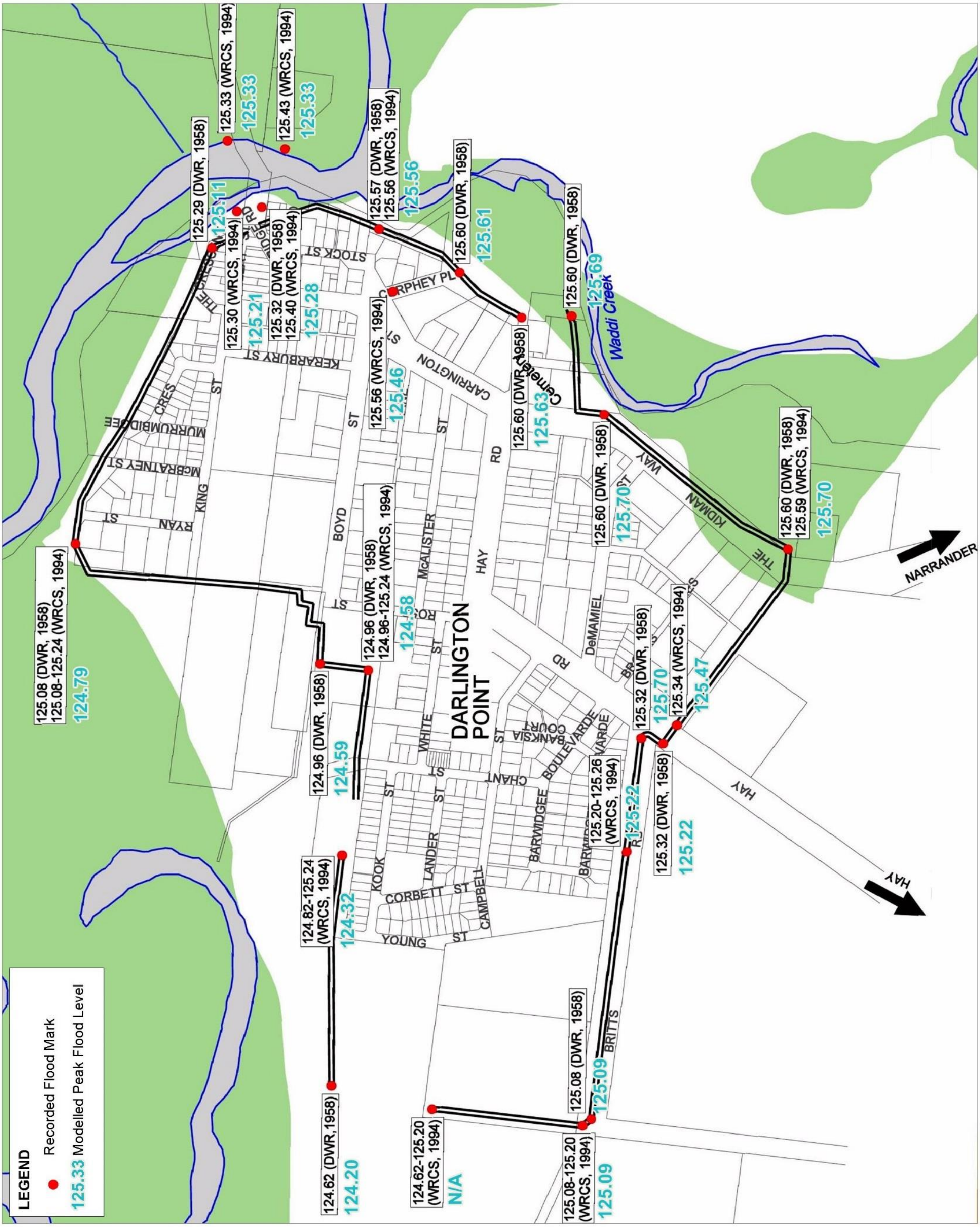


Figure 5-5 Modelled Murrumbidgee River Peak Flood Levels for Calibration Events

Without alternative sources of recorded peak water levels there is no other means by which to assess the model performance. However, there is some additional data available for the 1956 flood event within the *Darlington Point Levee Gradient Sensitivity Analysis* (WorleyParsons, 2009a).

The peak flow estimate determined by hydrographers following the 1956 event is given as 1045 m^3/s and is similar to that modelled within TUFLOW. However, this is limited to flows between Darlington Point and North Darlington Point and does not include bypass flows spilling across the roads to the north and south, which account for around an additional modelled 150 m^3/s. A map of recorded peak flood levels at Darlington Point is also available and is reproduced in Figure 5-6, together with the modelled peak flood levels.

It can be seen that there is a reasonable match between the modelled and observed levels, typically being within around 0.1 m difference. However, for flood mark locations along the western side of Darlington Point, the modelled levels are typically around 0.4 m lower than the observed. It should be noted that due to the event being some 60 years ago there have potentially been significant topographic changes that may influence local flood levels. Also, a levee was hastily constructed during the event, along the existing levee alignment. The exact details of the levee construction are unknown and depending on what was constructed where (and at what time), this could also significantly impact locally recorded flood levels. For the purposes of the model calibration simulation, the levee was included along the eastern and northern alignments, albeit with a breach location to allow flow through the town, as was known to have occurred.



Title:

July 1956 Recorded Peak Flood Mark and Modelled Peak Flood Level Comparison

Figure: 5-6

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6 Design Flood Conditions

6.1 Simulated Design Events

Design floods are hypothetical floods used for planning and floodplain management investigations. They are based on having a probability of occurrence specified as Annual Exceedance Probability (AEP) expressed as a percentage. Definition of an AEP is contained in Table 6-1.

Table 6-1 Design Flood Terminology

AEP	Comments
0.2%	A hypothetical flood or combination of floods which represent the worst case scenario with a 0.2% probability of occurring in any given year.
0.5%	As for the 0.2% AEP flood but with a 0.5% probability.
1%	As for the 0.2% AEP flood but with a 1% probability.
2%	As for the 0.2% AEP flood but with a 2% probability.
5%	As for the 0.2% AEP flood but with a 5% probability.
20%	As for the 0.2% AEP flood but with a 20% probability.
Extreme Flood / PMF[1]	A hypothetical flood or combination of floods which represent an extreme scenario.

1 A PMF (Probable Maximum Flood) is not necessarily the same as an Extreme Flood. This report has adopted the Extreme Flood terminology, as the method adopted (3 x 1% AEP flood flows) is not that of a PMF..

The design events to be simulated include the 20% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and Extreme Flood events. The 1% AEP flood is generally used as a reference flood for development planning and control for residential development.

In determining design flood conditions, it is necessary to consider the following:

- **Flood frequency analyses** at locations of historic flood records. These provide a statistical estimate of design peak flow conditions from the available recorded data and are used to in conjunction with the design rainfall outputs from the hydrological model to establish appropriate design flood conditions, particularly as the major inflow at the upstream extent of the hydraulic model.
- **Design rainfall parameters** (rainfall depth, temporal pattern and spatial distribution). These inputs drive the hydrological model, from which design flow hydrographs will be extracted as local inputs to the hydraulic model.
- **Simulation of a levee spillway** in accordance with OEH guidelines.

- **Sensitivity assessment** of adopted model parameters and conditions.

6.2 Flood Frequency Analysis

If the TUFLOW HPC model rating is reliable then the modelled peak flows at the Darlington Point gauge should be representative of the actual peak flow conditions during each flood event. A range of flood flow magnitude event hydrographs were simulated within TUFLOW and the modelled peak flow and water levels were used to derive a representative rating curve for the Darlington Point gauge. This rating curve is presented in Figure 6-1, together with the Rating 155 which is currently used at the site. The modelled 1974 rating curve is also presented. The adopted site rating is reasonably similar to those which have been modelled. However, for flows below 800 m^3/s the site rating provides slightly higher flows than the modelled rating. The modelled rating for the present-day conditions is also around 0.1 m higher than that of the modelled 1974 conditions for flows above 800 m^3/s.

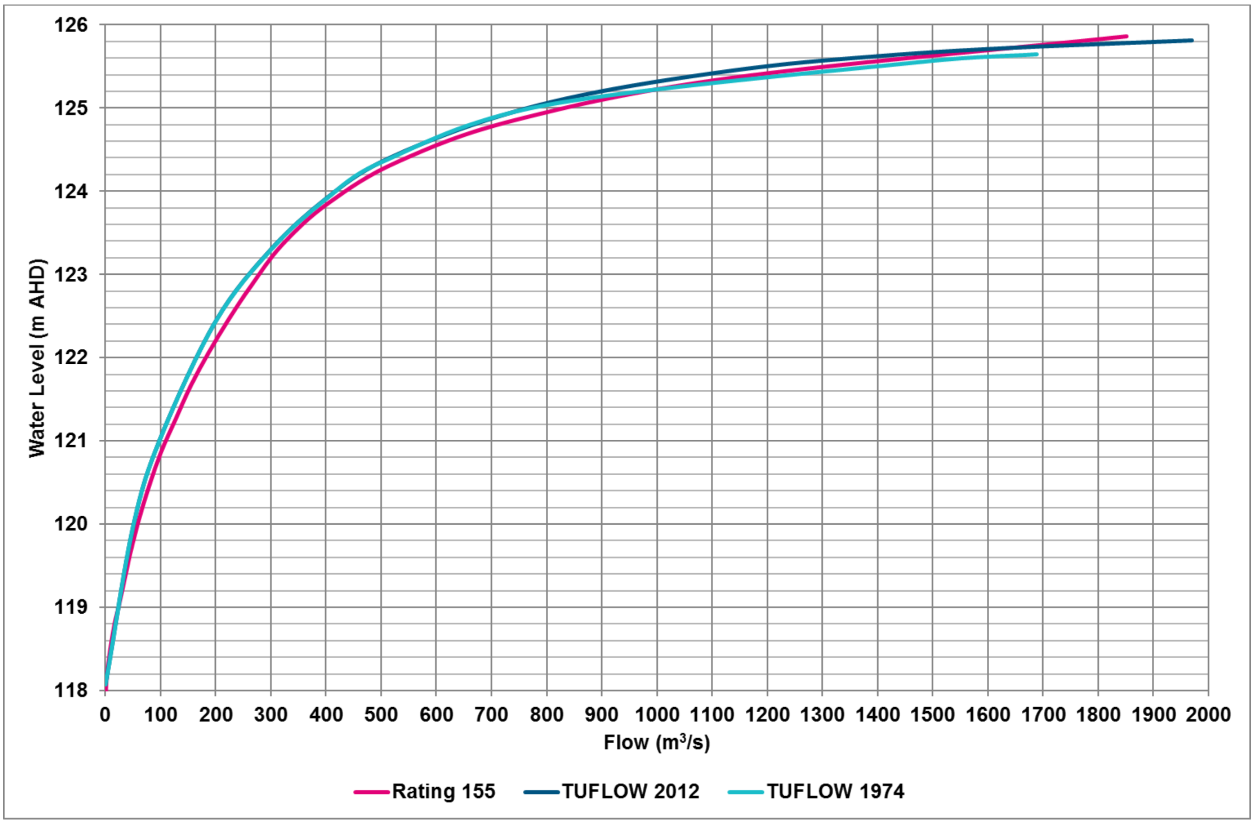


Figure 6-1 Modelled Rating Curve

The TUFLOW FLIKE extreme value analysis package was used to undertake the flood frequency analysis. Developed by Professor George Kuczera from the School of Civil Engineering at the University of Newcastle Australia, TUFLOW FLIKE is compliant with the recent major revision of industry guidelines for flood estimation, documented in ARR 2016.

The FLIKE analysis used a Bayesian inference method with the Log Pearson (LPIII) probability model. The FLIKE package has the capability to perform probabilistic analysis with other models, including Log-normal, Gumbel, Generalised Extreme Value and Generalised Pareto. However, the LPIII distribution was selected as it provided the best fit against the recorded data.

The flood frequency analysis had a total of 103 annual maxima available. The annual maxima (AMAX) for the years 1970 through 2016 were extracted from the Darlington Point gauge record available through the WaterInfo site. The data for the years 1914 through 1969 were obtained from the Darlington Point Levee Gradient Sensitivity Analysis. This initial AMAX series was than adjusted to be consistent with the modelled ratings. The peak flow series was first reduced by around 5% to convert from the site rating to the modelled rating. For flows above 800 m^3/s (essentially the model calibration events) the values were manually specified using the appropriate modelled rating. These adjustments are summarised in Table 6-2.

Table 6-2 Adjusted Annual Maxima Values

Flood Event	Site Rating Flow (m^3/s)	Modelled Rating Flow (m^3/s)
July 1956	1014	1190
September 1974	1368	1460
December 2010	820	775
March 2012	1311	1360
September 2016	838	791

There are four significant floods on record having occurred prior to installation of the stream gauge at Darlington Point. These floods occurred in 1852, 1853, 1870 and 1891. Previous investigations assessing the flood frequency at Wagga Wagga and Narrandera has focused on estimating the magnitude of these historical peak flows and their consequent inclusion (or not) as historical ungauged flows above specified flow thresholds. These investigations concluded that the construction of Burrinjuck Dam and the presence of floodplain vegetation have a significant influence over the relative magnitude of historic events.

Supplementing the Darlington Point gauge record with adjacent gauges for the period prior to 1913 would provide little in terms of input to the flood frequency analysis due to uncertainties surrounding the release flow regime of the dam, in addition to uncertainties associated with correlating flow magnitudes between each gauge location. The available data set at the Darlington Point gauge allows for an annual maximum series for a period of more than 100 years to be established, which is typically regarded as a good sample size for this type of analysis. It was therefore decided that extending the continuous annual series beyond the available dataset (1913-present) was not warranted.

Based on the review of the existing flood frequency analyses, only the 1870 flood can be justified for inclusion in the Darlington Point analysis, given significant uncertainty surrounding the other pre-record events. If adopted, the 1870 flood flow threshold (when accounting for construction of the Burrinjuck Dam) would be lower than the two largest events in the annual maxima record and therefore would have little impact on the analysis in any case.

The fitted LPIII distribution is presented in Figure 6-2 along with the 90% confidence limits and plotting positions of the observed annual maxima. The design peak flood flows derived from the Darlington Point flood frequency analysis are presented in Table 6-3. The previous design flood flow estimates from the 2009 Levee Gradient Sensitivity Analysis are also presented in Table 6-3 for comparison. The design peak flows are similar to those previously derived for the events up to the 1% AEP magnitude. However, the peak flows for the 0.5% AEP and 0.2% AEP events are lower than those which were previously derived, which is largely a function of the LPIII distribution being selected over the GEV. For comparison, when adopting the GEV distribution the revised Flood Frequency Analysis provides peak flow estimates around 2170 m^3/s and 2970 m^3/s for the 0.5% AEP and 0.2% AEP events respectively. This is significantly higher than the previously derived values and is likely due to the inclusion of the recent large magnitude flood event of March 2012.

Table 6-3 Design Peak Flood Flows

Design Event	This Study (m^3/s)	2009 Study (m^3/s)
20% AEP	500	510
10% AEP	690	670
5% AEP	880	850
2% AEP	1160	1140
1% AEP	1390	1410
0.5% AEP	1620	1730
0.2% AEP	1950	2280

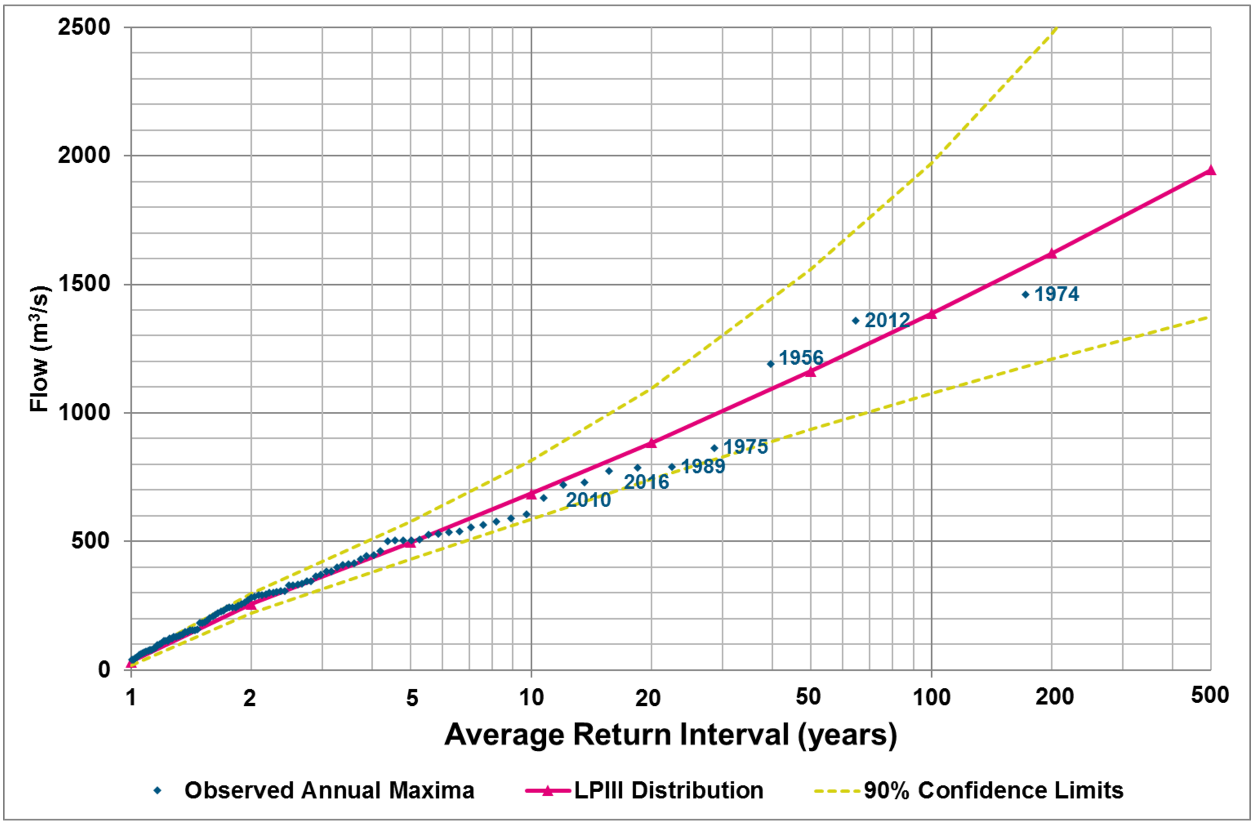


Figure 6-2 Flood Frequency Analysis for the Murrumbidgee River at Darlington Point

6.2.1 Adopted Design Flows

Having determined design peak flood flow magnitudes through Flood Frequency Analysis, an appropriate design flood hydrograph shape was derived. The model calibration events with recorded hydrograph records were plotted together and a representative design hydrograph shape was selected. Typical flood event durations were maintained for flow conditions above and below 800 m^3/s. The adopted design flood hydrographs are presented in Figure 6-3, with the calibration event hydrographs also presented for comparison. For more frequent flood events up to the 5% AEP magnitude the hydrograph extends over a period of around three weeks. It has a relatively flat shape, with the peak being reached after around six days. For the rarer flood events above the 5% AEP magnitude the broader three-week hydrograph shape was maintained, but the magnitude of the initial flood peak was further increased. This provides a hydrograph shape that is dominated by an initial peak extending over a duration of around ten days and then gently receding over the subsequent ten-day period.

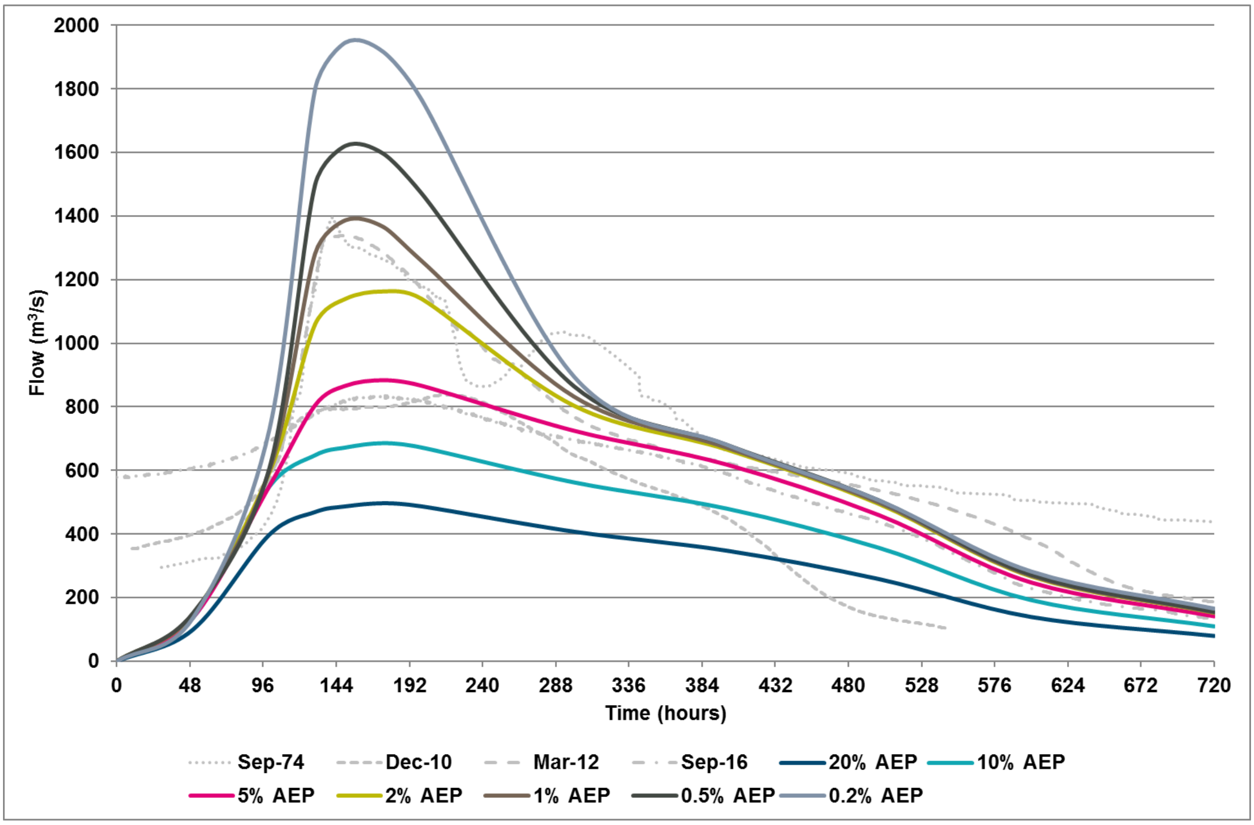


Figure 6-3 Adopted Design Flood Hydrographs for the Murrumbidgee River at Darlington Point

For this study, peak design flows on the Murrumbidgee River have been derived using a flood frequency analysis. As a hydrologic model was not developed for the Murrumbidgee River catchment, it was not possible to derive the PMF flood event using the standard Probable Maximum Precipitation method outlined in ARR. The “Extreme” flood terminology has therefore been adopted in this study, and represents an approximate PMF flood event. For large river systems such as the Murrumbidgee River, estimating an Extreme flood flow as three times larger than the 1% AEP flow is a standard approach and has been adopted for other flood investigations in the region, including further upstream on the Murrumbidgee River at Narrandera (Lyall and Associates, 2015). This study has therefore estimated an Extreme flood as three times larger than the 1% AEP design flood flow. If extrapolating the FFA in Figure 6-2, the Extreme Flood flow of around 4200 m^3/s represents a design event magnitude in the order of a 0.001% AEP, which is within the typical range expected of a PMF event.

6.3 Design Rainfall

Local catchment rainfall-runoff within the levee extent has also been considered for the determination of design flood conditions at Darlington Point.

The ARR 2016 update was released in December 2016 and currently represents the best practice guideline for the industry. The updated procedures provide some significant changes to previous procedures. Some of the most notable changes in ARR 2016 are summarised below:

- rainfall depths – the revised IFD rainfall estimates underpin the ARR 2016 release. The updated IFD analysis includes a significant period of additional rainfall data collected since the release of IFD 1987. Variation in rainfall between the 1987 and 2016 IFDs is location dependent
- rainfall losses – the estimation of initial and continuing loss rates is provided in ARR 2016 as gridded spatial data. Representative losses for catchments are extracted from the database which is a significant change from ARR 1987 whereby basic loss ranges were recommended for broad areas i.e. eastern or western NSW
- pre-burst rainfall – ARR 2016 provides procedures for pre-burst rainfalls for consideration along with design rainfall initial losses
- areal reduction factors – new equations were developed as part of ARR 2016 with regionalised parameters to define the areal reduction factor for catchments based on area and storm duration, and
- temporal patterns – each design duration now has a suite of 10 temporal patterns (opposed to a single temporal pattern) for each duration.

Input data for the design rainfall analysis can be obtained online through the ARR 2016 Data Hub. This data has been included in Appendix B.

6.3.1 Rainfall Depths

Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in ARR 2016. These curves provide rainfall depths for various design magnitudes (up to the 0.2% AEP) and for durations from 5 minutes to 96 hours. Table 6-4 shows the average design rainfall depths applicable to the centre of the Darlington Point township, based on the ARR 2016 IFDs.

The Probable Maximum Precipitation (PMP) is used in deriving the Probable Maximum Flood (PMF) event. The PMP is defined as “the theoretical greatest depth of precipitation that is physically possible over a particular catchment” (ARR 2016). The PMP has been estimated using the Generalised Short Duration Method (GSDM) derived by the Bureau of Meteorology (1998). The GSDM method for the estimation of the PMP provided an average rainfall intensity of 97 mm/h for the 6-hour storm duration.

Table 6-4 Average Design Rainfall Depths (mm)

Storm Duration (h)	Design Event Frequency							
	1-EY[1]	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
2	18.1	28.3	33.9	39.6	47.5	53.9	60.9	70.0
6	26.0	40.2	48.0	56.0	67.1	76.1	86.0	98.9
9	29.5	45.5	54.2	63.2	75.6	85.6	96.7	111
12	32.3	49.5	58.9	68.6	82.0	92.7	104	120
24	39.0	59.6	70.9	82.4	98.0	110	124	142
36	42.7	65.5	77.9	90.4	107	120	133	151
48	45.1	69.4	82.6	95.9	113	127	139	157
72	48.1	74.4	88.6	103	121	135	149	168

[1] Exceedances per Year (EY) is the number of times an event is likely to occur or be exceeded within any given year (ARR 2016)

6.3.2 Areal Reduction Factors

An Areal Reduction Factor (ARF) is to be applied to the design point rainfall depths and is dependent on catchment size. As previously noted, new equations have been developed as part of ARR 2016 with regionalised parameters to define an event specific areal reduction factor for catchments based on catchment size and storm duration. The calculated areal reduction factors for each of the modelled design events and durations are presented below in Table 6-5. ARFs have been determined for a 2.8 ha catchment.

Table 6-5 Areal Reduction Factors

Duration (h)	Design Event Frequency				
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
9	0.9925	0.9916	0.9908	0.9896	0.9888
12	0.9936	0.9927	0.9919	0.9907	0.9899
24	0.9962	0.9958	0.9954	0.9949	0.9945

6.3.3 Rainfall Losses

Initial and continuing loss values for pervious catchment areas (including pre-burst rainfall depths) were determined in accordance with methods outlined in ARR 2016 for a catchment located in the Murrumbidgee River basin. Storm initial loss rates and continuing loss rates are provided as gridded spatial data, based on geographical location. The initial loss (burst loss) for a study catchment is determined based on the following:

Burst Loss = Storm Initial Loss – Pre-burst rainfall

In the above equation, the storm initial loss is a fixed rainfall depth and the pre-bust rainfall depth is varied dependant on catchment location, storm duration and storm probability. More detail is provided within this section.

Impervious areas were assigned an initial loss of 1 mm/h and a continuing loss of 0 mm/h.

6.3.3.1 Storm Initial and Continuing Loss Rates

The pervious loss rates for the Murrumbidgee River catchment at Darlington Point were extracted from the ARR 2016 Data Hub (see Appendix B) and are as follows:

- Storm Initial Losses = 27.0 mm
- Storm Continuing Losses = 0.0 mm/h

6.3.3.2 Preburst Rainfall Depths

As discussed in Section 6.3.3, pre-burst rainfall depths are dependent on catchment location, storm duration and storm probability. The ARR Data Hub hosts a selection of pre-burst depth tables (i.e. Median, 10%, 25%, 75% and 90%) relevant to a catchments location.

The median pre-burst depths have been used in the estimation of design rainfall. Table 6-6 below shows the varied median pre-burst depths for each modelled design event and duration.

Table 6-6 Median Pre-burst Depths (mm)

Duration (h)	Design Event Frequency				
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
9	0.8	1.1	1.5	1.6	1.6
12	0.5	0.8	1.1	1.6	1.9
24	0.0	0.0	0.0	0.2	0.4

6.3.3.3 Burst Losses

The burst losses for the Murrumbidgee River catchment have been calculated using the value for storm initial loss and the median pre-burst depths. Design burst losses are shown in Table 6-7.

Table 6-7 Design Burst Losses (mm)

Duration (h)	Design Event Frequency				
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
9	26.2	25.9	25.5	25.4	25.4
12	26.5	26.2	25.9	25.4	25.1
24	27.0	27.0	27.0	26.8	26.6

6.3.4 Temporal Patterns

Temporal patterns are required to define what percentage of the total rainfall depth occurs over a given time interval throughout the storm duration. Under ARR 2016, ten temporal patterns are defined for each storm duration for each design event magnitude. The procedures for ARR 2016 provide for the selection of the temporal pattern that gives the peak flow closest to the mean of the peak flows from all ten temporal patterns. This method was followed to find the critical temporal pattern for each event duration.

Figure 6-4 shows the flow hydrographs at the outlet of sub-catchment 18 and 19 generated from each of the ten 1% AEP 9-hour duration design temporal patterns. The temporal pattern giving the mean peak flow is highlighted black (temporal pattern ID 4058). Due to the discrete nature of the sub-catchments behind the levee, not all catchment outlet points had the same critical temporal pattern. The temporal pattern deemed to give the best match across the whole local catchment area was selected and applied to all sub-catchments for each design event for simplicity, as the overall impact on the estimation of design peak flood levels is insignificant.

The temporal pattern ID adopted for each design event and duration is summarised in Table 6-8.

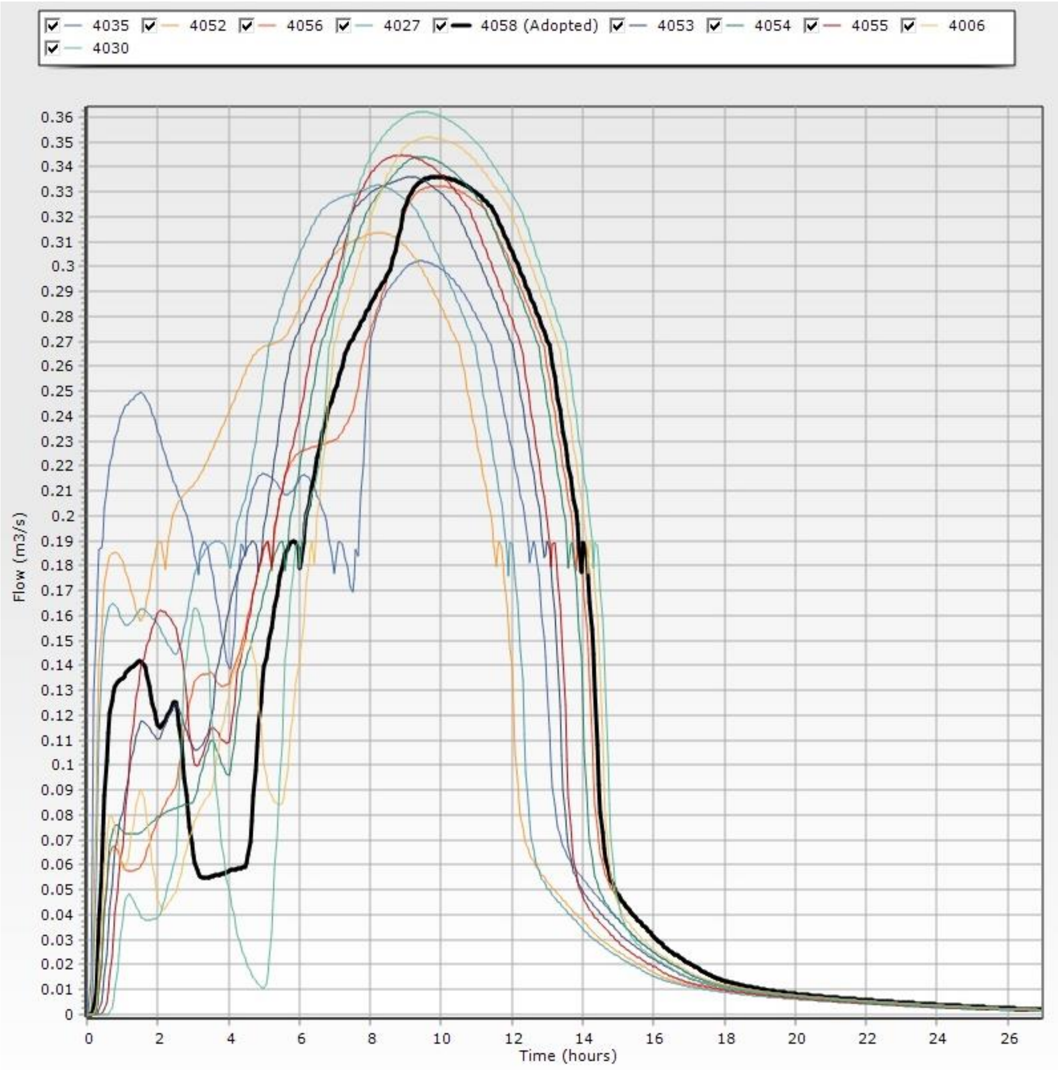


Figure 6-4 1% AEP 9-hour Duration Temporal Patterns for Outlet of Sub-catchment 18 and 19

6.3.5 Critical Durations

The critical duration is the storm duration for a given event magnitude that provides for the peak flood conditions at the location of interest. For example, small catchments are more prone to flooding during short duration storms, while for large catchments longer durations will be more critical.

The critical local catchment flood conditions are also dependent on the coincidence of flood conditions within the Murrumbidgee River. As levee cross-drainage structure outlets are elevated much higher than typical Murrumbidgee River levels, outlets would not become submerged until Murrumbidgee River levels reached or exceeded the 20% AEP design flood event. To consider a critical duration local rainfall event behind the levee occurring coincidentally with the peak of a Murrumbidgee River flood of similar magnitude would be overly conservative. Therefore, a 10% AEP Murrumbidgee River flood event was adopted to occur coincidently with all local catchment runoff events. Further detail is provided in Section 4.2.3.4.

Due to the flat nature of the local topography and the presence of the levee embankment, the total runoff volume is likely to be a principal determining factor for local catchment flood risk.

Table 6-8 summarises the critical storm durations adopted for each design flood event.

Table 6-8 Adopted Temporal Pattern and Critical Duration

Event	Temporal Pattern ID	Critical Duration
20% AEP	4154	24 h
10% AEP	4087	12 h
5% AEP	4087	12 h
2% AEP	4058	9 h
1% AEP	4058	9 h

6.4 Levee Spillway

The Darlington Point levee is designed to a 1% AEP standard of protection, with a freeboard of 0.75 to 1.0 m to the levee crest. Although the design level of the levee is above the 0.5% AEP and 0.2% AEP flood levels, failure of the levee becomes increasingly likely for events in excess of the design standard of protection.

The OEH Guidelines recommend that inundation within the levee due to potential failure should be considered for design flood events that exceed the levee design standard. The purpose of a spillway is to have controlled inundation of protected areas prior to levee failure. Controlled inundation of the town during flood events in excess of the levee design event is required so that if and when the levee does breach, the water level differential behind the levee compared to on the floodway is reduced, so effects of levee failure (e.g. high velocities) are also reduced.

A number of potential spillway locations were considered. The *Floodplain Risk Management Guideline No. 14 Spillways for Urban Levees (*DIPNR) recommends that the spillway be located at the downstream (lowest) side of town, to allow floodwaters to more safely inundate the town via a slower moving, backwater effect. In Darlington Point, there is a significant gradient in the mainstream flood water level along the length of the levee. This influences the effectiveness of a downstream spillway to inundate sufficient land behind the levee. Therefore, locating the levee spillway further upstream was required, to provide sufficient inflow to the town. An appropriate spillway location was found to be on the upstream side of the levee adjacent to Carrington Street. Although located upstream of town, this section of levee is subjected to significantly lower velocities than the alignment along Cemetery Road, Bridge Street and Ryan Street, while offering a higher river flood level than other locations on the western side of town. The location of the spillway can be seen on Figure 6-5.

Figure 6-5 Location of Assumed Levee Spillway

The level of the permanent spillway crest must be set at the overall levee design flood level plus freeboard. The spillway freeboard must be significantly less than the general levee freeboard to ensure that the levee does not overtop elsewhere prematurely, i.e. the spillway is at the 1% AEP flood level plus 0.5 m freeboard, whilst the broader levee is at the 1% AEP flood level plus 0.85 - 1.0 m freeboard.

For modelling purposes, the levee freeboard is effectively removed, by setting the spillway crest at the 1% AEP flood level, with the broader levee crest set at the 1% AEP flood level plus 0.5 m freeboard. This is the approach outlined in *Draft Floodplain Risk Management Guideline Modelling Urban Levees for the Estimation of Flood Damages* (DIPNR). The adopted 0.5% AEP and 0.2% AEP design events therefore involve simulation of spillway overtopping. The spillway and broader levee design crest is also overtopped during modelling of the Extreme event.

6.5 Climate Change

The impact of climate change on catchment inflows, due to increases in design rainfall intensities, has been considered in this study. Increase in flood producing rainfall events due to climate change can be assessed by undertaking sensitivity analyses on the design events, with up to a 30% increase in flow rates. For this study, the 0.5% AEP and 0.2% AEP events were adopted for the rainfall intensity assessment, as representative of an approximate 10% and 30% increase in flows respectively.

Current guidelines predict that a likely outcome of future climatic change will be an increase in extreme rainfall intensities. Climate Change in the Murrumbidgee Catchment (CSIRO, 2006) provides projected regional changes in rainfall intensities for each season and annually for the years 2030 and 2070. For the Murrumbidgee catchment, the annual projected increase in rainfall intensities for extreme rainfall events is +7% by 2030 and +5% by 2070. The document defines an extreme rainfall event as the 1 in 40 year 1-day event.

The NSW Government has also released a guideline (DECCW, 2007) for Practical Consideration of Climate Change in the floodplain management process that advocates consideration of increased design rainfall intensities of between 10% and 30%.

Due to the nature of the Murrumbidgee River catchment, it would be overly conservative to assume an increase in rainfall intensity of 30% would result in an equivalent increase in peak flow rate on the Murrumbidgee River. In lieu of developing a hydrological model of the upper catchment, it has been assumed that the 0.5% AEP design event would be indicative of a 1% AEP design event under climate change conditions. This method was also adopted by Lyall & Associates (2015) for climate change flood assessments at Narrandera.

Results of the sensitivity testing are contained in Section 7.4.

7 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 0.2% AEP for Murrumbidgee River catchment flooding. The Extreme Flood event has also been modelled. The adopted 0.5% AEP, 0.2% AEP and Extreme events assume activation of the levee spillway.

The impact of future climate change on flooding was also considered, focussing on the 1% AEP flood event.

The design flood results are presented in a separate flood mapping compendium. For the simulated design events including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and Extreme Flood events, a map of peak flood level, depth and velocity is presented covering the modelled area.

7.1 Peak Flood Conditions

7.1.1 Murrumbidgee River Flooding

The mainstream flood results are presented in a Mapping Compendium (maps A1-8, B1-8 and C5-7) for each design event magnitude simulated, incorporating a map of peak flood depth, velocity and water levels.

Peak flood levels at the Darlington Point Bridge Street gauge are shown in Table 7-1.

Table 7-1 Design Flood Levels at Darlington Point Bridge Street Gauge

Design Event	Peak Flood Level (m AHD)
20% AEP	124.3
10% AEP	124.8
5% AEP	125.2
2% AEP	125.5
1% AEP	125.6
0.5% AEP	125.7
0.2% AEP	125.8
Extreme	126.3

The protection afforded to Darlington Point by the levee is presented in Figure 7-1. Long sections of modelled peak flood levels are presented around the levee for each of the modelled design flood events. Initial levee chainage (i.e. chainage 0) is consistent with those used in previous studies and is presented for reference on Figure 7-1. The previously derived 1% AEP flood level (WorleyParsons, 2009a) and the levee design crest (2009 1% AEP + 1.0 m freeboard) have been presented for comparison. The assumed levee spillway location is also shown on Figure 7-1 (see Section 6.4 for further detail).

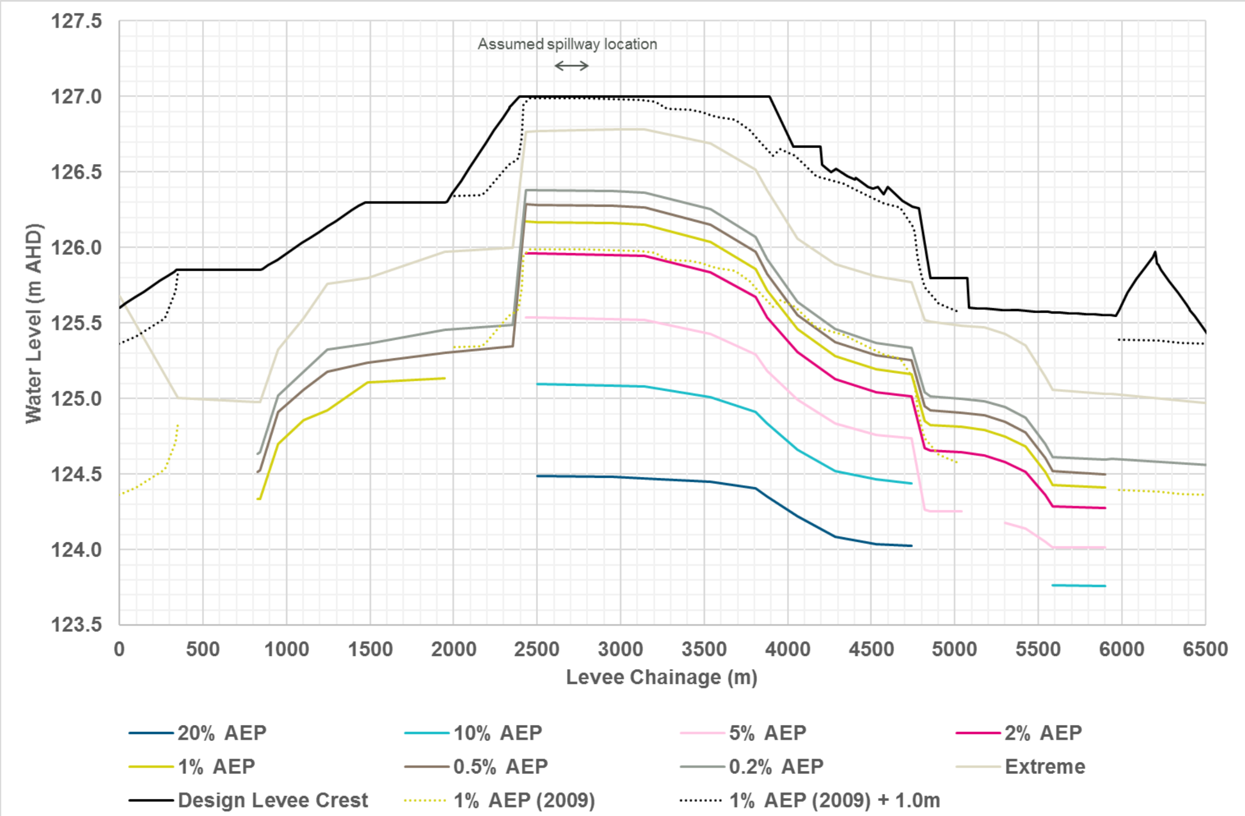


Figure 7-1 Darlington Point Levee Peak Design Flood Level Profiles

The results presented in Figure 7-1 indicate that along the eastern and northern sides of the levee the modelled 1% AEP flood levels are higher than those previously modelled upstream of Darlington Point Bridge and are lower than those previously modelled downstream of Darlington Point Bridge, by the order of +/- 150 mm. Along the western side of the levee the results are similar to those previously derived and along the southern side of the levee the results are significantly lower than those previously derived.

The results suggest that the Darlington Point levee may have a lower level of freeboard than previously understood, being around 0.85 m above the 1% AEP along the eastern side. For the 0.5% AEP and 0.2% AEP events, the levee will offer around 0.75 m and 0.65 m freeboard, respectively, if it remains structurally sound.

There is widespread inundation behind the levee at the 0.5% AEP, 0.2% AEP and Extreme mainstream flood events due to activation of the levee spillway. The lowest lying area of town is located north of Hay Road where modelled depths are in the order of 0.7 – 1.4 m at the 0.5% AEP flood event, increasing to around 1.0 – 1.8 m at the Extreme flood event. Within town, velocities are generally lower than 0.2 m/s. Localised higher velocities of up to 0.4 m/s and 0.7 m/s are modelled over road crests at the 0.5% AEP and Extreme flood event, respectively. Velocities over the spillway peak at 1.4 m/s and 1.8 m/s at the 0.5% AEP and Extreme flood events.

Peak flood levels long sections along the Murrumbidgee River channel alignment are provided in Appendix C. The long section alignment is shown on Figure 7-2. Chainages and peak flood level inundation extents for the 20% AEP, 5% AEP, 1% AEP and Extreme Flood event are given for reference. The Darlington Point bridge deck (main channel crossing and eastern channel crossing) will not surcharge during any of the design flood events simulated, including the Extreme flood event. The location of the bridge is shown on Figure 7-2.

Velocities within the Murrumbidgee River main channel peak at around 1.8 m/s at the 10% AEP and 2.5 m/s at the 1 % AEP event.

Properties in North Darlington Point located east of Uri Street become inundated by less than 0.25 m of floodwater at the 2% AEP event. At the 1% AEP event, the extent of inundation has increased to cover some properties south of Narrand St. Again, inundation depths are typically in the order of 0.25 m, with the exception of properties on Robertson Avenue, where the depth of floodwater affecting the backyards increases to over 1.0 m.

The Darlington Point Caravan Park is subject to a relatively high flood risk. Low-lying areas of the park become inundated by 0.1 m deep floodwater at the 20% AEP design event. By the 10% AEP event, the access road is cut and much of the park is inundated by over 0.5 m of floodwater. At the 1% AEP event, depths increase to around 1.5 m. Velocities through the area are generally quite low, due to the nature of inundation being a backwater effect from elevated river levels. Velocities range from 0.1 m/s at the 10% AEP event to 0.4 m/s at the 1% AEP event.

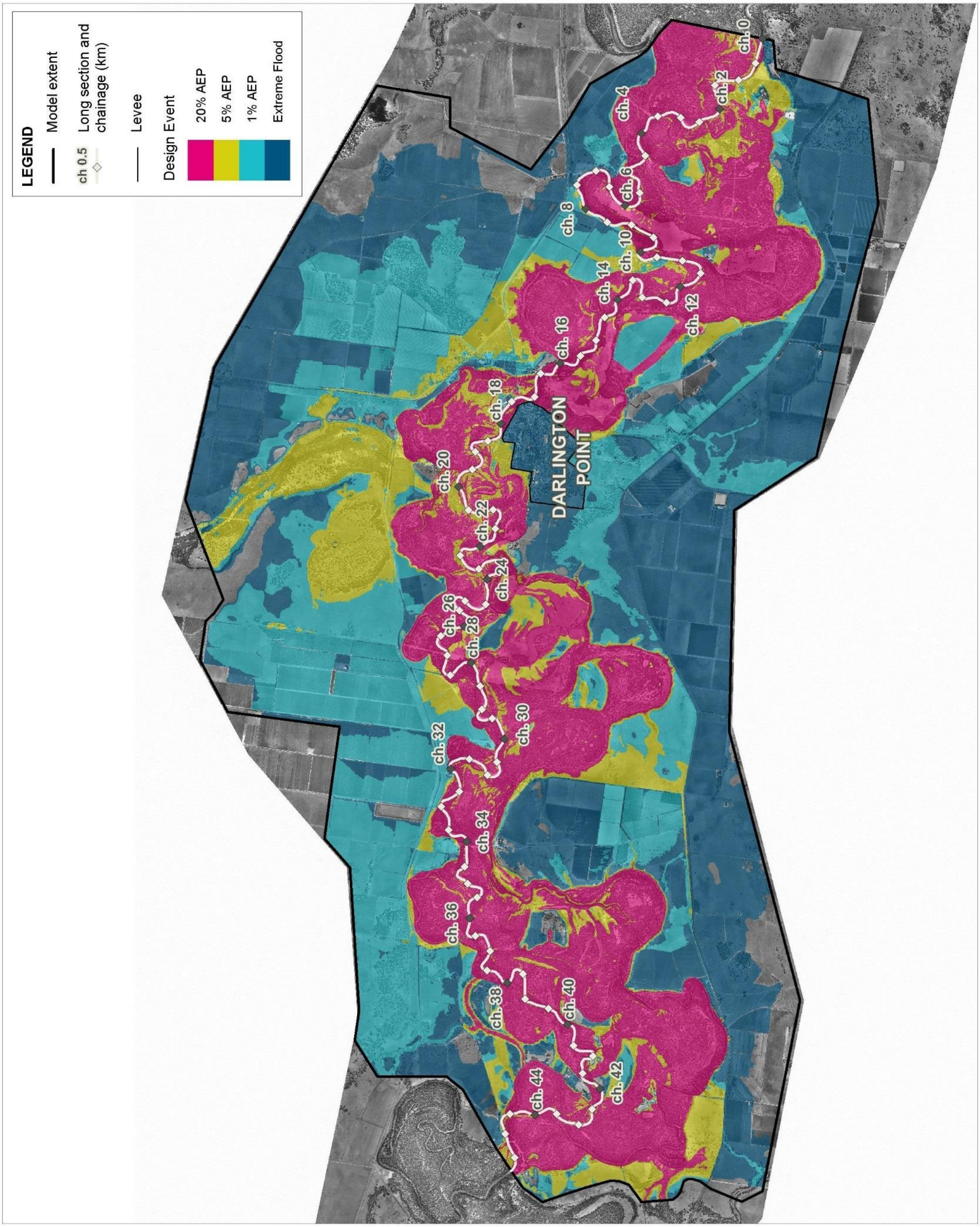
Areas in the study area located outside of the levee, including properties in North Darlington Point and on the broader Murrumbidgee River floodplain area, will be inundated for days or even weeks during large flood events.

With reference to the design flood mapping contained in the Mapping Compendium (specifically mapping series A), the modelled flood inundation extent can be seen to reach the lateral model boundaries for flood events equal to or larger than the 1% AEP design event. For situations such as this, the options for allowing flow to exit the floodplain are:

- Extend the model boundary further away from the area of interest, or
- Provide a boundary condition for flow to exit the model domain.

For the Darlington Point study area, the 2D model domain has been selected to cover the entire extent of available LiDAR survey data. Extending the model area further was not an option as no topographic information of a suitable quality was available to define the floodplain geometry.

With respect to the provision of boundary conditions, downstream boundaries are located to align with the main flood runners, as detailed in Section 4.2.3.4 and shown on Figure 4-3. As the floodplain grades toward the west, floodwater would naturally travel in an east to westerly direction, influencing the decision to omit additional boundaries elsewhere along the model perimeter. Due to the presence of many field embankments (which are predominantly aligned north-south) there is a tendency for floodwater to build-up behind embankments, significantly attenuating flood flows. For this reason, any additional flood storage provided in the model from floodwater unable to exit the model boundary would be insignificant in terms of overall flood storage offered behind field embankments, both within the model extent and beyond. It is considered that the hydraulic model setup is appropriate given the limitations in available survey data. However, the model limits should be extended as part of the Floodplain Risk Management Study, should suitable data become available.



Title:

Murrumbidgee River Chainages and Mainstream Design Flood Inundation Extents

Figure: **7-2**

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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7.1.2 Local Catchment Flooding

The local catchment runoff peak flood depths are presented in a Mapping Compendium (maps C1-4) for the 10% AEP, 5% AEP, 2% AEP and 1% AEP. Local catchment inundation for the 0.5% AEP, 0.2% AEP and Extreme Flood events are not mapped, as mainstream flooding over the levee spillway will result in the critical flood conditions in the town for these design event magnitudes.

Table 7-2 and Table 7-3 summarise the peak flood levels and depths behind the levee, for all design events simulated. Reporting locations are shown on Figure 7-3. For the 0.5% AEP, 0.2% AEP and Extreme flood events, the values in the Table 7-2 and Table 7-3 are reflective of mainstream flooding with activation of the levee spillway.

Local catchment runoff presents a minimal flood risk to Darlington Point. At the 1% AEP design event, inundation to road reserves and residential yards is largely limited to around 0.1 – 0.2 m depth. Aside from this, the following trafficable locations are most significantly affected:

- Carrington Street / Demamiel Street (reporting location D),
- The Ross Street / McAlister Street intersection (reporting location K), and
- South of the Bridge Street crossing at Punt Road (reporting location G).

Velocities throughout the town remain relatively low for all local catchment runoff scenarios modelled. At the 1% AEP event, the peak velocity is typically less than 0.15 m/s.

The critical flood conditions for local catchment runoff have been simulated to occur coincidently with a 10% AEP Murrumbidgee River level. As elevated tailwater levels prevent free drainage of runoff generated behind the levee, low-lying storage areas behind the levee will therefore remain inundated until the river level recedes sufficiently to allow drainage through the outlet structures. This can be in the order of days to weeks and will depend on the duration of the mainstream flood event.

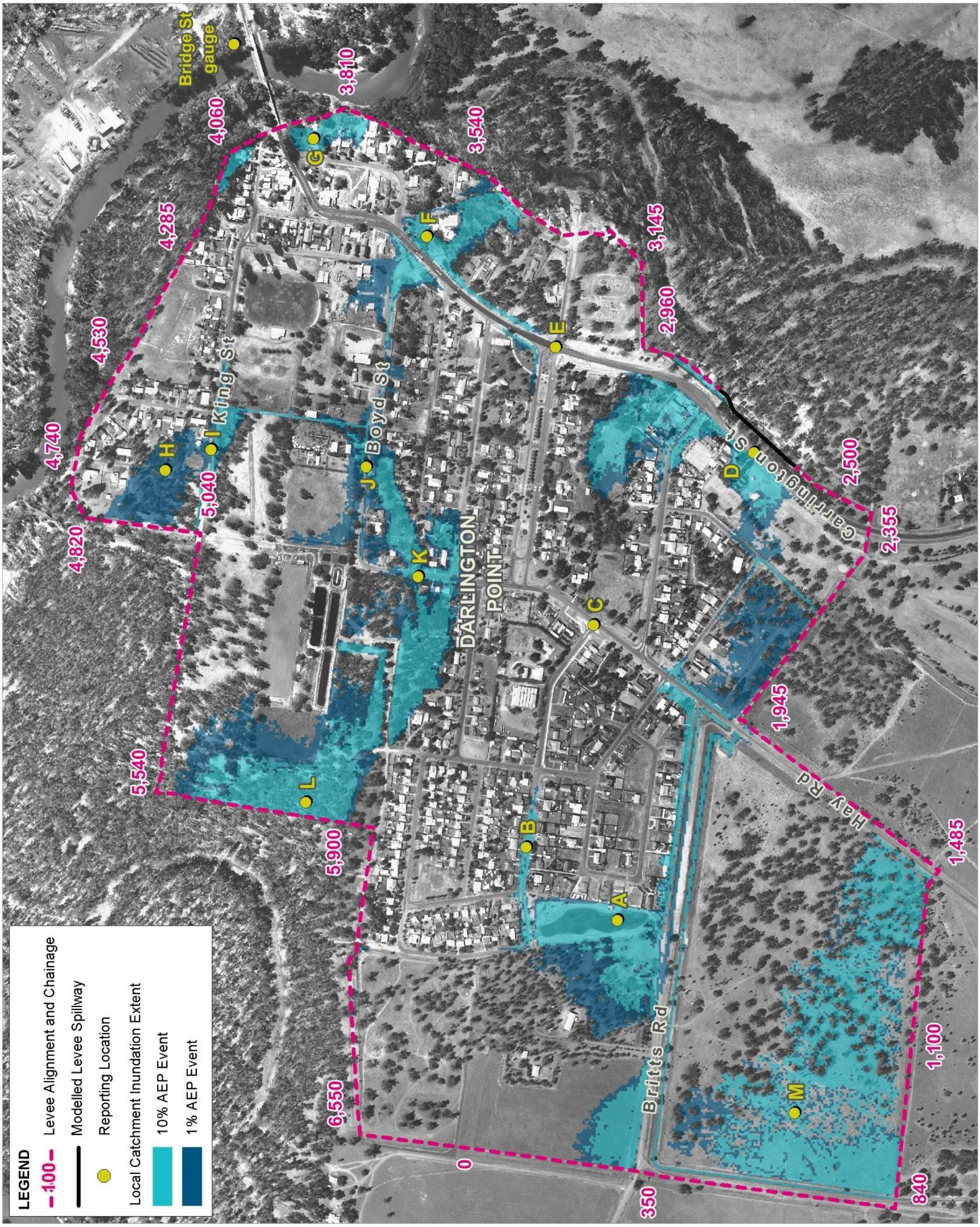
In identifying the critical local catchment flood conditions, an alternate scenario was simulated where all outlet structures were freely draining. For a scenario such as this, the period of inundation of trafficable locations such and Carrington Street /Demamiel Street is likely to be 12 – 24 hours. The exception to this is inundation of the road reserve at the Ross Street / McAlister Street intersection. The inability of modelled floodwater to drain from this location is influenced by the lack of cross-drainage across the ‘Area 4’ levee extension alignment. It is understood that a pumping system will be utilised to discharge local runoff from behind the levee onto the floodplain at this location. The modelled scenario is not representative of this and the period of inundation is therefore overly conservative.

Table 7-2 Peak Flood Level (m AHD) behind Darlington Point Levee

Reporting Location	Design Event						
	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	Extreme
A	125.11	125.17	125.22	125.25	125.47	125.65	125.85
B	125.44	125.45	125.46	125.46	125.47	125.65	125.86
C	-	-	-	-	125.44	125.68	125.95
D	-	-	-	-	125.47	125.68	126.05
E	-	-	-	-	-	125.67	125.88
F	-	124.04	124.16	124.23	125.41	125.67	125.88
G	124.81	124.85	124.87	124.91	125.41	125.67	125.88
H	-	124.21	124.23	124.24	125.41	125.67	125.87
I	-	-	-	124.29	125.41	125.67	125.87
J	-	-	-	-	125.41	125.67	125.87
K	124.16	124.26	124.30	124.35	125.41	125.67	125.88
L	123.67	123.75	123.80	123.86	123.96	125.61	125.73
M	124.61	124.62	124.62	124.62	124.64	125.64	125.86

Table 7-3 Peak Flood Depths (m) behind Darlington Point Levee

Reporting Location	Design Event						
	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	Extreme
A	0.68	0.74	0.79	0.82	0.95	1.13	1.34
B	0.07	0.08	0.09	0.09	0.09	0.27	0.49
C	-	-	-	-	0.02	0.25	0.52
D	-	-	-	-	0.90	1.11	1.47
E	-	-	-	-	-	0.11	0.32
F	-	0.04	0.16	0.23	1.34	1.60	1.80
G	0.16	0.20	0.23	0.26	1.24	1.50	1.70
H	-	0.01	0.03	0.04	1.28	1.53	1.73
I	-	-	-	0.07	1.25	1.51	1.71
J	-	-	-	-	1.12	1.38	1.58
K	0.24	0.34	0.39	0.44	1.52	1.78	1.98
L	0.20	0.28	0.33	0.39	0.98	2.63	2.75
M	0.04	0.05	0.05	0.05	0.07	1.08	1.30



Title:

Darlington Point Levee Chainages and Local Catchment Flooding Reporting Locations

Figure: 7-3

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Approx. Scale

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7.2 Flood Function

The flood function (or hydraulic categorisation) of a floodplain helps describe the nature of flooding in a spatial context and from a flood planning perspective can determine what can and can't be developed in areas of the floodplain. The hydraulic categories as defined in the Floodplain Development Manual are:

- **Floodway** - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage** - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood storage areas, if completely blocked would cause peak flood levels to increase by 0.1 m 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.

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 are essentially qualitative in nature. Of 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. However, an approach that is becoming increasingly accepted is to define the floodway extent as the area of floodplain conveying around 80% of the total flood flow, as defined by Thomas (2012). This is typically undertaken for the 1% AEP design flood event.

The modelled velocity-depth results were analysed through a number of floodplain cross-sections, to identify the extent of the area conveying around 80% of the total flow. This process was used to identify a suitable VxD threshold with which to map the 80% flow extent throughout the study area. For the Murrumbidgee River, a velocity-depth product threshold of around 0.25 (typically between 0.2 and 0.3 for selected cross-sections) at the 1% AEP was found to provide a good match to the flood extent conveying 80% of the total flow.

The flood fringe extents were identified using a similar approach to map areas of the floodplain containing the lowest modelled 5% of flood flow conveyance. The flood storage, or transitional areas between the floodway and flood fringe extents constitute the remaining 15% of total flood flow. Varying VxD thresholds for each event are summarised in Table 7-4.

Flood function mapping for the study area is included in a Mapping Compendium (maps A9-11 and B9-11) for the 5% AEP and 1% AEP events. A combined flood function map was also produced that considers a composite of all design flood events (including the Extreme flood). The purpose of this composite map is to provide a single reference map that improves the continuity of the mapped floodway and avoids the potential omission of floodway areas that become active above the 1% AEP magnitude. The VxD thresholds used for each design event are provided in Table 7-4.

Table 7-4 Average Velocity x Depth Thresholds for Floodway Definition

Event	Average Velocity x Depth Threshold	
	Floodway	Flood Fringe
0.2% AEP	> 0.30	< 0.25
0.5% AEP	> 0.28	< 0.22
1% AEP	> 0.25	< 0.19
2% AEP	> 0.22	< 0.16
5% AEP	> 0.17	< 0.11
10% AEP	> 0.14	< 0.08
20% AEP	> 0.10	< 0.04

The adopted flood function categorisation for the 1% AEP design event is summarised in Table 7-5.

Table 7-5 Flood Function Categories

Hydraulic Category	Categorisation Criteria	Description
Floodway	VxD > 0.25 at the 1% AEP event	Areas and flowpaths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	VxD > 0.19 at the 1% AEP event	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	The extent of the 1% AEP floodplain not classified as floodway or flood storage	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

Based on the flood function mapping for the 1% AEP event, the floodway is largely contained within the Murrumbidgee River channel and the adjacent vegetated floodplain areas. The township of Darlington Point is protected from mainstream flooding for the 1% AEP event. East of Kidman Way, North Darlington Point becomes flooded by depths of up to 0.8 m and is therefore classed as flood fringe.

7.3 Provisional Flood Hazard

The Flood Hazard Guideline 7-3 of the Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIDR, 2017) represents the current industry best practice with regards to defining flood hazard. The guideline considers a holistic approach to consider flood hazards to people, vehicles and structures. It recommends a composite six-tiered hazard classification, reproduced in Figure 7-4. The six hazard classifications are summarised in Table 7-6.

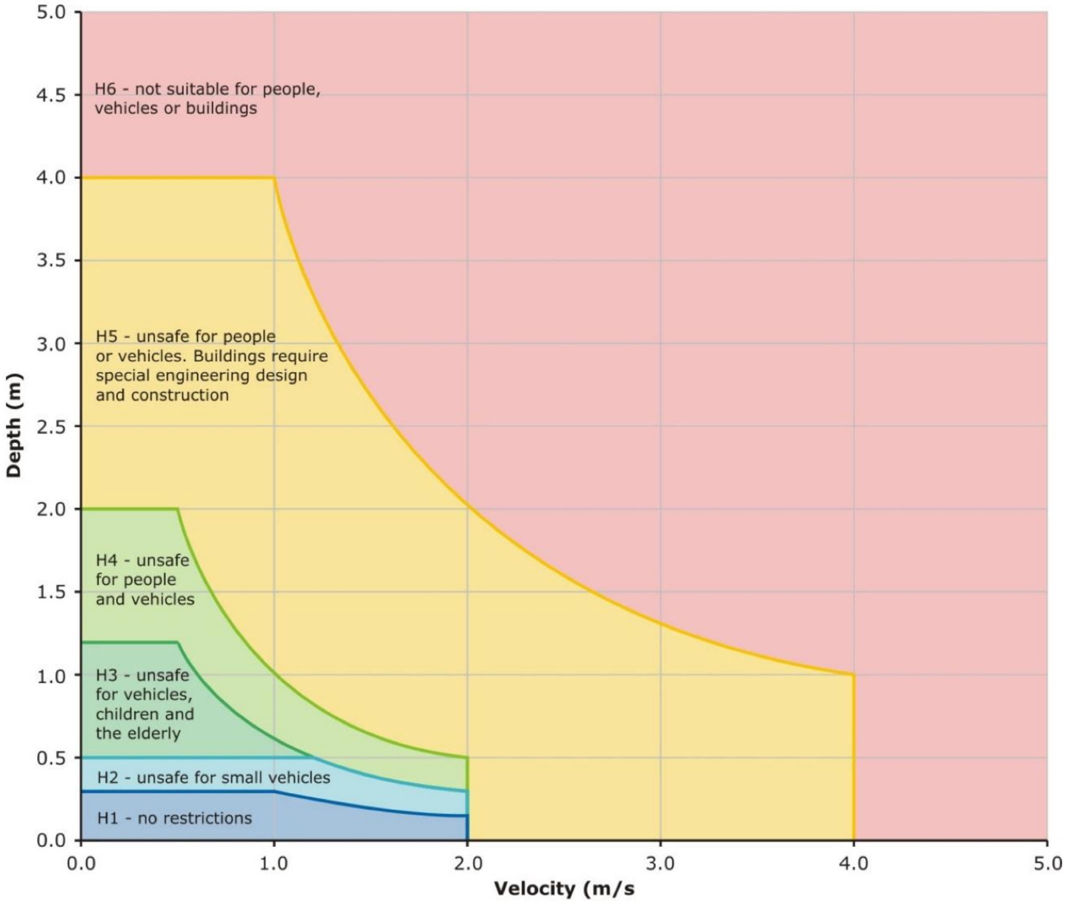

Figure 7-4 Combined Flood Hazard Curves – Vulnerability Thresholds

Table 7-6 Combined Flood Hazard Curves – Vulnerability Thresholds

Hazard Classification	Description
H1	Relatively benign flow conditions. No vulnerability constraints.
H2	Unsafe for small vehicles.
H3	Unsafe for all vehicles, children and the elderly.
H4	Unsafe for all people and vehicles.
H5	Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
H6	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.

It can be seen that the flood hazard level is 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 generally have no major threat.

Provisional hazard mapping based on the above criteria is included in the attached Mapping Compendium for the each of the design flood events considered (maps A12-19, B12-19 and C8-14).

For the 1% AEP event, flooding within the town and other inhabited areas on the broader Murrumbidgee River floodplain is typically classed as hazard category H1 or H2 and is indicative of relatively benign flow conditions that would not pose a significant flood risk to people, animals and vehicles. Some rural properties are subject to hazard category H3 at the 2% AEP event (driven by high flood depths of up to 1.0 m), with conditions becoming unsafe for vehicles, children and the elderly.

7.4 Sensitivity Assessment

As with all studies of this nature, it is important to recognise the underlying uncertainty in the assumptions used to establish design flood estimates. The adopted design flood conditions represent a "best-estimate." Sensitivity testing of key model parameters and inputs can give an indication of the likely bounds of uncertainty around adopted flood conditions.

The results presented in this section indicate that the adopted 1% AEP design flood conditions are within ± 0.25 m of the range of input parameters assessed. The inherent uncertainty in prediction of design flood levels is accounted for through Flood Planning Levels (FPLs), where freeboard is provided above the adopted 1% AEP design level. Recommendations around an appropriate FPL for Darlington Point is provided in Section 8.1.

7.4.1 Hydraulic Roughness

The sensitivity of modelled peak flood levels to the adopted Manning's 'n' roughness values were tested for the 1% AEP design event. Roughness values for all materials types within the channel and floodplain were increased and decreased by 25%.

Longitudinal profiles showing the result of this assessment for the Murrumbidgee River are shown in Figure 7-5. Peak modelled flood levels are presented in Table 7-7 at the end of this Section.

7.4.2 Peak Flow Estimation

While the Flood Frequency Analysis in Section 6.2 provides the best estimate of design flood flows for the catchment, the 90th percentile confidence limits give indication to the uncertainty associated with the approach. With reference to Figure 6-2, the 90th percentile bounds give a lower and upper bound of flood flow estimate for the 1% AEP design event of between 1100 and 2000 m^3/s, providing significant variation to the adopted 1390 m^3/s.

The 2% AEP and 0.2% AEP model simulations can be used to demonstrate the sensitivity of peak flood levels to this range of flow conditions, as they have peak flows of 1100 and 1950 m^3/s, respectively. Longitudinal profiles showing the result of this assessment for the Murrumbidgee River are shown in Figure 7-5. Peak modelled flood levels are presented in Table 7-7 at the end of this Section.

7.4.3 Climate Change

The potential impacts of future climate change in the form of increased rainfall intensities were considered for the 1% AEP design event. The projected increases in rainfall intensities expected for the study area and the approach adopted to incorporate these into the modelling is detailed in Section 6.5.

Longitudinal profiles showing the result of the climate change assessment for the Murrumbidgee River are shown in Figure 7-5. Peak modelled flood levels are presented in Table 7-7 at the end of this Section.

The 0.5% AEP peak Murrumbidgee River inflow is 17% higher than the 1% AEP event. This event typically results in peak flood levels in the order of 0.2 m higher than modelled at the 1% AEP event. It is also important to note that increased flows above the 1% AEP (i.e. the 0.5% and 0.2% AEP events) do result in more extensive inundation to the south of town across the Kidman Way. Provision of freeboard when defining the Flood Planning Level (FPL) and associated Flood Planning Area (FPA) would provide allowance for an expected increase in flood levels and area of flood inundation resulting from climate change. Details around the recommended interim FPL are contained in Section 8.1.

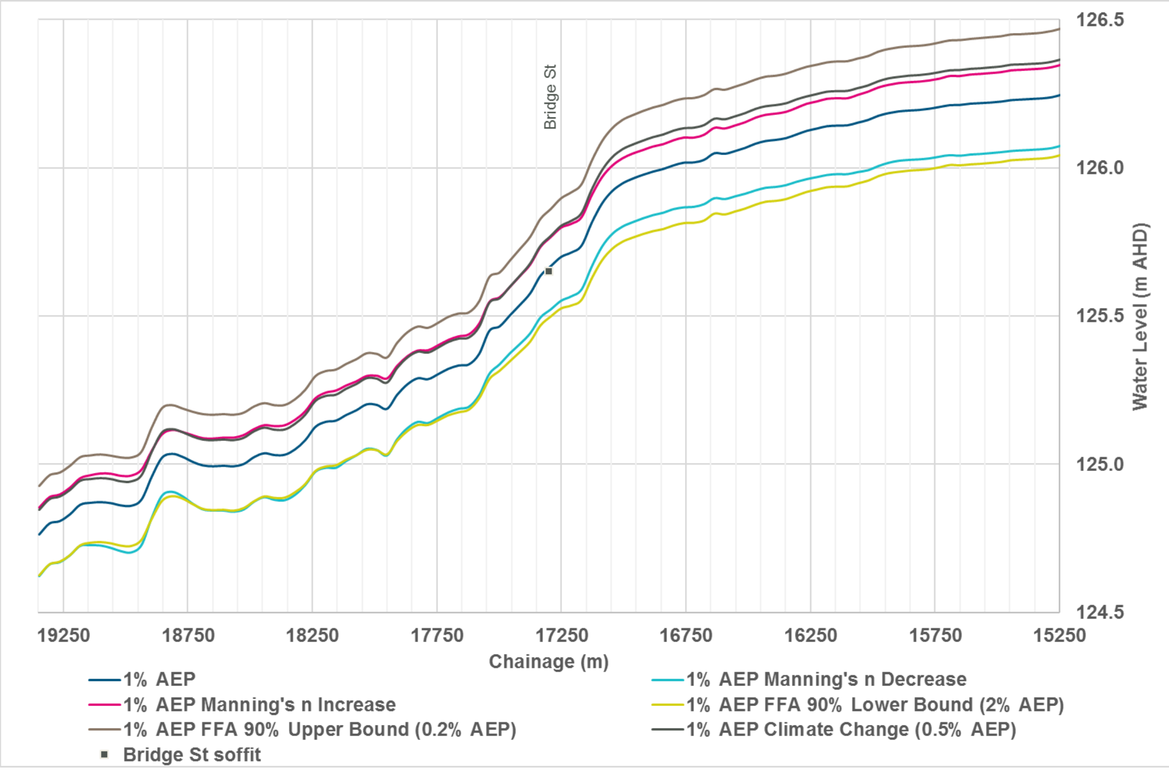

Figure 7-5 Murrumbidgee River Peak Flood Level Sensitivity

Table 7-7 Summary of Model Sensitivity Assessment – Peak Flood Levels (m AHD)

Location	1% AEP	1% AEP n -	1% AEP n +	1% AEP FFA 90% Lower Bound (2% AEP)	1% AEP FFA 90% Upper Bound (0.2% AEP)	1% AEP Climate Change (0.5% AEP)
Kidman Way / Murrumbidgee River Rd	125.6	125.5	125.6	125.5	125.6	125.6
Darlington St	126.1	126.0	126.2	126.0	126.3	126.2
Bridge St gauge	125.6	125.5	125.7	125.5	125.8	125.7
Caravan Park	125.8	125.7	125.9	125.6	126.0	125.9
Darlington Point Public Pool	-	-	-	-	125.7	125.4
Kidman Way (south)	126.0	-	126.1	-	126.1	126.1
Hay Road	125.1	-	125.2	-	125.3	125.2

8 Floodplain Risk Management Considerations

An increasingly important requirement of a Flood Study is to consider and investigate flood planning and flood risk management issues within the study area. This study will derive an interim Flood Planning Area, provide preliminary advice regarding emergency management and complete a baseline flood damages assessment.

8.1 Flood Planning Level

Flood Planning Levels (FPLs) are used for planning purposes, and directly determine the extent of the Flood Planning Area (FPA), which is the area of land subject to flood-related development controls. The FPL is the level below which Council places controls on development due to the hazard of flooding.

It is typical for the flood planning level to be derived from a designated design flood event (usually the 1% AEP design event) plus a 0.5 m freeboard allowance to account for a number of underlying uncertainties. This is the flood planning level definition as described in Clause 6.2 of the Murrumbidgee Local Environment Plan (LEP) 2013.

For Darlington Point, there are a number of challenges with regards to defining the FPA and appropriate FPLs. The traditional 0.5 m freeboard could be overly conservative given the relatively small increase in flood levels between the 1% AEP and 0.2% AEP events. Due to the relatively flat topography at Darlington Point this approach also effectively tags all properties within the study area as being within the FPA. The area protected by the Darlington Point levee, whilst flood-free at the 1% AEP with respect to the Murrumbidgee River, is subject to potential flood planning controls associated with the internal local catchment runoff.

It is recommended that an interim FPA be adopted within Council's Policy that includes the entire study area, with a freeboard of 0.3 m above the 1% AEP of either the Murrumbidgee River (areas outside the levee) or local catchment runoff (areas within the levee) flood levels. A thorough assessment of appropriate flood planning controls should be undertaken as part of a future Floodplain Risk Management Study and Plan.

8.2 Flood Damages Assessment

8.2.1 Types of Flood Damage

A flood damage assessment has been undertaken to identify flood affected property, to quantify the extent of damages in economic terms for existing flood conditions and to enable the assessment of the relative merit of potential flood mitigation options by means of benefit-cost analysis.

The general process for undertaking a flood damages assessment incorporates:

- Identifying properties subject to flooding;
- Determining depth of inundation above floor level for a range of design event magnitudes;
- Defining appropriate stage-damage relationships for various property types/uses;
- Estimating potential flood damage for each property; and

- Calculating the total flood damage for a range of design events.

The definitions and methodology used in estimating flood damage are summarised in the Floodplain Development Manual (DIPNR, 2005) and OEH (2007). Figure 8-1 summarises the “types” of flood damages as considered in this study. The two main categories are 'tangible' and 'intangible' damages. Tangible flood damages are those that can be more readily evaluated in monetary terms, while intangible damages relate to the social cost of flooding and therefore are much more difficult to quantify.

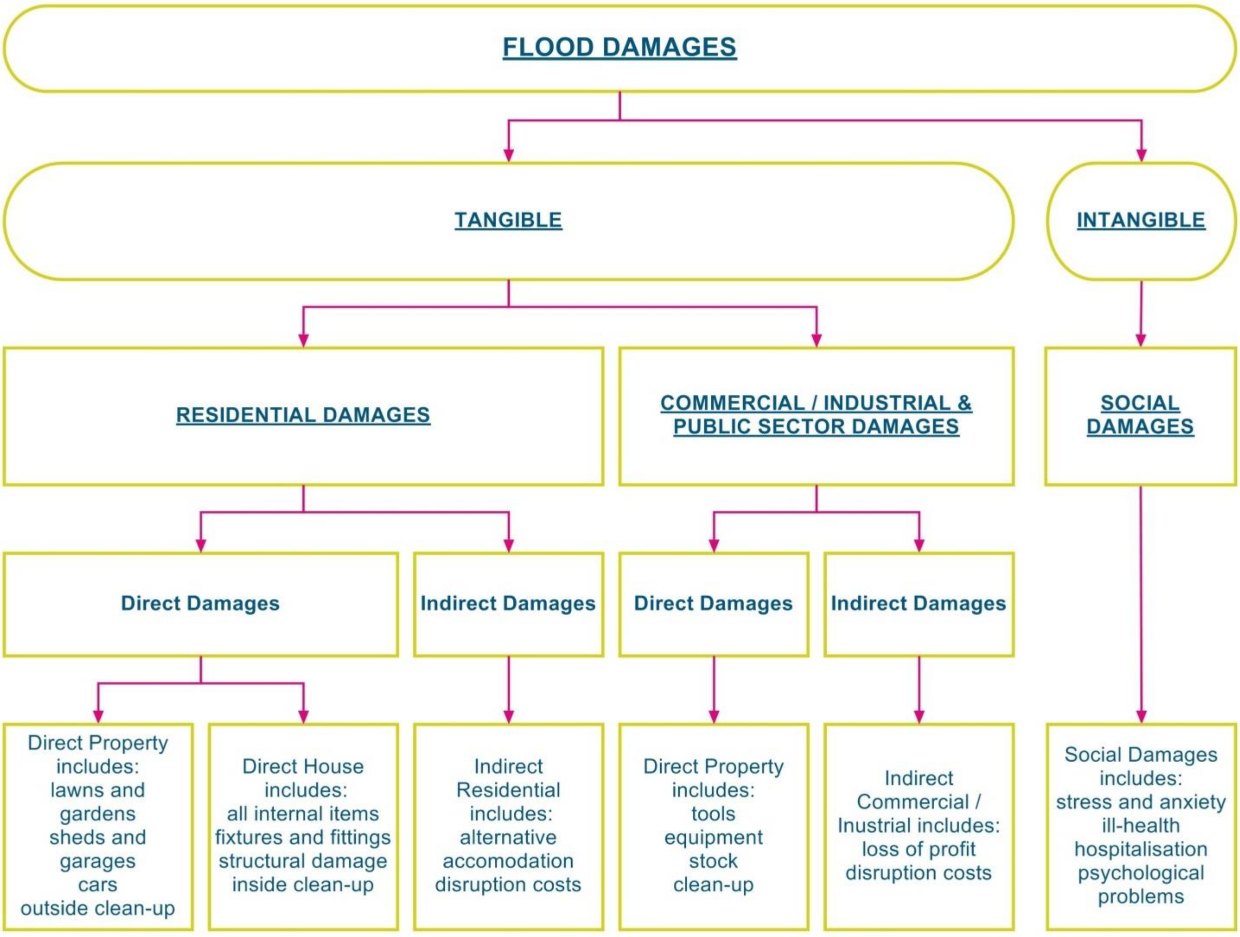

Figure 8-1 Types of Flood Damage

Tangible flood damages are further divided into direct and indirect damages. Direct flood damages relate to the loss, or loss in value, of an object or a piece of property caused by direct contact with floodwaters. Indirect flood damages relate to loss in production or revenue, loss of wages, additional accommodation and living expenses, and any extra outlays that occur because of the flood.

8.2.2 Basis for Flood Damage Calculations

Flood damages have been calculated using a database of potentially flood affected properties and a number of stage-damage curves derived for different types of property within the catchment. These curves relate the amount of flood damage that would potentially occur at different depths of inundation, for a particular property type. Residential damage curves are based on the OEH guideline stage-damage curves for residential property.

There is no existing property floor level survey available for Darlington Point. The floor levels for 426 properties in Darlington Point were estimated by Worley Parsons (2009b). Dwellings were classified as “slab on ground” or “transportable,” with floor levels assumed to be 0.2 m and 0.4 m above ground level, respectively. This dataset has been built upon for this study, with additional dwellings added where required to bring the total number of properties included in the database to 463. The 463 properties included in the flood damages assessment comprises of:

- 366 residential properties and 31 commercial properties protected by the levee, and
- 65 residential properties and one commercial property located outside of the levee (including North Darlington Point).

Ground levels at each property location have been extracted from the LiDAR DEM. The same floor level assumptions used by Worley Parsons (2009b) have been adopted for this study. Property floor level survey for nine properties located south of Darlington Point between the Sturt Highway was collected for this study and has been incorporated into the flood damages assessment.

Different stage-damage curves for direct property damage have been derived for:

- Residential dwellings (categorised into small, typical or raised categories); and
- Commercial premises (categorised into low, medium or high damage categories).

Apart from the direct damages calculated from the derived stage-damage curves for each flood-affected property, other forms of flood damage include:

- Indirect residential, commercial and industrial damages, taken as a percentage of the direct damages;
- Infrastructure damage, based on a percentage of the total value of residential and business flood damage; and
- Intangible damages that relate to the social impact of flooding and include:
  - inconvenience,
  - isolation,
  - disruption of family and social activities,
  - physical ill-health, and
  - psychological ill-health (e.g. anxiety).

The preliminary damage estimates derived in this study are for the tangible damages (direct and indirect) only. Whilst intangible losses may be significant, these effects have not been quantified, due to difficulties in assigning a meaningful dollar value.

Direct Damages

The peak depth of flooding was determined at each property for the range of modelled design flood events. The damages assessment utilised the following design flood conditions for properties located inside the levee:

- 10% AEP, 5% AEP, 2% AEP and 1% AEP local catchment runoff inundation, and
- 0.5% AEP, 0.2% AEP and Extreme mainstream flood inundation with levee spillway in accordance with OEH guidelines.

For properties located outside of the levee (including North Darlington Point), the 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and Extreme mainstream flood conditions were used for the damages assessment.

The associated direct flood damage cost to each property was then estimated from the stage-damage relationships. The flood damage curves include a flat $11,725 cost of external damages for any level of flood inundation incurred below floor level. For instances where the property is not inundated above floor level and the external flood depth is below 0.3 m, this value is considered to be overly conservative. Therefore, a nominal $5,000 value has been adopted for external flood damages for below floor flooding of less than 0.3 m depth. Total damages for each flood event were determined by summing the predicted damages for each individual property.

The Average Annual Damage (AAD) is the average damage in dollars per year that would occur in a designated area from flooding over a very long period of time. In many years there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there will be major flood damage (caused by large, rare flood events). Estimation of the AAD provides a basis for comparing the effectiveness of different floodplain risk management measures (i.e. the reduction in the AAD).

Indirect Damages

The indirect damages are more difficult to determine and would vary for each flood event, particularly with the duration of the flood inundation. Previous studies detailing flood damages from actual events have found that the indirect damages for residential properties are typically in the order of 20% of the direct damages. Given the relative uncertainty associated with the indirect damages a value of 20% of the direct damages has also been adopted for this study. The indirect damages associated with commercial properties are typically higher and a value of 40% of the calculated direct damages has been adopted.

8.2.3 Flood Damage Estimation

The assessment of the residential flood damages is presented in Table 8-1 for properties protected by the levee and Table 8-2 for properties located outside of the levee (including those in North Darlington Point). From this data the total AAD for residential properties was calculated as being $98,000 in direct damages and $20,000 in indirect damages, giving a total value of $118,000.

The assessment of the commercial flood damages for properties located behind the levee is presented in Table 8-3. The commercial property located outside of the levee remains free from inundation for all flood events so does not accumulate any damage costs. From this data the AAD for commercial properties was calculated as being $2,000 in direct damages and $1,000 in indirect damages, giving a total value of $3,000.

Public utilities and infrastructure include roads, railways, parklands and underground water, sewerage, power and telephone services and installations. The damages sustained by public utilities comprise the replacement or repair of assets damaged by floodwaters, the cost of clean-up of the installations, as well as the collection and disposal of clean-up material from private property. Damage incurred to public utilities and infrastructure during a flood event was estimated as 30% of the combined tangible (direct and indirect) damages to residential and commercial properties.

Table 8-1 Summary of Residential Flood Damages for Properties Protected by the Levee

Design Event	Properties Flooded Above Floor (and Ground)	Direct Damages ($)	Indirect Damages ($)	Total Damages ($)
20% AEP	0 (0)	$0	$0	$0
10% AEP	0 (4)	$20,000	$4,000	$24,000
5% AEP	0 (6)	$30,000	$6,000	$36,000
2% AEP	0 (8)	$40,000	$8,000	$48,000
1% AEP	2 (10)	$124,000	$25,000	$149,000
0.5% AEP	40 (79)	$2,424,000	$485,000	$2,909,000
0.2% AEP	206 (95)	$12,175,000	$2,435,000	$14,610,000
Extreme Flood	276 (94)	$16,869,000	$3,374,000	$20,243,000
AAD	**-**	**$60,000**	**$12,000**	**$72,000**

Table 8-2 Summary of Residential Flood Damages for Properties Location Outside of the Levee (including North Darlington Point)

Design Event	Properties Flooded Above Floor (and Ground)	Direct Damages ($)	Indirect Damages ($)	Total Damages ($)
20% AEP	0 (0)	$0	$0	$0
10% AEP	0 (1)	$12,000	$2,000	$14,000
5% AEP	1 (1)	$67,000	$13,000	$81,000
2% AEP	10 (10)	$526,000	$105,000	$631,000
1% AEP	24 (9)	$1,274,000	$255,000	$1,529,000
0.5% AEP	27 (11)	$1,633,000	$327,000	$1,960,000
0.2% AEP	32 (15)	$1,931,000	$386,000	$2,317,000
Extreme Flood	52 (8)	$3,427,000	$685,000	$4,113,000
AAD	**-**	**$38,000**	**$8,000**	**$46,000**

Table 8-3 Summary of Commercial Flood Damages Protected by the Levee

Design Event	Properties Flooded Above Floor	Direct Damages ($)	Indirect Damages ($)	Total Damages ($)
20% AEP	0	$0	$0	$0
10% AEP	0	$0	$0	$0
5% AEP	0	$0	$0	$0
2% AEP	0	$0	$0	$0
1% AEP	0	$0	$0	$0
0.5% AEP	0	$0	$0	$0
0.2% AEP	22	$463,000	$185,000	$648,000
Extreme Flood	26	$779,000	$312,000	$1,091,000
AAD	**-**	**$2,000**	**$1,000**	**$3,000**

The total tangible flood damages for all residential properties, commercial properties and the public sector were combined, as presented in Table 8-4.

From this data, the combined AAD was calculated as being $157,000, comprised as follows:

- $118,000 from residential properties (61% of this cost is from damage to properties protected by the levee),
- $3,000 from commercial properties (100% of this cost is from damage to properties protected by the levee), and
- $36,000 from infrastructure and public sector.

There is a significant difference to the flood damage stimates calaulated for this current study compared to that of WorleyParsons (2009b), where the combined annual average damage to central and North Darlington Point was estimated to be in the order of $640,000. As the WorleyParsosn study was completed prior to any upgrade works to the levee, it assumed that the exisiting, structurally comprimised levee would fail for floods greater than a 20% AEP occurance. For comparison, the previous study calculated that during a 2% AEP and 1% AEP event, some 154 and 201 properties in central Darlington Point would be inundated respectively, assuming that the levee would breach. It should be noted that the previous damage calculations also include a small portion of social damages, which have not been included in this study (see Section 8.2.2). The social damages were estimated as a flat rate per household affected by below floor or above floor flooding and typically made up between 5% to 15% of the total damage estimate, depending on the event considered.

Table 8-4 Summary of Total Tangible Flood Damages

Design Event	Residential Flood Damages ($)	Commercial Flood Damages ($)	Infrastructure and Public Sector Damages ($)	Total Tangible Flood Damages ($)
20% AEP	$0	$0	$0	$0
10% AEP	$38,000	$0	$11,000	$49,000
5% AEP	$117,000	$0	$35,000	$151,000
2% AEP	$679,000	$0	$204,000	$882,000
1% AEP	$1,678,000	$0	$503,000	$2,181,000
0.5% AEP	$4,869,000	$0	$1,461,000	$6,330,000
0.2% AEP	$16,927,000	$648,000	$5,273,000	$22,848,000
Extreme Flood	$24,356,000	$1,091,000	$7,634,000	$33,081,000
AAD	**$118,000**	**$3,000**	**$36,000**	**$157,000**

9 Conclusions

The objective of the study was to undertake a detailed flood study of the Murrumbidgee River at Darlington Point and to establish models as necessary for design flood level prediction.

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

- Collation of historical and recent flood information for the study area;
- Development of computer models to simulate hydrology and flood behaviour in the catchment;
- Calibration of the developed models using the available flood data, including the recent events of 2010, 2012 and 2016 and the historic events of 1956 and 1974;
- Prediction of design flood conditions in the catchment and production of design flood mapping series; and
- Definition of an interim flood planning area and calculation of baseline annual average flood damages.

Some key findings and outcomes from the study are detailed below.

There is some difference in the modelled peak flood levels derived in this study compared to those defined by WorleyParsons (2009), suggesting that the Darlington Point levee may have a lower level of freeboard than previously understood, being around 0.85 m above the 1% AEP along the eastern side and up to 1 m elsewhere along the levee perimeter. For the 0.5% AEP and 0.2% AEP events, the levee will offer around 0.75 m and 0.65 m freeboard, respectively, if it remains structurally sound.

There were a number of challenges with regards to defining an appropriate FPA and FPLs that was applicable to both areas protected by levee and those on the floodplain. It is recommended that an interim FPA be adopted within Council's Policy that includes the entire study area, with a freeboard of 0.3 m above the 1% AEP of either the Murrumbidgee River (areas outside the levee) or local catchment runoff (areas within the levee) flood levels. A thorough assessment of appropriate flood planning controls should be undertaken as part of a future Floodplain Risk Management Study and Plan.

During the later stages of this study, the NSW SME elevation data product for the broader Murrumbidgee River floodplain area near Darlington Point became available through the Geoscience Australia's Elevation Foundation Spatial Data (ELVIS) online portal. Updating and extending the model developed for this study to include this additional floodplain area in high resolution would allow for analysis of the flood immunity of the Sturt Highway south of Darlington Point.

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WorleyParsons (2014) *MR 321 Darlington Point Bridge and Road Upgrades Flood Impact Assessment.*

Appendix A Community Information Brochure and Questionnaire

What is the study about?

The main objective of the study is to characterise the flooding behaviour in and around Darlington Point 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 study area to simulate flood behaviour. Historical flood information such as rainfall records, peak water levels, flooded property details etc, are used to ensure the computer models are representative of the real flood behaviour.

Flood maps across the study area 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 Darlington Point and will assist Council 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 the NSW Government's Floodplain Management Program.

NSW GOVERNMENT Office of Environment & Heritage

Want more information?

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

Murrumbidgee COUNCIL

Tanya Paterson
Murrumbidgee Council
PO Box 5
Darlington Point NSW 2706
Ph (02) 6960 5500
e: tanyap@murrumbidgee.nsw.gov.au

BMT WBM

Mr Daniel Williams (Project Manager)
BMT WBM (Consultant)
Ph 4940 8882
e: *Daniel.Williams@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 28th April 2017.

Darlington Point Flood Study

Community Information Brochure

Darlington Point, September 2016 Flood Event

Murrumbidgee COUNCIL

BMT WBM

Introduction

Murrumbidgee Council is carrying out a flood study to understand flood risks in and around Darlington Point. This includes the Murrumbidgee River and adjacent floodplains, as well as the local rainfall and runoff occurring behind the levee that can become trapped when the river is up.

Council's Darlington Point 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.

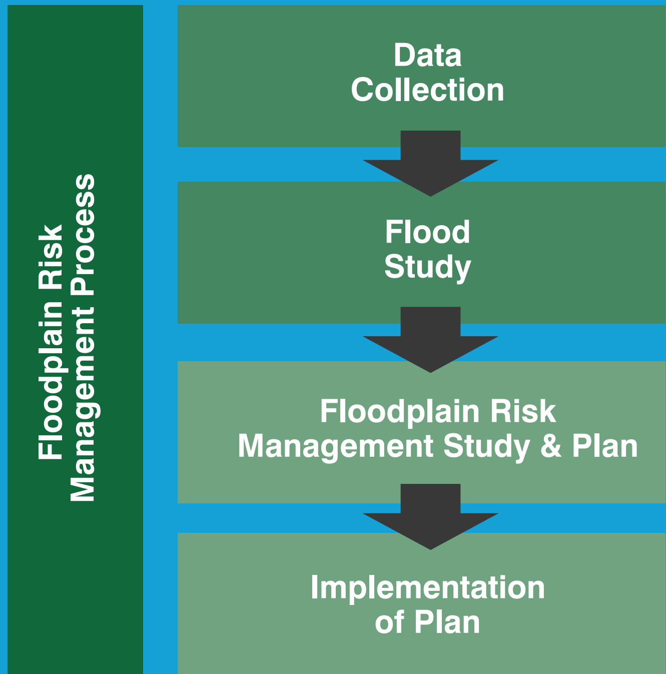
Aerial imagery of Darlington Point taken during the March 2012 Flood

Why do we need a study?

The Murrumbidgee River has a history of major flooding, including the significant events of 1891 1956 and 1974 and more recently the major events in 2010, 2012 and 2016.

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 study area.

The study will identify existing flood risk within flood prone areas at Darlington Point 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 Darlington Point area 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.

DARLINGTON POINT FLOOD STUDY

Murrumbidgee Council is undertaking a detailed flood study of Darlington Point and the surrounding area to help identify flooding problems. We are seeking the community's help by collecting information on any flooding or drainage problems that you may have experienced in the past. Please take a minute or two to read through these questions and provide responses wherever you can. Please return this form to Murrumbidgee Council in the enclosed envelope (no stamp required).

Contact Details (optional)

Name:____________________ Address:____________________________

Phone:____________________ Email:____________________________

Q1) How long have you lived and/or worked in the area?________________________

Q2) Have you been affected by flooding in the past? Y / N

If so, how were you affected, e.g. yard or house flooded, road flooded, etc.

Q3) Can you provide specific details of how high floodwaters reached? Y / N

If so, please give as much detail as possible, e.g. location, dates, times, depth of water, etc.

You can mark up the map overleaf to assist us and/or provide flood photos or videos if available.

Information relating to the 1956 flood is of particular interest, as it precedes the gauge records.

Q4) What do you think may have been the main source / cause of the flooding (e.g. river banks overtopping, blockage of bridges, etc.)?

Q5) Did you keep any rainfall records during any past storm events? Y / N

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

Q6) Are you concerned that your property could be flooded in the future? Y / N

If so, what makes you concerned?

Project Contacts

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Daniel.Williams@bmtwbm.com.au

Tanya Paterson (Murrumbidgee Council)
Ph: 02 6960 5500
tanyap@murrumbidgee.nsw.gov.au

BMT WBM

Murrumbidgee COUNCIL

Please provide any additional comments or information that you think will help the study

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Appendix B ARR 2016 Data Hub

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Results - ARR Data Hub
[STARTTXT]

Input Data Information
[INPUTDATA]
Latitude,-34.5967
Longitude,145.9341
[END_INPUTDATA]

River Region
[RIVREG]
division,Murray-Darling Basin
rivregnum,12
River Region,Murrumbidgee River
[RIVREG_META]
Time Accessed,08 August 2018 10:41AM
Version,2016_v1
[END_RIVREG]

ARF Parameters
[LONGARF]
Zone,Southern Semi-arid
a,0.254
b,0.247
c,0.403
d,0.351
e,0.0013
f,0.302
g,0.058
h,0.0
i,0.0
[LONGARF_META]
Time Accessed,08 August 2018 10:41AM
Version,2016_v1
[END_LONGARF]

Storm Losses
[LOSSES]
id,7162.0
Storm Initial Losses (mm),27.0
Storm Continuing Losses (mm/h),0.0
[LOSSES_META]
Time Accessed,08 August 2018 10:41AM
Version,2016_v1
[END_LOSSES]

Temporal Patterns
[TP]
code,MB
Label,Murray Basin
[TP_META]
Time Accessed,08 August 2018 10:41AM
Version,2016_v2
[END_TP]

Areal Temporal Patterns
[ATP]
code,MB
arealabel,Murray Basin
[ATP_META]
Time Accessed,08 August 2018 10:41AM
Version,2016_v2
[END_ATP]

BOM IFD Depths
[BOMIFD]
No data,No data found at this location!
[BOMIFD_META]
Time Accessed,08 August 2018 10:41AM
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[END_BOMIFD]

Median Preburst Depths and Ratios
[PREBURST]
min (h)\AEP(%),50,20,10,5,2,1,
60 (1.0),0.3  (0.021),0.6  (0.029),0.9  (0.032),1.1  (0.034),0.6  (0.015),0.2  (0.005),
90 (1.5),1.5  (0.082),1.1  (0.043),0.8  (0.026),0.5  (0.014),0.7  (0.016),0.8  (0.016),
120 (2.0),2.3  (0.113),1.6  (0.058),1.2  (0.036),0.8  (0.020),0.6  (0.013),0.5  (0.010),
180 (3.0),2.0  (0.087),1.7  (0.054),1.6  (0.041),1.4  (0.031),0.9  (0.018),0.6  (0.010),
360 (6.0),0.4  (0.015),1.0  (0.026),1.4  (0.030),1.8  (0.033),1.5  (0.022),1.2  (0.016),
720 (12.0),0.0  (0.000),0.5  (0.010),0.8  (0.014),1.1  (0.017),1.6  (0.019),1.9  (0.020),
1080 (18.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.6  (0.007),1.1  (0.011),
1440 (24.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.2  (0.002),0.4  (0.004),
2160 (36.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
2880 (48.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
4320 (72.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
[PREBURST_META]
Time Accessed,08 August 2018 10:41AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point
values remain unchanged.
[END_PREBURST]

10% Preburst Depths
[PREBURST10]
min (h)\AEP(%),50,20,10,5,2,1,
60 (1.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
90 (1.5),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
120 (2.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
180 (3.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
360 (6.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
720 (12.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
1080 (18.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
1440 (24.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
2160 (36.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
2880 (48.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
4320 (72.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
[PREBURST10_META]
Time Accessed,08 August 2018 10:41AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point
values remain unchanged.
[END_PREBURST10]

25% Preburst Depths
[PREBURST25]
min (h)\AEP(%),50,20,10,5,2,1,
60 (1.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
90 (1.5),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
120 (2.0),0.1  (0.003),0.0  (0.001),0.0  (0.001),0.0  (0.000),0.0  (0.000),0.0  (0.000),
180 (3.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
360 (6.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
720 (12.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
1080 (18.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
1440 (24.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
2160 (36.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
2880 (48.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
4320 (72.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
[PREBURST25_META]
Time Accessed,08 August 2018 10:41AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point
values remain unchanged.
[END_PREBURST25]

75% Preburst Depths
[PREBURST75]
min (h)\AEP(%),50,20,10,5,2,1,
60 (1.0),5.2  (0.322),6.4  (0.290),7.2  (0.274),8.0  (0.260),8.8  (0.238),9.3  (0.223),
90 (1.5),12.0  (0.645),12.9  (0.507),13.5  (0.444),14.1  (0.397),14.0  (0.329),13.9  (0.289),
120 (2.0),11.0  (0.539),12.0  (0.427),12.6  (0.376),13.2  (0.338),13.0  (0.278),12.9  (0.243),
180 (3.0),8.7  (0.372),10.5  (0.328),11.7  (0.306),12.8  (0.288),14.5  (0.271),15.7  (0.259),
```

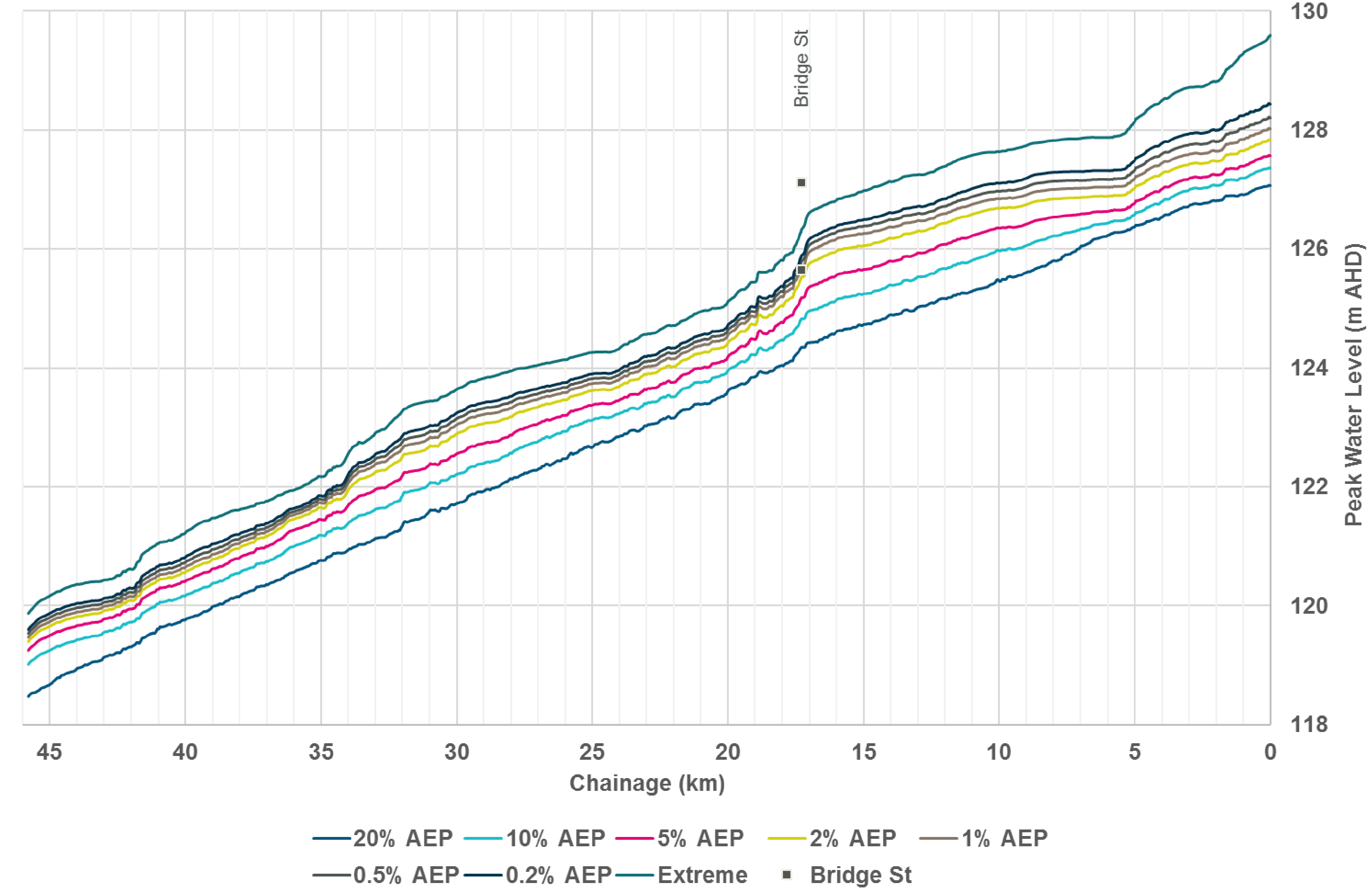
```
360 (6.0),6.6  (0.224),9.9  (0.248),12.1  (0.254),14.2  (0.256),17.4  (0.261),19.7  (0.262),
720 (12.0),2.5  (0.070),5.2  (0.105),6.9  (0.118),8.6  (0.126),14.0  (0.172),18.0  (0.196),
1080 (18.0),0.8  (0.019),2.2  (0.041),3.2  (0.049),4.1  (0.054),8.9  (0.098),12.5  (0.122),
1440 (24.0),0.0  (0.000),2.9  (0.048),4.8  (0.068),6.6  (0.081),8.6  (0.088),10.2  (0.092),
2160 (36.0),0.0  (0.000),0.9  (0.014),1.5  (0.019),2.0  (0.023),2.2  (0.021),2.4  (0.020),
2880 (48.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),1.2  (0.011),2.1  (0.017),
4320 (72.0),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),0.0  (0.000),
[PREBURST75_META]
Time Accessed,08 August 2018 10:41AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point
values remain unchanged.
[END_PREBURST75]

90% Preburst Depths
[PREBURST90]
min (h)\AEP(%),50,20,10,5,2,1,
60 (1.0),13.5  (0.833),18.4  (0.829),21.6  (0.816),24.7  (0.801),23.3  (0.631),22.2  (0.533),
90 (1.5),19.8  (1.063),23.7  (0.930),26.3  (0.864),28.8  (0.811),27.0  (0.636),25.7  (0.534),
120 (2.0),25.7  (1.256),25.1  (0.895),24.7  (0.737),24.3  (0.622),28.3  (0.604),31.3  (0.589),
180 (3.0),21.2  (0.906),23.8  (0.746),25.6  (0.671),27.3  (0.613),30.1  (0.563),32.2  (0.531),
360 (6.0),21.2  (0.726),22.8  (0.571),23.8  (0.501),24.8  (0.448),31.9  (0.479),37.1  (0.493),
720 (12.0),11.5  (0.318),17.1  (0.348),20.9  (0.356),24.4  (0.358),28.1  (0.345),30.9  (0.335),
1080 (18.0),7.1  (0.175),11.3  (0.205),14.1  (0.215),16.8  (0.220),23.0  (0.253),27.7  (0.270),
1440 (24.0),2.1  (0.048),12.2  (0.205),18.9  (0.267),25.3  (0.308),24.5  (0.251),23.9  (0.217),
2160 (36.0),0.4  (0.008),8.4  (0.128),13.7  (0.175),18.7  (0.207),14.4  (0.134),11.1  (0.093),
2880 (48.0),0.0  (0.000),3.9  (0.057),6.5  (0.079),9.0  (0.094),16.3  (0.145),21.8  (0.173),
4320 (72.0),0.0  (0.000),0.3  (0.005),0.6  (0.007),0.8  (0.008),12.4  (0.102),21.0  (0.156),
[PREBURST90_META]
Time Accessed,08 August 2018 10:41AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point
values remain unchanged.
[END_PREBURST90]

Interim Climate Change Factors
[CCF]
2030,0.85 (4.3%),0.845 (4.2%),0.974 (4.9%),
2040,1.086 (5.4%),1.05 (5.3%),1.341 (6.7%),
2050,1.303 (6.5%),1.283 (6.4%),1.734 (8.7%),
2060,1.478 (7.4%),1.539 (7.7%),2.212 (11.1%),
2070,1.629 (8.1%),1.775 (8.9%),2.753 (13.8%),
2080,1.741 (8.7%),2.036 (10.2%),3.26 (16.3%),
2090,1.793 (9.0%),2.316 (11.6%),3.748 (18.7%),
[CCF_META]
Time Accessed,08 August 2018 10:41AM
Version,2016_v1
Note,ARR recommends the use of RCP4.5 and RCP 8.5 values
[END_CCF]

[ENDTXT]
```

Appendix C Murrumbidgee River Design Peak Flood Level Long Sections


Bridge St
130
128
126
124
122
120
118
Peak Water Level (m AHD)
45
40
35
30
25
20
15
10
5
0
Chainage (km)
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
0.2% AEP
Extreme
Bridge St

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