Wagga Wagga Special Activation Precinct

Flooding and Water Quality

Final Adopted Scenario Report

Department of Planning, Industry and Environment

R03 J1233 Rev 1

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Cover Photograph: Culverts along Dukes Creek at Horseshoe Road, photo taken during site inspection by Heath Sommerville, July 2019.

Executive Summary

The Wagga Wagga Special Activation Precinct (SAP) provides an opportunity to develop a world class business precinct and transport hub. The Precinct seeks to capitalise on key linear transport infrastructure features; being the Inland Rail and the Olympic Highway to provide opportunity associated with freight and logistics, agribusiness and advanced manufacturing.

This final adopted scenario report builds on both the technical baseline study of flooding and water quality (Rhelm, 2019a) and the subsequent scenario testing report (Rhelm, 2019b).

This flooding and water quality investigation has been completed in conjunction with a wide range of disciplines including sustainability assessments (prepared by Dsquared Consulting) and utilities and environmental investigations (prepared by WSP) and with data inputs from the Department of Planning, Industry and Environment (DPIE) and Wagga Wagga City Council (WWCC).

Watercourses Overview

The Precinct is located to the north of Wagga Wagga on the fringe of the Murrumbidgee River floodplain. The Precinct is located within portions of the Dukes Creek catchment (a tributary of the Murrumbidgee River) and the Eunanoreenya (also referred to as the Eunony Valley) tributary of Wheel of Fortune Creek, which is also a tributary of the Murrumbidgee River. Some previous reports refer to this creek as Schillers Creek (Urban Concepts, 1995 and Eco Logical, 2008). The Inland Rail line runs along the ridge line between the Dukes Creek and Eunony Valley Tributaries.

A substantial distance upstream of the Precinct on the Murrumbidgee River is Burrinjuck Dam, which is the headwater for the Murrumbidgee River. Blowering Dam is also upstream of the Precinct on the Tumut River (a major tributary of the Murrumbidgee River).

Much of Dukes Creek is ephemeral and portions only flow during or immediately after a reasonable volume of rainfall. The upper catchment contains a series of large ponds that are currently used for the management of runoff from the Wagga Saleyards (Wagga Wagga Livestock Marketing Centre). There are also a series of small online storages (farm dam type ponds) in the vicinity of the Olympic Highway. Downstream of Horseshoe Drive the creek is difficult to distinguish and any flow is conveyed largely as overland flow.

Likewise, much of the Eunanoreenya Valley tributary of Wheel of Fortune Creek is ephemeral and many areas identified as creeks in published information have no distinguishable creek bed or banks and instead flow is conveyed as shallow overland flow. The upper catchment also contains a series of large former wool combing ponds which are not currently utilised for water management purposes.

Floodplain Overview

The southern sections of the Precinct interact with the Murrumbidgee River floodplain. However, the majority of floodplain risk management requirements for the Precinct are related to runoff directly from the Precinct and the immediate adjacent easterly catchment rather than from the external, much larger, Murrumbidgee catchment.

Baseline flooding assessments of the Precinct documented in this report have the aim of understanding the existing flood risk. The baseline studies flag areas that should be set aside for the conveyance of flood flows. These areas are symbiotic with riparian corridor requirements (particularly where there is flood-dependent vegetation). A preliminary evaluation of riparian corridor widths was made for the baseline assessment to inform areas to be set aside for that purpose. The scenarios tested adapted the preliminary recommendations and the final adopted scenario is a further adaptation to provide a multi-function corridor that seeks to meet riparian corridor, flooding and water quality objectives as well as other objectives.

Potential land use changes should not alter the flood risk both onsite (for existing premises and dwellings with the Precinct) and externally. In this regard, opportunities to develop centralised infrastructure (i.e. regional flood detention basins) that facilitate a more efficient and economic approach to the management of flood risk have been identified and incorporated in the testing of each scenario and further refinement was completed to develop the final adopted scenario.

Surface Water Quality

The management of surface water quality has been integrated into the final adopted scenario with the intention of achieving sustainability, visual amenity, urban design and engineering functionality outcomes for the Precinct as a whole.

A number of existing premises within the Precinct are licenced under the Protection of the Environment Operations Act, 1997, however specific controls on the quality of water discharged from those premises (i.e. surface flows leaving the site) are not set.

Water quality in Dukes Creek and the Eunanoreenya Valley tributary (when flowing, noting both systems are ephemeral) is likely to be representative of the rural and semi-rural land use that is representative of the current land use of the majority of the Precinct. It is likely that the concentrations of nutrients and faecal contamination indicator organisms are elevated. In times of peak flow, it is expected that concentrations of suspended solids are likely to be high. There may be present in higher concentrations some other toxicants related to rural land use (pesticides and herbicides). Given the soil types in the region and previous identification of salinity issues, it would be expected that the salinity of surface water may be elevated.

The approach to water quality treatment (also referred to as water sensitive urban design) is:

- Roof rainwater capture and re-use (for internal and external purposes) at a rate of 20kL rainwater tank per hectare of roof area within Industrial Zones (assumed that 30% of the zone is roof area)
- Primary treatment of runoff using a gross pollutant trap (the proprietary product CDS was used for the analysis)
- Secondary treatment of runoff using bioretention basins. The bioretention would form the base area and the area (airspace) above would operate as the flood detention basin during larger events.

It is recommended that a program of baseline monitoring be implemented to better understand the existing surface water quality and to inform the long-term evaluation of the impact of the Precinct development on the receiving waters.

Summary of Approach to Managing Flooding and Water Quality

A combined total of 61.61ha and 554,000 m^3 is required for the final adopted scenario for the purposes of flood detention (to manage flood impacts) and water quality.

A Green Infrastructure Overlay is proposed to be set aside within the Precinct, and where this relates to creek systems its purpose being to convey low and high flows (up to the 0.5%AEP flood event). The combined flood detention and water quality basins are proposed to be located where possible within the outer portions of the Overlay, where it relates to creeks.

A series of culvert upgrades along the Olympic Highway and East Bomen Road will be required to ensure flood immunity of these roads up to the design flood event (0.5%AEP).

Table of Contents

Appendices

List of Figures

Acronyms and Abbreviations

1D	One-Dimensional
2D	Two- Dimensional
AHD	Australian Height Datum
AEP	Annual Exceedance Probability
AIDR	Australian Institute for Disaster Resilience
ARI	Average Recurrence Interval
AR	Assessment Report (IPCC)
ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
DCP	Development Control Plan
DCS	Debris Control Structure
DECC	Department of Environment and Climate Change (now largely DPIE)
DECCW	Department of Environment, Climate Change & Water (now largely DPIE)
DEE	Department of Energy and Environment (Cth)
DEM	Digital Elevation Model
DLWC	Department of Land and Water Conservation (now largely DPIE)
DoI (Water)	Department of Industry (Water) (formerly DPI Water) (now DPIE)
DPE	Department of Planning and Environment (now DPIE)
DPIE	Department of Planning, Industry and Environment
DPI Water	Department of Primary Industries – Water (Now DPIE)
FFL	Finished Floor Level
FPL	Flood Planning Level
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
GIS	Geographic Information System
Ha	Hectares
IFD	Intensity-Frequency-Duration
IPCC	Intergovernmental Panel on Climate Change
ISEPP	State Environmental Planning Policy (Infrastructure) 2007
km^2	Square kilometres
LEP	Local Environment Plan

LGA	Local Government Area
LiDAR	Light Detention and Ranging
m^2	Square metres
m^3	Cubic metres
m/s	Metres per second
m^3/s	Cubic metres per second
mAHD	metres to Australian Height Datum
mm	Millimetres
MOFFS	Major Overland Flow Flood Study (for Wagga Wagga) (WMAWater, 2011)
m/s	Metres per second
NSW	New South Wales
OEH	Office of Environment and Heritage (now DPIE)
OSD	On Site Detention
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RCP	Representative Concentration Pathway
SES	State Emergency Service
TBRG	Tipping Bucket Rain Gauge
VRZ	Vegetated Riparian Zone
WSUD	Water sensitive urban design
X_SEC	Cross section

Glossary[1]

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3 /s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3 /s or larger event occurring in any one year (see ARI).
Assessment Report	Reports prepared by the Intergovernmental Panel on Climate Change (IPCC) appropriately every seven years dealing with global climate change in terms of both emissions and the potential effects of those emissions as projections.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
catchment	The land area draining through the mainstream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3 /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).
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

[1] Many of the definitions in this glossary have been derived directly from the Floodplain Development Manual (NSW Government, 2005)

flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the flood liable land concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the standard flood event in the 1986 manual.

flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. • existing flood risk: the risk a community is exposed to as a result of its location on the floodplain. • future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. • continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual. This has largely been replaced in practice by the H1-H6 classification system within AIDR (2017).

hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well-being of the State=s rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site-specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. major flooding: appreciable urban areas are flooded, and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to water level. Both are measured with reference to a specified datum.

stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.

1 Introduction

1.1 Project Overview

The Wagga Wagga Strategic Activation Precinct (Figure 1-1) provides an opportunity to develop a world class business precinct and transport hub. The Precinct seeks to capitalise on key linear transport infrastructure features; being the Inland Rail and the Olympic Highway to provide opportunity associated with freight and logistics, agribusiness and advanced manufacturing.

In order to plan these opportunities, an appreciation of the existing characteristics and constraints related to flooding and surface water quality is required. A baseline assessment of these characteristics was used to inform the development of three scenarios and these three scenarios were tested to determine their potential effects. Following assessment of the three scenarios a final scenario has been developed that considers key requirements for the precinct in relation to water quality treatment, detention, flooding and conveyance of water through the site.

1.2 Purpose of Report

This report has been prepared to:

- document the outcomes of technical baseline assessments of flooding and water quality within the Precinct
- document the outcomes of scenario testing assessments of flooding and water quality within the precinct.
- document the outcomes of the final scenario assessment of flooding and water quality within the precinct.

The assessment addresses both water quantity and quality and riparian corridors.

1.3 Study Area Description

The Precinct is located at the headwaters of two tributaries of the Murrumbidgee River:

- Dukes Creek
- Unnamed tributaries of Eunanoreenya Valley (hereby referred to as the Eunony Valley Tributaries) which discharge into Wheel of Fortune Creek.

The Precinct study area is provided in Figure 1-1.

Floodplains are commonly defined by either the extent of ‘mainstream’ flooding (generally associated with an open channel, creek or river) or ‘overland flow’ flooding (associated with the capacity of the underground stormwater drainage system being exceeded). Some areas are affected by both types of flooding.

The Wagga Wagga Strategic Activation Precinct Investigation Area, in the vicinity of Bomen, is located north-east of Wagga Wagga. The area covers approximately 4,180 hectares. Approximately 600 to 750 hectares of this is already developed as a business park. Bomen Business Park supports a variety of existing businesses including food manufacturing industries, an abattoir, chemical manufacturing, a canola crushing and oil refinery, manufacturing industries, equipment, lead and battery recycling, and Wagga Wagga Councils Livestock Marketing Centre.

The existing rail line runs along the ridge line between the Dukes Creek and Eunony Valley Tributaries. The majority of the Bomen Business Park currently discharges into the Dukes Creek catchment. Portions of the existing Bomen Business Park area, within the Precinct are also serviced by an underground system of stormwater pits and pipes. The area can be affected by overland flow flooding when their capacity is exceeded.

1.4 Report Structure

This report is structured as follows:

- Data and Design Guidance Sources (Section 2)
- Catchment and Meteorological Characteristics (Section 3)
- Hydrological Investigations (Section 4)
- Hydraulic Investigations (Section 5)
- Implications of Flood Behaviour for Precinct Planning (Section 6)
- Floodplain Management Plan Review (Section 7)
- Surface Water Quality (Section 8)
- Riparian Corridors (Section 9)
- Climate change and its projected effects on flooding and water quality (Section 10)
- Effects of Dam Break from Upstream Dams (Section 11)
- Scenario Development (Section 12)
- Scenario Testing (Section 13)
- Flood Impact Assessment (Section 14)
- Final Scenario Development (Section 15)
- Final Scenario Flood Impact Assessment (Section 16)
- Recommendation and Conclusions (Section 17).

Electronic data for this project was transferred to DPIE as part of this study.

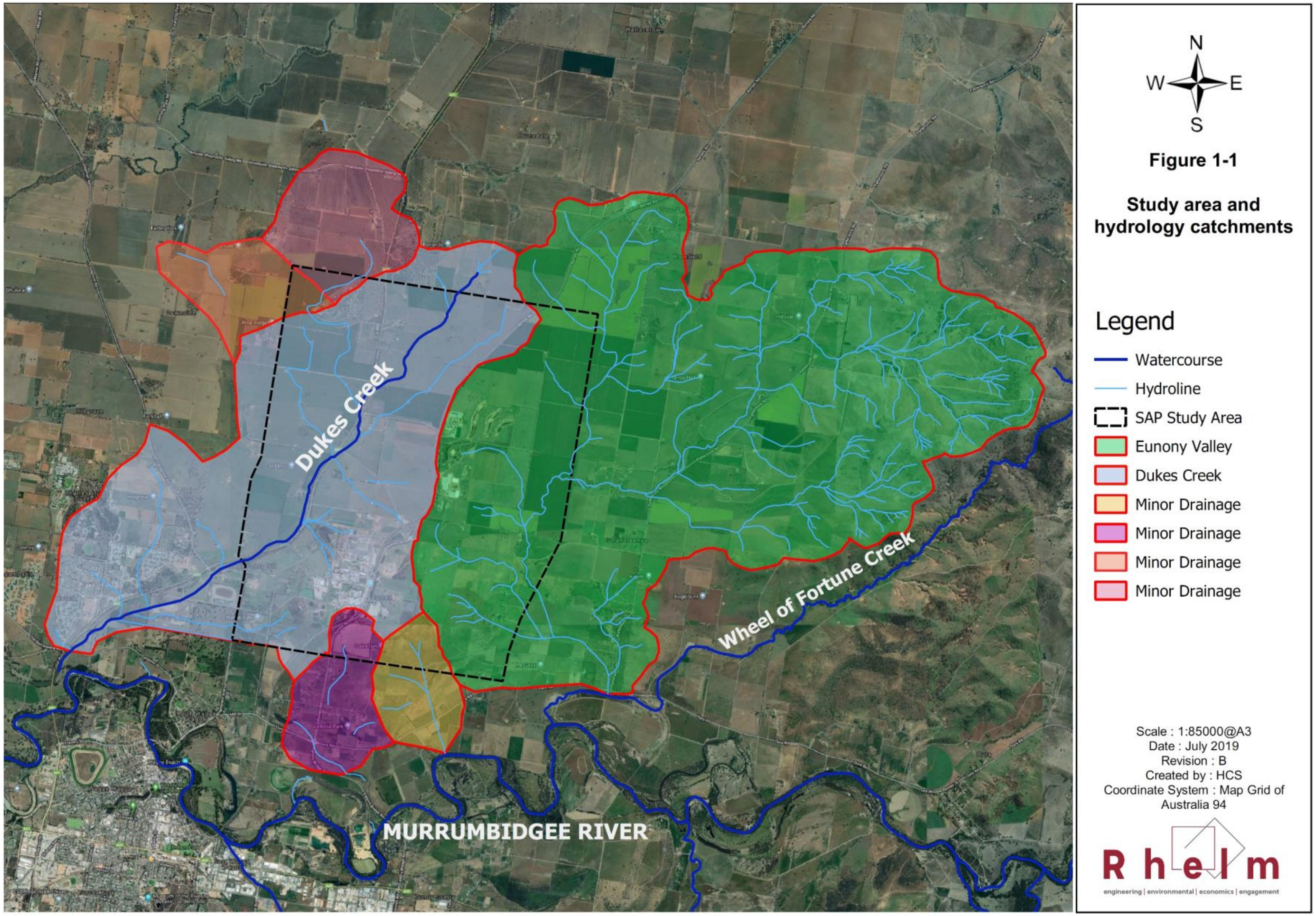


Figure 1-1 Study Area and Creek Systems

2 Data and Design Guidance Sources

2.1 Department of Planning, Industry and Environment

The Department of Planning, Industry and Environment (DPIE) provided access to spatial land use planning information for the Precinct area and assisted with the sourcing of a range of data sets from various state agencies for the project.

The Department of Environment and Climate Change (DECC) (now DPIE) captured Light Detection and Ranging (LiDAR) survey for the Murrumbidgee region. These data sets include aerial photography and ground levels survey data.

LiDAR survey was captured from February 2008 to May 2008 and includes the southern section of the Precinct. This LiDAR data was captured to facilitate the assessment of flooding associated with the Murrumbidgee River floodplain and as such does not extend to the upper portions of Dukes Creek and Wheel of Fortune Creek.

The LiDAR survey captured has a vertical accuracy of +/- 0.15 m to one sigma. Spatial resolution was +/- 0.60 m to one sigma. The data was sourced directly from Wagga Wagga City Council as a point cloud data set (referred to in this report as the point cloud LiDAR set).

For the upper catchments the ground surface information was sourced from Elevation and Depth – Foundation Spatial Data (also referred to as the ELVIS data set). The available data is set as a 5m grid with a stated accuracy of +/- 0.3 m (95% confidence) and vertical accuracy of +/- 0.80 m (95% confidence). This is referred to in this report as the 5m DEM LiDAR. This is a national dataset and is not as detailed or accurate at the 2008 site captured LiDAR.

The level of accuracy provided by the LiDAR is within a typical range and within acceptable vertical accuracy limits to adequately define the ground surface for the study. The LiDAR is also sufficient to define the hydrology sub catchments and drainage paths.

Further information regarding LiDAR data can be found at:

http://spatialservices.finance.nsw.gov.au/__data/assets/pdf_file/0004/218992/Elevation_Products_Specification_and_Desciption_LiDAR.pdf (Accessed 25 July 2019).

2.2 Wagga Wagga City Council

Wagga Wagga City Council (Council) manages the drainage infrastructure within the Precinct and is the primary waterway and floodplain manager (with assistance from DPIE, formerly the Office of Environment and Heritage).

Council has an extensive repository of spatial data relevant to flooding and drainage. This includes:

- Pits and pipes data (in GIS format, containing the spatial extent of pits and pipes, dimensions and pipes). The data defines the location of pits and pipes, pipe sizes but did not include pipe and pit inverts. For the limited area of stormwater drainage infrastructure this is sufficient to define the spatial layout. The inverts can be assumed based on the ground surface.
- Design plans for the recently constructed Merino Road. This is suitable for updating the 2008 LiDAR to include the road as it was developed after this LiDAR was captured. The design plans contain details of the cross drainage infrastructure.

- Local Environment Plan spatial data (in GIS format showing zoning and other features relevant to potential land use and associated runoff generation). This data set was sourced in digital format from DPIE.

A number of relevant documents created or held by Council are relevant to flooding, drainage and water quality. These are:

- Wagga Wagga City Council Stormwater Policy (2002)
- Wagga Wagga Stormwater Management Plan (2013-2017)
- Wagga Wagga City Council Engineering Guidelines for Subdivisions and Developments (2017)
- Stormwater Development Services Plan (DSP) (WMAWater, ongoing).

Council has completed a number of flood studies for their area that are relevant to the Special Activation Precinct. These are:

- Wagga Wagga Major Overland Flow Flood Study (WMAWater, 2011) (MOFFS)
- Wagga Wagga Revised Murrumbidgee River Floodplain Risk Management Study and Plan (WMAWater, 2018)
- Wagga Wagga Detailed Flood Model Revision (WMAWater. 2014).

Flood extent mapping associated with the MOFFS and Murrumbidgee River (1% AEP and PMF) was provided in digital format by Council via DPIE.

The Wagga Wagga Major Overland Flow Floodplain Risk Management Study was in progress at the time of preparation of this baseline report (A. Mason, Wagga Wagga City Council *pers comm*). Rhelm has sought to collaborate with the consultant engaged for the delivery of that study (WMAWater) to ensure consistency in key assumptions for the baseline flood assessments. A key update of the MOFFS model is the revision of hydrologic inputs to contemporary standards using the most recent update to Australian Rainfall and Runoff (Ball et al, 2019). Mapping for this update is not yet available for public release (C. Goonan, WMAWater, *pers comm*).

The inability to compare flood results could lead to conflicts in this flood mapping and the current ongoing studies. Consistency would be improved by having access to the ongoing MOFFS results including the hydrology and current mapping based on ARR2019. The studies should be consistent, and it would reduce uncertainty to directly assess the assumptions and results. However, it is anticipated that there is unlikely to be a material difference in the overall flood extents.

Council were consulted to obtain available flood information such as images, flood marks and historical damages. No information was available for the study area. The lack of historical flood marks and levels is understandable given the infrequent flooding of the upper catchment areas. This limits the calibration options for the study, but this is consistent with most studies in regional areas. ARR2019 provides best practice approaches to managing situations with no calibration data.

Council was also consulted with regard to anecdotal or other information on a number of matters, such as historical blockages of structures (during flood events). In this regard, Council had no information regarding blockage of structures (such as bridges and other waterways crossings). This was not unexpected, and the approaches outlines in ARR2019 were used in lieu of observed information.

Council conducts water quality monitoring of the Murrumbidgee River and its associated Lagoons. Testing is conducted for nutrients (Wagga Wagga City Council, https://wagga.nsw.gov.au/city-of-wagga-

wagga/environment/sustainability/wateraccessed 29 July 2019). No testing is conducted for the creek systems in the Precinct.

2.3 Former Office of Environment and Heritage (now DPIE)

The NSW Office of Environment and Heritage (OEH) (now DPIE) has oversight of flood and stormwater quality at state level. DPIE is tasked with the implementation of numerous state policies, including the flood-prone land policy.

DPIE is the custodian of the NSW Government's Floodplain Development Manual (2005), which is the key guiding document in the management of flood-prone land.

In addition to the Floodplain Development Manual (NSW Government, 2005), DPIE (and its predecessor organisations, including OEH, DECCW, DECC, DNR, DLWC) have issued Floodplain Risk Management Guidelines. These guidelines cover a diverse range of topics including:

- Understanding flood behaviour
- Assessing flood damage
- Climate change
- Other flood management concerns
- Supporting emergency management.

The guidelines can be found at http://www.environment.nsw.gov.au/topics/water/floodplains/floodplain-guidelines.

2.4 Bureau of Meteorology

The Bureau of Meteorology (BoM) is an agency of the Australian Government which has rainfall gauges in the vicinity of the Precinct.

There are no known flood flow or level gauges operated by BoM (or any other organisations) in the Precinct area. This was expected given the infrequency of flooding and limited flood risk. This does not alter the approach to assessing the hydrology and hydraulics for the region.

In addition to rainfall and flood gauges, BoM also collects data relevant to the water cycle, including evaporation and solar radiation.

As model calibration/validation was not a requirement of studies for the Precinct, data was not collated from any of the gauges for the purposes of historical flood analysis or calibration. A summary of relevant information is provided in Section 3.6.

2.5 Eunony Valley Association and Community

The Eunony Valley Association was involved with supplying information and data to the project. Mr Bill Shulz assisted with a site inspection on 12 July 2019 examining the road crossings and areas influenced by flooding within the lower catchment for the Eunony Valley Tributaries.

Images of past flooding were supplied for the project. Discussion with the Eunony Valley Association members provided anecdotal information on the flooding behaviour, timing and frequency. The images of the flooding and discussions of the flood behaviour during various events allows for anecdotal assessment of the hydraulic model and modelling results. This provides useful context for quality checking the flood results.

The images supplied are reproduced in Appendix A.

2.6 Australian Rainfall and Runoff

Australian Rainfall and Runoff is a national guidance document, originally published by The Institution of Engineers, Australia (e.g. 1987 Edition, Pilgrim (Ed)) and currently published by the Australian Government (through Geoscience Australia, Ball et al, 2019). The document has been used extensively as the basis for design flood estimation for flood studies and for urban stormwater drainage design.

2.6.1 1987 Version

The 1987 version of the document (Pilgrim, Ed, 1987) incorporates information such as:

- Intensity Frequency Duration (IFD) relationships
- Storm Temporal Patterns
- Advice on losses for hydrological modelling
- Blockage for urban stormwater drainage systems (pits and pipes).

This version has since been superseded and is no longer in use for new projects. This approach is not suited to this assessment.

2.6.2 2016 Version

The 2016 version of the document (Ball et al, 2016) was a draft of a major overhaul of the 1987 version and incorporated information such as:

- Updated IFD relationships (using rainfall data collected since the analysis for the 1987 version was conducted).
- Updated Storm Temporal Patterns
- Advice on blockage for structures such as culverts and bridges (not discussed in the 1987 version)
- Advice on climate change adjustments associated with emission-related projections.

Some of the specific parameters associated with the guideline are provided through the *ARR Data Hub* (http://data.arr-software.org/).

2.6.3 2019 Version

The 2019 version of the document (Ball et al, 2019) is a minor revision of the information contained in the 2016 version following industry consultation. It is referred to as ARR2019 in this report.

2.6.4 NSW Specific Guidance

OEH (now DPIE) in January 2019 published a guidance on incorporating the updated Australian Rainfall and Runoff into flood studies in NSW. The *Floodplain Risk Management Guide: Incorporating 2016 Australian Rainfall and Runoff in studies* (OEH, 2019) is a key document in application of Australian Rainfall and Runoff. In particular, there is specific guidance related to rainfall losses that is of particular relevance to this investigation.

2.7 Minor Drainage System Review

2.7.1 Physical Infrastructure Data (Pits and Pipes)

Council has identified the location of all stormwater system pits and pipes in the Precinct area. These are shown in Figure 2-1. The only data identified was for infrastructure within the Bomen Business Park. This drainage is relatively disconnected with individual networks discharging into local low points or holding cells for the saleyards (Livestock Marketing Centre).

Whilst pipe sizes and inverts are available for some pipes in the Precinct, others are missing from the data set. The pipe sizes can be inferred based on upstream and downstream pipes and inverts can be assumed based on typical ground surface to invert depth and surrounding available information. This will have only minor influence on the study area as the stormwater system is only designed to manage frequent rainfall and flood events. This flood assessment is looking at rare, high intensity events which will substantially exceed the capacity of the local stormwater system. As a result, the missing data has little impact on the study.

Figure 2-1 Pits and Pipes (Source Wagga Wagga City Council)

2.7.2 Physical Infrastructure Data (On-site Detention)

Within the catchment there are businesses that have a form of on-site detention (OSD). These include ROBE, the former wool combing ponds, Enirgi, Southern Oil, Teys and the Stock Saleyards. Throughout the catchment are a number of farm dams located on drainage lines which are not formal detention structures but will provide some form of detention of flow.

For the purposes of this assessment these ponds have been assumed to be at the level recorded in the available survey. This assumption is suitable as the LiDAR would typically capture the standing water level of the basin. This provides a conservative estimate of the volumetric storage capacity available for the basins.

2.8 Major Drainage System Review

2.8.1 Riverine

The Murrumbidgee River System is relatively well studied, with a Flood Study and Floodplain Risk Management Study adopted by Council for this system (Section 2.2). However, these models typically only extend up the tributaries as far as the backwater influence of the Murrumbidgee River so do not cover the full Precinct area.

Whilst the flood behaviour for much of the study area does not have any current definition of flood behaviour, where information is available, it has been used for the purposes of comparison for this study (Section 5.2). The Murrumbidgee River is a complex system with multiple tributaries and storages. The Flood Study results are used to manage the Murrumbidgee River floodplain. This removes the risk of differences being predicted over this well studied area.

2.8.2 Physical Infrastructure Data (Channels and Culverts)

Cross drainage details for major roads such as the Olympic Highway and Merino Road were provided by both Council and Transport for NSW (formerly Roads and Maritime Services). Culvert data included location, size and length, but typically did not include invert levels. Bridge details were provided as work as executed drawings in PDF format which included dimensions and invert levels.

Field inspections were conducted by Rhelm on 20 June 2019 and 15 July 2019 to observe the cross drainage structures throughout the Precinct area. A summary of some of the photographs taken can be found in Appendix B.

Although not ideal, missing culvert invert data was mitigated by field inspection of the condition and location of the culverts relative to the ground surface. This allowed for a reliable estimate of the culverts or bridge inverts to be completed relative to the study ground surfaces. This limits the influence of the missing data on the study and allows the system to operate as observed from the filed inspections.

2.8.3 Major Drainage Historical Data

2.8.3.1 Historical Floods

The City of Wagga Wagga website (www.wagga.nsw.gov.au, accessed 25 July 2019) notes that:

> *There have been years of frequent floods, i.e. in one year 1974 Wagga Wagga had five floods all over 8.92 m and there was severe flooding in the 1950 to 1956 period. In other long periods 1939 to 1949 and 1960 to 1970 no floods occurred. Significant floods have occurred in Wagga Wagga in 1852, 1853, 1870, 1891, 1925, 1950, 1952, 1974, 1991 and 2012 with the largest recorded flood of 10.97 metres occurring in 1844. There have been two floods greater than the 1974 flood.*

However, this discussion relates to flooding of the Murrumbidgee River, which only marginally affects the Precinct directly. A detailed history of flooding of the study area was not available, although Council notes that flooding of the study area was less frequent:

> *Flooding of the City area in the south flood plain was frequent and to a lesser extent flooding occurred in the North Wagga Wagga village.*

As identified in Section 2.5, information provided by the Eunony Valley Residents Association shows flooding in the eastern portions of the Precinct in March 2010 and December 2010.

The available flood information is consistent with most rural investigations. Most studies do not have recorded levels and flood marks, particularly in regional areas with limited infrastructure at flood risk. The limited historical data does mean there is limited validation opportunity, however the information from the Eunony Valley Association does assist with flood behaviour assessment of the Eunony Valley flooding.

2.9 Previous Modelling – Hydrology

Numerical modelling for the Dukes Creek catchment has been undertaken using the WBNM modelling software as part of the Wagga Wagga Major Overland Flow Flood Study (MOFFS, WMAWater, 2011). The WBNM modelling for this study was not made available for the purposes of this assessment.

The available study was based on the ARR87 data (Section 2.6.1) which has undergone a number of changes in the ARR2106 and ARR2019 releases. It is understood that this study is currently being updated to ARR2019, but the results of this assessment are not yet available (see Section 2.2). The impact of not having the original hydrological model is not significant as the hydrology was completed using the ARR87 approach which needed to be updated. It would be of value for later stages of the Precinct planning process to compare the hydrology results, but it would be expected that there will be differences.

Of more influence is the ability of this study to compare the current ongoing MOFFS investigation which is also using ARR2019 (A. Mason, *pers comm*). This may cause some inconsistency with the hydrology between the two studies. However, it is anticipated that the difference may not be significant.

2.10 Previous Modelling – Hydraulics

A TUFLOW model was developed for the Wagga Wagga Major Overland Flow Flood Study (WMAWater, 2011). This model was not made available to inform the preparation of this report. However, this model only extended upstream as far as the available point cloud LiDAR (Figure 2-2), which was slightly further upstream than the extent of Murrumbidgee River backwater effects. While there is limited information covering the study area, where information is available this has been used for the purposes of comparison for this study. (Section 5.2). It would improve the comparison to have electronic results for the Dukes Creek study area for the full range of design events and details of the hydraulic modelling approach.

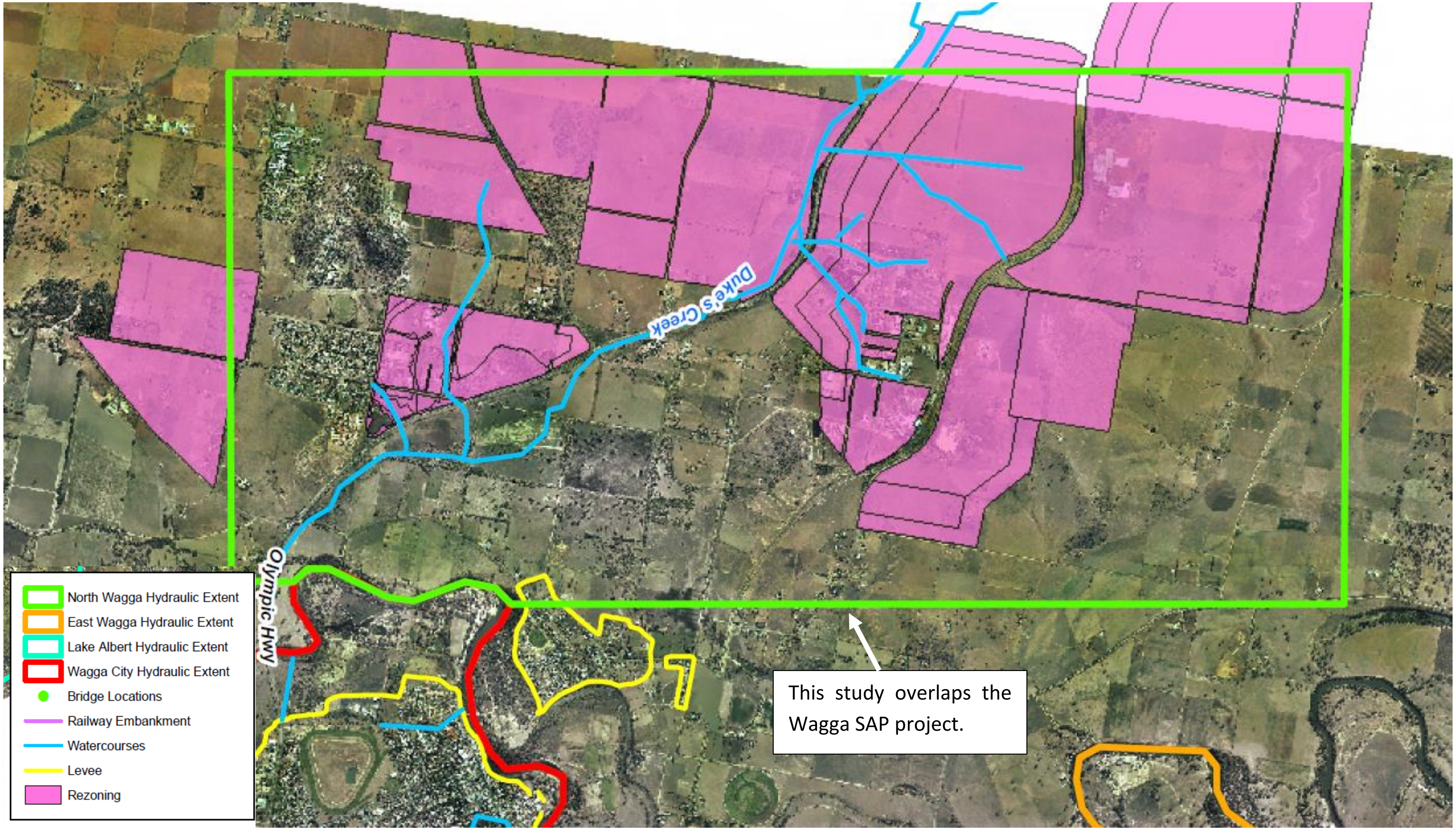


Figure 2-2. Extract of WMAwater (2011) Flood Study Extent (Source: WMAwater, 2011)

3 Catchment and Meteorological Characteristics

3.1 Topographic and Creek/Channel Data

3.1.1 LiDAR

LiDAR data provides the most comprehensive survey data that is available across the entire Precinct area and those areas in the catchments upstream of the Precinct. As outlined in Section 2.1, LiDAR from 2009 (point cloud LiDAR) was sourced for this study where available and the national 5m DEM LiDAR data was used for the remaining area. Figure 3-1 shows the topography of the Precinct and surrounds.

3.1.2 Other Survey

LiDAR data is generally of a lower accuracy within vegetated areas and where there are changes in levels within the spacing of data (i.e. such as along a creek bank and bed). No cross sections are available for the study area nor feature survey. However, many of the creeks are poorly defined and lack significant in-bank capacity. Therefore, the LiDAR data may provide a reasonable representation of the capacity of the channel, sufficient for masterplan purposes flood analysis.

Bridge and culvert information has been made available from Council in the form of a spatial location and infrastructure size. No invert information was supplied with this data. For the Olympic Highway, TfNSW provided spatial layers of the culverts and bridge structures, images of the current condition and infrastructure sizes. Invert data was supplied as part of work as executed drawings. A summary of the available data is provided in Figure 3-2.

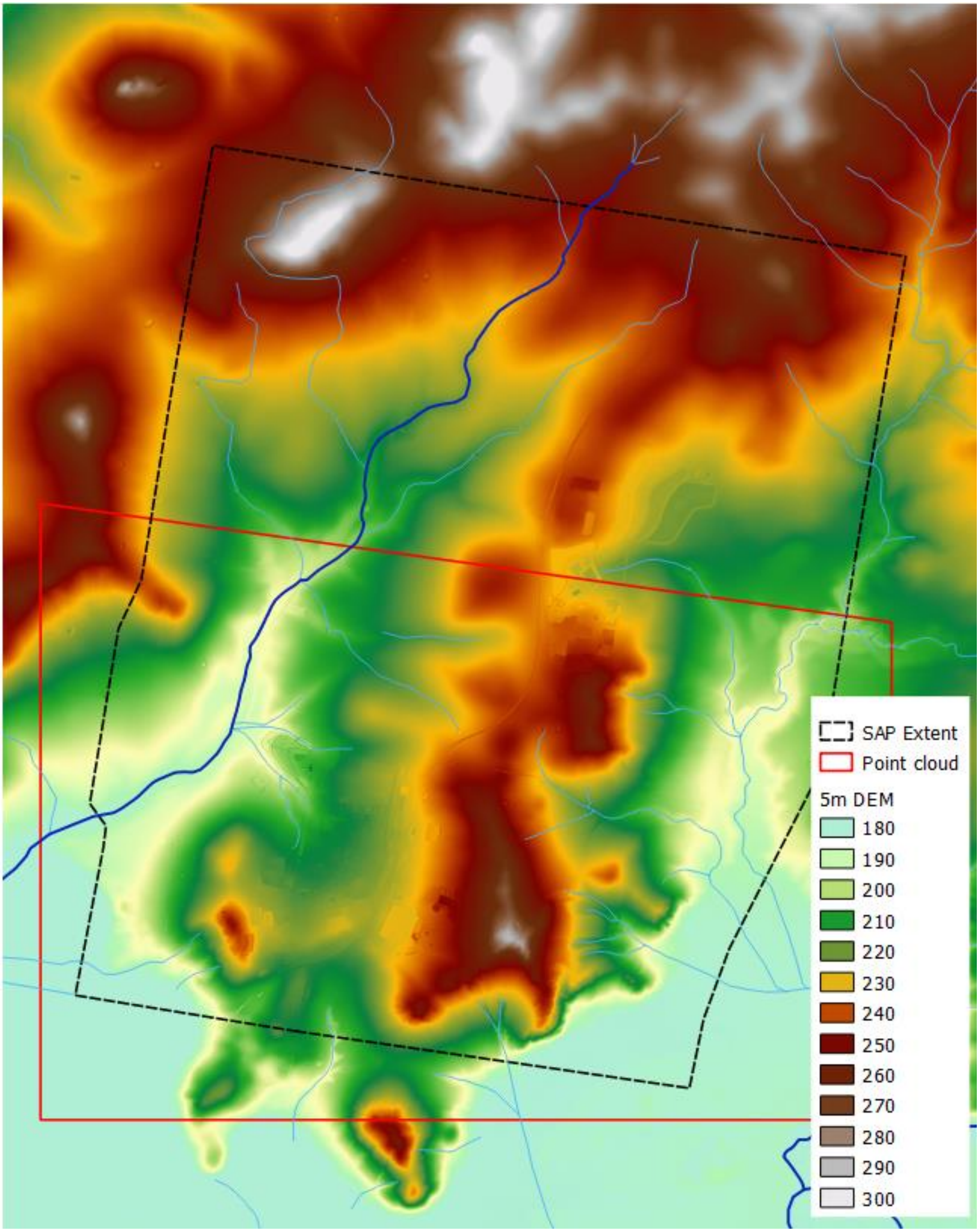


Figure 3-1 Precinct Topography

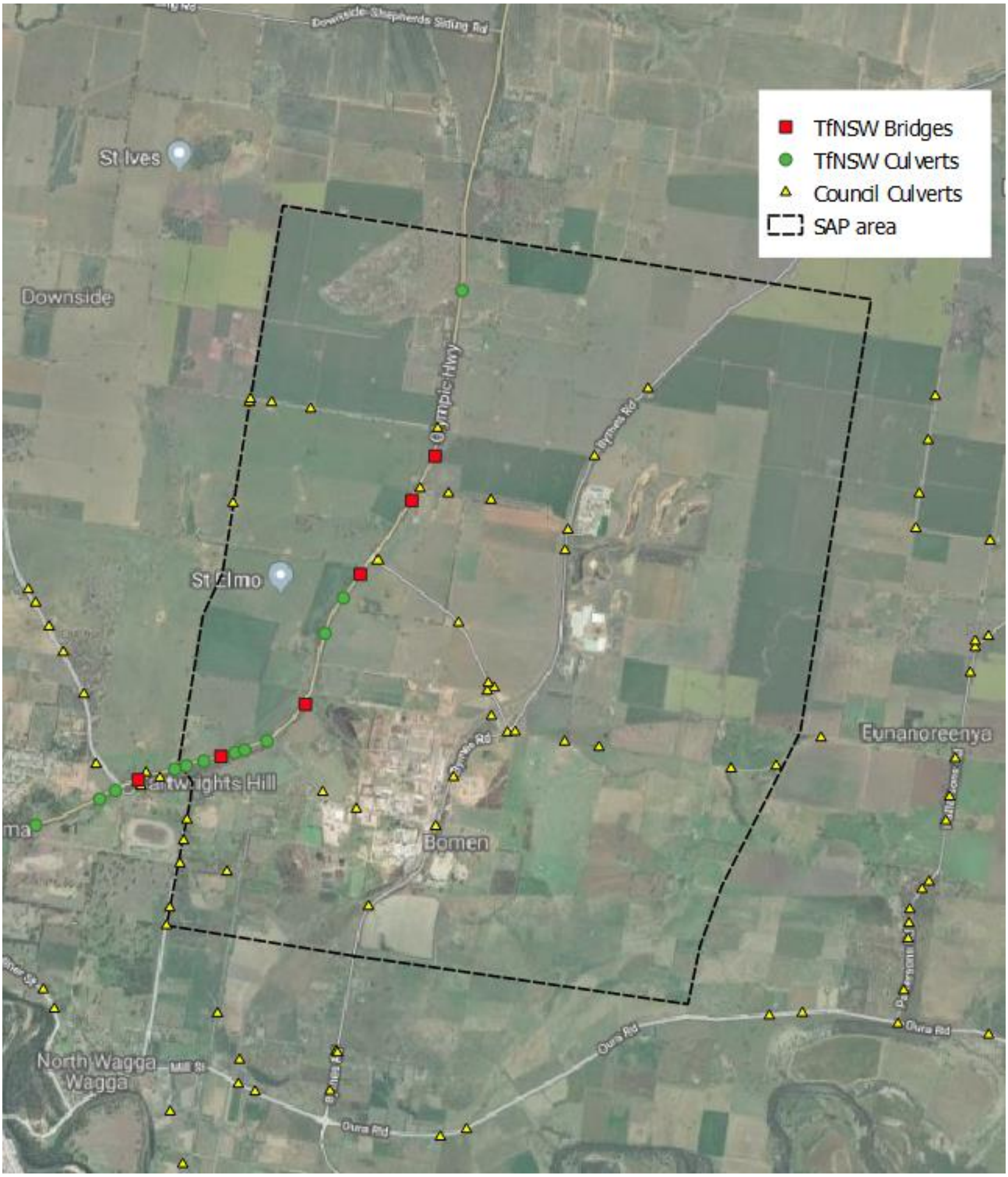


Figure 3-2 Culvert and Bridge Data Available

3.2 Catchment Mapping

Catchment mapping has been completed to subcatchment level for the purposes of the establishment of the hydrological model (Section 2.2). This mapping is shown in Figure 3-3.

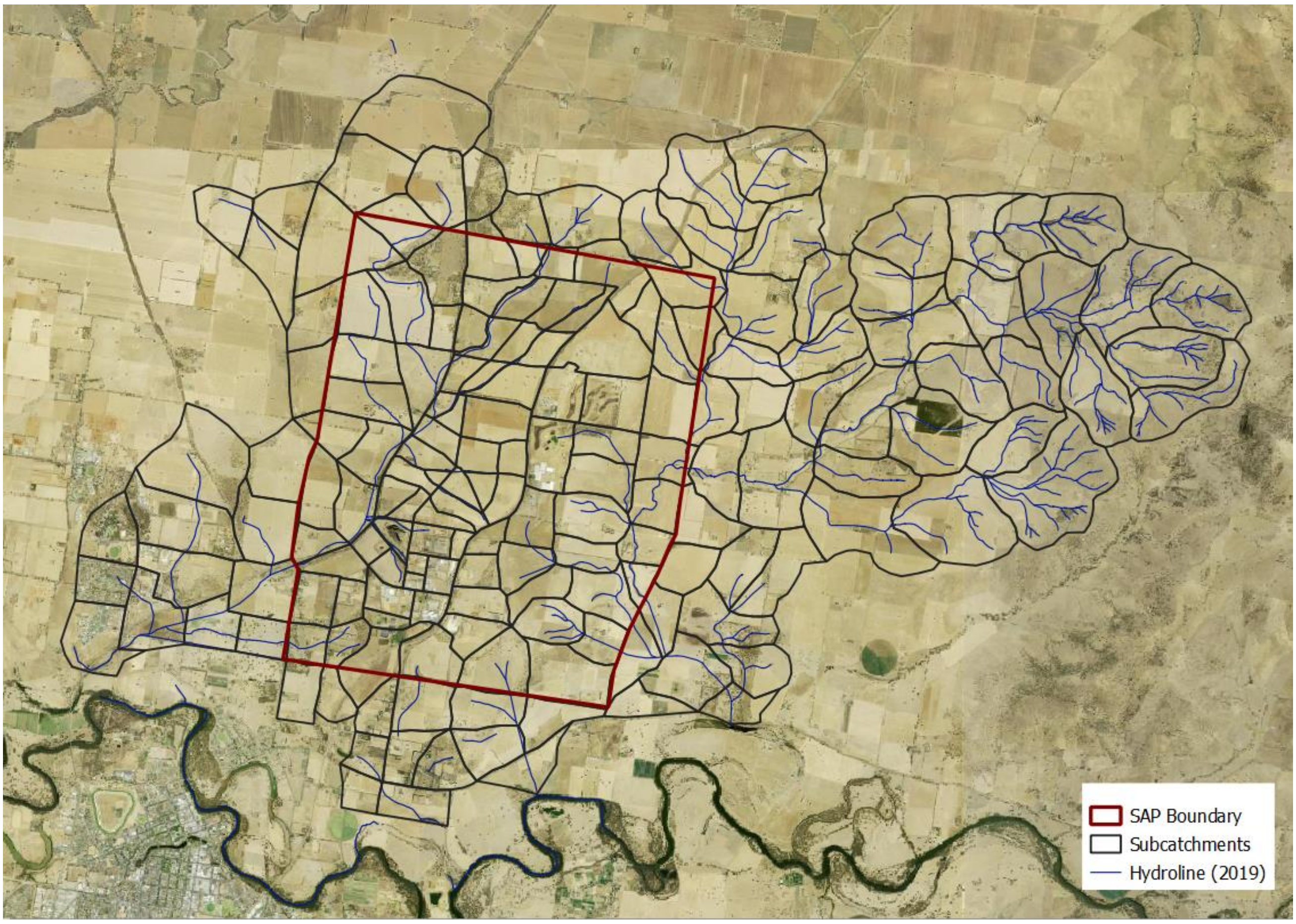


Figure 3-3 Sub-catchment Mapping

3.3 Aerial Photography

Aerial photography from 2014 was sourced from the Department of Finance, Services and Innovation (NSW Imagery Web Service, 2014). This photography is shown in Figure 1-1 and this same photography has been used as the base layer for those figures in this document that incorporate aerial photography. It has been assumed to be representative of the existing site conditions.

Aerial photography is used to assist with determining appropriate values for parameters in hydraulic modelling, such as:

- Roughness
- Building outlines.

3.4 Land Use

Land use information for the baseline conditions was sourced from field inspections, aerial photography and the Wagga Wagga Local Environment Plan (2010) Zoning Map (Figure 3-4).

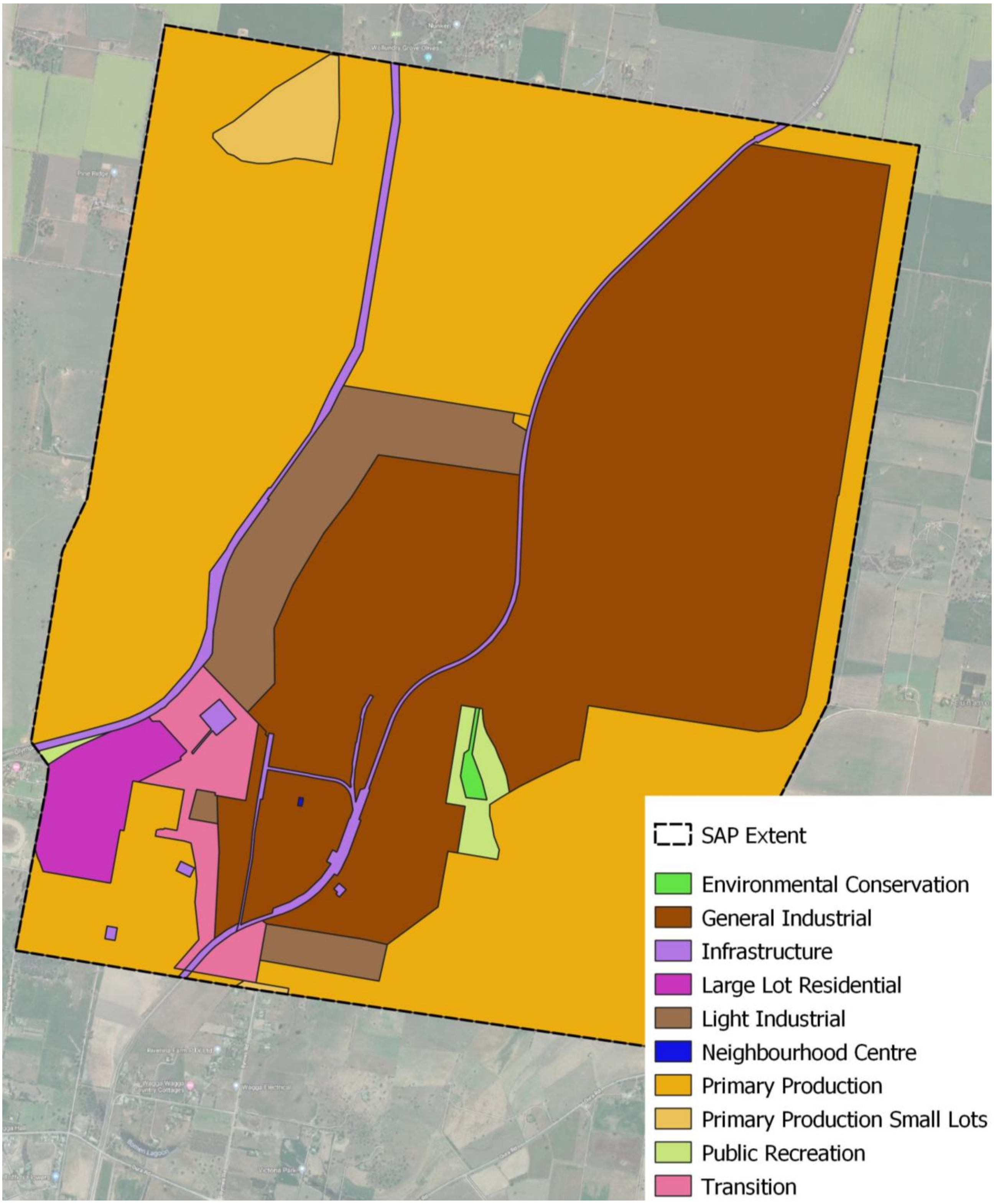


Figure 3-4 Land Use Zoning (Source: Wagga Wagga Local Environment Plan, 2010)

3.5 Soils and Soil Characteristics

The geology of the precinct is predominantly defined by the Department of Land and Water Conservation (1997) under the East Bomen (eb) soil class (see Figure 3-5). This is characterised as:

Landscape— undulating rises of Silurian Wantabadgery Granodiorite. Local relief 15 - 40 m; slope gradients 3 - 10%. Broad crests and ridges, long waning slopes, and shallow drainage depressions. Almost completely cleared tall woodland.

Soils— shallow to moderately deep (40 - 150 cm) Eutrophic Red Dermosols on crests and ridges; deep (80 - 200 cm) Eutrophic Brown Dermosols on slopes; and moderately deep (80 – 150 cm) Eutrophic Brown Dermosols in drainage lines.

Limitations— moderate erosion hazard, moderately acid and locally shallow soil.

An example of the soil composition of the Precinct is shown in Figure 3-5. The soil profile consists of a dull loam (0 – 10cm) over a series of light clays (10 – 175 cm). The run-on is low to moderate on most slopes but is high near drainage depressions. Soil is prone to hardsetting and gully erosion is noted along most drainage lines. This soil type is reasonably consistent across the Precinct area as shown in Figure 3-6.

Figure 3-5 Example of the Soil Types in the Precinct area (Source: Department of Land and Water Conservation, 1997)

At the downstream end of the drainage lines the soil type changes at the Murrumbidgee River floodplain which is predominantly alluvial floodplain which comprises of silty clays over alluvial river sediments.

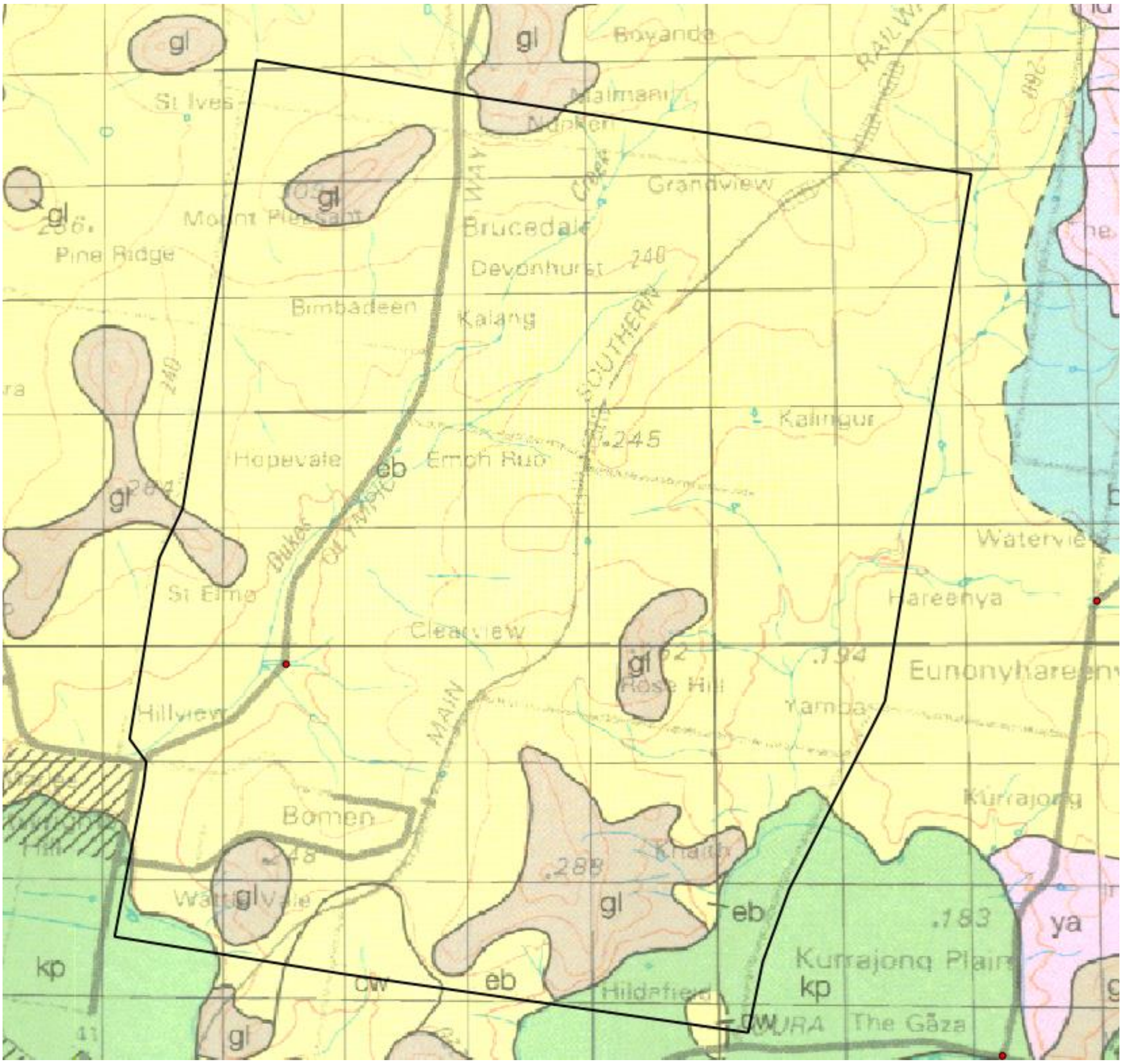


Figure 3-6 Soil type across the study area (Source: Department of Land and Water Conservation, 1997)

3.6 Rainfall

Data for rainfall in the Precinct and surrounds has been captured by the Bureau of Meteorology (BoM) over a 78-year period, at a daily or 24-hour totals rainfall gauge. Rainfall statistics for this gauge from BoM are summarised in Table 3-1. These statistics show that:

- Mean annual rainfall is approximately 572 mm
- Annual rainfall has ranged from roughly 245 – 1019 mm
- Highest daily rainfall recorded was 249 mm in March 1956.

The Wagga Wagga Major Overland Flood Study (WMAWater, 2011) noted that major rainfall and associated flooding events occurred in:

- Feb 1974
- April 1974
- April 1970
- December 1975
- December 1975
- December 1971
- January 1964
- September 1985
- February 2010.

Table 3-1 shows the date of highest daily rainfall and indicates for all March records that this was on the 8 March 2010 (110.8 mm) and similar for all December records that this was on the 9 December 2010 (67.6 mm). This coincides with the flood information provided by local residents (Section 2.8.3.1). This suggests that for the 77 year records that the event on 8 March 2010 is the largest daily rainfall event to have occurred locally and therefore could potentially represent a 1 in 80 AEP (or 1.25% AEP) design event.

Table 3-1 Monthly Climate Statistics for WAGGA WAGGA (AMO) [072150] (Source, Bureau of Meteorology Climate Statistics, Accessed 26/07/2019)

Statistic Element (for Years 1950-2018	January	February	March	April	May	June	July	August	September	October	November	December	Annual	No. of Years
Mean rainfall (mm)	40.5	40.2	44.6	39.7	50.6	50.4	54.4	50.7	49.2	56.4	46.3	46.6	571.5	77
Highest rainfall (mm)	174.4	187.2	249.2	216.9	190.3	138.8	130	101.4	171	181.7	152.4	213.4	1019.2	78
Date of Highest rainfall	1984	2011	1956	1974	1942	1991	1993	1983	2016	1974	2011	1988	2010	N/A
Lowest rainfall (mm)	0	0	0	0.5	4.6	0.8	1.8	6.4	4.1	0.6	0	0.5	245.2	78
Date of Lowest rainfall	1957	1968	2004	1967	2006	1984	1982	1982	1946	2002	1946	1967	1967	N/A
Decile 1 monthly rainfall (mm)	7	4.1	1.7	8.6	8.1	18.7	22	10.1	16.8	15.4	11.9	4.7	403.4	77
Decile 5 (median) monthly rainfall (mm)	31.6	26.6	26.8	29.2	40.4	44.5	52.4	50	45.9	48.5	40.5	38	566	77
Decile 9 monthly rainfall (mm)	84.1	85.3	108	85.3	104.2	91	93.7	89.3	83.1	109.9	93.1	91.4	762.2	77
Highest daily rainfall (mm)	91.8	69.1	110.8	78	91.2	50.2	46	44.4	49.8	55.8	57.8	67.6	**110.8**	78
Date of Highest daily rainfall	11/1/1974	17/2/1972	8/03/2010	16/4/1969	30/5/1978	7/6/1991	13/7/1975	26/8/1983	10/9/2016	5/10/1974	30/11/2011	9/12/2010	**8/03/2010**	N/A
Mean number of days of rain	5.5	5.3	5.6	6.7	9.2	11.3	13.5	12.9	10.4	9.3	7.5	6.3	103.5	77
Mean number of days of rain >= 1 mm	4	4	4	4.8	6.2	7.4	9.1	8.8	7.1	6.9	5.5	4.6	72.4	78
Mean number of days of rain >= 10 mm	1.3	1.3	1.3	1.1	1.4	1.5	1.4	1.2	1.4	1.8	1.5	1.6	16.8	78
Mean number of days of rain >= 25 mm	0.4	0.3	0.4	0.3	0.3	0.2	0.1	0.1	0.2	0.4	0.3	0.5	3.5	78

4 Baseline Hydrological Investigations

An XP-RAFTS hydrological model was developed which covered the full catchment area of the Precinct site and upstream catchment areas. The subcatchment breakdown for the model is shown in Figure 3-3. The two main catchments of Dukes Creek and the Eunony Valley Tributaries are the focus, however additional drainage areas were included in the hydrology where they influenced the Precinct area.

Inputs to the model and the data sources for those inputs are summarised in Sections 4.1 to 4.5 . Subcatchment parameters for the baseline conditions are summarised in Appendix C.

The sub-catchments were delineated based on the LiDAR survey data. The LiDAR survey data was available for the full catchment area. The two LiDAR data sets and their extents are shown in Figure 3-1. The 5m DEM LiDAR extended over the entire upper catchment area.

4.1 Percent Impervious

Percentage impervious areas are largely a factor of development intensity and were determined from aerial imagery (Section 3.3) and Council asset layers (Section 2.7.1 and 2.8.2). High resolution aerial imagery was provided by Council and was supplemented by freely available online imagery and land use maps.

The impervious percentages adopted for the model were:

- Residential 60%
- Industrial 90%
- Road corridors 95%
- Railway corridor 80%
- Open land 2%
- Plantations 0%

4.2 Roughness

Roughness parameters influence how quickly runoff occurs in a sub-catchment. Similar to the percentage impervious, the values were determined from an examination of aerial imagery and were largely dependent on land use.

Roughness values adopted for the catchments were:

- Roads / carparks 0.020
- Railway corridor 0.030
- Parks and open space 0.045
- Riparian Vegetation 0.060
- Industrial 0.080
- Residential development 0.120

4.3 Runoff Routing

Routing refers to the transfer of flows from one sub-catchment to another. This routing can be done in XP-RAFTS through either specifying a lag time between sub-catchments (10 minutes for example) or inputting a typical cross section, roughness and length and allowing XP-RAFTS to compute the lag time based on the flow volume. For this model, lag links were used to define the routing.

4.4 Rainfall Losses

Rainfall intensities and hyetographs for the design storms were based on ARR2019 (Ball et at, 2019), using data sourced from the BoM and the ARR Data Hub (arr.ga.gov.au). The unadjusted ARR2019 losses estimated for the Precinct are an initial loss of **26.0 mm** and a continuing loss of **4.6 mm/h**. It is noted that additional investigation has been done on losses within NSW and these supplied losses are required to be adjusted based on this revised guidance.

OEH (2019) provide a revised approach for the derivation of losses for NSW. OEH (2019) advise that the losses should be determined based on the following hierarchy:

1. *Use the average of calibration losses from the actual study on the catchment if available.*
2. *Use the average calibration losses from other studies in the catchment, if available and appropriate for the study.*
3. *Use the average calibration losses from other studies in the similar adjacent catchments, if available and appropriate for the study.*
4. *Use the NSW FFA-reconciled losses (See Map & Appendix C Table C3) available through the ARR Data Hub. These losses may be used within the catchment in which they were derived (available through the ARR Data Hub) or similar adjacent catchments with appropriate scrutiny.*
5. *Use default ARR data hub continuing losses with a multiplication factor of 0.4. This is used with the unmodified ARR Data Hub initial losses which requires the application of additional scrutiny to the balance between initial loss and pre-burst to ensure it is reflective of flood history and observations for the catchment being investigated in the lead-up to events.*

Steps 1 to 3 are not applicable for this study due to the absence of streamflow gauges or flood observations. Step 4 determined that there are five FFA-reconciled catchment losses in the vicinity of the catchment, with two being in relatively close proximity. The five closest loss adjusted catchments are shown in Table 4-1 and the nearby catchments of Ladysmith and Book are shown in Figure 4-1.

Table 4-1 FFA adjusted loss rated nearby to Wagga Wagga

Gauge Name	Number	Distance	ARR19 Losses		FFA Adjusted Losses	
			Initial Loss (mm)	Continuing Loss (mm/h)	Initial Loss (mm)	Continuing Loss (mm/h)
Ladysmith	410048	18km	27.6	4.47	**50.0**	**1.57**
Book	410156	22km	28.1	4.45	**31.9**	**2.33**
Batlow Road	410061	65km	29.0	4.97	**25.5**	**2.04**
Jingellic	401013	99km	28.8	4.74	**49.7**	**0.83**
Yambla	401015	105km	25.7	4.60	**37.6**	**3.74**

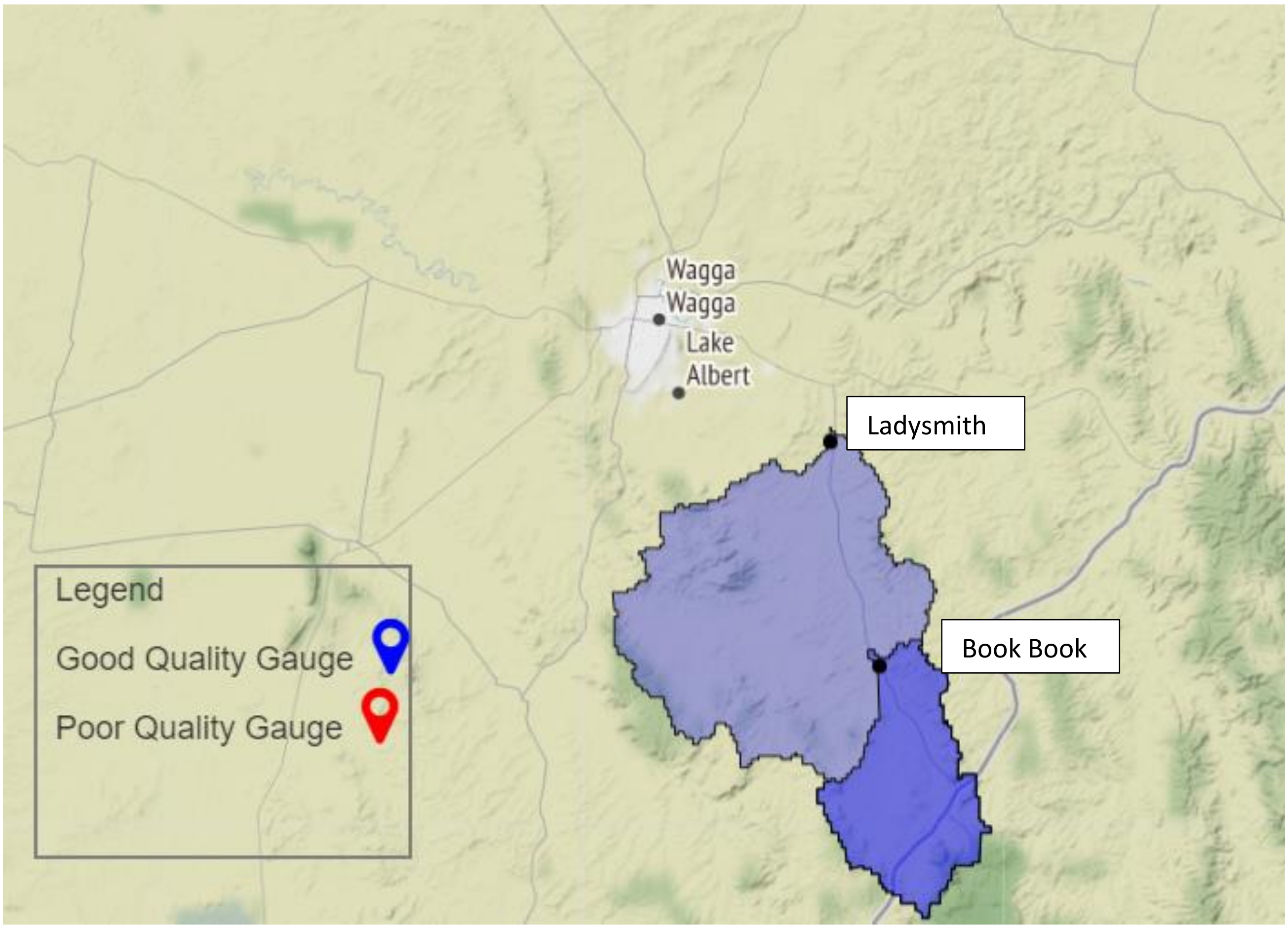


Figure 4-1 Nearby FFA adjusted loss locations (OEH, 2019)

The losses stated under the Data Hub and for the FFA adjusted losses are complete storm losses. The storms generated for design based on ARR2019 are storm bursts only and losses are required to be adjusted from the complete storm loss to the burst only loss. The relationship between the loss is based on the following equation from ARR2019 and is shown in Figure 4-2:

$$IL_s = IL_{pre\text{-}burst} + IL_b$$

Where:

IL_s is the initial loss for the complete storm.

$IL_{pre\text{-}burst}$ is the loss attributed to rainfall in the lead up to the burst event

IL_b is the loss attributed to the design rainfall burst.

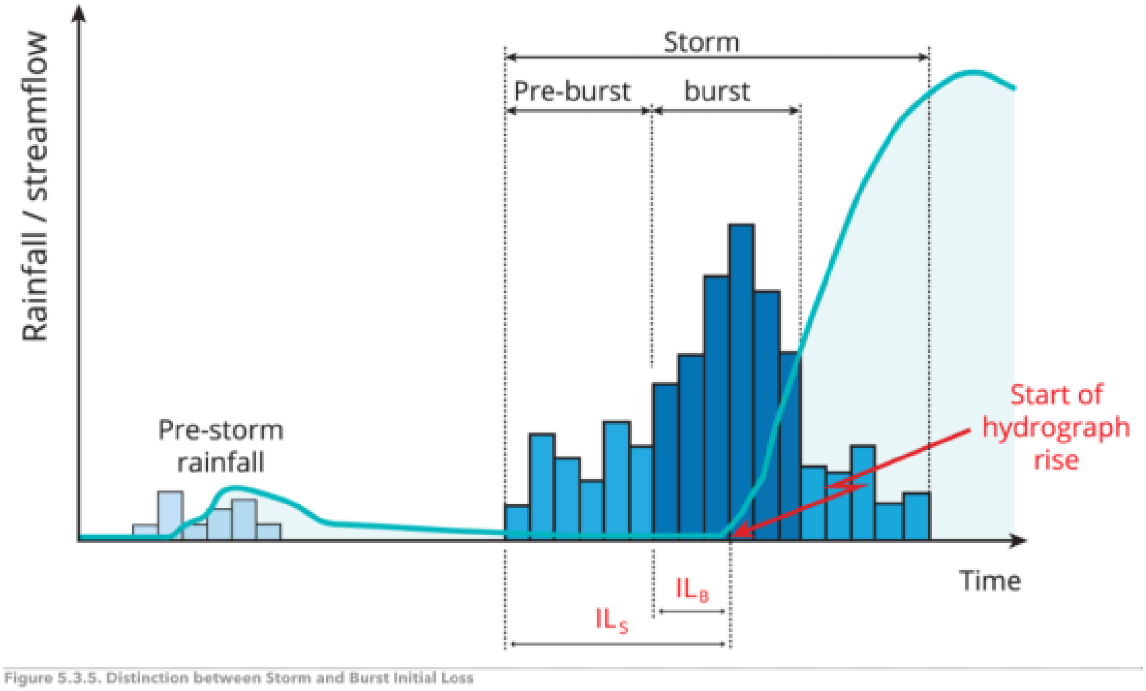


Figure 4-2 Distinction between storm and burst initial loss (source: ARR Book 5, Figure 5.3.5)

The pre-burst data has been supplied on the Data Hub for a range of expected conditions. Given consideration of the median event for the design conditions, this is the most relevant and important estimate of the pre-burst losses. The median pre-burst losses are shown in Table 4-2 for the 50% AEP to 1% AEP. The data shown is the initial loss for the pre-burst followed by the ratio of pre-burst to the full storm loss.

The main observation from this data was that the maximum pre-burst loss in terms of mm was for the 1% AEP, 720 minute event at 5.5 mm. This is small relative to the estimate losses based on the FFA adjusted catchment data. Similarly, there was very little variation across the design events for the pre-burst losses.

Table 4-2 Median Pre-burst losses for Wagga Wagga

Median Pre-burst Depths and Ratios ($IL_{pre\text{-}burst}$)						
min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	1.8 (0.090)	1.6 (0.058)	1.5 (0.044)	1.4 (0.035)	0.9 (0.019)	0.5 (0.010)
90 (1.5)	2.8 (0.124)	1.9 (0.060)	1.3 (0.034)	0.7 (0.016)	0.6 (0.012)	0.5 (0.009)
120 (2.0)	4.4 (0.179)	3.2 (0.094)	2.5 (0.060)	1.7 (0.035)	0.8 (0.014)	0.1 (0.001)
180 (3.0)	3.0 (0.108)	2.9 (0.075)	2.8 (0.062)	2.8 (0.052)	1.6 (0.025)	0.7 (0.010)
360 (6.0)	2.2 (0.064)	1.3 (0.027)	0.7 (0.012)	0.1 (0.001)	1.2 (0.016)	2.1 (0.024)
720 (12.0)	0.1 (0.002)	1.0 (0.017)	1.5 (0.024)	2.1 (0.028)	4.0 (0.044)	5.4 (0.053)
1080 (18.0)	0.0 (0.000)	0.3 (0.005)	0.5 (0.006)	0.6 (0.008)	2.5 (0.025)	3.8 (0.034)
1440 (24.0)	0.0 (0.000)	0.2 (0.002)	0.3 (0.003)	0.4 (0.004)	0.6 (0.006)	0.8 (0.007)
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)

The FFA adjusted initial losses for Ladysmith and Book are 50.0 and 31.9 mm respectively and, as per the OEH (2019) guidance, these should be used in preference to the ARR2019 data. The average of these locations was rounded to 40 mm. This estimated initial loss has then been adjusted based on the pre-burst information to get the estimated burst loss. Given the range of median pre-burst losses the larger pre-burst loss of 5 mm was applied to be conservative. This resulted in an estimated initial loss of 35 mm.

The continuing loss for both locations decreased from ARR2019 stated 4.46 mm/h down to 1.57 and 2.33 mm/h for Ladysmith and Book respectively. This loss can be averaged to 2.0 mm/h. This was adopted as the continuing loss for the hydrology.

As a check, Step 5 in the OEH (2019) hierarchy has also been assessed. Step 5 is to apply a factor 0.4 to the ARR2019 continuing loss. This adjusts the continuing loss from ARR2019 from 4.6 mm/h down to 1.84 mm/h. This is consistent with the estimated continuing loss based on nearby FFA adjusted loss results.

The losses adopted for the hydrological modelling are shown in Table 4-3.

Table 4-3 Adopted losses for the XP-RAFTS Model

Losses	Initial Loss	Continuing Loss	Reason
Pervious Area	35 mm	2.0 mm/h	Average of nearby loss adjusted catchments adjusted to account for pre-burst losses.
Impervious Area	1 mm	0 mm/h	In line with ARR2019 standard and urban modelling best practice.

4.5 ARR2019 IFD

The rainfall depths were extracted from the Bureau of Meteorology website for the area using a location at:

- Latitude: 35.063 (S)
- Longitude: 147.438 (E).

The rainfall depths for each annual exceedance probability (AEP) and duration extracted are shown in Table 4-4.

Table 4-4 Extracted design rainfall depths (ARR2019 Data Hub)

		Annual Exceedance Probability (AEP)						
Duration	**Duration in min**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.50%**	**0.20%**
10 min	10	13.7	16.5	19.3	23.1	26.1	29.3	33.5
15 min	15	16.9	20.3	23.7	28.4	32.1	36.0	41.2
20 min	20	19.2	23.1	27.0	32.3	36.5	40.9	46.8
25 min	25	21.0	25.3	29.5	35.3	39.9	44.7	51.1
30 min	30	22.5	27.1	31.6	37.8	42.7	47.8	54.7
45 min	45	25.9	31.1	36.3	43.4	48.9	54.8	62.6
1 hour	60	28.3	34.0	39.6	47.3	53.3	59.7	68.3
1.5 hour	90	31.9	38.1	44.4	53.0	59.7	66.9	76.4
2 hour	120	34.5	41.2	48.0	57.1	64.3	72.1	82.5
3 hour	180	38.4	45.8	53.3	63.4	71.3	80.0	91.6
4.5 hour	270	42.7	50.9	59.1	70.2	79.0	88.7	102
6 hour	360	46.0	54.8	63.5	75.5	84.9	95.5	109
9 hour	540	51.2	60.8	70.5	83.7	94.1	106	121
12 hour	720	55.3	65.5	75.9	90.0	101	114	130
18 hour	1080	61.4	72.7	84.0	99.6	112	126	144
24 hour	1440	66.1	78.1	90.2	107	120	134	154
30 hour	1800	69.9	82.4	95.1	112	126	139	158

5 Baseline Hydraulic Investigations

Hydraulic modelling of the baseline conditions was undertaken using the TUFLOW software package (version 2018-03-AC). This section discusses:

- Model Development (Section 5.1)
- Calibration and Validation (Section 5.2)
- Design Flood Modelling (Section 5.3)
- Flood Behaviour (Section 5.4).

The key details of the TUFLOW model are provided in Map G001, incorporated at the end of this report.

5.1 Model Development

5.1.1 DEM

The DEM for the TUFLOW model was constructed based on the available LiDAR data as identified in Section 3.1.1.

5.1.2 Grid Cell Resolution

A resolution of 5m was adopted for the hydraulic modelling. This resolution was sufficiently small to provide data on flood behaviour appropriate for the study, while not resulting in significant model run times.

5.1.3 Pipe Network

There was a limited pit and pipe network within the Precinct area. Drainage networks are present in the Bomen Business Park (Section 2.7.1), with the drainage network including in the model shown in Figure 2-1.

Some regions of the pipe network had missing data for both inverts and pipe sizes. This data was infilled based on the following assumptions:

- 600mm cover of pipes and culverts, unless otherwise suggested by nearby survey.
- Missing pipe sizes were assumed to the same as the largest of any upstream pipes.

Whilst incorporated in the model, the pipe network is largely not of significant interest for the purposes of masterplan scale analysis.

5.1.4 Culvert and Bridge Data

Cross drainage structures were incorporated along the Olympic Highway (Section 2.8.2) and at key crossings for waterways.

5.1.5 Roughness

Model roughness was delineated based on available aerial photography and confirmed during site visits. The roughness values adopted are summarised in Table 5-1. It should be noted that as building envelopes were not explicitly defined in the hydraulic model, roughness values for industrial and residential developments have been increased to account for buildings.

Table 5-1 Roughness Values

Land Use	Manning's 'n' Roughness
Pasture / Cleared / Open Space	0.045
Residential	0.12
Industrial	0.08
Roads	0.02
Rail	0.03
Plantations	0.09
Vegetation	0.06

5.1.6 Hydrological Inputs

Flows from the hydrological model (Section 4) were entered into the TUFLOW model via source-area (SA) polygons, which generally align with the sub-catchments from the XP-RAFTS model. This method applies the flow to the lowest cell within the SA polygon. As the flow increases, and the water level in the cell rises, adjacent cells become wet, and the inflow is then applied to these wet cells as well. In some situations, streamlines were also used to spread inflows along the creek lines and flowpaths.

For upstream catchment areas outside of the Precinct area, flows have been applied at the TUFLOW model boundary to represent these upper catchment inflows.

5.1.7 Downstream Boundaries

The primary downstream boundary conditions of the hydraulic model are governed by water levels in the Murrumbidgee River. The Murrumbidgee River is a significantly larger catchment which requires a much longer duration of rainfall to achieve a peak flood level (WMAWater, 2018).

These different flood mechanisms can result in a large flood occurring the Murrumbidgee River while there is only a relatively small event in the Precinct catchments. Applying a 1% AEP in the Murrumbidgee River at the same time as a local 1% AEP event is likely to be overly conservative and represent a far less frequent event.

As such, a lower AEP event was adopted in the Murrumbidgee River as the boundary condition for design event modelling. The adopted coincident flooding is summarised in Table 5-2.

The peak flood levels in the Murrumbidgee River have a gradient across the southern boundary of the Precinct model. As such, two downstream boundary conditions have been adopted, an eastern and a western boundary, with the western boundary being lower to represent the water level gradient in the Murrumbidgee River. The peak levels adopted for these boundaries are also summarised in Table 5-2.

A third, smaller boundary exists in the north-west corner of the model to manage flows off the ridge that run north-west into the adjacent catchment area rather than into the Precinct. A free outfall has been provided at this location.

Table 5-2 Coincident Flooding in the Murrumbidgee River Boundary Conditions

Local Catchment AEP	Murrumbidgee River AEP	Eastern Boundary Water Level (mAHD)	Western Boundary Water Level (mAHD)
10%	10%	182	179
5%			
2%	5%	182.5	180
1%			
0.5%			
0.2%			
PMF	1%	184	181.5

5.2 Calibration and Validation

Due to the lack of suitable historic data within the study area (e.g. recorded flood marks that have been surveyed to Australian Height Datum), a full calibration against historical events was not possible. In order to provide confidence in the model, a validation assessment has been undertaken through comparing the hydraulic model results with previously published flood extents from the Wagga Wagga Major Overland Flow Flood Study (MOFFS, WMAWater, 2011).

The comparison, shown in Figure 5-1, shows a good correlation between downstream levels and mainstream flooding in Dukes Creek. Upstream of the Bomen Business Park also shows a good correlation, however flooding through the business park is somewhat different in the models. This is likely due to a combination of application of upstream boundaries and survey data and the variance in input rainfall (ARR87 versus ARR2019). The fact that mainstream flooding and the upper tributaries show a relatively good match suggest that the model is sufficient robust for the purposes of assessing scenarios for the Precinct.

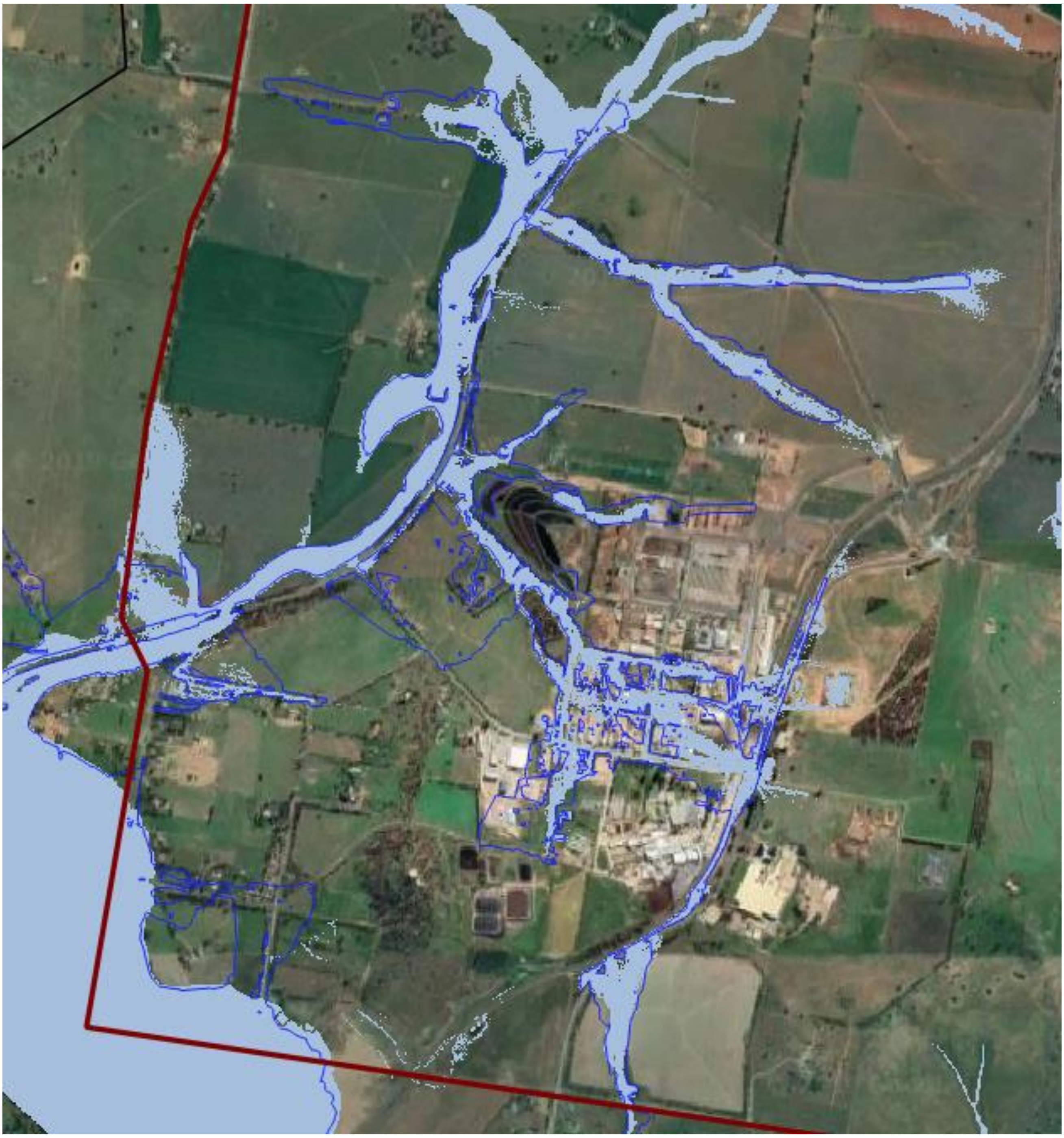


Figure 5-1 TUFLOW Model Validation

5.3 Design Flood Modelling

5.3.1 Scenarios Run

Using the parameters as identified in Section 5.1, the hydrological and hydraulic models were analysed for the PMF, 0.2% AEP, 0.5% AEP, 1% AEP, 2% AEP, 5% AEP and 10% AEP events. Each event was run for the critical duration(s) and temporal pattern(s) determined from the hydrological modelling (Section 4). The scenarios run for each event are summarised in Table 5-3. A flood extent comparison for three of the events (10%AEP, 1%AEP and PMF) is provided in map G101.

Table 5-3 Event Critical Durations

Design Event	Critical Duration (minutes)
PMF	15, 360
0.2% AEP	15, 360
0.5% AEP	15, 360
1%	15, 360
2%	15, 360
5%	20, 360
10%	20, 360

5.3.2 Model Results

5.3.2.1 Flood Depth and Velocity

To report the flood depths and velocity, the following post processing of model peak result grids was carried out:

- The median plus one event (or rank six of ten) storm was selected for each event/duration combination. This assessment was carried out for each grid cell in the model, so the selected median storm will be location specific and will vary across the study area.
- The maximum was then taken of the two median storms to prepare the peak grids in the figures described below.

Peak depth and velocity maps have been prepared for each event. The maps represent an envelope of peak results for those events for which multiple durations or temporal patterns have been run.

Peak depths are shown in maps G201 to G206.

Peak velocities are shown in maps G301 to G306.

These maps are attached to the end of this report.

5.3.2.2 Flood Hazard

Flood hazard (a function of flood depth and velocity) varies with flood severity (i.e. for the same location, the rarer the flood the more severe the hazard) and location within the floodplain for the same flood event. This varies with both flood behaviour and the interaction of the flood with the topography.

It is important to understand the varying degree of hazard and the drivers for the hazard, as these may require different management approaches. Flood hazard maps can inform emergency and flood risk management for existing communities, and strategic and development scale planning for future areas.

The hazard categories mapped are summarised in Figure 5-2. These are based on the categories as defined in the AIDR (2017) Guideline.

Flood hazard mapping for the design events is shown in maps G401 to G406.

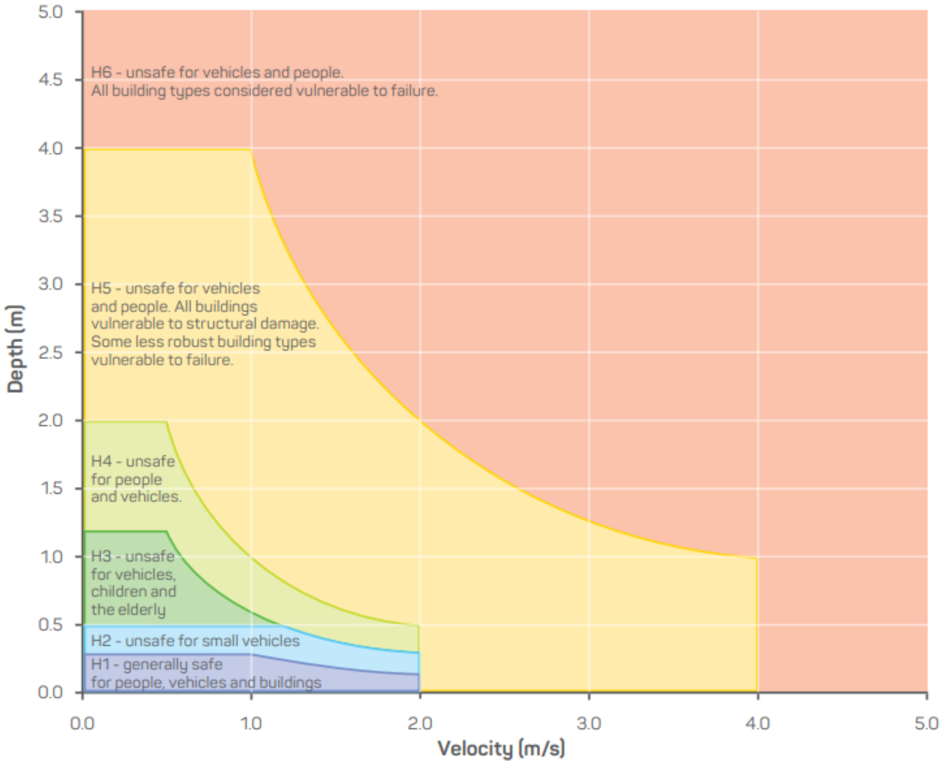


Figure 5-2 Flood Hazard Categories (Source: AIDR, 2017)

5.3.2.3 Flood Function

Identifying the flood functions of the floodplain is a key objective of best practice in flood risk management in Australia, because it is essential to understanding flood behaviour. The flood function across the floodplain will vary with the magnitude in an event. An area which may be dry in small floods may be part of the flood fringe or flood storage in larger events and may become an active flow conveyance area in an extreme event. In general flood function is examined in the defined flood event (DFE), so it can be accommodated as part of floodplain development, and in the PMF changes in function relative to the DFE can be considered in flood risk management.

The hydraulic categories (also known as flood function), as defined in the Floodplain Development Manual (2005), are:

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

- Flood 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.

An initial classification of flood function for this study was undertaken using a criterion set out in Thomas and Golaszewski (2012):

- Floodway – Velocity x Depth Product is greater than $0.5m^2/s$;
- Flood Storage – Velocity x Depth product is less than $0.5m^2/s$ and depth is greater than 0.5m; and
- Flood Fringe – areas in the flood extent outside of the above criteria.

The initial results have been refined to ensure continuity of floodways.

The mapping is provided in G503, G504 and G506 for the 1% AEP, 0.5%AEP and PMF events.

5.3.2.4 Road Overtopping

Using the results of the TUFLOW modelling, an initial evaluation of the overtopping of key roads by floodwaters is provided in map G601 for the various design flood events considered. The map is overlaid with the extent of the 1%AEP flood and the various overtopping locations are tabulated with the depth of overtopping. Five locations along the Olympic Highway and one location along East Bomen Road were identified to be affected by overtopping to various degrees. The depth of overtopping is limited in the 1%AEP event, up to approximately 0.25 m.

6 Implications of Baseline Flood Behaviour for Precinct Planning

6.1 Dukes Creek

Dukes Creek commences north of the study area and conveys runoff from the western half of the Precinct. The far north-western corner of the Precinct drains west to an adjacent catchment and does not interact with Dukes Creek.

Flooding along the reaches of Dukes Creek and its tributaries is typically well contained in events up to 0.2% AEP event. While the PMF shows an increase in lateral flood extent, the flows are still contained to the primary flowpaths, with only isolated regions of breakout flows at tributary confluences.

Velocities are generally low for events up to the 0.2% AEP event, with peak velocities in Dukes Creek and its tributaries of 2.5 and 1.5 metres per second respectively. In the PMF event, the activation of additional flow area, coupled with increased flow rates resulted in some local regions experiencing velocities in excess of 4 metres per second.

As would be expected given the velocities and depths, flood hazard remains low for the tributaries, typical H1 or H2, for events up to the 0.2% AEP. Both of these are classed as safe for pedestrians. Within Dukes Creek, hazards increase to H3 in the 5% AEP (unsafe for children and the elderly), H5 in the 1% AEP (unsafe for all pedestrians, with some expected building damage) and H6 in the PMF (unsafe for all pedestrians and all buildings at risk of failure).

Flooding along Dukes Creek also impacts access through overtopping of the Olympic Highway. Overtopping is observed to commence in the 10% AEP, by depths of up to 0.15 metres near the intersection of Trahairs Road. Further south, near Old Bomen Road, overtopping of 0.2 metres occurs in the 1% AEP event. The intersection of Bomen Road is only inundated in the PMF event.

It should be noted that design levels of the highway were not available, and that crest levels were extracted from available LiDAR survey (Section 2.1). While the behaviour in larger events is likely representative, the overtopping in the smaller events may be due to the accuracy of the road crest levels.

The only major development that is flood affected with the Dukes Creek catchment is the Bomen Business Park. In the 10% AEP overland flows are typically contained with road reserves with minimal impacts on adjacent lots. Some lot affectation occurs in the 5% AEP, but widespread affectation does not occur until the 1% AEP. However, depths remain modest (typically less than 0.2 metres) up to the 0.5% AEP event. In the PMF, depths increase substantially with flooding of up to 0.8 metres occurring across developed lots.

While local roads within the Bomen Business Park become flood affected by depths of greater than 0.2m in the 1% AEP, the access road from the Business Park to the highway remains open in all events except the PMF.

6.2 Eunony Valley

The eastern half of the study area drains to the Eunony Valley Tributaries. The major flow from these tributaries enters the Precinct approximately halfway along the eastern boundary, runs southerly for approximately 2.6 kilometres, before exiting the Precinct to join with Wheel of Fortune Creek. There are also some local tributaries within the Precinct which convey runoff from the central ridge into the primary flowpath.

Flooding is generally well contained in events up to the 0.2% AEP. In the PMF event, flood affectation substantially increases, though this is largely shallow with depths below 0.2m. The major flowpaths, while wider, remain well contained even in the PMF event.

Velocities are marginally higher in the Eunony Valley Tributary than Dukes Creek with velocities of up to 2.5 and 3 metres per second observed in the 5% AEP and 1% AEP respectively. In the PMF event, velocities in excess of 4 metres per second are common.

Due to the increased velocity, hazards along the Eunony Valley Tributary are higher than Dukes Creek. Hazard classed as H5 (unsafe for all pedestrians and buildings at risk of damage) occurs in the 10% AEP. H6 hazard (unsafe for all pedestrians and buildings at risk of failure) occur in the 1% AEP, though are restricted to the main channel. The smaller tributaries typically have hazards of H1 or H2, both safe for pedestrians, for events up to the 0.2% AEP. In the PMF, these smaller tributaries experience hazards of H5 and H6.

The major Eunony Valley Tributary crosses East Bomen Road just before it exits the Precinct. Overtopping of this road occurs in the 10% AEP, with overtopping depths in the order of 0.1 metres. Overtopping depths increase to 0.25 and 1.3 metres in the 1% AEP and PMF respectively.

In the upper catchment, a local tributary also overtops Trahairs Road in the PMF by depths of up to 0.22 metres.

Similar to the Olympic Highway, crest levels for these roads were taken from the available LiDAR data.

6.3 Murrumbidgee River

The Murrumbidgee River was observed to have only a minor role in flooding across the Precinct. No interaction of Dukes Creek with Murrumbidgee River flooding was observed within the study area (although the model area did extend this far). In the west, Murrumbidgee River impacts were restricted to the south-west corner of the site. Murrumbidgee River flooding intrudes approximately 250 metres in the PMF at this location.

In the east, some interaction between Eunony Valley flows and Murrumbidgee River flows were observed within the Precinct in the 1% AEP event and above. In the PMF event, this interaction extended up to East Bomen Road. Flooding in the east also intruded further into the Precinct, reaching 650m from the boundary in the PMF event.

7 Floodplain Management Plan Review

A Floodplain Risk Management Study and Plan has been prepared for the Murrumbidgee River within the Wagga Wagga local government area (WMAWater, 2018). The report recommends a number of flood mitigation options and discusses emergency management for the Wagga Wagga region.

The Major Overland Flow Floodplain Risk Management Study and Plan (MOFFRMS&P), covering a portion of the Precinct was in progress at the time of the preparation of this report. As such, this plan was not available for review. Key recommendations of this report could be incorporated in the MOFFRMS&P for any Council-related recommendations for the Precinct and adjacent areas.

7.1 Flood Modification Works

With regard to the options recommended for further investigation, none of the options are likely to impact the flood behaviour within the Precinct. The only option that has the potential to have an effect is an option to raise Oura Road to improve emergency evacuation.

The initial results in the Study (WMAWater, 2018) show some increases to peak flood levels of 0.2 – 0.3m arising from this option. These increases would impact the tailwater levels for local catchment floods through the Precinct. However, it is not expected that they would extend far upstream, and the Risk Management Study (WMAWater, 2018) notes that they could likely be mitigation during detailed the detailed design phase.

No other options had impacts that affect the Precinct.

7.2 Emergency Management

The emergency management discussion provided in the Floodplain Risk Management Study (WMAWater, 2018) is largely not directly applicable to the Precinct. The Floodplain Risk Management Study focuses on flooding from the Murrumbidgee River, which has a long duration, with ample warning times, and the major townships are protected by levees. However, there are implications for access from the Precinct to services within Wagga Wagga itself as these will be cut off for a number of days in the event of a flood in the Murrumbidgee River.

Within the Precinct, flood warning times for emergency management are much shorter, with no warning available at all for flash flooding. Furthermore, no flood protection infrastructure is currently in place and would be required. As such the emergency management issues and responses discussed in the Risk Management Study (WMAWater, 2018) are not applicable to the Precinct.

8 Surface Water Quality – Baseline Conditions

8.1 Stormwater Quality

Stormwater quality and the quality of flows that are delivered to receiving waters is affected by a number of catchment conditions:

- Diffuse sources – being primarily impervious and pervious surfaces (and contaminants that are deposited and washed off the surface, this includes pollutants from the tracts of existing agricultural land within the Precinct)
- Point sources – including:
  - discharges from licenced premises within a catchment (licenced under the Protection of the Environment Operations Act, 1997). There are a number of licenced premises already located within the Precinct (primarily at Bomen) and all of these premises have requirements for the implementation of Stormwater Management Plans:
    - Austrak – Concrete works (railway sleeper manufacturing)
    - Enirgi Power Storage Recycling - Metallurgical activities and resource recovery.
    - Riverina Oils and Bioenegy – Agricultural processing (canola seed to oil and energy)
    - Rodney's Transport Service – Waste Storage.
    - Southern Oil Refining - Petroleum products and fuel production and resource recovery (recovery of oil from waste oil via treatment)
    - Wagga Wagga Livestock Marketing Centre – Saleyards (cattle and sheep)
    - Bomen Industrial Pre-Treatment Sewage Treatment Facility (BISTF) – (1000 – 5000 ML discharge treatment facility, inclusive of the reticulation system that services the facility and therefore sewer overflows).
  - illegal discharges.

Leachate from landfills (unknown in the Precinct) and other groundwater inflows to gaining streams (i.e. where the direction of groundwater is toward a stream) also has the potential to affect the quality of receiving waters.

Historically there has been an incident at the former Wool Combing site where the water storage basin overtopped during a storm event which resulted in contaminated water flowing down through the Eunony Valley catchment. This site is no longer used for water storage. This highlights an issue of legacy contamination issues that should be investigated prior to the proposed use of any existing infrastructure.

There are no known stormwater quality monitoring data sets for the waterways within the Precinct. Monitoring of the receiving water, the Murrumbidgee River, is undertaken (reported in Section 2.2). However, this is commonly conducted under low flow conditions and is representative of base flow conditions but is unlikely to capture time varying conditions through rainfall events for parameters such as nutrients (e.g. nitrogen and phosphorous), water clarity (e.g. turbidity or suspended solids).

8.2 Pollution Control Devices

A number of the licenced premises (under the PoEO Act) have treatment ponds or basins for the purpose of capture of surface runoff from their premises. Water from these ponds is generally treated before discharge or re-used. There are no known pollution control devices within the Precinct that are independent of specific premises, apart from a recently constructed stormwater filter pond that has been constructed as part of road works completed for Merino Road (at the intersection of Merino Road and Olympic Highway, see Figure 8-1).

Figure 8-1 Stormwater Filter Downstream of Merino Road Intersection with Olympic Highway (20 June 2019)

8.3 WSUD Targets and Treatment Approaches

Wagga Wagga City Council has a Stormwater Policy (POL 037) that has been in place since 2002 (Revision 6, August 2017 is the latest adopted version). The policy sets out Council's requirements as the local authority for the management and regulation of stormwater.

The policy deals with both quantity and quality aspects of stormwater management with the aim of:

- minimising stormwater impacts on aquatic ecosystems;
- minimising flooding impacts; and
- utilising stormwater as a water resource.

Council has also prepared a Stormwater Management Plan for the Local Government Area (2013-2017) and Engineering Guidelines for Subdivisions and Developments (2017). The stormwater management plan deals primarily with stormwater quantity and the upgrade of pit and pipe systems; however, it does state that:

Initiatives such as Water sensitive urban design (WSUD), collection and reuse of rainwater, peak storm flow attenuation methods, in-stream stormwater treatment, recovery and reuse are all considered to be of critical importance in the future development of the stormwater systems. WSUD must be carefully considered given the potential impact of surcharging up-gradient groundwater systems that may exacerbate down-slope salinisation.

Following a review of existing Council policy and guidelines, Council does not appear to set specific load reduction targets for development for the management of diffuse source pollutants (such as from roads and hard stand areas outside of the control of licencing under the Protection of the Environment Operations Act, 1997).

The NSW State Government has set water quality and river flow objectives for the Murrumbidgee River and Lake George (DNR, 2006) (see Figure 8-2).

For urban development areas the objectives are as follows:

- Water Quality Objectives
  - Protection of Aquatic ecosystems
  - Visual amenity
  - Secondary contact recreation, as a short-term objective, within 5 years
  - Primary contact recreation: assess opportunities to achieve as a longer-term objective, 10 years or more
- River Flow Objectives
  - Protect pools in dry times
  - Protect natural low flows
  - Maintain natural rates of change in water levels
  - Minimise effects of weirs and other structures.

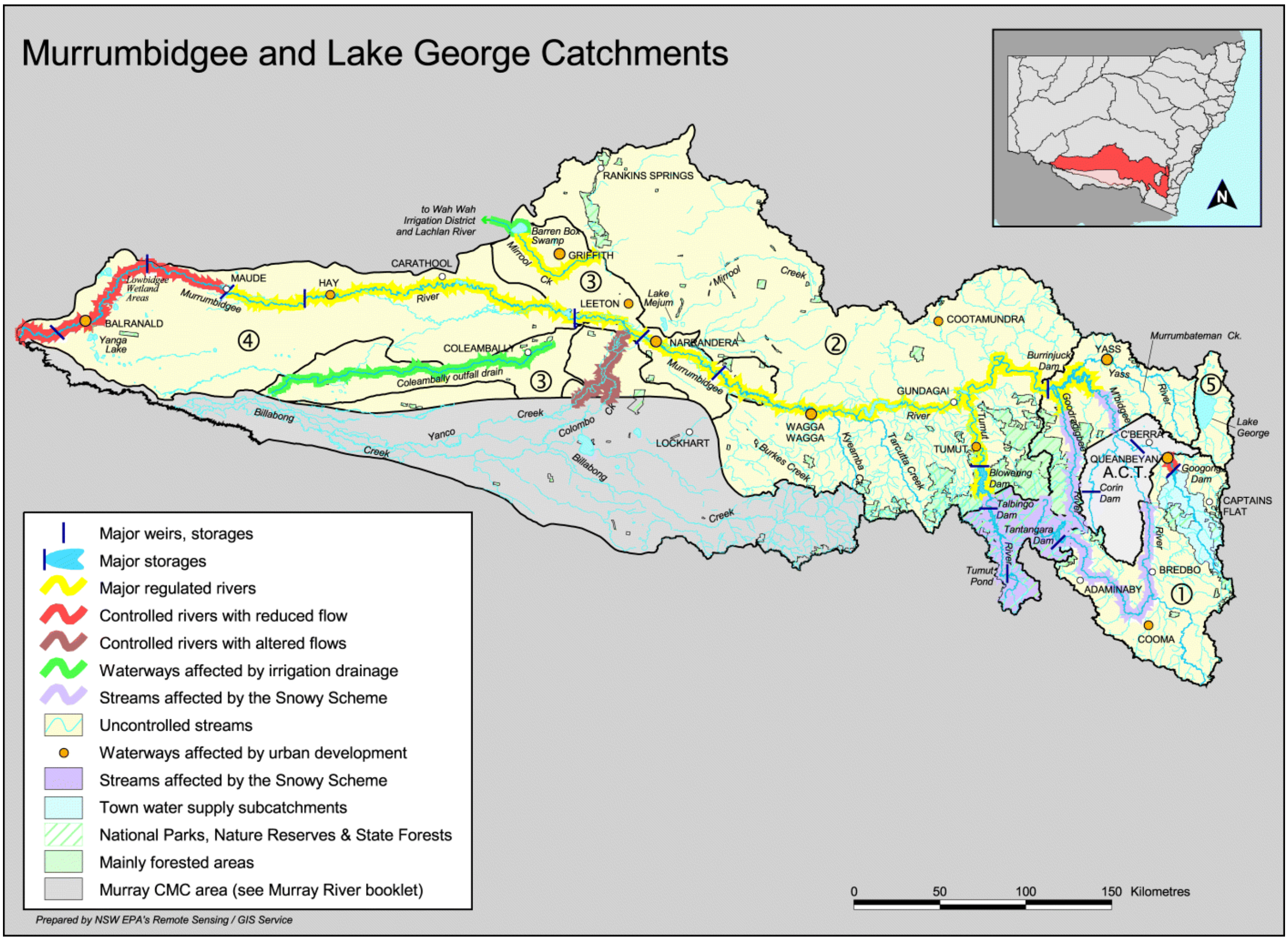


Figure 8-2 Murrumbidgee and Lake George Catchments (Source, DNR, 2006)

In the absence of specific guidance and in the context of the water quality objectives established for the Murrumbidgee River, typical load reduction targets for urban development commonly adopted across NSW are provided in Table 8-1. The targets are largely independent of actual receiving water hydrodynamic and ecological processes as these are often undefined insofar as they are able to guide development control.

Table 8-1 Potential Pollution Reduction Targets

Pollutant	% Post Development Average Annual Load Reduction
Gross pollutants	90
Total Suspended Solids	85
Total Phosphorous	65
Total Nitrogen	45
Total Hydrocarbons	90

Part 3 Section 3 of Council's Engineering Guidelines for Subdivisions and Developments (2017) discusses WSUD as a concept but does not provide specific guidance on pollutant load reduction requirements. It states that:

Urban stormwater is to be managed as both a resource and for protection of receiving waters. Except in saline recharge areas, Council encourages outcomes that promote the retention of water on site and relieves potential of flooding on areas downstream.

Part 3 Section 4.7.3 of Council's Engineering Guidelines for Subdivisions and Developments (2017) state for gross pollutant traps that:

The selection of a Gross Pollutant Trap (GPT) is subject to Council approval and the designer shall apply the following criteria in designing GPT:

- *Selecting a design flow rate will require the designer to balance the cost and space requirements of the device (a higher design flow will usually require a larger facility with additional costs) and the volume of water that could bypass the unit and avoid treatment.*
- *The minimum design flow should be 1 year ARI peak flow. The designer will include the provision of all-weather access to treatment sites, permitting crane access to GPT units, which should be assumed to require cleaning every six months. In new developments or public areas, the design will ensure maintenance vehicles are able to travel in a forward direction at all times.*
- *The designer is to ensure that the quality of the water being discharged will meet the requirements of Council, and to submit supporting evidence to Council for review and approval.*

Part 6 of the Engineering Guidelines for Subdivisions and Developments (2017) *Guidelines for Landscaping and Measures for Erosion, Sedimentation and Pollution Control* provides overview information for pollution control.

Part 6 Section 8 of Council's Engineering Guidelines for Subdivisions and Developments (2017) state that:

Drainage and channel works should be carried out to prevent increased stormwater runoff from proposed subdivisions where that runoff is likely to accelerate erosion of any downstream watercourse(s).

Where practical to do so, a constructed wetland should be provided downstream from all other treatment facilities to intercept and treat all runoff from the site where more than 15,000 square metres will be disturbed.

Wetlands should not be regarded as a substitute for erosion and sediment control at source. In some circumstances, wetlands may be part of an integrated strategy or a complimentary measure designed to improve water quality.

It is important to note that specific WSUD approaches, such as bioretention systems and managed aquifer recharge and harvesting for reuse, require consideration of the local conditions, such as soil types, suitability of aquifers, groundwater levels, contamination, annual rainfall, demand for harvested water (e.g. sport fields irrigation for regional scale strategies). Matters such as demand for harvested water will be dependent on land use identified within the Precinct. There are opportunities for WSUD at a development scale and/regional scale. It is most likely that options such as aquifer recharge will not be appropriate for the Precinct given the soil and geology conditions and the potential risks associated with contaminant mobilisation.

9 Riparian Corridors

9.1 Requirements under the Water Management Act, 2000

There are two main creek systems with very limited existing riparian corridors within the Precinct:

- Dukes Creek (flowing north to south-west, to the Murrumbidgee River)
- Wheel of Fortune Creek and its tributaries (flowing north-south to the Murrumbidgee River).

The Natural Resource Access Regulator (NRAR) is responsible for matters under the Water Management Act, 2000 (WM Act) and associated regulation. The management of development on foreshore land (being that land within 40 m of the top of the highest bank of an identified waterway) is the subject of Part 3 of the WM Act. In support of this Act, NRAR has prepared Guidelines for Riparian Corridors (NRAR, 2018). These guidelines describe the use of the 'Strahler' system for stream ordering to identify the width of riparian corridor (referred to as vegetated riparian zone or VRZ) that is required to be associated with an identified waterway. Schedule 2 of the WM (General) Regulation (2018) indicates that Strahler stream ordering should be undertaken using the hydroline dataset, being an online geographical information system.

Using the Strahler system, the creeks have been classified in Figure 9-1 and their corresponding recommended VRZ requirement from Table 1 of NRAR (2018) is reproduced in Table 9-1.

Table 9-1 Recommended Riparian Corridor (RC) Widths (Source: NRAR, 2018)

Watercourse type	VRZ width (each side of watercourse)	Total RC width
1st order	10 metres	20 metres + channel width
2nd order	20 metres	40 metres + channel width
3rd order	30 metres	60 metres + channel width
4th order and greater	40 metres	80 metres + channel width

Note: Where a watercourse does not exhibit the features of a defined channel with bed and banks, the NRAR may determine that the watercourse is not waterfront land for the purposes of the WM Act.

Preliminary mapping of the VRZs using available hydroline centreline data was undertaken (Figure 9-1). The corridors are shown purely as the required distance from the top of bank (i.e. no channel width is included), noting that a VRZ width is an average overall within an area of development and can vary in width to work around existing constraints (such as infrastructure) (NRAR, 2018).

Field inspections on 20 June 2019 and 15 July 2019 reveal that defined banks are largely absent from the watercourses that are shown on the hydroline map within the majority of the Strategic Activation Precinct. Further investigations would be required to confirm the extent of banks and beds in the event that development might require the relocation or modification of a stream.

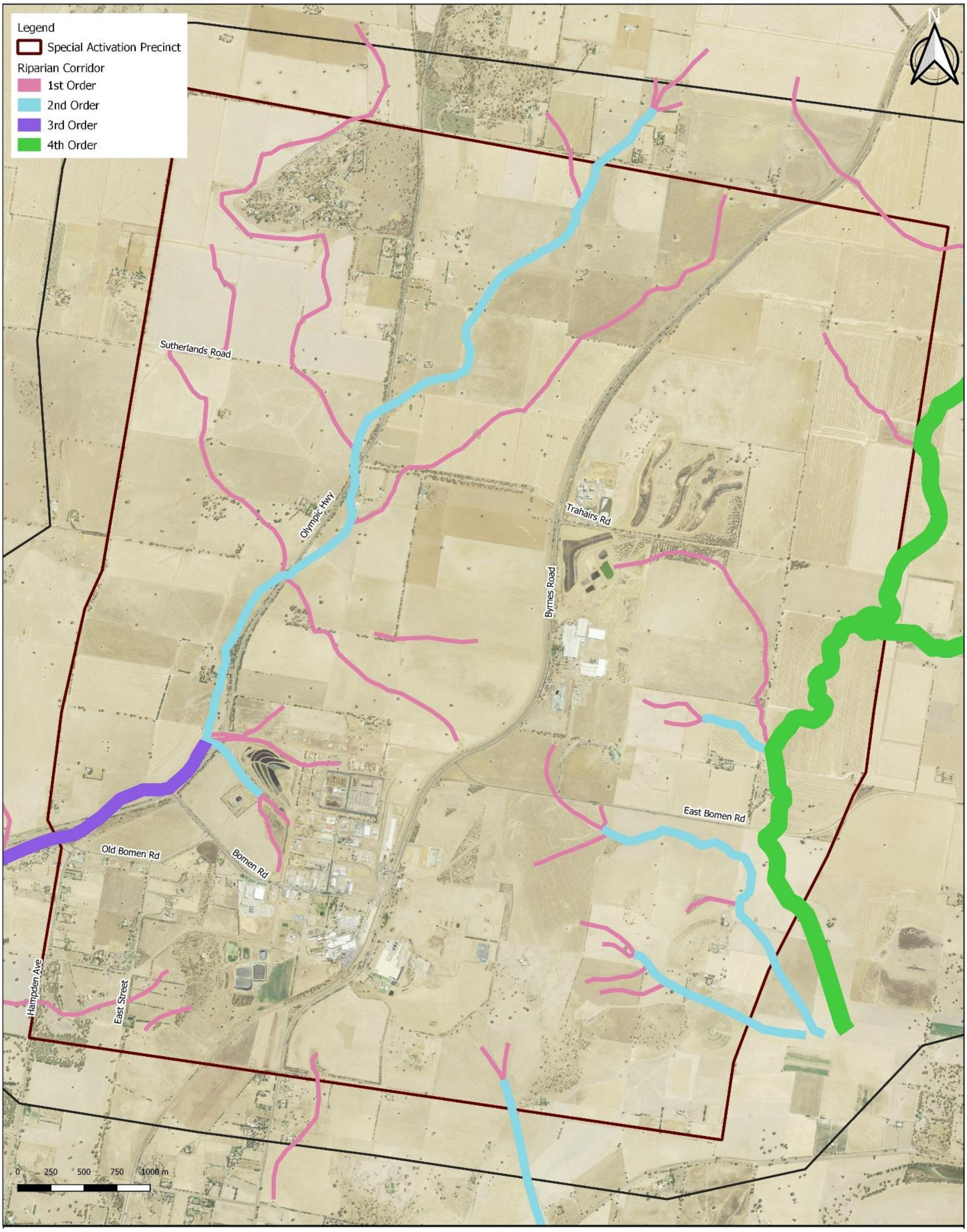


Figure 9-1 Preliminary Riparian Corridors in Accordance with NRAR (2018) Requirements

9.2 Wagga Wagga City Council Waterway Requirements

Wagga Wagga City Council's (2017) Engineering Guidelines state that *Urban Streams should be managed in a way that is consistent with State Government Policy*. It is also states the following:

A river or stream is any perennial or intermittent stream of water with a catchment area of more than two square kilometres.

It does not matter whether it is flowing in a natural channel, or in a natural channel that has been artificially improved, or in any artificial channel that has changed the course of a stream of water. Nor does it matter where it flows to, including any affluent, confluent, branch or other stream.

These guidelines do not apply to:

- *gullies, which are different to streams in that they are a drainage line lacking any overbank flow or floodplain*
- *drainage lines not mapped on 1:4000 scale or the photo maps as a broken or unbroken line.*

Therefore, streams can be usually identified by:

- *an obvious channel*
- *presence of a floodplain.*

Where the principles refer to urban streams they are referring to the whole riparian system including the bed and banks, streamside vegetation, riparian land and stream flow.

10 Projected Effects of Climate Change on Flooding and Water Quality

10.1 Overview

As the Strategic Activation Precinct Planning process will ultimately deliver infrastructure and development that has a design life or effective life of 80 – 100 years, accounting for the projected effects of climate change is an important aspect for design to ensure that the Precinct is fit for purpose for present and future generations.

The relevant effects of climate change on flooding and water quality include:

- Changes to the annual volume and distribution of rainfall (for day to day conveyance of flows and for analysis and design of water quality treatment systems, particularly for features such as large scale rainwater capture and re-use tanks and regional water quality treatment basins)
- Changes to evapotranspiration (affecting the overall water balance)
- Changes to storm event rainfall intensity (for minor and major flooding).

Other projected effects of climate change that are relevant but trigger more indirect effects are:

- Changes to temperature (primarily increases, resulting in potential greater demand for potable and/or non-potable water for water-related industrial processes, landscape irrigation; effects on vegetation within WSUD facilities such as bioretention systems)
- Changes to relative humidity (indirect effects on vegetation and additional discharge of water from air-conditioning systems)
- Changes to solar radiation (precipitating a greater need for green spaces to absorb those increases).

There are a number of relevant frameworks and policies (Section 10.2) and data (Section 10.3) to inform the quantum of the projected effects of climate change on flooding and day to day water flows and how these might be accounted for in the design of the Precinct.

10.2 International, National, State and Local Frameworks, Policies and Guidelines

10.2.1 International

The projected effects of climate change are documented in studies coordinated at an international level by the Intergovernmental Panel for Climate Change (IPCC). At the time of preparation of this report, the most up to date assessment of climate change was the fifth Assessment Report (also known as AR5, released in 2014). The assessment process runs in seven-year cycles and the sixth assessment report (AR6) is anticipated for release in 2021. The previous report, AR4, was released in 2007.

10.2.2 National

In Australia, the coordination of the response to climate change at a Commonwealth level is the responsibility of the Department of the Environment and Energy (DEE). In NSW, the Department of Planning, Industry and Environment (DPIE) (formerly the Office of Environment and Heritage, OEH) is the lead agency for climate change. Locally, Wagga Wagga City Council has responsibility for adaptation and mitigation for their related infrastructure and services within the frameworks of the Commonwealth and State strategies and policies.

The Australian Government has set the direction for climate resilience and adaptation in the *National Climate Resilience and Adaptation Strategy* (Commonwealth of Australia, 2015). This strategy provides high level guidance. Informing this strategy is technical information relevant to the Precinct Planning, which is described in Section 10.3.

As part of the *National Strategy for Disaster Resilience* (Commonwealth of Australia, 2011), Handbook 7 of the Australian Disaster Resilience Handbook Collection was issued to guide floodplain management in Australia (*Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia,* AIDR, 2017). Section 5.5 of AIDR (2017) *states that*

> *"A changing climate is expected to affect both catchment and coastal flooding. Depending upon the location, this may alter the frequency and scale of flooding and its associated impacts due to both sea level rise, and changes to annual, seasonal and flood-producing rainfall events. This might affect catchment flood events in areas across Australia, and coastal flooding in the lower portion of coastal waterways where coast and catchment flooding can interact. Flood investigations provide an opportunity to assess and report on the potential impacts of change on flood behaviour, the risk to the community and the adaptability of management measures to change. Impact assessments should consider relevant government and industry guidance, and the best available, broadly accepted information on the potential scale of changes. The impacts of changes to rainfall and sea level rise should be considered separately, to understand the drivers of change, and in combination, to assess the potential cumulative impacts".*

AIDR (2017) does not provide specific guidance on climate change projections to be utilised for flooding assessments but does give examples of potential adaptive solutions for new development, such as for Strategic Precinct Planning. These are:

- strategic land-use planning that builds consideration of climate change into decisions to rezone land to allow for more intense development
- land-use strategies that may encourage consolidated urban development on less-vulnerable land with surrounding more-vulnerable land used for communal purposes
- designs that are adaptable – for example, levees or houses that are designed to be able to be readily raised in the future if necessary
- designs that consider the proposed life of structures, particularly those meant to be short term (note that design life and the actual working life of the structure may bear little resemblance).

10.2.3 State

The NSW Government has developed a *Climate Change Policy Framework* (OEH, 2016). The framework indicates that the role of the NSW Government is to *implement policies to plan for climate risks and provide targeted support for households, communities and businesses that is fair, efficient and in the public interest.* The Framework indicates that the policy direction is to *Reduce risks and damage to public and private assets in NSW arising from climate change.* The rationale for this is that *Climate change will lead to more extreme weather, heatwaves and sea level rise, which increase the risk of direct costs to public and private assets and services. The government will manage the impact of climate change on its assets and services by embedding climate change considerations into asset and risk management. The government will also reduce barriers that would prevent effective private sector adaptation by providing information and a supportive regulatory framework for adaptation measures at the local level.*

The Floodplain Development Manual (NSW Government, 2005) (see Section 2.3) is the guiding document for the management of floodplains. The Manual was issued prior to many contemporary climate change related policies and documents; however, it references the need to consider the effects of climate change in the evaluation of future and residual risks. In a similar fashion to AIDR (2017), the Manual does not include specific guidance on climate change projections to be utilised for assessments.

The Floodplain Risk Management Guideline – *Incorporating 2016 Australian Rainfall and Runoff in studies* (OEH, 2019), a companion document to the Floodplain Development Manual (NSW Government, 2005). The guidance recommends a 5% increase in design rainfall per °C of projected warming. For newer flood studies, where ARR2019 IFD are used (see Section 4), there are site-specific IFD factors that can be derived from the ARR DataHub (for different Representative Concentration Pathway (RCP) projections). The key recommendations of this guideline indicate that rainfall intensity increases ranging from 4.1% up to 20.2% (under RCP8.5 by 2090) are predicted. Most contemporary flood studies consider these potential increases as part of sensitivity analyses.

10.2.4 Local

Locally, Wagga Wagga City Council recently completed the *Climate Change Risk & Adaptation Action Plan - Wagga Wagga* (Edge Environment, 2018). The Plan seeks to identify the various risks associated with a changing climate to 10 asset types owned by Council and adaptation actions to respond to those risks. New development is not considered in detail; however, it is important that any new infrastructure and development are planned for and designed to accommodate the projected effects of climate change.

In 2019/2020 Council is intending to prepare a *Climate Emergency Plan*.

10.3 Projections

10.3.1 Annual and Seasonal Rainfall and Evapotranspiration

In terms of projections, the central repository for these for Australia is located at https://www.climatechangeinaustralia.gov.au/en/ (referred to here as the 'National Projection') and the central repository for NSW is located at http://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW (referred to here as the NSW NARCLiM projections). The two data sets vary slightly with respect to the origin of the information (being global climate models version 3 or 5, referred to as CMIP3 and CMIP5 respectively) and the scale at which they are available.

The NSW NARCliM projections represent the largest and most robust set of dynamically downscaled regional climate projections available for NSW and the ACT. However, NARCliM information is derived from the CMIP3 models and uses only a single emissions scenario (the IPCC 'A2' emissions scenario, referenced in AR4, which is representative of a relatively high emissions scenario)

(http://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM/CMIP3-vs-CMIP5, accessed 27 July 2019). The future conditions information extends to the year range 2060-2079.

The national climate projections cover a range of emissions scenarios and use the latest generation of global climate models from CMIP5 (up to 2090). The national projections also provide some dynamically and statistically downscaled projections for certain parts of Australia. However, the downscaling area does not cover the Precinct location at the same scale as the NSW NARCliM projections.

As a consequence, for the purposes of this report, a mixture of data from the NSW NARCLiM dataset and the National Projections has been sourced. The key information for the locality from NARCLiM is shown in Figure 10-1 to Figure 10-5 respectively for annual, summer, autumn, winter and spring rainfall. The information shows that the change in rainfall is not likely to be substantive (an increase of 5-10%) from a hydrological perspective for the analysis of features such as stormwater quality treatment, for which a reliability range of +/- 20% is considered to be reasonable for design purposes. As a comparison, the climate analogues from the National Projections for 2090 for RCP 8.5 (the highest emissions scenario considered) is a reduction of 23% in annual rainfall (maximum consensus). This is of a greater concern and has the potential to reasonably affect the operation of WSUD functionality for systems such as rainwater tanks, bioretention systems, stormwater harvesting systems and any facilities that are dependent on relatively frequent and consistent rainfall events.

A review of the NarCliM data indicated that changes to evapotranspiration is not readily available in the same format as the rainfall change information. Data from various models from the National Projections were considered and show an increase of 15-20% in evapotranspiration under RCP8.5 at 2090.

Figure 10-1 Climate Change Projections- Annual Mean Precipitation (Source: NSW NARCliM)

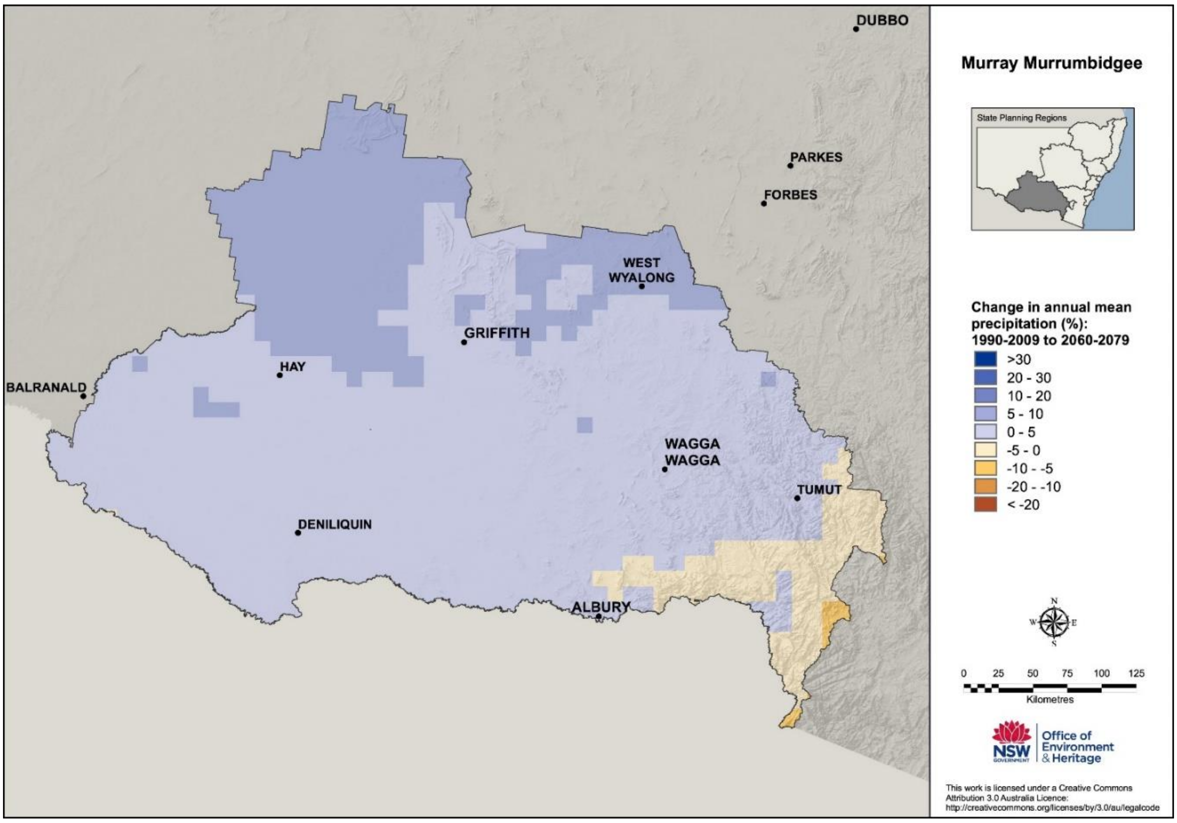


Figure 10-2 Climate Change Projections- Summer Precipitation (Source: NSW NARCliM)

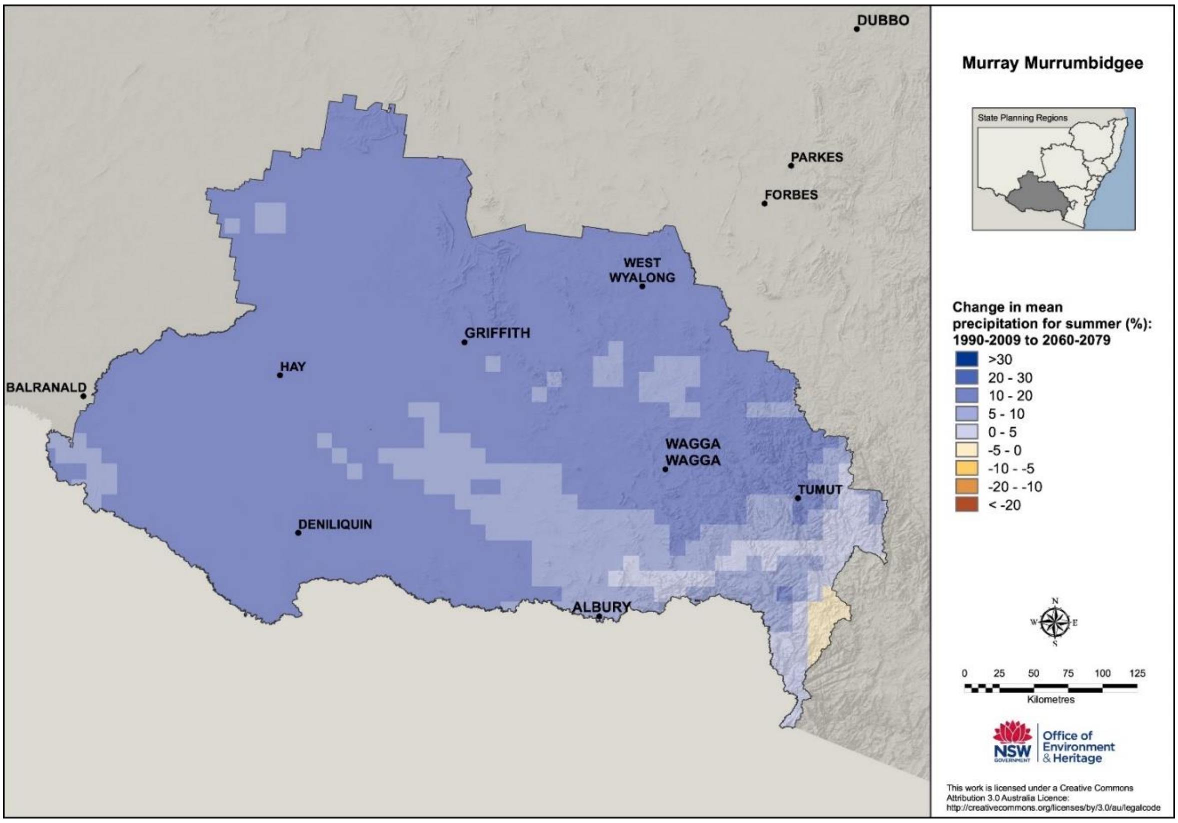


Figure 10-3 Climate Change Projections- Autumn Precipitation (Source: NSW NARCliM)

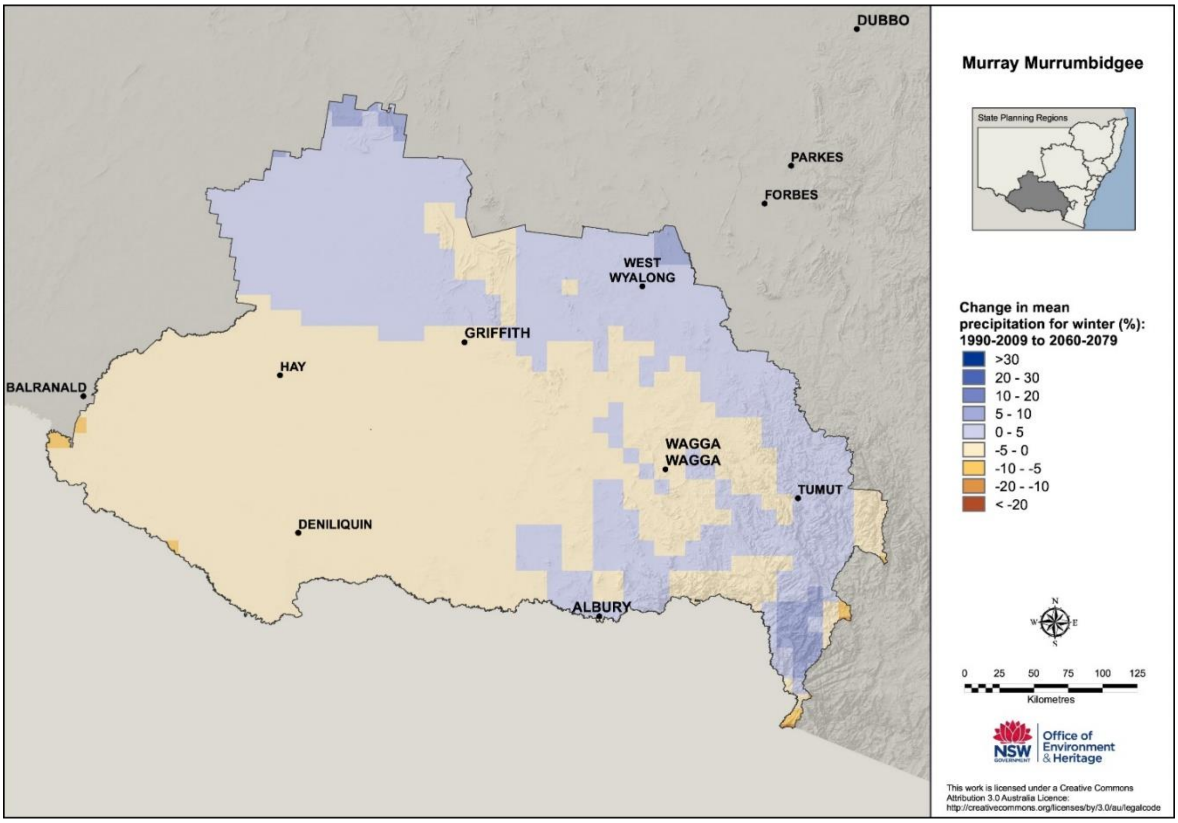


Figure 10-4 Climate Change Projections- Winter Precipitation (Source: NSW NARCliM)

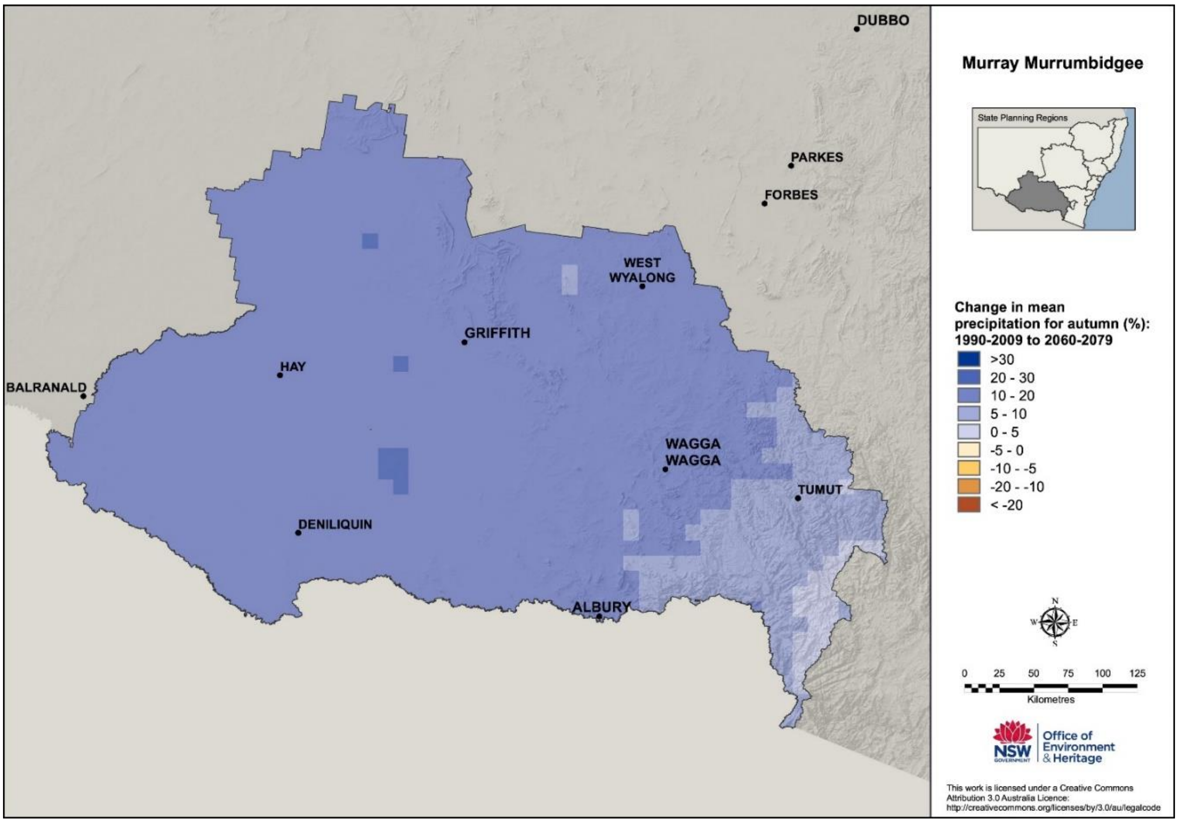
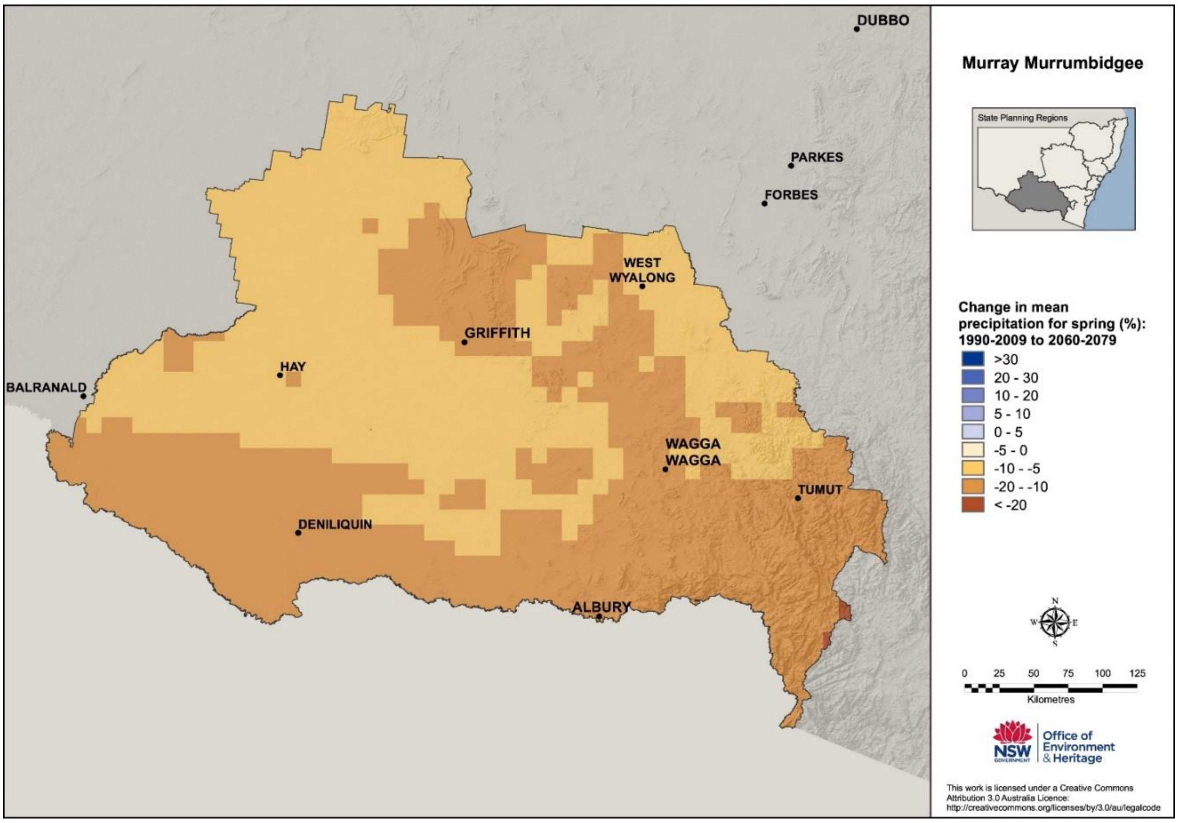


Figure 10-5 Climate Change Projections- Spring Precipitation (Source: NSW NARCliM)



10.3.2 Flooding – Intensity-Frequency Duration Projections within ARR2016

The analysis of potential changes to IFD relationships undertaken for Australian Rainfall and Runoff 2016 (Ball et al, 2016) and incorporated in ARR2019 (Ball et al, 2019) uses dynamical downscaling as per that discussed in Section 10.3.1. The downscaling has been completed using AR5 (CMIP5) emissions scenarios, which refer to 'representative concentration pathways' for emissions or RCPs. The RCP scenarios vary slightly from the scenarios considered in the models used for the annual and seasonal rainfall NARCliM modelling (Section 10.3.1). However, for the purposes of planning, the variance is not considered to be significant.

Book 1, Chapter 6 (Bates et al, 2019 in Ball et al, 2019), presents an overview of climate change considerations. Bates et al (2019) suggests that:

- The minimum basis for design should be the low emissions scenario (RCP4.5).
- The maximum consensus case for the high emissions scenario (RCP8.5) should also be considered based on the outcomes of a screening analysis.

Table 10-1 lists the recommended increases in rainfall to address climate change for the 2019 IFD relationships from the ARR2019 DataHub. A screening analysis has determined that the potential consequences of infrastructure failure in the Precinct could be high and therefore it is recommended that the upper limit RCP8.5 should be utilised for planning purposes. Combined with adopting a 2090 projection based on the life of the infrastructure, it would be appropriate to factor up ARR2019 IFD by nearly 20% to account for climate change.

Table 10-1 ARR2016 DataHub Interim Climate Change Factors (Values are of the format temperature increase in degrees Celsius, % increase in rainfall)

Year	RCP 4.5	RCP 6.0	RCP 8.5
2030	0.816 (4.1%)	0.726 (3.6%)	0.934 (4.7%)
2040	1.046 (5.2%)	1.015 (5.1%)	1.305 (6.6%)
2050	1.260 (6.3%)	1.277 (6.4%)	1.737 (8.8%)
2060	1.450 (7.3%)	1.520 (7.7%)	2.214 (11.4%)
2070	1.609 (8.2%)	1.753 (8.9%)	2.722 (14.2%)
2080	1.728 (8.8%)	1.985 (10.2%)	3.246 (17.2%)
2090	1.798 (9.2%)	2.226 (11.5%)	3.772 (20.2%)

10.4 Recommendations for Strategic Activation Precinct Planning

It is recommended that Precinct Planning flood modelling consider an increase of up to 20% in rainfall intensity to represent conditions that are likely to be in place for the longer term. In practice it is noted that an increase of this magnitude on 1%AEP rainfall depths (see Table 4-4) results in effectively a 0.5% rainfall depth. This means that a flood planning event of a 0.5%AEP or 1 in 200 AEP would be the appropriate event to plan for.

It is recommended that the design of WSUD facilities consider (as sensitivity analyses) the potential reductions in annual rainfall of up to 20% and increase in evapotranspiration of 20% for facilities that have a long design life (out to 2090). Facilities will need to be designed with adaptive capacity given the potential change over their lifetime. For facilities with a shorter design life (such as 10-20 years) these will need to be designed to the existing scenario but will need to ensure their overall plan area set aside can accommodate design changes for adaptation purposes.

11 Effects of Dam Break from Upstream Dams

The largest storages in the Murrumbidgee catchment are Blowering Dam, Burrinjuck Dam, Talbingo Dam and Jounama Pondage (Figure 11-1). Flows released from these dams are conveyed through Wagga Wagga.

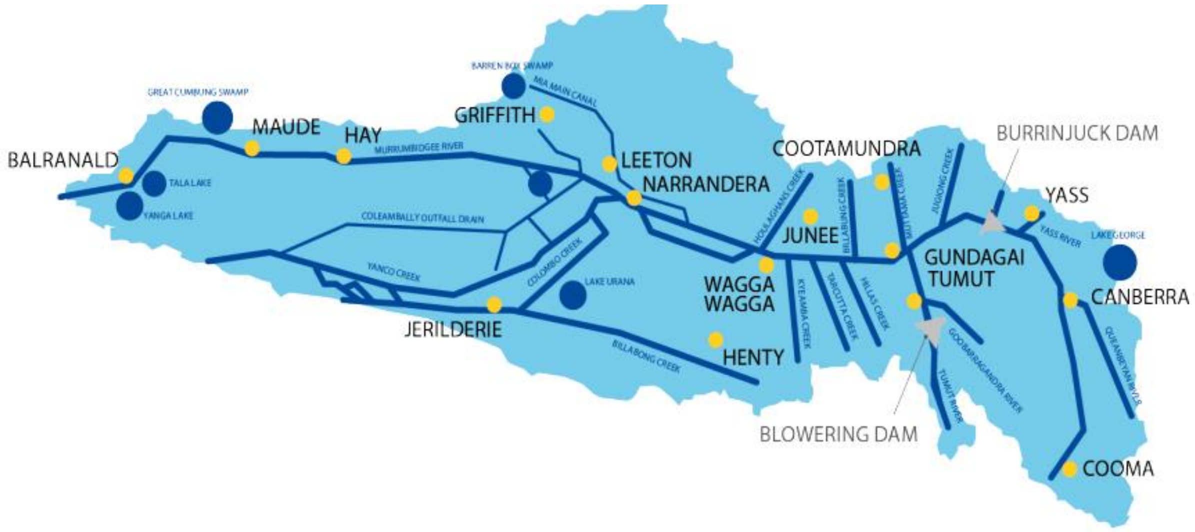


Figure 11-1 Schematic of the Murrumbidgee River showing major dam locations (Source: WaterNSW)

Whilst Blowering and Burrinjuck dams are substantive in their construction, NSW Dam Safety legislation lists both as being ‘prescribed’ dams. At the time of preparation of this report, Dam Safety legislation was in transition with the Dam Safety Act 2015 and the associated Regulation (2019) coming into force on 1 November 2019.

Each dam is considered in the downstream Local Flood Plans and are well protected with Burrinjuck Dam having a PMF rated spillway following an upgrade in 1994. Blowering Dam can safely pass half of the PMF event. The smaller storages of Jounama Pondage would likely to be absorbed into Blowering Dam. Talbingo Dam is the most upstream dam in the Tumut River system and failure could lead to cascade failure through Jounama Pondage and Blowering Dam.

11.1 Key Structures

11.1.1 Lake Burrinjuck

Burrinjuck Dam is described within the NSW SES Local Flood Plan for Wagga Wagga as:

> *“Burrinjuck Dam is a concrete gravity dam located in a narrow gorge downstream of Canberra. The dam was constructed between 1907 and 1928 to store water for irrigation in the Murrumbidgee Irrigation Areas and for hydroelectric power generation. The Dam’s catchment is 13,000 square kilometres and a submerged storage area, at full supply level of 5500 ha. The maximum height of the dam wall is 93m above the lowest point of the foundation. The spillways are located on either side of the main wall and consist of side channel spillways at the left and right abutments and three spillway chutes controlled by sector gates. Since upgrade works in 1994 the dam is no longer considered to be deficient and is now capable of safely passing the PMF. The sheer magnitude of the volume of floodwaters generated by the*

> *catchment means that it is impossible to significantly reduce peak flood flows, even with the existence of large dams within the catchment." – Wagga Wagga Local Flood Plan (NSW SES).*

Past studies for the assessment of Burrinjuck Dam include:

- Burrinjuck Dam PMF Assessment – NSW State Government, 2001;
- Burrinjuck Dam Failure Study – NSW State Government, 1994.

11.1.2 Blowering Dam

Blowering Dam is described within the NSW SES Local Flood Plan for Wagga Wagga as:

> *"Blowering Dam, completed in 1968, consists of a 112 metre high earth and rockfill structure with a central clay core, concrete chute spillway, four outlet valves and an 80MW hydro-electric power station. At full supply level the lake formed has a surface area of 4460 hectares. The dam has a catchment area of 1,630 square kilometres and a storage capacity of 1,630,000 megalitres. A further 190,000 megalitres is available for flood storage to reduce flooding in downstream areas. The dam stores water that has been released from upstream storages. The large amount of water released from those storages to meet the demand for electricity in winter, is held in Blowering until summer when it is needed by farmers for irrigation. Releases are controlled by the four outlet valves and the Hydro-electric power station, which have a combined capacity of 23,000 ML/day. Blowering's spillway has a capacity of 203,000 ML/day. The dam can safely pass a flood of only half the PMF without overtopping the dam wall. Releases flow down the Tumut River, towards Tumut." – Wagga Wagga Local Flood Plan (NSW SES).*

11.1.3 Talbingo Dam

Talbingo Dam is a storage structure that has an active capacity of 160,400 megalitres. Before the spillway is activated the storage can hold 921,400 megalitres. The primary release from the dam are via the Tumut 3 Intake Structure which can pass 1,133 m^3/s. The dam spillway is set at the dam crest and can pass 4,248 m^3/s of flow this flows to a spillway with no scour protection, so this release is avoided at all costs. Releases flow through to the Jounama Pondage and onto Blowering Dam.

11.1.4 Jounama Pondage

Jounama Pondage is a 43,500 megalitre capacity with an active capacity of 27,800 megalitres. The spillway is gated with capacity of 3,395 m^3/s and captures released from Talbingo Dam. Due to the limit size of the structure it is likely that failure would have a minimal impact with the discharges being absorbed by Blowering Dam.

11.2 Travel Times

Failure of the major dams is expected to cause a rapid rise in floodwaters at Wagga Wagga. The rising flood waters would be fast flowing and consisting of large amounts of debris. The three failure scenarios outlined in emergency management documentation include:

1. Failure of Burrinjuck Dam
2. Failure of Blowing Dam in isolation
3. Failure of Talbingo Dam
4. Failure of Talbingo Dam leading to cascade failure of Jounama and Blowering Dams.

In the event of dam failure, warnings and evacuations would occur. For dam failure at Burrinjuck Dam there would be a warning time of around six hours. Following works in 1994 the dam now has capacity to pass the predicted PMF over the spillway. The risk of failure is extremely low with the dam managing to be overtopped historically prior to upgrade. Since these events the dam has been increased in height to manage the PMF event and the spillway capacity has increased to pass the PMF event. Of all the dams upstream of Wagga Wagga, Burrinjuck Dam would cause the most impact if it failed although this would be predominantly within the Murrumbidgee River floodplain, downstream of the Precinct.

For the Tumut River storages, from the time of dam failure to Wagga Wagga is expected to be 21 hours before the flooding arrives under the Probable Maximum Precipitation failure scenario. This reduces to approximately 19.5 hours for the cascade failure scenario of the system.

In either case there is some warning available for Wagga Wagga. The likely impacts are similar to large scale flooding for the Murrumbidgee River with key road crossing to be closed. Due to the high debris loads bridges would be closed and residents across the floodplain and surrounds would be evacuated. Bomen Business Park and the Precinct are areas that could potentially be used for evacuation and refuge if required.

12 Concept Scenario Development – Core Objectives

Core flooding and water quality objectives for concept scenario development were identified at the baseline phase of the Precinct planning process and confirmed through Enquiry by Design workshops with a multi-disciplinary team in August 2019 (Jensen Plus, 2019). The core objectives are outlined below.

Details of the concept scenarios devised to meet these core objectives are provided in Section 13.1.

12.1 Core Objectives for Flooding

The core objectives for flooding are:

- Flood planning areas and levels are to be set at the 0.5%AEP (or 1 in 200 AEP event) to ensure land is set aside for the managing of the existing and future flood risk associated with climate change (Section 10.4).
- Floodways defined for the 1 in 200 AEP flood event should be set aside for conveyance of flood flows. These areas are largely consistent with the location and width of riparian corridors.
- The effects of a change in impervious fraction should be managed such that the creation of additional flows do not impact:
    - flood levels downstream of the site; or
    - flow durations in creeks and watercourses (that would result in erosion of watercourse bed and banks).
- Flows should not be over attenuated to ensure environmental flows are maintained, particularly under low rainfall conditions.
- Due to the Precinct largely being affected by flash flooding, shelter in place provisions are appropriate for emergency response for rare and extreme flood events, except for the southern portion of the Precinct which is affected by long duration flooding from the Murrumbidgee River. Wherever shelter in place is utilised as a strategy, concurrent building controls are required to ensure any buildings within flood-prone areas have sufficient structural capacity to withstand flood forces up to extreme events.

12.2 Core Objectives for Water Quality

The core objectives for water quality are:

- Water quality load reduction targets as per Table 12-1 (see Section 8.3 for background information) for all types of development within the Precinct to ensure that key surface water pollutants are controlled.
- To consider the potential risks associated with climate change (Section 10.4), design of WSUD facilities consider (as sensitivity analyses) the potential reductions in annual rainfall of up to 20% and increase in evapotranspiration of 20% for facilities that have a long design life (out to 2090). Facilities will need to be designed with adaptive capacity given the potential change over their lifetime. For facilities with a shorter design life (such as 10-20 years) these will need to be designed to the existing scenario but will need to ensure their overall plan area set aside can accommodate design changes for adaptation purposes.
- Treatment strategies for water quality are to be mindful of soil salinity and contamination issues.
- Control of water discharges from scheduled premises should be consistent with the requirements of the Protection of the Environment Operations Act, 1997. Water associated with industrial processes is assumed to be discharged to the wastewater treatment system for treatment at the Bomen

Industrial Treatment Facility. Only surface water falling as rain on roofs and hard stand areas requires treatment as part of the surface water treatment approaches in this assessment.

Table 12-1 Pollution Reduction Targets

Pollutant	% Post Development Average Annual Load Reduction
Gross pollutants	90
Total Suspended Solids	85
Total Phosphorous	65
Total Nitrogen	45
Total Hydrocarbons	90

12.3 Core Objectives for Riparian Corridors

The core objectives for water quality are:

- Land should be set aside for the provision of riparian corridors and establish formal creeks where they are currently ill-defined.
- Corridors provide an opportunity to better control flood flows that currently spread in an uncontrolled manner across large areas.
- Riparian corridors should perform a broad range of environmental functions including:
  - Water quality improvements – shading of creeks reduces water temperature, vegetation provides an additional filter for surface flows discharged to the creeks
  - Wildlife corridor – a linkage for fauna and fish to utilise.

In terms of how these objectives were translated through the scenario development process, the key outcome lies in the proposed provision of both 'Landscape Protection' and 'Green Infrastructure' overlays (Jensen Plus, 2019).

Follow up aspects relevant to the outcomes of scenario testing are as follows:

- A more detailed review of the extent of watercourse bed and banks is required to fully inform the land take associated with provisions for riparian corridors.
- Consultation with the Natural Resource Access Regulator (NRAR) to determine where first order stream riparian corridors can be set aside is required as a next step.

12.4 Cross Discipline Objectives

12.4.1 Urban Design/Built Form

The key urban design objective that is inter-related to surface water management is that of site coverage.

For the purposes of scenario testing the following planning assumptions were made (Jensen Plus, 2019):

- Maximum 30% building site coverage.
- Maximum 40% hardstand site coverage.
- Minimum 30% pervious or soft site coverage, including green infrastructure.

In terms of translating these objectives for scenario testing, these maxima and minima listed above were altered and re-allocated in some circumstances for the purposes of hydrological and water quality modelling to ensure a conservative outcome for the testing, which allows for incremental changes to site coverage over time which can occur. The assumptions adopted are provided in Section 13.1.

12.4.2 Sustainability

The core objectives for sustainability outcomes for water were discussed with Dsquared Consulting (Collier-Davy, *pers comm*) in the preparation of this report and relate to the capture and re-use of rainwater.

The objectives were agreed to be:

- 50% of the industrial catchment areas are roof and that 100% of runoff from that roof area is captured for reuse (i.e. in a rainwater tank)
- Re-use of captured rainwater assumed to be 0.1 kL/day/1000m^2 of roof area (internal use) and 20kL/yr/1000m^2 (external use).

12.4.3 Biodiversity

The core objective for biodiversity is the retain as many trees and stands of native vegetation (including endangered ecological communities and the like listed under the NSW *Biodiversity Conservation Act, 2016* or the *Environment Protection and Biodiversity Conservation Act, 1999 (Cth)* and to maximise the amount of habitat provided in green corridors across the Precinct.

As a consequence, the riparian corridor design cross section and roughness have been designed to convey flood flows but also retain existing vegetation where possible. Final designs will require modification to the assumed creek design profile to achieve the retention of trees and stands of vegetation where possible and to plant out the corridor with a relative high density of vegetation in the core riparian zone (assumed to have a relatively high 'roughness' for the purposes of flood impact assessment).

12.4.4 Land Contamination and Salinity

The core objectives for land and contamination are to prevent migration/mobilisation of contaminants.

It was therefore assumed that given the potential land contamination and salinity issues in the soils in the region, that no concentrated infiltration would occur from any water quality treatment facility.

There may be instances where flood detention or water quality treatment facilities could be identified to be located in areas affected by contamination.

There are two key existing large water storage basins in the Precinct:

- Wool Combing site - where the water storage basin previously overtopped during a storm event which resulted in contaminated water flowing down through the Eunony Valley catchment. This site is no longer used for water storage.
- Saleyards basins – these facilities are currently used as capture and re-use for runoff from the Saleyards.

Given the legacy contamination issues these storage basins should be deferred from inclusion as features to manage water quantity and quality associated with changes to the Precinct. They could be upgraded to service local development.

12.4.5 Utilities - Stormwater Drainage

The core objectives for local stormwater drainage (for individual sites and local road pit and pipe systems) are to manage nuisance overland flows under regularly occurring rainfall events (up to and including the 5%AEP design event). This is consistent with the major/minor drainage system concept outlined in *Australian Rainfall and Runoff* (Ball et al, 2019).

This flooding and water quality scenario testing report generally deals with design flood events for the 10%AEP and greater. For water quality it has been assumed that runoff from individual sites and from local roads within the Precinct would be directed via stormwater pits and pipes to a series of regional water quality treatment systems.

13 Concept Scenario Testing

13.1 Overview of Scenarios Tested

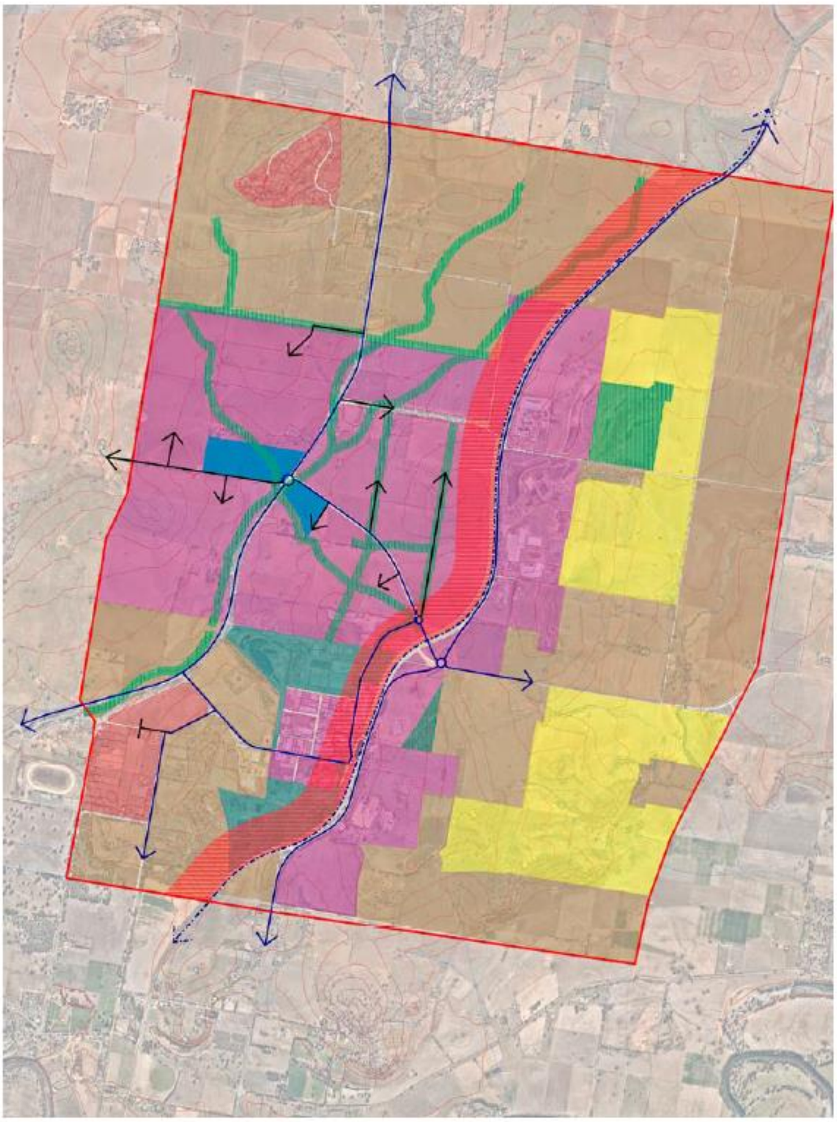
Three concept scenarios were devised through the Enquiry by Design workshop process (Jensen Plus, 2019). For the purpose of this report they are described as:

- High Growth, low/high amenity - Scenario 4
- Compact - Scenario 5
- Think Big - Scenario 7.

These are described below.

13.1.1 High Growth, low/high amenity - Scenario 4

Scenario 4 is shown in Figure 13-1.



AUG 2019
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N

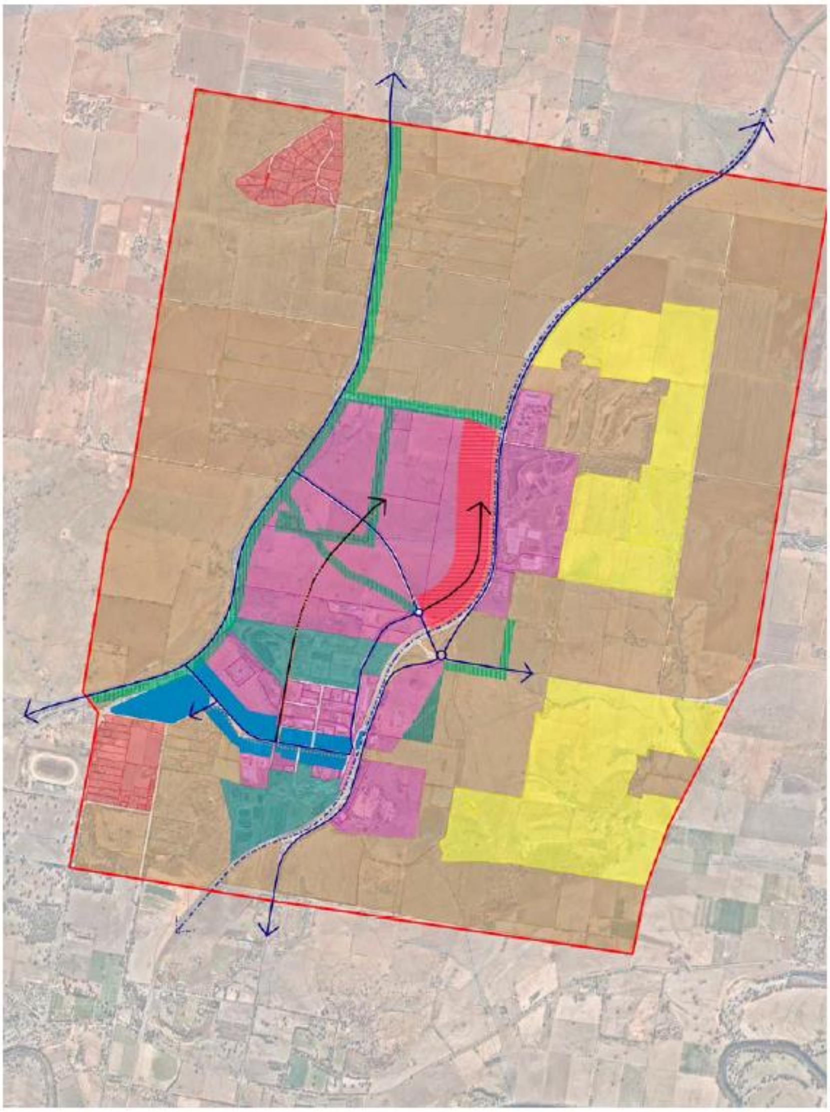
Sub Precinct	ha
Regional Enterprise	1276
Intensive Liverstock Agriculture	112
Commercial Gateway	37
Solar	476
Landscape Protection	1911
Residential	118
Sub Total	3930
No sub precinct (e.g. existing road reserves)	250
Total	4180

Overlay	ha
Rail Terminals	299
Green Infrastructure	249
Large Allotments	0

Figure 13-1 Scenario 4 High Growth Low/High Amenity (After Jensen Plus, 2019)

13.1.2 Compact – Scenario 5

Scenario 5 is shown in Figure 13-2.



AUG 2019
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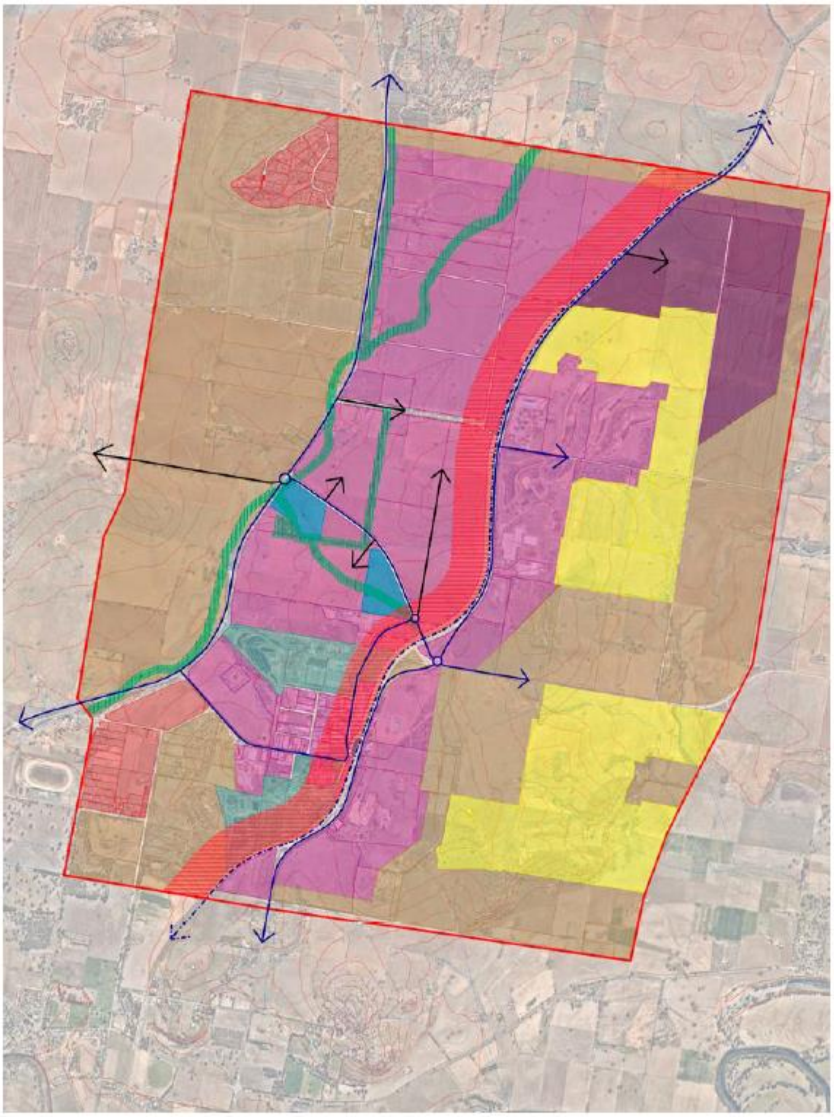
Sub Precinct	ha
Regional Enterprise	647
Intensive Liverstock Agriculture	111
Gateway	63
Solar	502
Landscape Protection	2511
Residential	96
Sub Total	3930
No sub precinct*	250
Total	4180

Overlay	ha
Rail Terminals	68
Green Infrastructure	134
Large Allotments	0

Figure 13-2 Scenario 5 Compact (After Jensen Plus, 2019)

13.1.3 Think Big – Scenario 7

Scenario 7 is shown in Figure 13-3.



AUG 2019
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N

Sub Precinct	ha
Regional Enterprise	1508
Intensive Liverstock Agriculture	114
Gateway	34
Solar	502
Landscape Protection	1653
Residential	119
Sub Total	3930
No sub precinct*	250
Total	4180

Overlay	ha
Rail Terminals	299
Green Infrastructure	143
Large Allotments	219

Figure 13-3 Scenario 7 Think Big (After Jensen Plus, 2019)

13.2 Land Use Change Effects

13.2.1 Impervious Area Change

For the purposes of scenario testing the following assumptions were made and adapted from those in Section 12.4.1 to represent a conservative case for development in the Precinct. These are:

- Maximum 50% building site coverage.
- Maximum 90% hardstand site coverage.

These changes affect the way in which rainfall is converted into runoff and necessitate the provision of flood detention systems to control the additional volume and rate of runoff. The approach to managing this change is described in Section 13.3.

13.2.2 Roughness Change

Changing the land use from rural land use to hard stand areas not only changes the way in which rainfall is converted to runoff, it also changes the land surface. For the purposes of calculating flood flows this affects the parameter known as 'roughness'. Hard stand areas are relatively 'smooth' as compared to vegetated lands. This change can speed up flood flows across those surfaces and change the timing of the peak of those flood flows.

Roughness values from the baseline assessment were retained where appropriate (refer Section 5.1.5). New roughness layers were developed for the proposed development zones. These additional layers are summarised in Table 13-1.

The approach to managing this change is described in both Sections 13.3 and 13.4.

Table 13-1 New Roughness Zones for Developed Areas

Land Use	Manning's 'n' Roughness
Commercial Gateway	0.08
Large Lot Regional Enterprise Zone / Livestock Agriculture	0.06
Regional Enterprise Zone	0.08
Green Infrastructure / Landscape Protection	0.06

13.3 Flood Detention Basin Sizing

Flood detention basins are the most common way of controlling the generation of additional runoff associated with urbanisation described in Sections 13.2.1 and 13.2.2.

Flood detention basin sizing was conducted using the RAFTS hydrological model (Section 4).

The sizing process assessed the land use change based on the three scenarios (Section 13.1). The land use changes cause the impervious fraction of the catchment to change which leads to increased rates of runoff.

The hydrological model was re-run for each scenario using the adjusted land use fraction impervious assumptions (Section 13.2.1). This resulted in increases in runoff and flows through the major systems. These increases were required to be mitigated using detention basins.

The basins have been assumed to have a base sloping up at a 1(h): 6(v) embankment. The spillways are set at 1.5m to maintain safe operation. The flow over the spillway has been designed to reach a maximum of 300 mm which results in a full supply level of 1.8m. The top of the bank has been set at 2.0m to allow some freeboard for the basins. The top of bank has a 2m wide area for access, stability and maintenance. A typical embankment is shown in Figure 13-4. The storage footprint has been based on the required water surface area and the full width of the embankment. Additional land may be required for access tracks, maintenance and differing configurations of the basin design. No allowance for the influence of existing land slope has been assumed at this stage which is reasonable for the purpose of initial concept sizing.

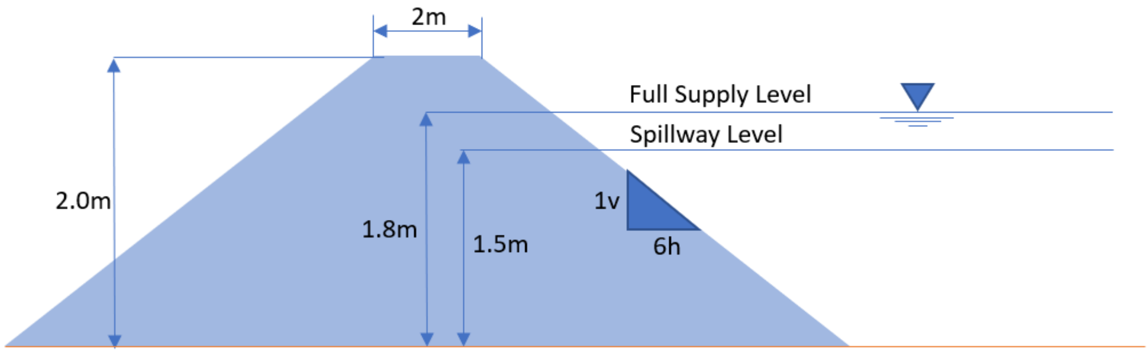


Figure 13-4 Embankment assumptions for Detention Basin Design

The process for sizing the basins was to examine the runoff behaviour between the existing conditions and the developed scenario being assessed.

Each basin was sized by:

- Assuming the outlet can pass the existing conditions 20% AEP flow. This controlled the outlet sizing from the basin. The outlet was set at the base of the embankment with the aim to detain the outlet flows to match the existing 20% AEP peak flow rates.
- The spillway was sized by examining the peak flow in the design 0.5% AEP event. The spillway was sized so that the maximum flow passed over the spillway at an assumed 300mm depth matched the existing 0.5% AEP peak flows.
- The remaining flows generated from the catchment were then detained within the basin. This was an iterative process examining the design events for each scenario. The basin size was increased until the basin maintained levels below the top of bank while meeting the outlet and spillway controlled flow rates.

The subcatchments (Section 3.2) were maintained from the existing conditions to ensure that the flow changes could be directly assessed. Where there was opportunity to have more centralised basins the subcatchments have been grouped together for this assessment. Figure 13-5, Figure 13-6 and Figure 13-7 show the land use assumptions and the subcatchments used for the basin sizing.

Table 13-3 shows the basin sizes for Scenario 5. The required land for this scenario is 14.33 ha. The total volume required is 184,600 m^3.

Table 13-4 shows the basin sizes for Scenario 4. The required land for this scenario is 25.42 ha. The total volume required is 353,500 m^3.

Table 13-5 shows the basin sizes for Scenario 7. The required land for this scenario is 29.42 ha. The total volume required is 405,400 m^3.

It has been assumed that there is one basin per drainage area, however this may not be practical for the final orientation and layout of the site. The storage identified can potentially be decentralised in some locations into smaller basins (pending checks that these behave in a similar fashion to the larger basin).

At this stage of concept testing the sizing indicates the likely storage required based on the conservative fraction impervious percentages.

Table 13-2 Basin sizing for Scenario 5

Hydrology Catchment number (See Figure 13-5)	Easting	Northing	Required land area for basin (Ha)	Basin volume at Full Supply Level (m^3) [1.8m depth]
41	539543	6121221	0.87	15600
44	539007	6119640	0.49	5200
58	539666	6122047	0.49	5200
76	537289	6117557	0.49	5200
86	536419	6117598	0.49	5200
99	537280	6119265	0.60	7800
101	536932	6119113	0.49	5200
102	536522	6119786	0.49	5200
104	536936	6119706	0.60	7800
105	537351	6119568	0.60	7800
108	537173	6119920	0.60	7800
109	537792	6120687	0.54	6500
110	537672	6120370	0.87	15600
113	538537	6120766	0.87	15600
114	537338	6121354	0.49	5200
115	537881	6120954	0.49	5200
118	536696	6120107	0.69	10400
119	536838	6120715	0.49	5200
120	537382	6120936	0.49	5200
121	537204	6121101	0.49	5200
130	538751	6121817	0.54	6500
131	537641	6121599	0.49	5200
152	535664	6119219	0.49	5200
153	535470	6119033	0.49	5200
169	538253	6121903	0.69	10400

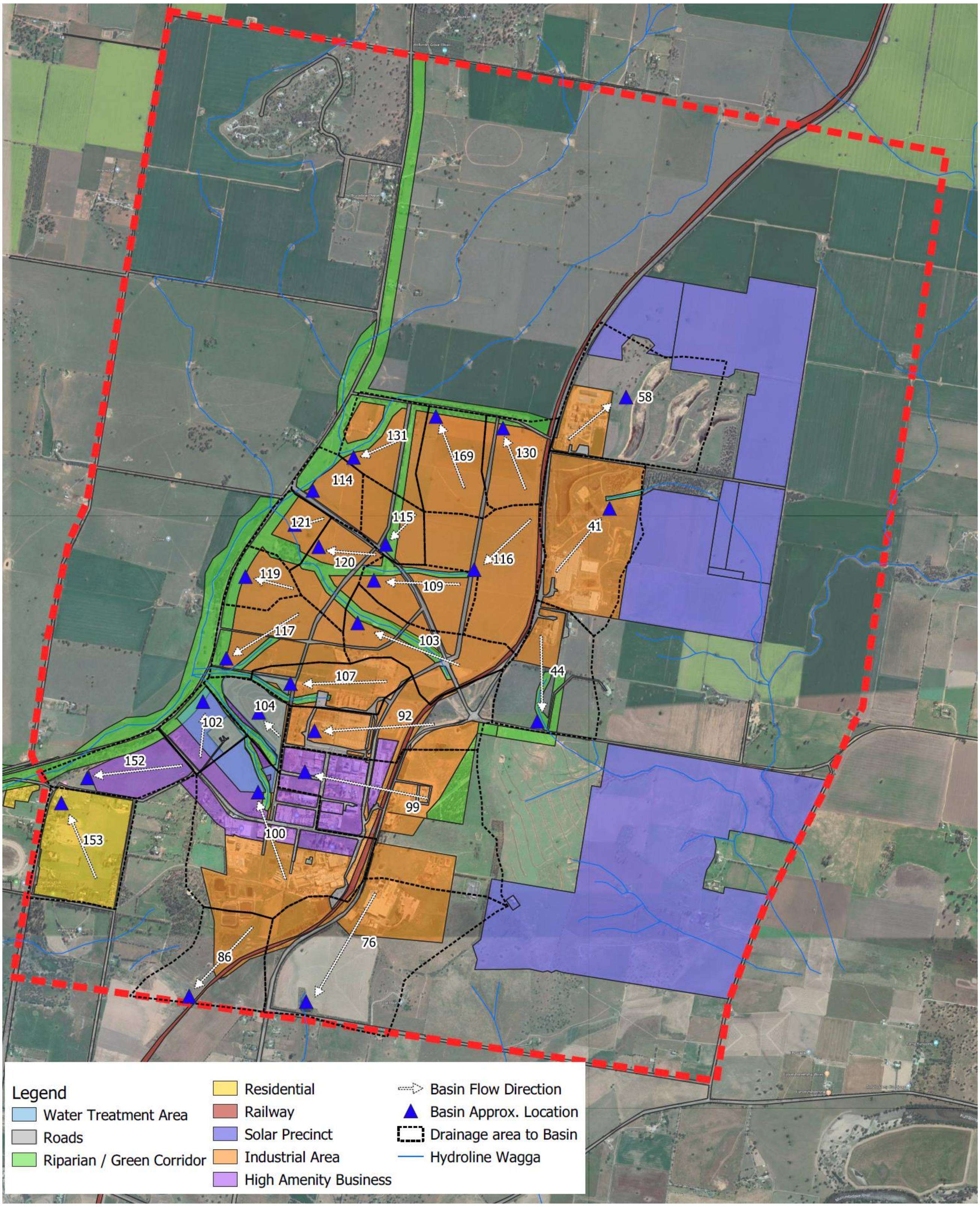


Figure 13-5 Runoff subcatchments for Scenario 5

Table 13-3 Basin sizing for Scenario 4

Hydrology Catchment number (See Figure 13-6)	Easting	Northing	Required land area for basin (Ha)	Basin volume at Full Supply Level (m^3) [1.8m depth]
41	539528	6121225	0.87	15600
43	539707	6120286	0.49	5200
44	539009	6119615	0.69	10400
58	539916	6122006	0.96	18100
60	540644	6122857	0.49	5200
76	537850	6118031	0.54	6500
77	537279	6117545	0.87	15600
86	536379	6117567	0.69	10400
92	538174	6119627	0.49	5200
93	538037	6119245	0.54	6500
94	537890	6118717	0.60	7800
99	537262	6119275	0.60	7800
101	536939	6119120	0.78	13000
102	536504	6119776	0.37	2600
104	536906	6119699	0.60	7800
105	537369	6119555	0.60	7800
108	537191	6119920	0.60	7800
109	537805	6120673	0.54	6500
110	537676	6120379	0.69	10400
113	538567	6120776	0.87	15600
114	537338	6121354	0.49	5200
115	537872	6120941	0.49	5200
118	536719	6120116	0.69	10400
119	536772	6120676	0.49	5200
120	537383	6120941	0.49	5200
121	537182	6121111	0.49	5200
127	539182	6122764	0.69	10400
128	539035	6122567	0.60	7800
129	538365	6122066	0.78	13000
130	538759	6121804	0.54	6500
131	537641	6121599	0.49	5200
140	537238	6121631	0.69	10400
142	536343	6122281	0.69	10400
143	536737	6121625	0.69	10400
145	536330	6121367	0.69	10400
146	536474	6120641	0.69	10400
148	536328	6120197	0.69	10400
152	535657	6119209	0.49	5200
153	535448	6119018	0.49	5200
169	538264	6121905	0.69	10400
172	537768	6122167	0.49	5200

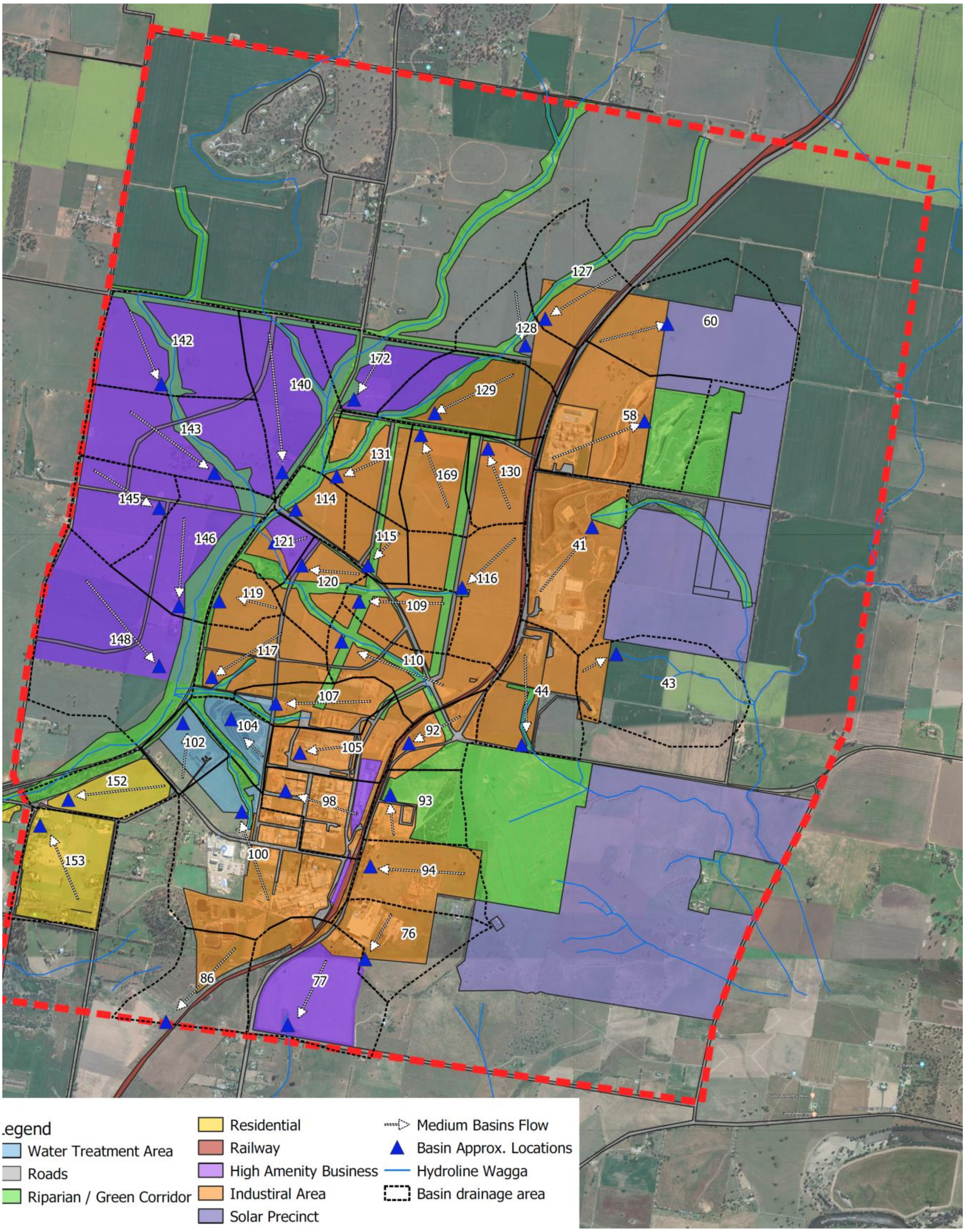


Figure 13-6 Runoff subcatchments for Scenario 4

Table 13-4 Basin sizing for Scenario 7

Hydrology Catchment number (See Figure 13-7)	Easting	Northing	Required land area for basin (Ha)	Basin volume at Full Supply Level (m^3) [1.8m depth]
33	541766	6123666	0.49	5200
35	541769	6122533	0.49	5200
39	541048	6123050	0.60	7800
40	541636	6122459	0.69	10400
41	539535	6121221	0.78	13000
42	540385	6121316	0.87	15600
44	539013	6119630	0.60	7800
58	539940	6122001	0.96	18100
59	541572	6122142	0.49	5200
60	540640	6122852	0.49	5200
74	540599	6122020	0.49	5200
76	537842	6118028	0.54	6500
77	537321	6117630	0.87	15600
86	536380	6117559	0.69	10400
92	538175	6119630	0.49	5200
93	538037	6119238	0.54	6500
94	537895	6118712	0.54	6500
99	537262	6119275	0.60	7800
101	536927	6119118	0.78	13000
102	536529	6119800	0.49	5200
104	536941	6119742	0.54	6500
105	537364	6119581	0.60	7800
108	537181	6119920	0.60	7800
109	537794	6120684	0.54	6500
110	537649	6120384	0.69	10400
113	538562	6120769	0.87	15600
114	537338	6121354	0.49	5200
115	537869	6120946	0.49	5200
118	536679	6120082	0.69	10400
119	536785	6120678	0.49	5200
120	537383	6120941	0.49	5200
121	537182	6121111	0.49	5200
122	540188	6123686	0.78	13000
123	539725	6123166	0.69	10400
126	539110	6123972	0.49	5200
127	539168	6122758	0.69	10400
128	539022	6122563	0.60	7800
129	538336	6122099	0.78	13000
130	538722	6121809	0.54	6500
131	537641	6121599	0.49	5200
132	538834	6123904	0.60	7800
133	538494	6122972	1.04	20700
152	535584	6119198	0.49	5200
153	535451	6119062	0.49	5200
169	538216	6121881	0.69	10400
171	538168	6122629	0.60	7800
172	537729	6122149	0.49	5200
173	539311	6123839	0.49	5200

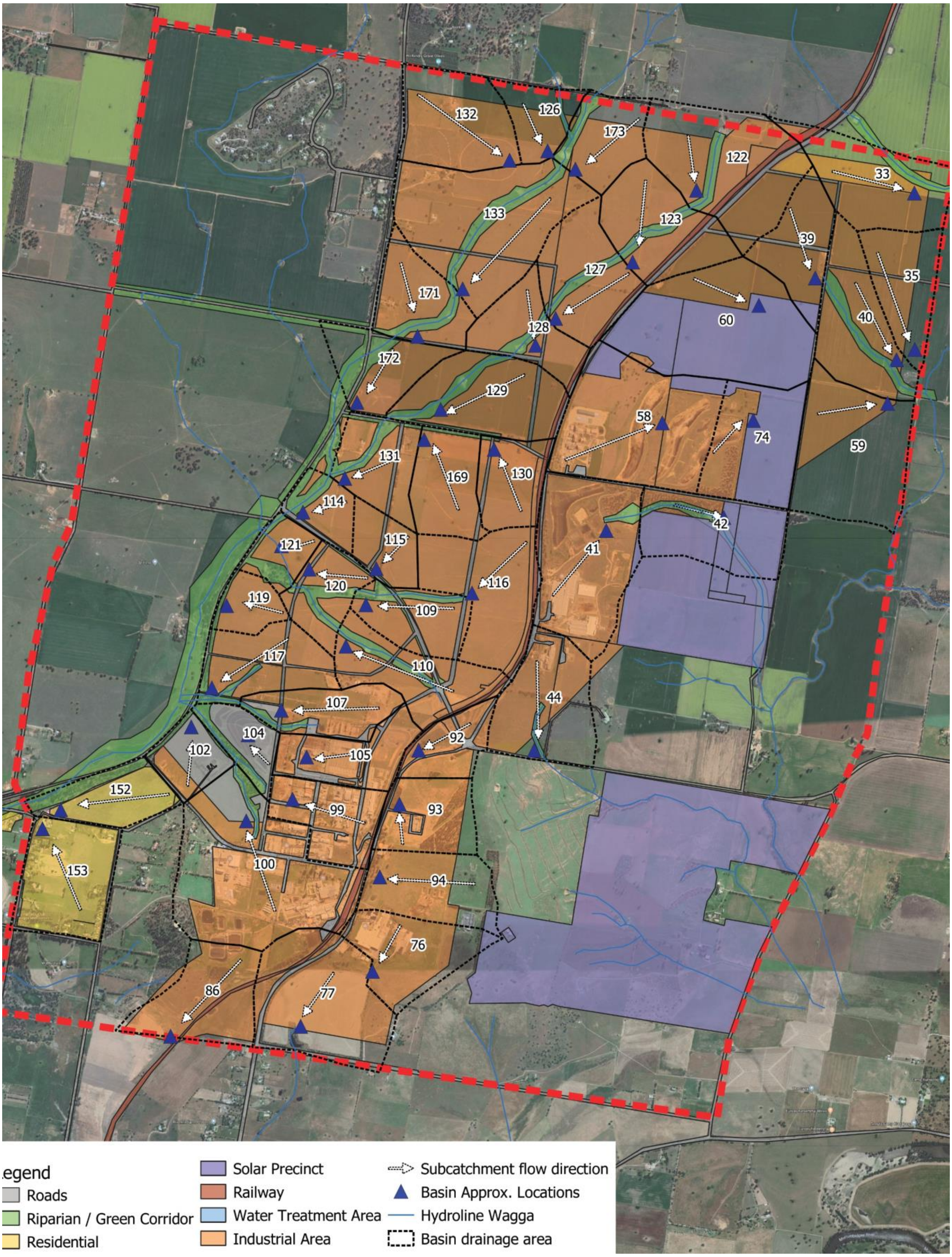


Figure 13-7 Runoff subcatchments for Scenario 7

Following the design and sizing of the basins the developed options were assessed within RAFTS for the 20%, 10%. 5%, 2%, 1%, 0.5%, 0.2% and 0.05% AEP events across the full range of durations. The peak flows within the catchment were compared to the existing conditions throughout the study area to ensure that the basins were bringing the peak flow rates back to the existing rates. The basins were checked to ensure that they were not overtopped during any of the design events.

The flows from the basin scenarios were used as inputs for the flood impact assessment to evaluate the effects on flooding in the hydraulic model (Section 14).

13.4 Waterway and Riparian Corridor Design

A waterway and riparian corridor concept design was prepared using general natural channel design principles with the intention to meet the objectives listed in Sections 12.3 and 12.4.3.

A cross section of the concept developed in shown in Figure 13-8. Figure 13-9 shows typical riparian vegetation in the region (noting that the understorey is more representative of the likely intrusion of the effects of adjacent rural areas).

The design cross section for waterways has the following key features:

- Retention of existing watercourse bed levels where possible
- Low flow channel (approximately 50%AEP flow conveyance) – 1:3 bank slopes with an initial estimate of bed width of 2 m and 0.75 m depth.
- Mid-flow channel component – to convey flows up to the 5%AEP – 1:6 bank slopes.
- High flow channel component – to convey flows up to the 0.5%AEP – 1:8 bank slopes.

It has been assumed that the corridor would be vegetated with appropriate local plant species at a relatively dense planting scale to achieve biodiversity and flood hydraulics objectives.

This design channel was inserted into the existing terrain using the 12D design software and then the terrain was gridded into a 5m digital elevation model to be inserted into the hydraulic model for scenario testing. The design was initially developed to cover all three design scenarios (Section 13.1) and then elements were truncated in the DEM to represent only those portions of the watercourses that would be rehabilitated as part of the Precinct works. The design across the relevant portions of the whole Precinct is shown in Figure 13-10 (Dukes Creek South) and Figure 13-11 (Dukes Creek North).

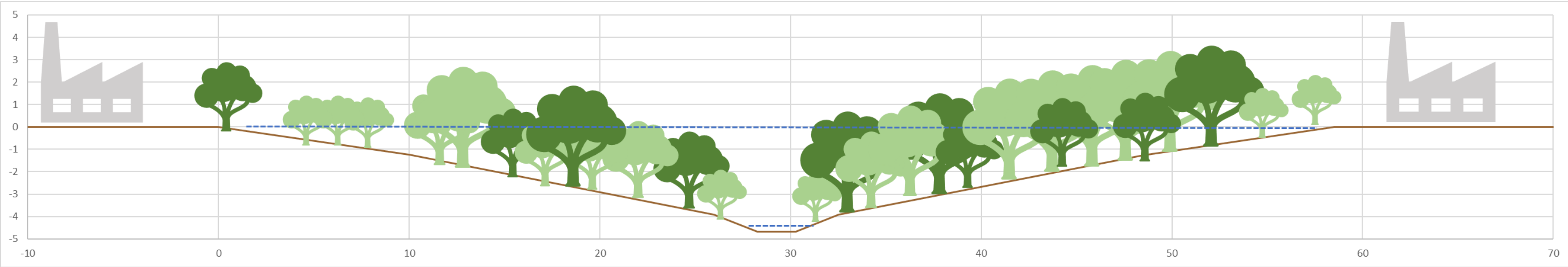


Figure 13-8 Concept Riparian Corridor (Cross Section) (Dimensions are approximate)

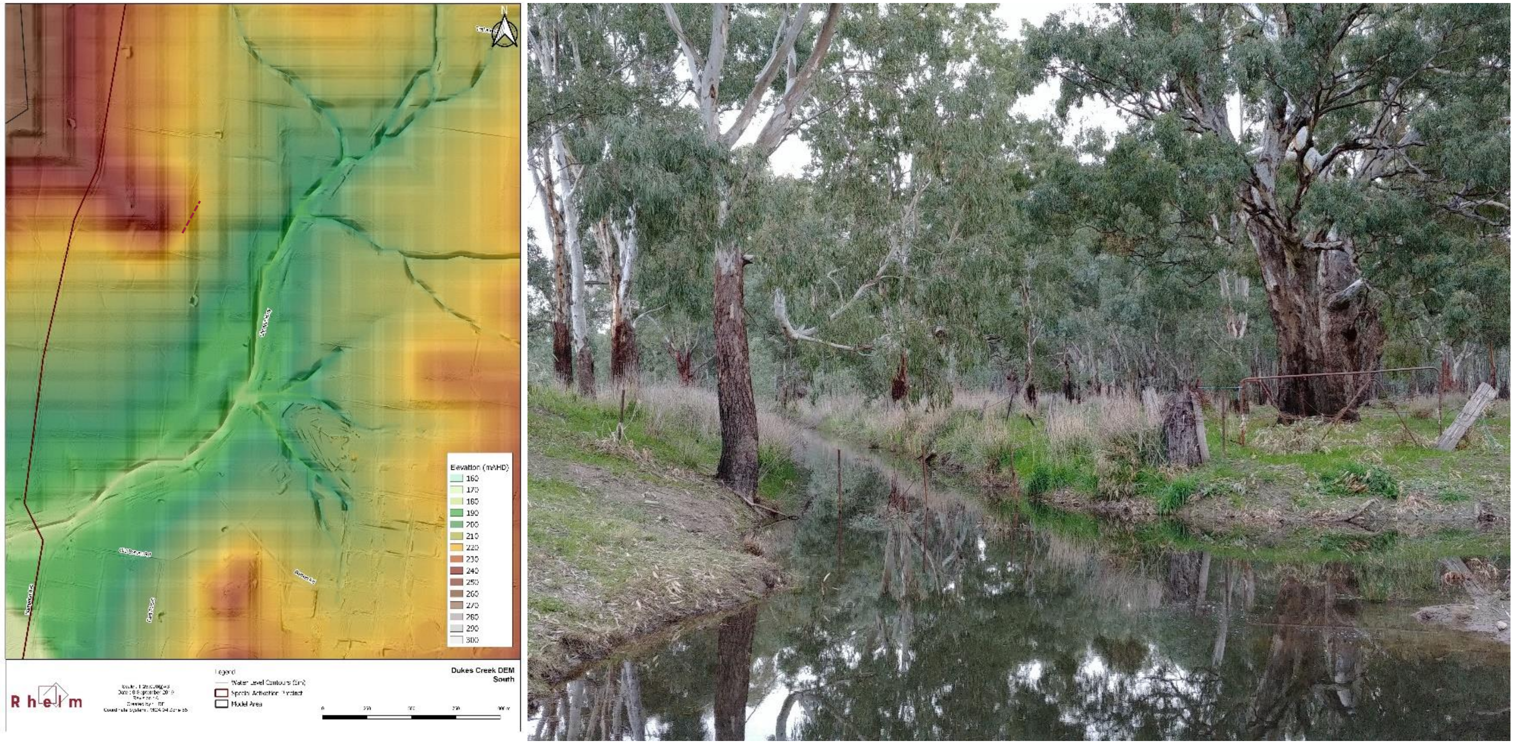


Figure 13-9 Design Terrain Example and Typical Riparian Vegetation in the Region

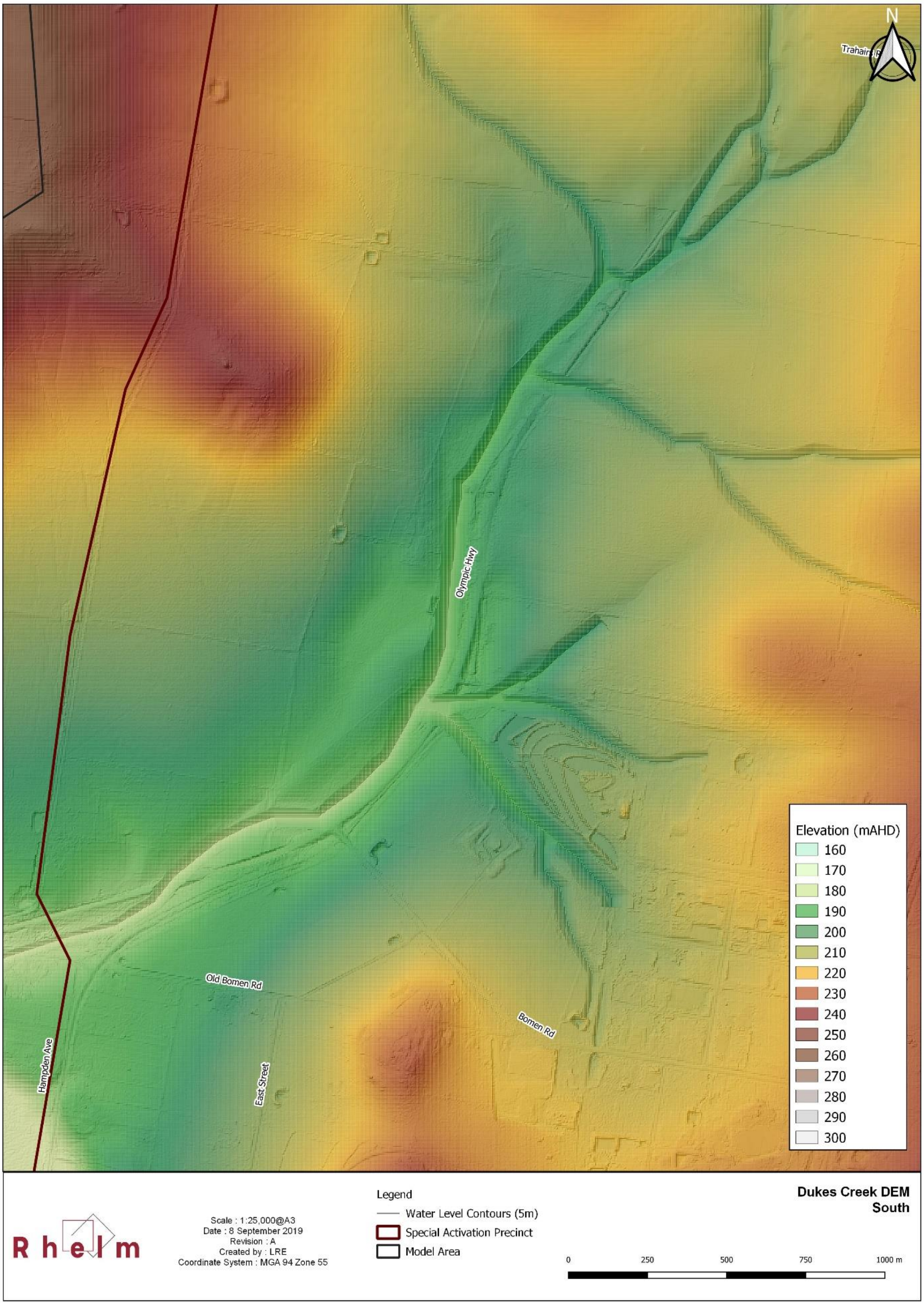


Figure 13-10 Concept Terrain with Design Waterway and Riparian Corridor – Dukes Creek South

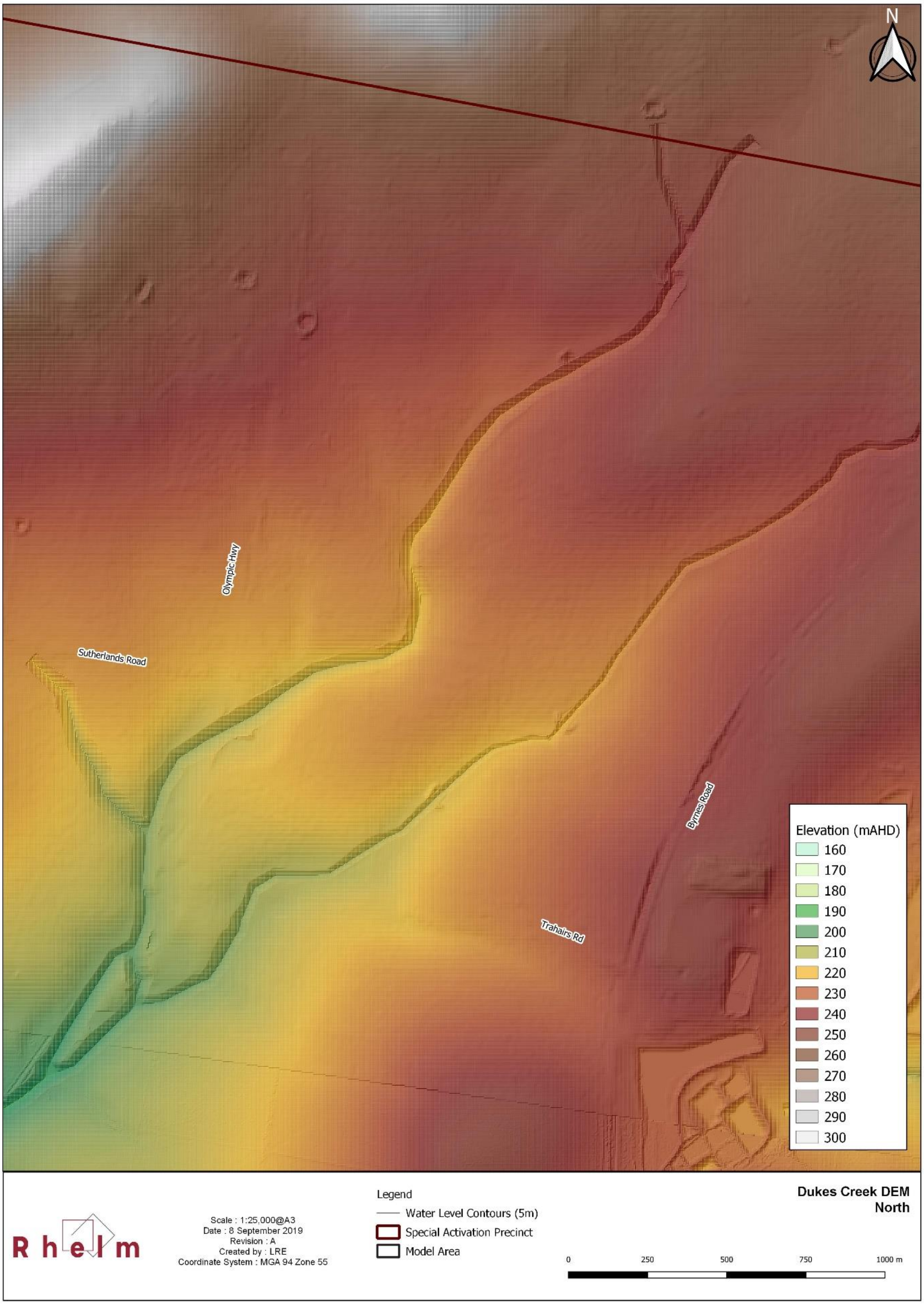


Figure 13-11 Concept Terrain with Design Waterway and Riparian Corridor – Dukes Creek South

13.5 Water Quality Treatment Facility Sizing

13.5.1 Overview

The water quality treatment facility sizing was conducted using the catchment modelling software, MUSIC. The inputs to MUSIC were consistent with the hydrology and the catchment setup for fraction impervious and runoff for the detention basin sizing.

The three scenarios were assessed using aggregated hydrological subcatchments (Section 3.2) to allow for regional testing of different water quality treatment train options to meet the pollutant load reduction targets set in Table 12-1.

The sub catchments align with the detention basin assessment (Section 13.3) and the water quality and detention can overlap in their design and application.

13.5.2 Model Set Up

MUSIC model parameters have been generally adopted from the latest guidelines for the Sydney water supply catchment area (WaterNSW, 2019). These guidelines represent the most up to date approaches recommended for pollutant load-based water quality modelling in NSW.

The parameters adopted in the model are outlined in the following tables:

- Table 13-1 – Dominant soil type in the study area
- Table 13-2 – Baseflow pollutant concentration inputs
- Table 13-3 – Storm flow pollutant concentration inputs
- Table 13-4 – Gross Pollutant Trap (GPT) assumptions
- Table 13-5 – Assumptions for Swales, Bioretention Systems and Constructed Wetlands

Table 13-5 Dominant soil type characteristics within Study area

Rainfall Runoff Parameters - Dominant soil description	Soil storage capacity (mm)	Field Capacity (mm)	Infiltration capacity coefficient - a (mm/d)	Infiltration capacity exponent - b (mm/d)	Daily recharge rate (%)	Daily baseflow rate (%)	Daily seepage rate (%)
Light Clay	98	73	135	4	10	10	0

Table 13-6 Assumed Baseflow Pollutant Concentrations

Concentration (mg/L-log10)	Total suspended solids		Total phosphorus		Total Nitrogen	
Land use/zoning	mean	std. dev	mean	std. dev	mean	std. dev
Industrial	1.2	0.17	-0.85	0.19	0.11	0.12
Agricultural	1.3	0.13	-1.05	0.13	0.04	0.13
Rural residential	1.15	0.17	-1.22	0.19	-0.05	0.12

Table 13-7 Assumed Storm Flow Pollutant Concentrations

Concentration (mg/L-log10)	Total suspended solids		Total phosphorus		Total Nitrogen	
Land use/zoning	mean	std. dev	mean	std. dev	mean	std. dev
Industrial	2.15	0.32	-0.6	0.25	0.3	0.19
Agricultural	2.15	0.31	-0.22	0.3	0.48	0.26
Rural residential	1.95	0.32	-0.66	0.25	0.3	0.19

Table 13-8 Gross Pollutant Trap Assumptions (CDS)

CDS GPT		
	Input (mg/L)	Output (mg/L)
Low flow bypass	0	
High flow bypass	50% of peak 63.2% AEP	
Total Suspended Solids	0	0
	75	75
	1000	350
Total Phosphorous	0	0
	0.5	0.5
	1	0.85
Total Nitrogen	0	0
	0.5	0.5
	5	4.3
Gross pollutants	0	0
	15	1.5

Table 13-9 Assumptions for Swales, Bioretention Systems and Constructed Wetlands

Swale	
Vegetated depth	0.25 m
Bioretention Systems (with Submerged Zone)	
Extended Detention Depth	200-500mm
Clean filter media (mm)	300-500mm
Clean Coarse Sand	50mm
Clean Sand and Carbon Source	300mm
Gravel	150mm
Bioretention Swales	
Extended Detention Depth	0.05m
Low flow bypass	set to infiltration rate of filter media
Length (m)	50
Width (m)	0.8
Saturated hydraulic conductivity (mm/h)	200
Low flow bypass (m^3/s)	0.0022
Bioretention Parameters	

Saturated hydraulic conductivity (mm/hr) - Sandy loam (50% of total for modelling)	120
Filter depth	0.4m to 1m
TN content of filter media (mg/kg)	400
Orthophosphate content of filter media (mg/kg)	40
Exfiltration rate (mm/hr)	0
Overflow weir width	surface area / 10
Submerged zone with carbon present	0.2 - 0.4m deep (less than 300mm to avoid phosphorus leaching)
Bioretention sizing	2% of upstream imp catchment
Wetlands	
Extended Detention Depth	0.5m
Detention time	72 hrs
Vegetation cover	50% (default)

13.5.3 Water Quality Treatment Options

Three treatment train options were considered for the three scenarios considered. These are as follows:

- Option 1:
  - Capture and re-use of roof runoff - 20kL rainwater tank per hectare of roof area within Industrial Zones (assumed that 50% of the zone is roof area)
  - Gross Pollutant trap for primary treatment of surface runoff (assumed to be a CDS unit)
  - Secondary treatment lined bioretention system with a 0.2m submerged zone (for drought resistance).
- Option 2:
  - Capture and re-use of roof runoff – 20kL rainwater tank per hectare of roof area within Industrial Zones (assumed that 50% of the zone is roof area)
  - Gross Pollutant trap for primary treatment of surface runoff (assumed to be a CDS unit)
  - Secondary treatment lined bioretention (without submerged zone).
- Option 3:
  - Capture and re-use of roof runoff - 20kL rainwater tank per hectare of roof area within Industrial Zones (assumed that 50% of the zone is roof area)
  - Gross Pollutant trap for primary treatment of surface runoff (assumed to be a CDS unit)
  - Constructed Wetland (lined).

To determine the required treatment areas subcatchments were aggregated in MUSIC to determine an average treatment area required (Table 13-6). This table links the fraction impervious to the required treatment based on the subcatchment area. This relationship has been applied to each of the three scenarios.

Table 13-10 Derived water quality contribution to achieve target treatment based on fraction impervious

Percentage Impervious Range	Percentage of total catchment area		
	Option 1 Bioretention with 0.2m Submerged Zone	Option 2 Bioretention without submerged zone	Option 3 Constructed Wetlands
10 - 20%	0.1%	0.07%	1.9%
20 - 30%	0.3%	0.08%	2.0%
30 - 40%	1.8%	0.13%	2.4%
40 - 50%	3.3%	0.15%	2.5%
50 - 60%	4.3%	0.21%	2.8%
60 - 70%	5.0%	0.22%	3.0%
70 - 80%	5.8%	0.23%	3.2%
80 - 90%	6.8%	0.24%	3.6%

The subcatchment have been assessed based of the areas defined in Figure 13-5, Figure 13-6 and Figure 13-7 for the detention basin assessment.

For the three treatment options, Table 13-6 indicates that the bioretention system with 0.2m submerged zone required the largest land allocation however is the most resilient due to the drought tolerance of the submerged zone.

13.5.4 Water Quality Treatment for Scenario Testing

The results of the water quality treatment sizing is provided in Table 13-7, Table 13-8 and Table 13-9 for Scenarios 5, 4 and 7 respectively.

The key outcomes are the load reduction targets for phosphorous drive the sizing of facilities. The sizing required is as follows:

- Upper limit of total treatment area for Scenario 5 is 55.4 ha, mid-range of 31.52 ha
- Upper limit of total treatment area for Scenario 4 is 91.2 ha, mid-range of 52.93 ha
- Upper limit of total treatment area for Scenario 7 is 144.4 ha, mid-range of 80.51 ha

Table 13-11 Water treatment area allocated for Scenario 5 for the three treatment approaches

Subcatchment (see Figure 13-5)	Average Fraction Imp.	Bioretention with 0.2m Submerged Zone		Bioretention without submerged zone		Constructed Wetlands	
		Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)
41	85.1	6.8%	5.50	0.2%	0.20	3.6%	2.94
44	85.0	6.8%	0.76	0.2%	0.03	3.6%	0.41
58	85.0	6.8%	1.14	0.2%	0.04	3.6%	0.61
76	85.0	6.8%	2.92	0.2%	0.10	3.6%	1.57
86	85.0	6.8%	1.16	0.2%	0.04	3.6%	0.62
99	55.8	4.3%	3.40	0.2%	0.17	2.8%	2.21
101	68.7	5.0%	5.05	0.2%	0.22	3.0%	3.03

Subcatchment (see Figure 13-5)	Average Fraction Imp.	Bioretention with 0.2m Submerged Zone		Bioretention without submerged zone		Constructed Wetlands	
		Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)
102	59.5	4.3%	0.98	0.2%	0.05	2.8%	0.63
104	67.7	5.0%	1.07	0.2%	0.05	3.0%	0.64
105	71.7	5.8%	3.57	0.2%	0.14	3.2%	1.95
108	83.4	6.8%	2.31	0.2%	0.08	3.6%	1.24
109	82.1	6.8%	2.14	0.2%	0.08	3.6%	1.14
110	77.3	5.8%	2.84	0.2%	0.11	3.2%	1.55
113	86.6	6.8%	4.47	0.2%	0.16	3.6%	2.39
114	66.4	5.0%	1.03	0.2%	0.05	3.0%	0.62
115	76.3	5.8%	1.29	0.2%	0.05	3.2%	0.70
118	74.8	5.8%	2.56	0.2%	0.10	3.2%	1.40
119	68.8	5.0%	0.88	0.2%	0.04	3.0%	0.53
120	70.6	5.8%	1.67	0.2%	0.06	3.2%	0.91
121	52.3	4.3%	0.82	0.2%	0.04	2.8%	0.53
130	83.2	6.8%	2.08	0.2%	0.07	3.6%	1.12
131	65.5	5.0%	1.83	0.2%	0.08	3.0%	1.10
152	47.2	3.3%	1.12	0.2%	0.05	2.5%	0.84
153	54.9	4.3%	2.33	0.2%	0.12	2.8%	1.51
169	85.3	6.8%	2.48	0.2%	0.09	3.6%	1.33

Table 13-12 Water treatment area allocated for Scenario 4 for the three treatment approaches

Subcatchment (see Figure 13-6)	Average Fraction Imp.	Bioretention with 0.2m Submerged Zone		Bioretention without submerged zone		Constructed Wetlands	
		Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)
41	84	6.8%	5.50	0.2%	0.20	3.6%	2.94
43	85	6.8%	0.73	0.2%	0.03	3.6%	0.39
44	85	6.8%	2.77	0.2%	0.10	3.6%	1.48
58	85	6.8%	4.29	0.2%	0.15	3.6%	2.30
60	85	6.8%	1.49	0.2%	0.05	3.6%	0.80
76	85	6.8%	1.76	0.2%	0.06	3.6%	0.94
77	63	5.0%	3.94	0.2%	0.17	3.0%	2.36
86	85	6.8%	0.89	0.2%	0.03	3.6%	0.48
92	85	6.8%	1.36	0.2%	0.05	3.6%	0.73
93	85	6.8%	0.74	0.2%	0.03	3.6%	0.40
94	77	5.8%	2.69	0.2%	0.10	3.2%	1.47
99	89	6.8%	2.59	0.2%	0.09	3.6%	1.39
101	85	6.8%	5.06	0.2%	0.18	3.6%	2.71
102	13	0.1%	0.03	0.1%	0.02	1.9%	0.44
104	12	0.1%	0.03	0.1%	0.01	1.9%	0.41
105	88	6.8%	2.46	0.2%	0.09	3.6%	1.32
108	75	5.8%	1.99	0.2%	0.08	3.2%	1.08
109	69	5.0%	1.57	0.2%	0.07	3.0%	0.94
110	69	5.0%	2.43	0.2%	0.11	3.0%	1.46
113	82	6.8%	4.47	0.2%	0.16	3.6%	2.39
114	64	5.0%	1.03	0.2%	0.05	3.0%	0.62
115	79	5.8%	1.29	0.2%	0.05	3.2%	0.70
118	80	5.8%	2.56	0.2%	0.10	3.2%	1.40
119	84	6.8%	1.20	0.2%	0.04	3.6%	0.64
120	70	5.8%	1.67	0.2%	0.06	3.2%	0.91
121	58	4.3%	0.82	0.2%	0.04	2.8%	0.53
127	85	6.8%	1.09	0.2%	0.04	3.6%	0.58
128	85	6.8%	0.64	0.2%	0.02	3.6%	0.34
129	70	5.8%	3.53	0.2%	0.14	3.2%	1.92
130	81	6.8%	2.08	0.2%	0.07	3.6%	1.12
131	69	5.0%	1.83	0.2%	0.08	3.0%	1.10
140	56	4.3%	2.80	0.2%	0.14	2.8%	1.82
142	60	5.0%	3.78	0.2%	0.17	3.0%	2.27
143	63	5.0%	4.02	0.2%	0.18	3.0%	2.41
145	56	4.3%	2.38	0.2%	0.12	2.8%	1.55
146	51	4.3%	2.83	0.2%	0.14	2.8%	1.84
148	70	5.0%	3.67	0.2%	0.16	3.0%	2.20

152	45	3.3%	1.12	0.2%	0.05	2.5%	0.84
153	60	5.0%	2.71	0.2%	0.12	3.0%	1.63
169	79	5.8%	2.13	0.2%	0.08	3.2%	1.16
172	49	3.3%	1.22	0.2%	0.05	2.5%	0.92

Table 13-13 Water treatment area allocated for Scenario 7 for the three treatment approaches

Subcatchment (see Figure 13-7)	Average Fraction Imp.	Bioretention with 0.2m Submerged Zone		Bioretention without submerged zone		Constructed Wetlands	
		Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)
33	85.0	6.8%	5.24	0.2%	0.19	3.6%	2.81
35	85.0	6.8%	3.70	0.2%	0.13	3.6%	1.98
39	85.2	6.8%	2.49	0.2%	0.09	3.6%	1.33
40	71.9	5.8%	3.19	0.2%	0.12	3.2%	1.74
41	86.3	6.8%	5.50	0.2%	0.20	3.6%	2.94
42	85.0	6.8%	3.58	0.2%	0.13	3.6%	1.92
44	85.0	6.8%	3.85	0.2%	0.14	3.6%	2.06
58	85.0	6.8%	6.44	0.2%	0.23	3.6%	3.45
59	85.0	6.8%	5.22	0.2%	0.19	3.6%	2.80
60	23.0	0.3%	0.26	0.1%	0.08	2.0%	2.04
74	85.0	6.8%	3.69	0.2%	0.13	3.6%	1.98
76	71.7	5.8%	2.64	0.2%	0.10	3.2%	1.44
77	85.0	6.8%	5.35	0.2%	0.19	3.6%	2.87
86	85.0	6.8%	5.33	0.2%	0.19	3.6%	2.85
92	87.8	6.8%	1.69	0.2%	0.06	3.6%	0.90
93	79.1	5.8%	2.10	0.2%	0.08	3.2%	1.14
94	85.0	6.8%	3.13	0.2%	0.11	3.6%	1.68
99	90.4	6.8%	2.59	0.2%	0.09	3.6%	1.39
101	72.7	5.8%	6.74	0.2%	0.26	3.2%	3.68
102	80.7	6.8%	1.55	0.2%	0.06	3.6%	0.83
104	65.4	5.0%	1.07	0.2%	0.05	3.0%	0.64
105	90.7	6.8%	2.46	0.2%	0.09	3.6%	1.32
108	83.6	6.8%	2.31	0.2%	0.08	3.6%	1.24
109	81.4	6.8%	2.14	0.2%	0.08	3.6%	1.14
110	79.3	5.8%	2.84	0.2%	0.11	3.2%	1.55
113	86.0	6.8%	4.47	0.2%	0.16	3.6%	2.39
114	65.9	5.0%	1.03	0.2%	0.05	3.0%	0.62
115	88.7	6.8%	1.50	0.2%	0.05	3.6%	0.80
118	80.7	6.8%	2.98	0.2%	0.11	3.6%	1.59
119	83.7	6.8%	1.20	0.2%	0.04	3.6%	0.64
120	70.8	5.8%	1.67	0.2%	0.06	3.2%	0.91

Subcatchment (see Figure 13-7)	Average Fraction Imp.	Bioretention with 0.2m Submerged Zone		Bioretention without submerged zone		Constructed Wetlands	
		Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)	Area for Treatment (%)	Area required (Ha)
121	65.7	5.0%	0.96	0.2%	0.04	3.0%	0.57
122	85.0	6.8%	6.42	0.2%	0.23	3.6%	3.44
123	81.5	6.8%	3.66	0.2%	0.13	3.6%	1.96
126	85.0	6.8%	1.61	0.2%	0.06	3.6%	0.86
127	81.6	6.8%	3.43	0.2%	0.12	3.6%	1.84
128	82.2	6.8%	2.43	0.2%	0.09	3.6%	1.30
129	77.1	5.8%	3.53	0.2%	0.14	3.2%	1.92
130	89.1	6.8%	2.08	0.2%	0.07	3.6%	1.12
131	75.7	5.8%	2.14	0.2%	0.08	3.2%	1.17
132	85.0	6.8%	2.48	0.2%	0.09	3.6%	1.33
133	78.8	5.8%	5.83	0.2%	0.23	3.2%	3.18
152	45.5	3.3%	1.12	0.2%	0.05	2.5%	0.84
153	60.3	5.0%	2.71	0.2%	0.12	3.0%	1.63
169	87.3	6.8%	2.48	0.2%	0.09	3.6%	1.33
171	85.0	6.8%	2.61	0.2%	0.09	3.6%	1.40
172	55.0	4.3%	1.56	0.2%	0.08	2.8%	1.02
173	58.1	4.3%	1.43	0.2%	0.07	2.8%	0.93

14 Concept Flood Impact Assessment

The flood impact assessment for the scenarios was undertaken using the TUFLOW software package (version 2018-03-AC) in the same fashion as the baseline flood assessment (Section 5).

This section discusses:

- Model Development (Section 14.1)
- Design Flood Modelling (Section 14.2)
- Scenario Flood Behaviour (Section 14.3).

14.1 Model Development

The development scenarios were incorporated into the base TUFLOW hydraulic model (Section 5) through:

- A revised terrain with the proposed riparian corridors (Section 13.4) integrated into the DEM;
- Revised inflow boundaries from the updated RAFTS models, to take account of the proposed detention basins (Section 13.3); and,
- A revised roughness layer to represent the proposed development scenarios. The roughness values adopted are discussed in Section 13.2.2. Roughness layers were digitised from the option layouts shown in Figure 13-1, Figure 13-2 and Figure 13-3.

In all other respects, the scenario hydraulic models remained the same as the base case hydraulic model.

14.2 Design Flood Modelling

14.2.1 Scenarios Run

Each scenario was run for the 10% AEP and 0.5% AEP events for the critical 360 minute duration. As per the base case modelling, each event was run for 10 different temporal patterns, with the median being extracted as the representative event.

Furthermore, the large development scenario, Scenario 7, was run for the PMF event as a sensitivity assessment to examine how the riparian corridors behave in extreme flood events and to identify whether additional flow paths are required for the safe conveyance of flows in an extreme event.

14.2.2 Model Results

Model results for the scenarios have been processed and prepared in line with the methodology used for the base case results, as discussed in Section 5.3.2.

Scenario 4 results are shown in map series G801-1 to G801-4 for depth, velocity, hazard and flood function respectively.

Scenario 5 results are shown in map series G802-1 to G802-4 for depth, velocity, hazard and flood function respectively.

Scenario 7 results are shown in map series G803-1 to G803-4 for depth, velocity, hazard and flood function respectively.

The PMF sensitivity assessment peak depths are shown in map G901.

These maps are attached to the end of this report.

14.3 Scenario Flood Behaviour

Each scenario met the core objectives set out in Section 12.1.

Specifically, the results reported in Section 14.2.2 indicate that each scenario:

- Conveyed the 0.5% AEP event within the riparian corridors;
- Contained the 0.5% AEP floodway within the riparian corridors;
- Retained the base case critical flow duration of 6 hours;
- Downstream levels remained consistent with the base case results; and,
- Demonstrated that the 10% AEP flows resulted in the activation of all riparian corridors indicating that flows are not over attenuated.

Some localised pockets of overland flow and ponding occurred along the highway. While some of this flooding could simply be removed by local regrading during a future stage, some regions are more significant, such as that occurring along the eastern side of the highway between Bomen Road and East Bomen Road. The flood behaviour in all scenarios suggests that an open channel or similar may be required to convey this water to the nearest cross drainage structure.

The PMF sensitivity results (Map G901) showed that flooding upstream of East Bomen Road within the tributaries of Dukes Creek, and within Dukes Creek itself, is fully contained within the riparian corridor. Downstream of East Bomen Road, the PMF extends beyond the riparian corridor on the western bank; the eastern bank remains constrained by the Olympic Highway.

In the eastern region of the Precinct, the PMF results show some sheet flow occurring downstream of the existing ponds, as a result of flow from these basins discharging over the northern crest of the basins.

Flood level difference plots are shown in map series G804-1 to G804-4 for the three scenarios for the 0.5%AEP and the PMF for Scenario 7 respectively. These plots provide an assessment of impact and indicate that there are some minor impacts outside of the Precinct that are likely to be readily resolved by optimisation of the riparian corridor and waterway design and potential minor alterations to regional detention basin sizing.

15 Final Scenario Analysis

15.1 Core Objectives

The core objectives for the final scenario remain the same as those detailed for the concept scenarios in Section 12.

15.2 Overview of Final Adopted Scenario

The final adopted scenario is shown in Figure 15-1. The approach to manage surface water includes a series of proposed multi-function green infrastructure corridors ('Green Infrastructure Overlay') within the Precinct (to meet riparian corridor and flood conveyance requirements), in concert with combined water quality treatment and detention infrastructure to capture, treat and attenuate the additional runoff associated with the land use change from rural uses to industrial conditions ('Regional Enterprise', 'Rail Terminal', 'Commercial Nodes' land use and associated 'New Roads' in Figure 15-1) to baseline conditions. The proposed flood and water quality facilities have been integrated as far as possible into the green infrastructure corridor.

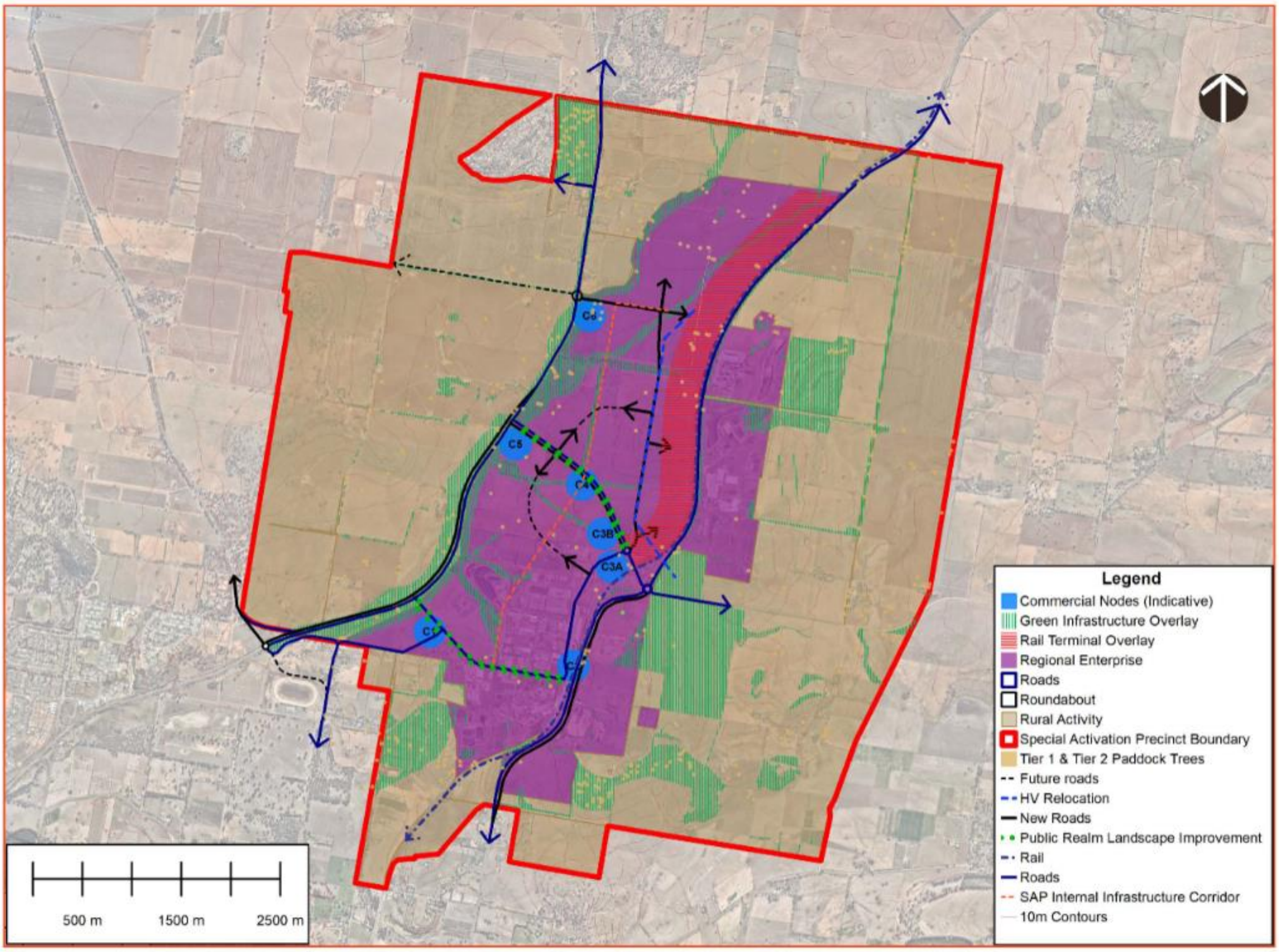


Figure 15-1 Refined Structure Plan – Final Adopted Scenario (Source: JensenPlus, 2020)

The scenario has been considered in a series of Stages, being 1A, 1B, 1C, 1D, 1E, 2 and 3. The analysis has been cognisant of the staging to ensure that flood and water quality infrastructure is aligned with the staging proposed as described below. Note, the staging discussed and shown below is indicative only.

The scenario includes some existing development that already has surface water management facilities, such as that at Bomen. No additional facilities have been considered for this land.

15.3 Land Use Change Effects

15.3.1 Impervious Area Change

The impervious area change assumptions adopted for the concept scenarios have been refined for the final scenario following further consultation and thus determination of typical industrial land use proposed within the Precinct within the New Regional Enterprise Sub Precinct. These assumptions are:

- Maximum 30% building site coverage.
- Maximum 40% hardstand ground site coverage.

This equates to 70% impervious land use within industrial land use zones within the New Regional Enterprise Sub Precincts. New roads have been assumed to be 100% impervious.

15.3.2 Roughness Change

Roughness values from the baseline assessment were retained where appropriate (refer Section 5.1.5). New roughness layers developed for the concept options were adapted for proposed development areas in the final adopted scenario (refer Section 13.2.2).

15.4 Flood Detention Basin Sizing

As per the concept scenario testing detailed in Section 13, flood detention basins have been adopted to attenuate post development flows from the Precinct to baseline rates prior to discharge into downstream waterways.

Final scenario flood detention basin sizing was conducted using the RAFTS hydrological model (refer to Section 4).

The sizing methodology has been further refined from the concept scenario testing detailed in Section 13 to enable a more efficient use of space. This has been achieved by refining the multi-functional approach to combining bioretention (water quality) and detention storage basins. Embankment slopes for the detention basins have been refined following more detailed analysis of the site.

The proposed detention basins have been located above the proposed bioretention systems as shown in Figure 15-2. The base of the detention basin has been set at the extended detention level of the bioretention basin. The internal embankment slope from the base of the detention basin is set to 1(h): 6(v). The external embankment sloping down to meet the existing surface, where required, has been set to 1(h): 3(v). The spillway heights and full supply levels have been further refined from the concept scenario testing by analysing each of the basin's requirements individually. An example spillway height of 1.5m, full supply level of 1.8m and top of bank at 3m is shown in Figure 15-2.

The top of bank has a 2m wide area for access, stability and maintenance. The storage footprint has been based on the required water surface area and the full width of the embankment. Additional land may be required for access tracks, maintenance, differing configurations of the basin design and topographical constraints. As such, land take is to be further refined at the detailed bioretention and detention basin design stage.

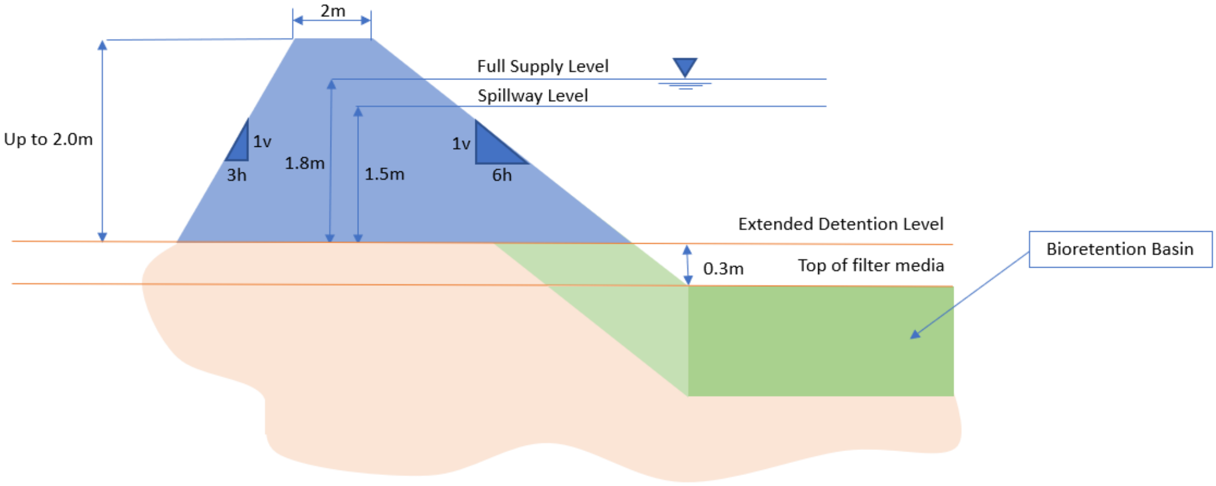


Figure 15-2 Embankment assumptions for Combined Detention/Bioretention Basin Design

The process for sizing the basins is in line with the process undertaken for the concept scenario testing detailed in Section 13.3.

The detention basin sub catchments were refined to be consistent with the proposed Staging for the Precinct and in line with water quality treatment catchments detailed in Section 15.6 enabling multipurpose detention and water quality treatment assets to be implemented. In addition, where possible, the basin assets have been consolidated to reduce maintenance and maximise developable area within the Precinct, whilst still achieving water quality treatment and detention requirements.

The detention basin sub catchments, and associated basin asset locations and land area requirements (noting these are based on conceptual design), are shown in Figure 15-3. Table 15-1 provides the corresponding sizing and Staging details.

Following the completion of the basin sizing investigation detailed in this report Rhelm were engaged to undertake a supplementary investigation into alternatives for detention basin sizing for the precinct. This is detailed in the *Wagga Wagga Special Activation Precinct – Flooding and Water Quality - Supplementary Assessments of Detention Basin Options* (Rhelm, 2020).

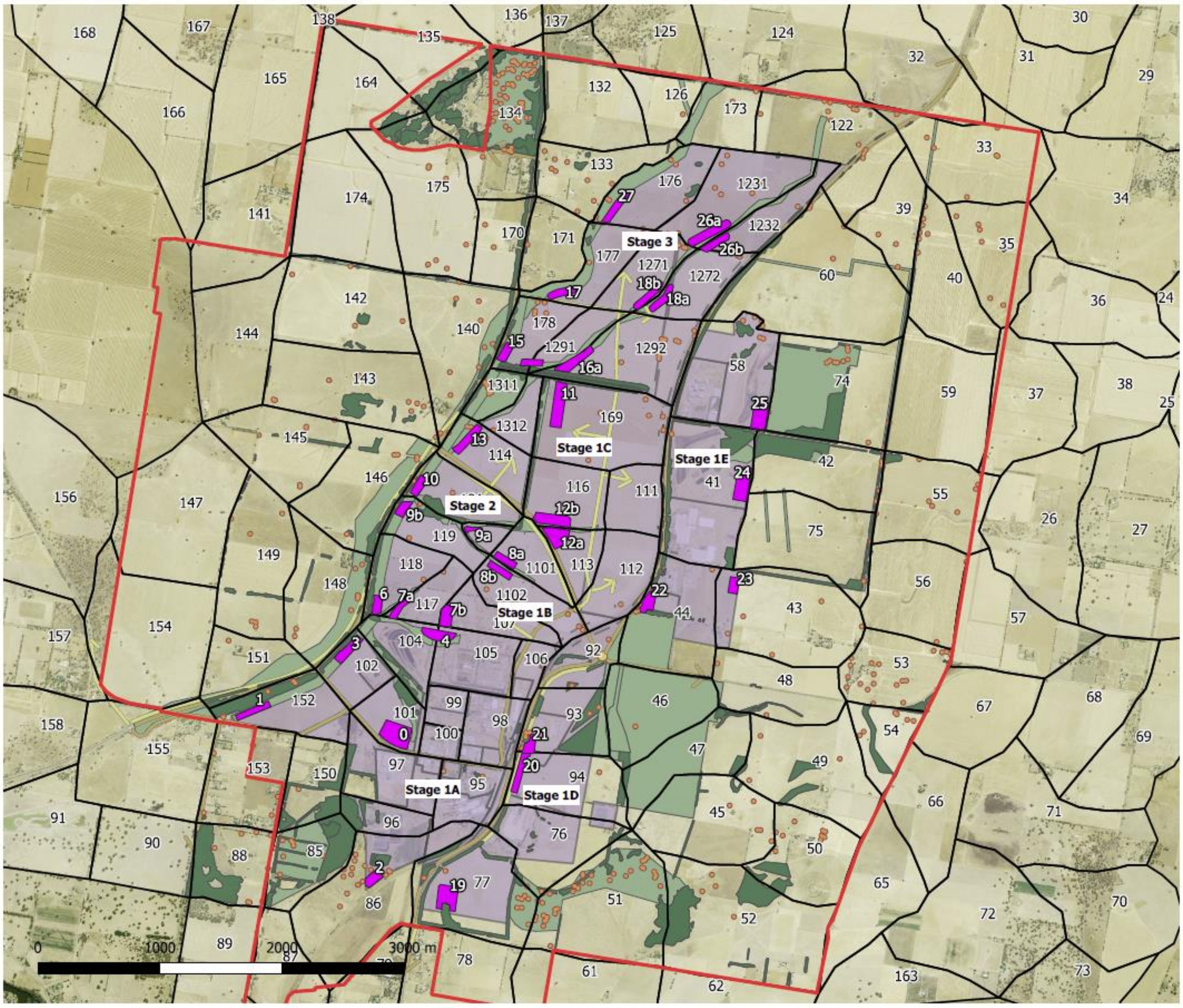


Figure 15-3 Final Adopted Scenario Hydrological Sub catchments and Locations of Proposed Flood/Water Quality Basins (Pink)

As per the concept scenario testing detailed in Section 13.3, following the conceptual design and sizing of the basins, the final developed scenario detention basins were assessed within RAFTS for the 20%, 10%. 5%, 2%, 1%, 0.5%, 0.2% and 0.05% AEP events across the full range of durations. The peak flows within the catchment were compared to the baseline conditions throughout the study area to ensure that the basins attenuate peak flow rates back to the baseline levels. The basins were then checked to ensure that there was no overtopping up to the 0.5%AEP design event.

The outflows from the final adopted scenario detention basins were used as inputs for the final adopted scenario flood impact assessment to evaluate the effects on flooding in the hydraulic model (Section 0).

The final adopted concept detention basin sizing, detailed in Table 15-1, indicates the likely storage required and associated detention depth, based on the adopted fraction impervious percentage values and land uses. The total estimated land take for the combined detention/water quality basins within the Precinct equates to 61.61ha (616,100m^2).

Confirming of the sizing when design of each Stage is undertaken, and further analysis of the outlet configuration will be required at the detailed design stage of each detention basin asset in order to refine the volume of detention required. It is anticipated that a multi-stage outlet arrangement will be required to ensure flows in more frequent events are attenuated in an appropriate manner.

Table 15-1 Detention Basin Sizing for Final Adopted Scenario

Catchment ID	Hydrological Catchment ID	Stage	Detention Depth (m)	Detention Volume (m^3)	Land Take Area (including provision for embankment and maintenance) (m^2)
0 & 5	101	Stage 1A	1.40	42,932	41,000
1	152	Stage 1A	1.00	11,036	14,300
2	86	Stage 1A	1.10	9,807	12,000
3	102	Stage 1A	1.00	14,543	18,300
4	105	Stage 1A	0.80	12,962	19,800
7b	107	Stage 1B	0.90	11,180	15,800
8a	1,101	Stage 1B	1.50	11,370	10,900
8b	1,102	Stage 1B	1.50	11,937	11,400
11	169	Stage 1C	1.30	36,599	34,000
12a	113	Stage 1C	1.30	24,295	23,500
12b	116	Stage 1C	1.30	26,345	25,200
19	77	Stage 1D	1.00	24,079	28,900
20	94	Stage 1D	1.00	13,869	17,500
21	93	Stage 1D	1.00	8,789	11,700
22	44	Stage 1E	0.80	10,370	16,200
23	43	Stage 1E	1.50	9,993	9,800
24	41	Stage 1E	1.00	24,079	28,900
25	58	Stage 1E	0.60	13,335	26,000
6	118	Stage 2	1.00	7,762	10,600
7a	117	Stage 2	1.00	8,527	11,400
9a	120	Stage 2	1.00	2,645	4,300
9b	119	Stage 2	1.00	7,273	10,000
10	121	Stage 2	1.00	8,789	11,700
13	114	Stage 2	1.20	17,614	18,800
15	178	Stage 3	1.50	11,792	11,300
16a	1,292	Stage 3	1.20	20,650	21,600
16b	1,291	Stage 3	1.20	7,867	9,300
17	177	Stage 3	2.00	19,106	13,900
18a	1,272	Stage 3	1.80	20,743	16,000
18b	1,271	Stage 3	1.80	21,372	16,400
26a	1,231	Stage 3	2.00	38,408	25,300

Catchment ID	Hydrological Catchment ID	Stage	Detention Depth (m)	Detention Volume (m^3)	Land Take Area (including provision for embankment and maintenance) (m^2)
26b	1,232	Stage 3	2.00	18,560	13,600
27	176	Stage 3	2.00	25,002	17,500

15.5 Waterway and Riparian Corridor Design

A waterway and riparian corridor concept approach for the Final Adopted Scenario is the same as that proposed for the concept scenario detailed in Section 13.4, noting that it extends only to those areas where a green infrastructure corridor is proposed (i.e. only those areas shown with a green infrastructure corridor (see Figure 15-1) would have creek works required to achieve a riparian corridor as per the concept in Figure 13-8, noting that the width of the corridor varies). As such, the concept design cross sections informing the design terrain have been maintained where a green infrastructure corridor is shown for the final adopted scenario flood impact assessment (Section 0).

15.6 Water Quality Treatment Facility Sizing

15.6.1 Overview

Water quality treatment facility sizing for the final adopted scenario was undertaken in the modelling software, MUSIC, in line with the approach undertaken in the concept scenario testing detailed in Section 13.5. An overview of the sizing approach is provided in Section 13.5.1.

Roof runoff from each industrial sub catchment within the Precinct is to be captured in a rainwater tank system for reuse. Tank overflow, and ground runoff from within the subcatchment is to be conveyed through an internal drainage network to be treated via a Gross Pollutant Trap (GPT) flowing into a bioretention basin (with a submerged zone to aid in drought-proofing) prior to discharge into the associated downstream riparian corridor. The conceptual approach is shown in Figure 15-4.

A Rocla CDS (3030) unit has been adopted in the assessments for the removal of gross and other pollutants. The performance of this unit has been assumed in line with numerous NSW Council guidelines incorporated within the MUSIC-Link component of the MUSIC software. If other units are proposed at a later stage then analysis to confirm their equivalence in terms of pollutant removal performance will be required.

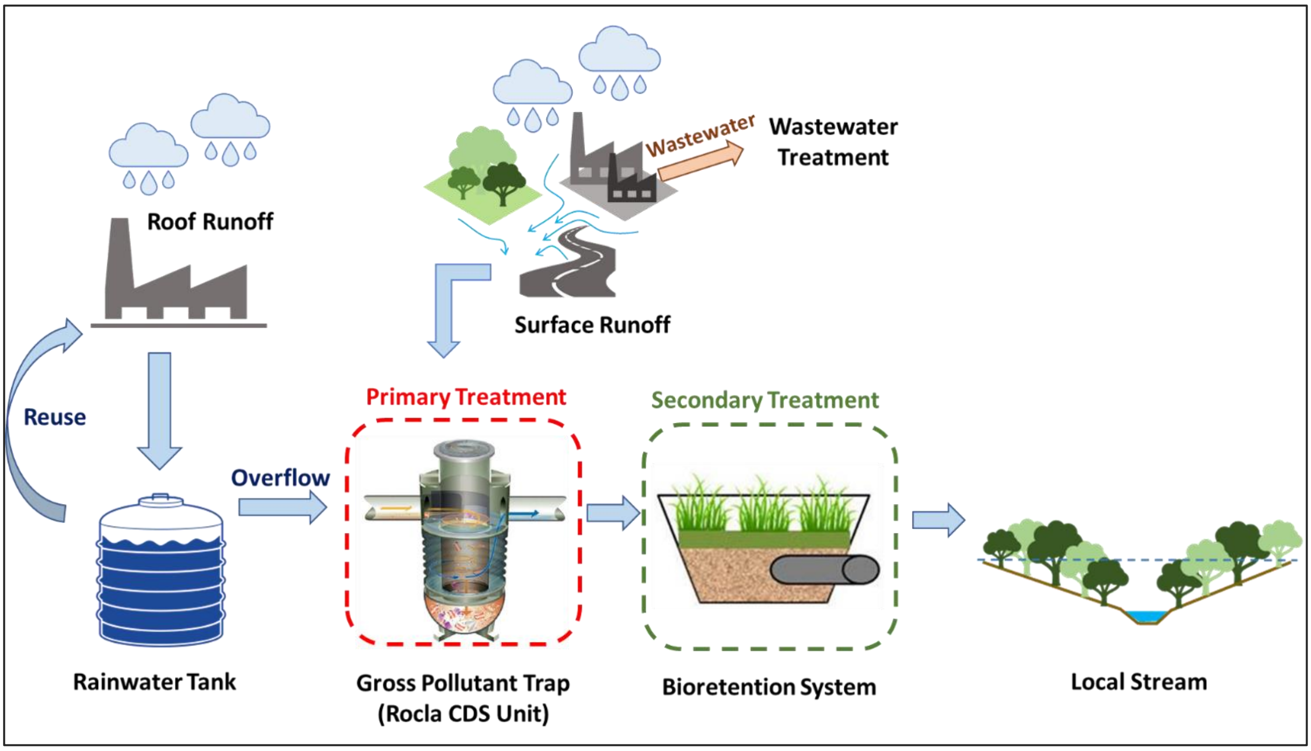


Figure 15-4 Water Quality Treatment Conceptual Approach

15.6.2 Model Set Up

The MUSIC model set up, including parameters adopted, are in line with those adopted with one of the approaches used for the Concept Water Quality Treatment Facility Sizing (Section 13.5), and this has been further refined where required for the Final Adopted Scenario. The parameters adopted in the model are outlined in the following tables:

- Table 15-2– Dominant soil type in the study area
- Table 15-3– Baseflow pollutant concentration inputs
- Table 15-4 – Storm flow pollutant concentration inputs
- Table 15-5 – GPT Rocla CDS inputs
- Table 15-6 – Rainwater Tank inputs
- Table 15-7 - Assumptions for Bioretention Systems.

Table 15-2 Dominant soil type characteristics within Study area

Rainfall Runoff Parameters - Dominant soil description	Soil storage capacity (mm)	Field Capacity (mm)	Infiltration capacity coefficient - a (mm/d)	Infiltration capacity exponent - b (mm/d)	Daily recharge rate (%)	Daily baseflow rate (%)	Daily seepage rate (%)
Light Clay	98	73	135	4	10	10	0

Table 15-3 Assumed Baseflow Pollutant Concentrations

Concentration (mg/L-log10)	Total suspended solids		Total phosphorus		Total Nitrogen	
Land use/zoning	mean	std. dev	mean	std. dev	mean	std. dev
Industrial	1.2	0.17	-0.85	0.19	0.11	0.12
Agricultural	1.3	0.13	-1.05	0.13	0.04	0.13
Rural residential	1.15	0.17	-1.22	0.19	-0.05	0.12

Table 15-4 Assumed Storm Flow Pollutant Concentrations

Concentration (mg/L-log10)	Total suspended solids		Total phosphorus		Total Nitrogen	
Land use/zoning	mean	std. dev	mean	std. dev	mean	std. dev
Industrial	2.15	0.32	-0.6	0.25	0.3	0.19
Agricultural	2.15	0.31	-0.22	0.3	0.48	0.26
Rural residential	1.95	0.32	-0.66	0.25	0.3	0.19

Table 15-5 Gross Pollutant Trap Inputs (CDS 3030)

CDS 3030	Input (mg/L)	Output (mg/L)
Low flow bypass	0	
High flow bypass	Varies up to 1.75m3/s	
Total Suspended Solids	0	0
	75	75
	1000	300
Total Phosphorous	0	0
	0.5	0.5
	10	7
Total Nitrogen	0	0
	50	50
Gross pollutants	0	0
	100	2

Table 15-6 Rainwater Tank Inputs

Rainwater Tank Inputs	
Roof area as percentage of catchment	30%
Rainwater tank volume per hectare of roof area	20kL
Internal reuse demand	0.1kL/day/(1000m^2 of roof area)
External reuse demand	20kL/yr/(1000m^2 of ground area)

Table 15-7 Assumptions for Bioretention Systems

Bioretention Systems (with Submerged Zone)	
Extended Detention Depth	200-500mm
Clean filter media (mm)	300-500mm
Clean Coarse Sand	50mm
Clean Sand and Carbon Source	300mm
Gravel	150mm
Bioretention Parameters	
Saturated hydraulic conductivity (mm/hr) - Sandy loam (50% of total for modelling)	120
Filter depth	0.5m
TN content of filter media (mg/kg)	400
Orthophosphate content of filter media (mg/kg)	40
Exfiltration rate (mm/hr)	0
Overflow weir width	surface area / 10
Submerged zone with carbon present	0.2m

15.6.2.1 High Flow Bypass

The proposed high flow bypass configuration has been modelled to allow flows up to the (1 EY) (63.2% AEP) to flow through the CDS unit. Flows up to the 4 EY are then allowed to be conveyed from the CDS unit to the bioretention system. Flows greater than the (1 EY) (63.2% AEP) and 4 EY will bypass the CDS unit and bioretention system respectively, and flow directly into a high flow bypass channel/pipe within the detention component of the system.

15.6.2.2 Riparian Corridor

It has been assumed that 50% of the riparian corridor located within each subcatchment will drain directly to the creek without passing through the proposed treatment system as associated runoff will not produce a pollutant load requiring treatment. A conservative assumption that the other 50% of the corridor will require some form of treatment in the event that the outer 50% of the VRZ may include facilities and some hard stand areas such as pathways and the like.

15.6.3 Proposed Water Quality Treatment for Final Scenario

In summary, the proposed water quality treatment and rainwater harvesting system to be implemented within each sub catchment of the Precinct includes the following:

- Capture and re-use of roof runoff - 20kL rainwater tank per hectare of roof area within Industrial Zones (assumed that 30% of the industrial zone is roof area)
- Gross Pollutant trap for primary treatment of surface runoff (assumed to be a Rocla CDS unit)
- Bioretention system with a 0.2m submerged zone (for drought resilience) for secondary treatment prior to discharge into the downstream creek network.

To determine the required treatment areas, sub catchments were input into MUSIC to determine the treatment area required.

The sub catchment breakdown input for the industrial areas incorporated within the MUSIC model is similar to the hydrological sub-catchments but varies slightly in numbering. It is shown in Figure 15-5.

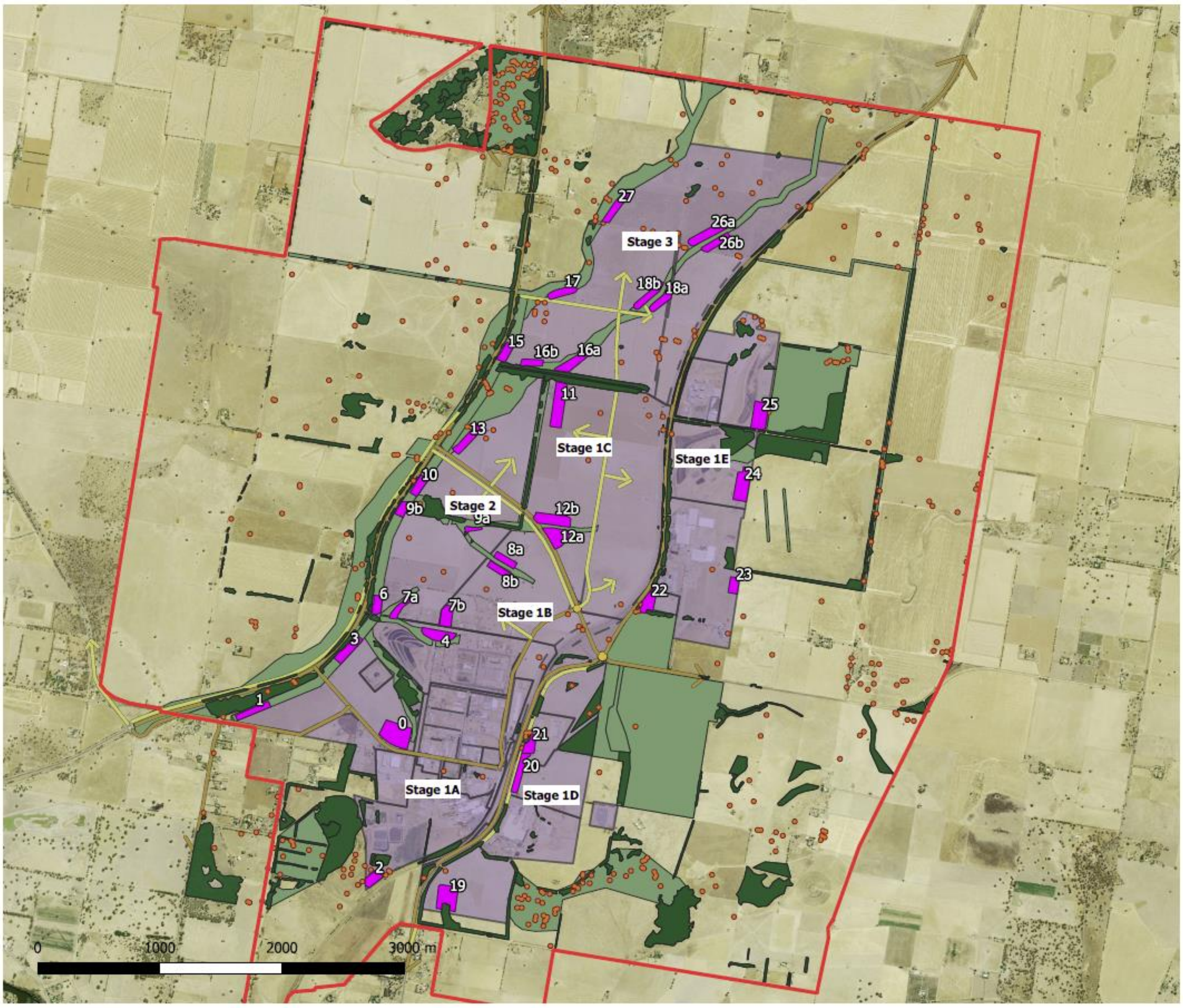


Figure 15-5 Water Quality Treatment Subcatchment Plan

An example of the proposed treatment train as modelled in MUSIC is shown in Figure 15-6.

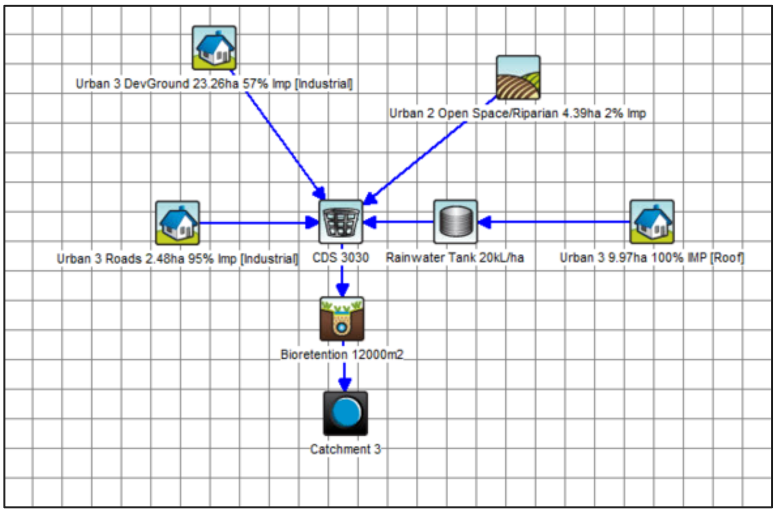


Figure 15-6 MUSIC Model Proposed Treatment Train Example

The results of the water quality treatment sizing for each sub catchment, in addition to corresponding detention volume and land take, are provided in Table 15-8.

Overall bioretention and detention basin layout showing land take requirements is shown in Figure 15-7.

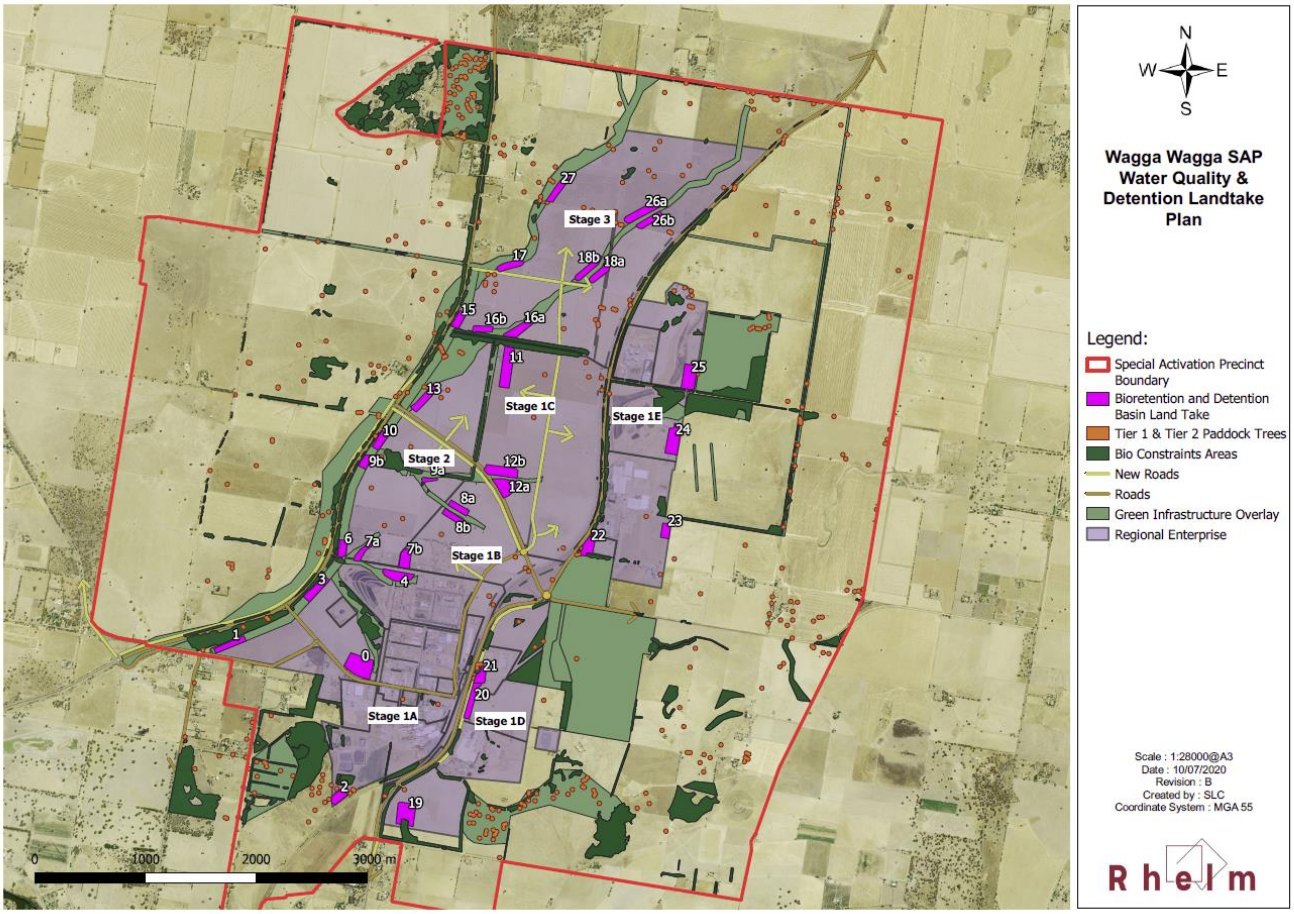


Figure 15-7 Water Quality and Detention Land-take Plan

Table 15-8 Water Quality Treatment Area, Detention Volume and Land Take allocated for Final Scenario

Catchment ID	Stage	Water Quality Treatment Area (m2)	Detention Volume (m3)	Land Take Area (including provision for embankment and maintenance) (m2)
0 & 5	Stage 1A	27,985	42,932	41,000
1	Stage 1A	9,715	11,036	14,300
2	Stage 1A	7,612	9,807	12,000
3	Stage 1A	13,023	14,543	18,300
4	Stage 1A	14,917	12,962	19,800
7b	Stage 1B	11,159	11,180	15,800
8a	Stage 1B	5,967	11,370	10,900
8b	Stage 1B	6,290	11,937	11,400
11	Stage 1C	25,401	36,599	34,000
12a	Stage 1C	16,451	24,295	23,500
12b	Stage 1C	17,935	26,345	25,200
19	Stage 1D	22,120	24,079	28,900
20	Stage 1D	12,386	13,869	17,500
21	Stage 1D	7,612	8,789	11,700
22	Stage 1E	11,814	10,370	16,200
23	Stage 1E	5,139	9,993	9,800
24	Stage 1E	22,120	24,079	28,900
25	Stage 1E	21,093	13,335	26,000
6	Stage 2	6,657	7,762	10,600
7a	Stage 2	7,367	8,527	11,400
9a	Stage 2	2,008	2,645	4,300
9b	Stage 2	6,203	7,273	10,000
10	Stage 2	7,612	8,789	11,700
13	Stage 2	12,850	17,614	18,800
15	Stage 3	6,203	11,792	11,300
16a	Stage 3	15,226	20,650	21,600
16b	Stage 3	5,342	7,867	9,300
17	Stage 3	7,127	19,106	13,900
18a	Stage 3	9,113	20,743	16,000
18b	Stage 3	9,425	21,372	16,400
26a	Stage 3	15,734	38,408	25,300
26b	Stage 3	6,890	18,560	13,600
27	Stage 3	9,715	25,002	17,500

15.7 Concept Culvert Crossing Sizing

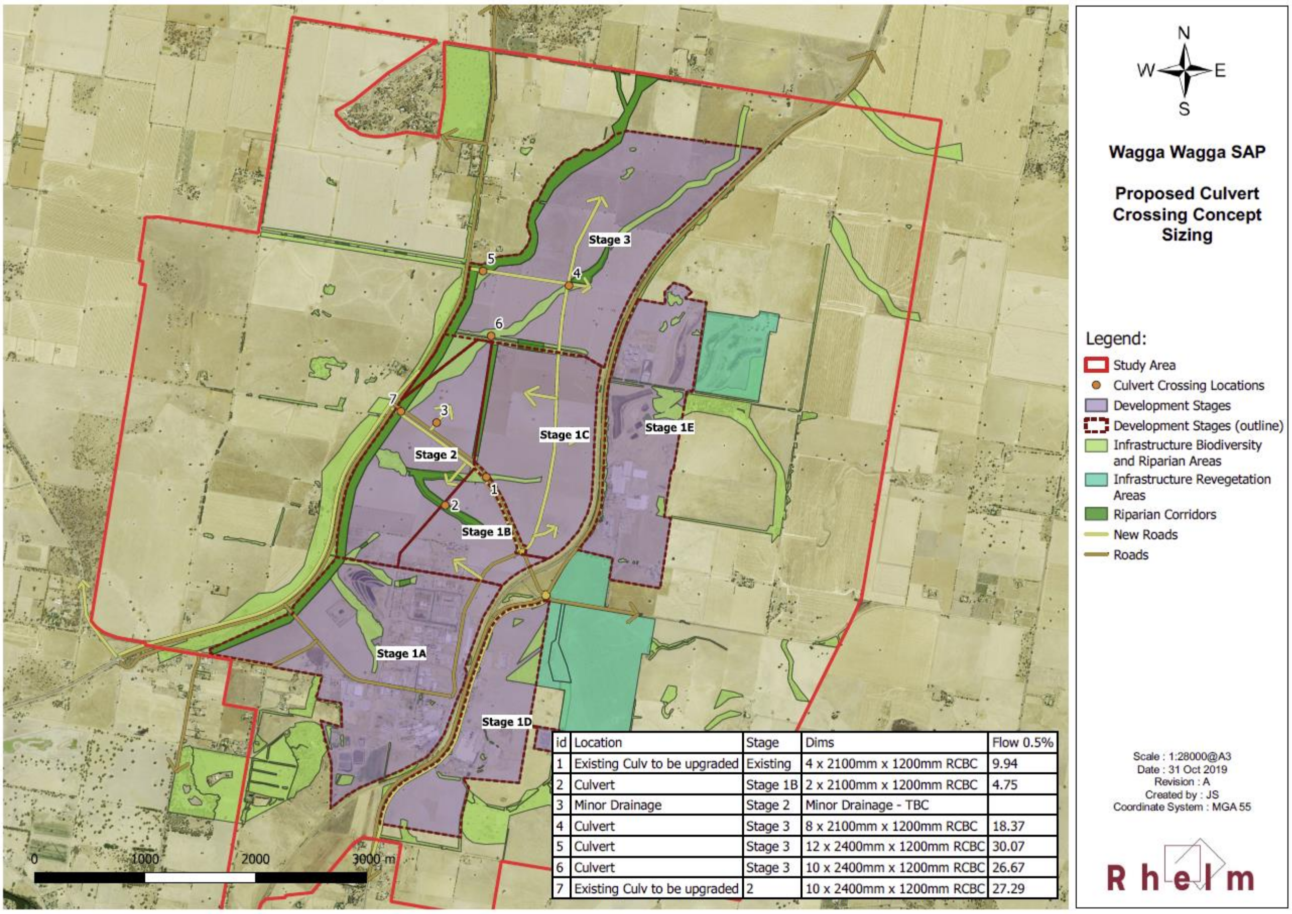
Proposed culvert crossings in key locations within the Precinct have been sized as part of the final adopted scenario analysis to inform infrastructure upgrade costing and planning. Sizing has been undertaken to convey 0.5% AEP post development flows using the software HY-8.

The culvert analysis includes five proposed culverts, and two existing crossings to be upgraded to convey 0.5% AEP flows.

Assumptions include the following:

- 1% culvert grade
- 50% blockage
- 600mm freeboard to finished surface level
- Tailwater conditions based on assumed downstream slope.

The key locations of culverts sized are shown in Figure 15-8. Proposed dimensions calculated are provided in Table 15-9.



id	Location	Stage	Dims	Flow 0.5%
1	Existing Culv to be upgraded	Existing	4 x 2100mm x 1200mm RCBC	9.94
2	Culvert	Stage 1B	2 x 2100mm x 1200mm RCBC	4.75
3	Minor Drainage	Stage 2	Minor Drainage - TBC	
4	Culvert	Stage 3	8 x 2100mm x 1200mm RCBC	18.37
5	Culvert	Stage 3	12 x 2400mm x 1200mm RCBC	30.07
6	Culvert	Stage 3	10 x 2400mm x 1200mm RCBC	26.67
7	Existing Culv to be upgraded	2	10 x 2400mm x 1200mm RCBC	27.29

Figure 15-8 Concept Culvert Crossings in Key Locations

Table 15-9 Concept Culvert Crossing Proposed Dimensions

	Culvert	Stage	Dimensions	Flow (m^3/s)
1	Existing culvert to be upgraded	Existing	4 x 2100mm x 1200mm RCBC	9.94
2	Proposed	Stage 1b	2 x 2100mm x 1200mm RCBC	4.75
4	Proposed	Stage 3	8 x 2100mm x 1200mm RCBC	18.37
5	Proposed	Stage 3	12 x 2400mm x 1200mm RCBC	30.07
6	Proposed	Stage 3	10 x 2400mm x 1200mm RCBC	26.67
7	Existing culvert to be upgraded	Stage 2	10 x 2400mm x 1200mm RCBC	27.29

Note, additional crossings within the Precinct may be required as it is dependent on proposed grading of the site. More detailed analysis of the upgrades, including flood impact assessment will be required as part of the road and associated crossings is required in later design stages.

16 Final Adopted Scenario Flood Impact Assessment

The flood impact assessment for the Final Adopted Scenario was undertaken using the TUFLOW software package (version 2018-03-AC) in the same fashion as the baseline flood assessment (Section 5).

This section discusses:

- Model Development (Section 16.1)
- Design Flood Modelling (Section 16.2)
- Scenario Flood Behaviour (Section 16.3).

16.1 Model Development

The development scenarios were incorporated into the base TUFLOW hydraulic model (Section 5) through:

- A revised terrain with the proposed creeks and riparian corridors integrated into the DEM (Figure 16-1). The riparian corridors followed the same design criteria as was adopted for the concept options (refer Section 13.4);
- Revised inflow boundaries from the updated RAFTS models, to take account of the effects of the proposed detention basins; and,
- A revised roughness layer to represent the proposed development scenarios (Figure 16-2).

In all other respects, the scenario hydraulic models remained the same as the base case hydraulic model. The proposed culvert upgrades discussed in Section 15.7 are not incorporated in the impact assessment as more detailed analysis of the overall road upgrade requirements will be required in later design stages.

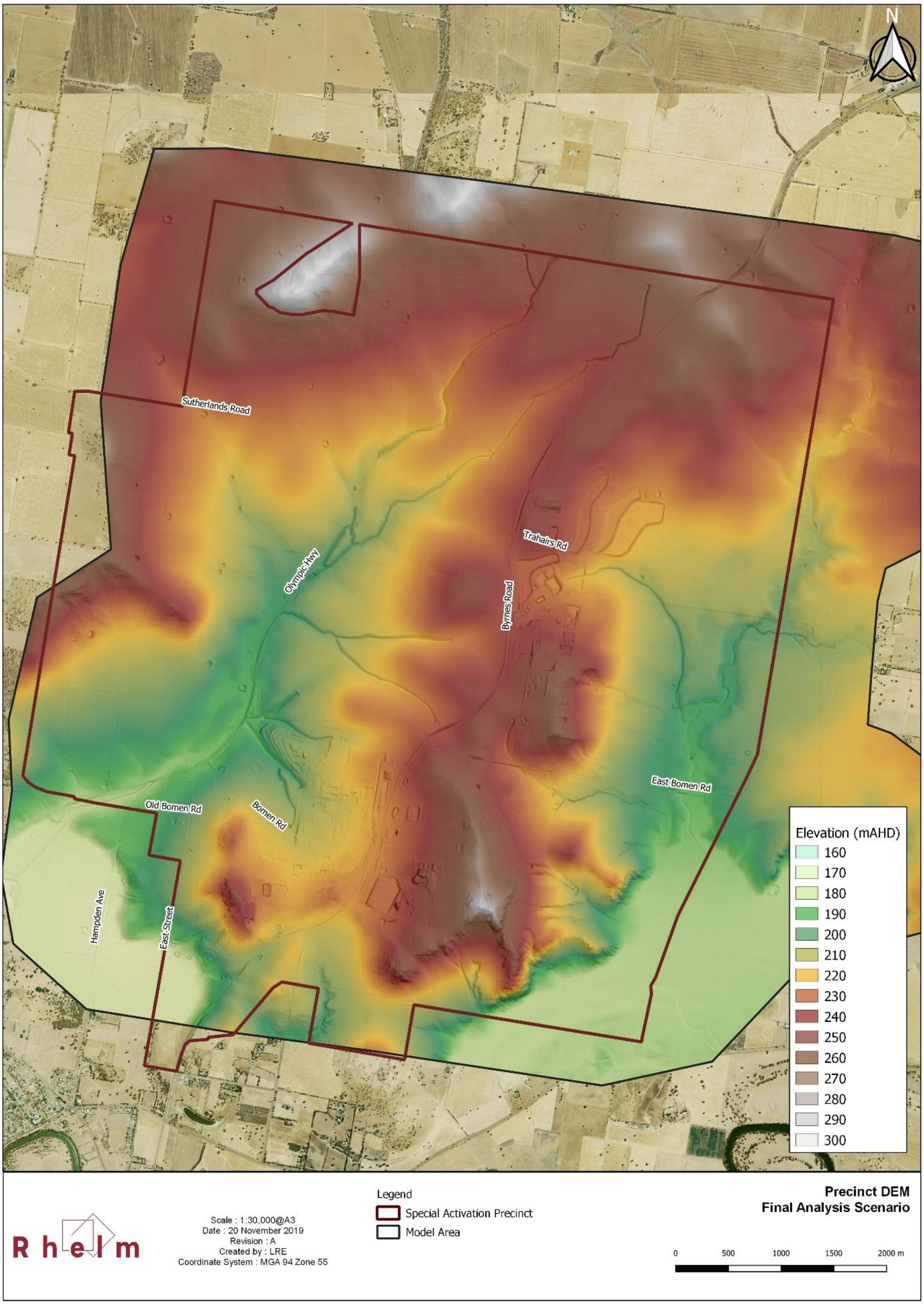


Figure 16-1 Digital Elevation Model (DEM) – Final Adopted Scenario

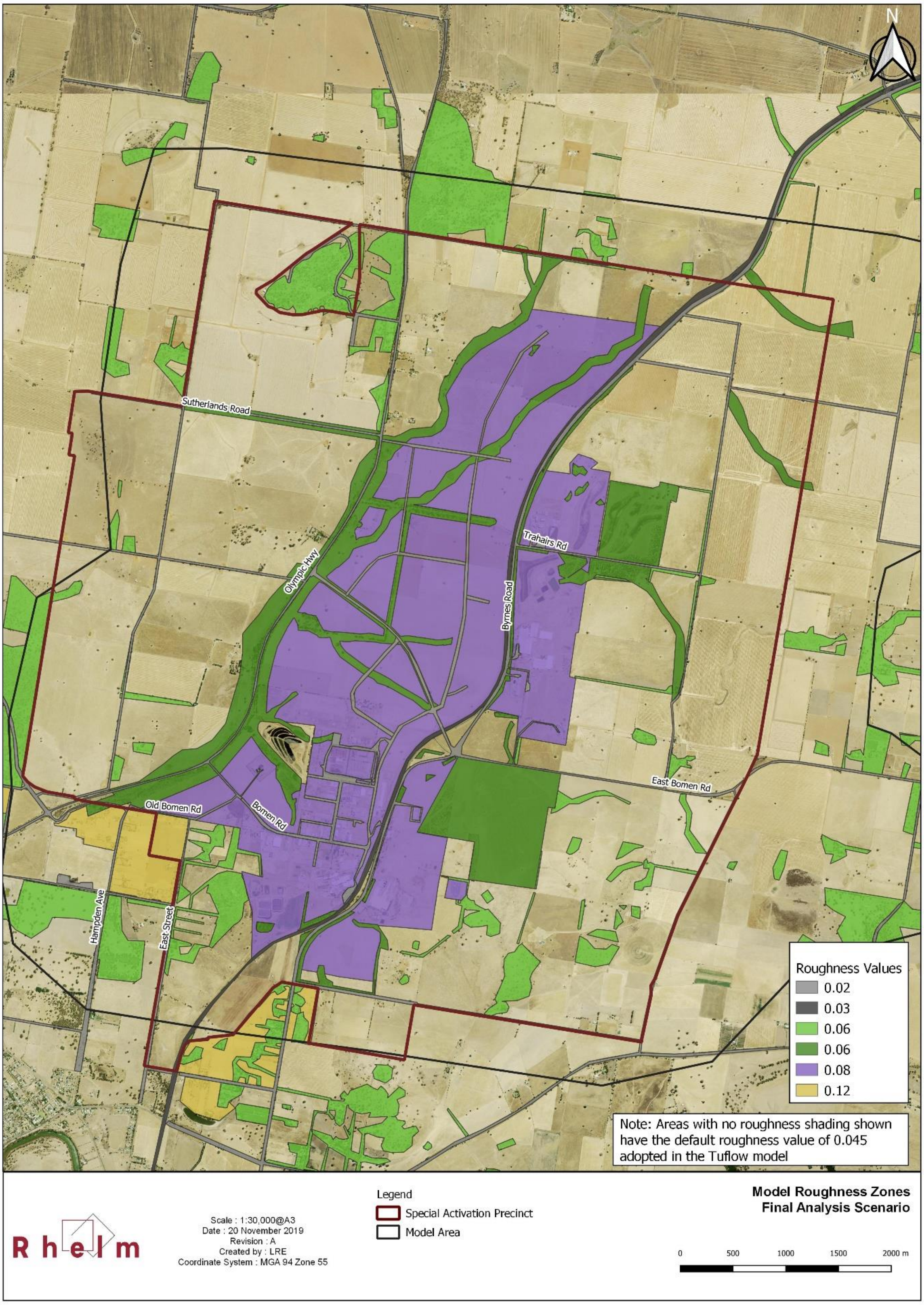


Figure 16-2 Hydraulic Roughness Map – Final Adopted Scenario

16.2 Design Flood Modelling

16.2.1 Models Run

The final layout scenario was run for the 10% AEP and 0.5% AEP events for the critical 360 minute duration. As per the base case modelling, each event was run for 10 different temporal patterns, with the median being extracted as the representative event.

Furthermore, the final scenario layout was run for the PMF event as a sensitivity assessment to examine how the riparian corridors behave in extreme flood events and to identify whether additional flow paths are required for the safe conveyance of flows in an extreme event.

16.2.2 Model Results

Model results for the scenarios have been processed and prepared in line with the methodology used for the base case results, as discussed in Section 5.3.2.

The final scenario layout results are shown in map series G1001-1 to G1001-4 for depth, velocity, hazard and flood function respectively. The PMF sensitivity assessment peak depths are shown in G1101.

These maps are attached to the end of this report.

16.3 Final Scenario Layout Flood Behaviour

The final scenario layout met the core objectives set out in Section 12.1.

Specifically, the results reported in Section 16.2.2 indicate that each scenario:

- Conveyed the 0.5% AEP event within the riparian corridors;
- Contained the 0.5% AEP floodway within the riparian corridors;
- Retained the base case critical flow duration of 6 hours;
- Downstream levels remained consistent with the base case results; and,
- Demonstrated that the 10% AEP flows resulted in the activation of all riparian corridors indicating that flows are not over attenuated.

Some localised pockets of overland flow and ponding are evident along the Olympic Highway and in some other locations, such as between Bomen Road and East Bomen Road, in a behaviour similar to the concept options. As noted for the concept options, while some of this flooding could simply be removed by local regrading during a future stage, some regions are more significant, such as that occurring along the eastern side of the highway between Bomen Road and East Bomen Road. The flood behaviour suggests that an open channel or similar may be required to convey this water to the nearest cross drainage structure.

In similar results to the concept options, the PMF sensitivity results (Map G1101) showed that PMF flooding within the proposed development is largely contained within the riparian corridor. There was some minor overbank flow in tributary that runs adjacent to Trahairs Road. This flooding could likely be removed by the formalisation of this flowpath. Beyond the development extent (west of the Olympic Highway) flooding remained consistent with the base case flood behaviour.

In the eastern region of the Precinct, the PMF results show some sheet flow occurring downstream of the existing ponds, as a result of flow from these basins discharging over the northern crest of the basins.

Flood level difference plots are shown in map series G1201-1 to G1201-2 for the 0.5% AEP and 10% AEP for the final scenario layout respectively. These plots provide an assessment of impact and indicate that there are some minor impacts outside of the Precinct that are either confined to areas to be retained for riparian corridors or likely to be readily resolved by:

- limiting the amount of additional vegetation that is planted in these areas while the channel remains unchanged, or
- optimisation of the riparian corridor through appropriate waterway design to increase flow conveyance, or
- potential minor alterations (increasing the volume capacity) to regional detention basin sizing.

There is a location identified for residential development in the Cartwrights Hill area immediately adjacent to the Precinct (east of Horseshoe Road). This area has been identified to have a likely flood impact as it encroaches on the flood extent of Dukes Creek, noting that this area is affected by backwater from the Murrumbidgee River. It is recommended that the extent of this residential development area be reconsidered given these identified flood impacts.

17 Recommendations and Conclusions

Key recommendations arising from the results of the final scenario analysis are:

- **Regional Flood Detention**: With the provision of a system of regional detention basins the impact of the change in land use from a largely rural setting to an urbanised environment can be managed effectively. Sizing of the basins has been undertaken in conjunction with water quality treatment facility sizing for the concept selected for the Precinct.
- **Regional Water Quality**: With the provision of a system of regional water quality facilities and mandatory roof rainwater capture and re-use across the Precinct the impact of the change in land use from a largely rural setting to an urbanised environment can be managed. Sizing of the facilities on a conceptual basis has been undertaken for the Final Scenario. Diversion of flows from areas not within the Precinct (e.g. with a bypass pipe or diversion channel) may be required to bypass some bioretention assets to ensure they only treat the areas associated with the Precinct. Water quality and detention systems are consolidated into multi-purpose basins to manage the overall land required for stormwater treatment and detention purposes, and thus maximises developable area within the precinct. The overall land required for flooding and water quality treatment is approximately 60 hectares, much of which has been integrated into the proposed green infrastructure corridors.
- **Culvert upgrades**: Upgrades to some culverts along the Olympic Highway are proposed to ensure the Highway has a flood immunity up to the 0.5%AEP flood event. Sizing of these upgrades on a conceptual basis has been undertaken. In addition, sizing of proposed culverts in other key locations within the Precinct has been undertaken as part of the final scenario analysis (Section 15.7).
- **Waterway Design and Flood Conveyance**: The 0.5%AEP design flood can be safely conveyed within the riparian corridor and associated design waterway cross section (Section 13.4). This design channel could be refined further to optimise the earthworks required to achieve the landform and to maximise vegetation retention as part of later design stages.
- **Flood Impact**: The final concept scenario flood impact as shows there are some minor flood impacts which are contained within the green infrastructure corridor. These are likely to be readily resolved by limiting the amount of additional vegetation that is planted in these areas while the channel remains unchanged, optimisation the riparian corridor and waterway design or potential minor alterations to regional detention basin sizing. This optimisation would be undertaken as part of the detailed design of the Precinct, where other local features and local constraints would be considered in further detail.
- **Additional flowpaths for Probable Maximum Flood Flows**: There are some minor land areas that will be affected by PMF flows and provision for the safe conveyance of these flows will need to be made incorporating elements such as appropriate site design to avoid buildings blocking flow paths, and unfenced or open style fencing areas.

As outlined in Section 7, the Major Overland Flow Floodplain Risk Management Study and Plan (MOFFRMS&P), covering a portion of the Precinct was in progress at the time of the preparation of this report (under the auspices of the NSW Government Floodplain Management Program, locally overseen by Wagga Wagga City Council). As such, this plan was not available for review. Key recommendations of this report could be incorporated in the MOFFRMS&P for any Council-related recommendations for the Precinct and adjacent areas.

18 References

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APPENDIX A

Historical Flood Photographs

Taken:

6/12/2010 6:50am

Location:

Chain Gate & Whyanwah

Taken:

6/12/2010 6:50 am

Location:

Looking over southern Eunony Valley

Taken:

7/03/2010 3:46 pm

Location:

East Bomen Road

Taken:

7/03/2010 3:46 pm

Location:

East Bomen Road

Taken:

7/03/2010 3:22 pm

Location:

Eunony Valley, unknown

Taken:

7/03/2010 3:38 pm

Location:

Eunony Valley, unknown

Taken:

7/03/2010 3:20 pm

Location:

Looking north into industrial land, unknown location.

Taken:

7/03/2010 3:05 pm

Location:

Unknown

Taken:

7/03/2010 5:59 pm

Location:

Windmills Lane to Fawcetts

Taken:

7/03/2010 5:59 pm

Location:

Looking south along Windmill Lane

Taken:

18/11/2010 8:22 am

Location:

Eunony Valley view west towards Industrial area and solar farm location.

APPENDIX B

Cross Drainage Structures

Baseline Conditions

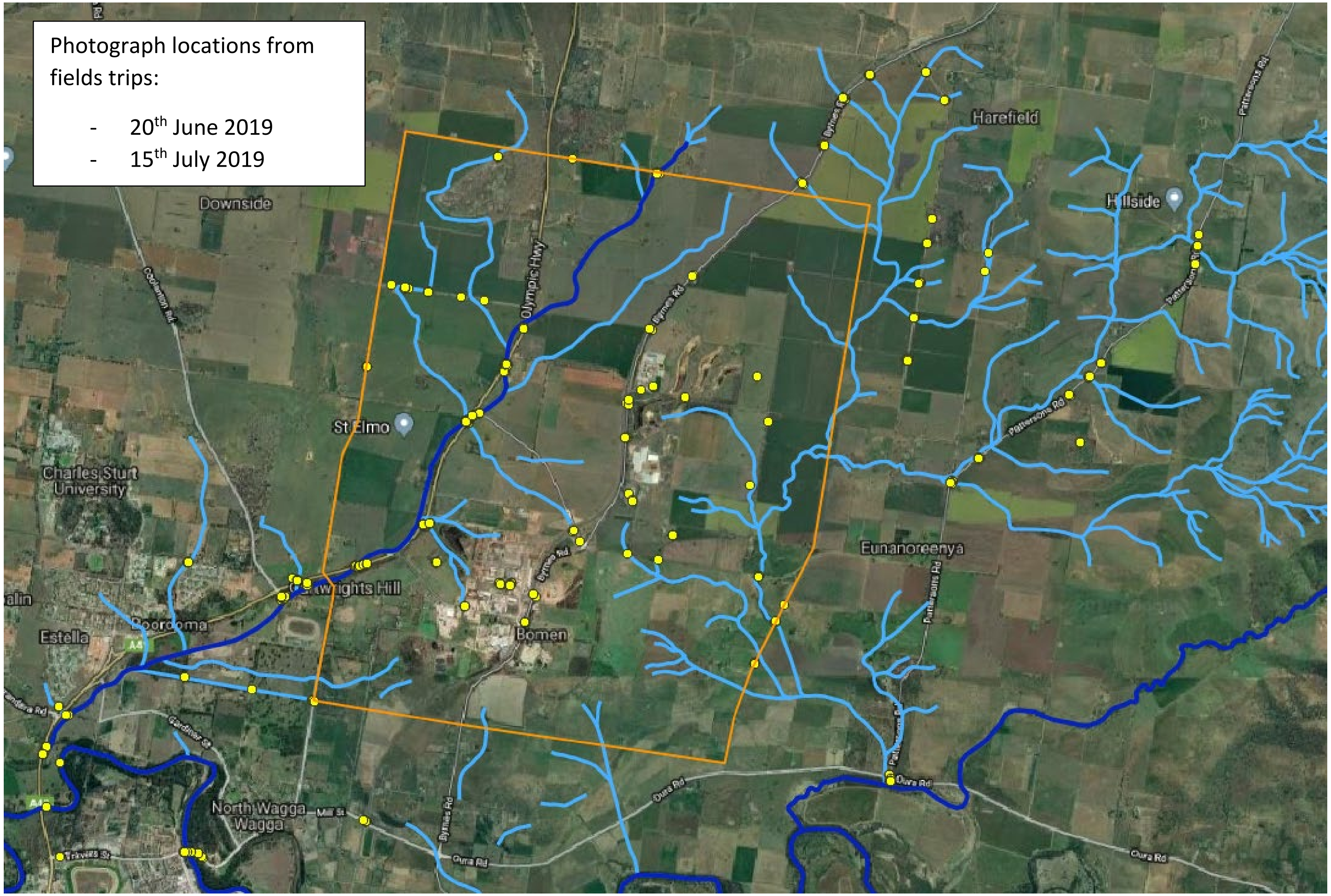

Photograph locations from fields trips:
- 20th June 2019
- 15th July 2019
Harefield
Hillside
Downside
St Elmo
Charles Sturt University
Eunanoreenya
Bomen
North Wagga Wagga
Estella
Boorooma
Olympic Hwy
Byrnes Rd
Pattersons Rd
Oura Rd

Photo	Location
	Dukes Creek Olympic Hwy Near Cartwrights Hill
	Flows from Bomen Industrial Estate downstream of the Saleyard Storage basins. Old culverts where original road existed.
	Culverts under the Olympic Hwy downstream of the Bomen Industrial Estate (downstream of the Saleyard Storage basins)

	Dukes Creek under Merino Drive
	Dukes Creek under Olympic Hwy near Merino Drive intersection
	Dukes Creek under Olympic Hwy Near Brucedale

	Dukes Creek under Bruce Hwy
	Dukes Creek under Mary Gilmore Road
	Culvert under East Bowmen Road near ROBE

	East Bomen Road crossing with Eunony Valley Tributary
	Gobbagombalin Bridge
	Wiradjuri Bridge

	Railway bridge (North Wagga)
	Livestock transfer laneway near the saleyards
	Gardiner Street over Dukes Creek

	Culverts under Hampden Avenue
	Culverts Under Horseshoe Drive
	Culverts Under Horseshoe Drive

	Culverts Under Horseshoe Drive for Dukes Creek
	Culverts under Poiles Road upstream of the Olympic Hwy
	Culverts under Pattersons Road at the upper end of the Eunony Valley Triburaies.

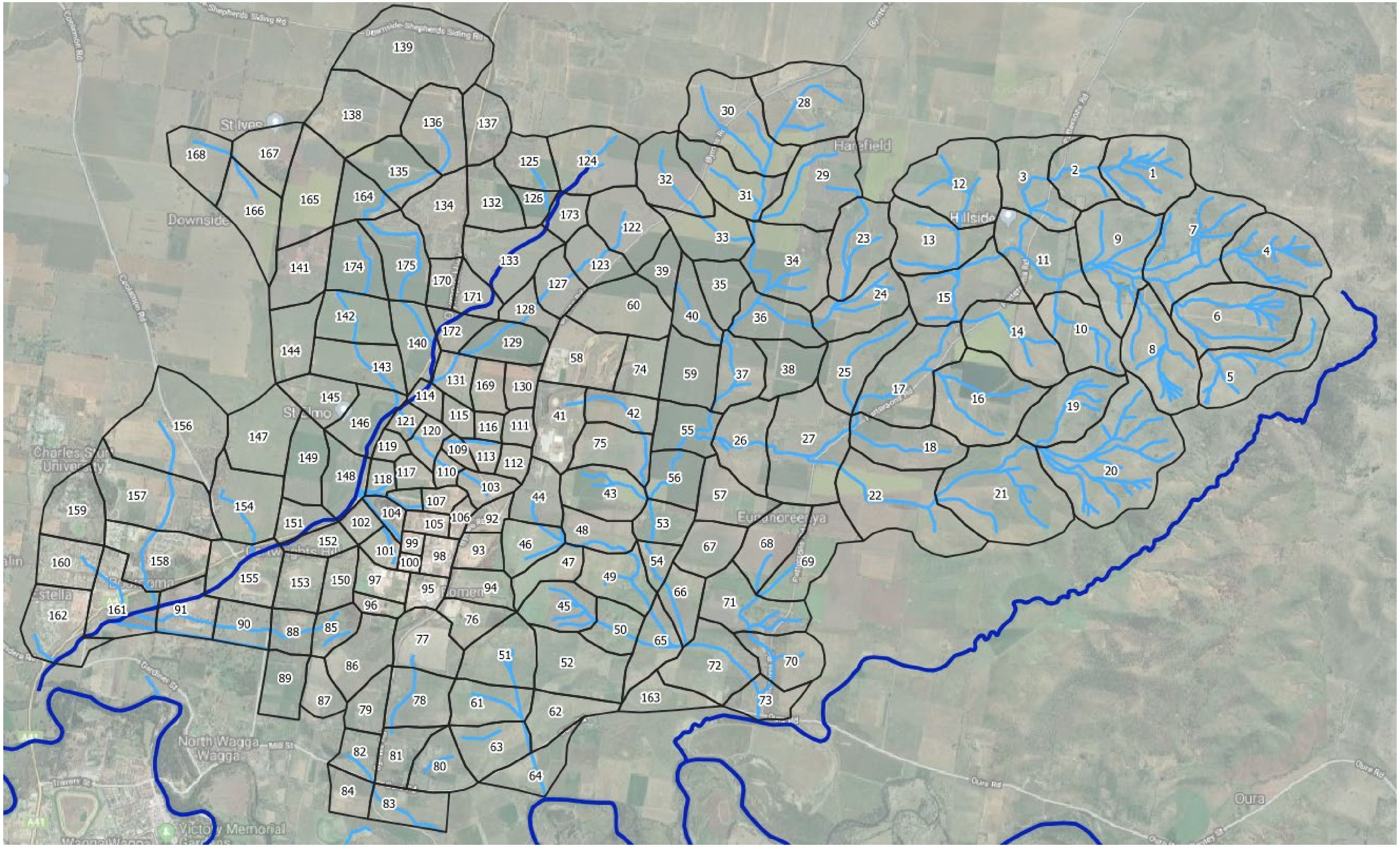
	Culverts downstream of the drop structure under the railway, Byrnes Road.
	Railway culvert and drop structure along Byrnes Road
	Railway culvert along Byrnes Road

	Detention basin at Enirgi Battery Recycling Centre
	Culverts under Byrnes Road with railway culvert upstream.
	Byrnes Road underpass

	Culvert adjacent to the Byrnes Road underpass
	Railway culvert near the rail terminal

APPENDIX C

Subcatchment Parameters (Baseline Conditions)


St Ives
Downside
Harefield
Hillside
St Elmo
Charles Sturt University
Boorooma
Estella
North Wagga Wagga
Eunanoreenya
Oura
Victory Memorial Gardens

XP Rafts Subcatchment parameters

Id	Easting	Northing	Area (Ha)	Slope (%)	Catchment Roughness	Imper-vious (%)	U/S Node	D/S Node	Lag (min)	Impervious Area (Ha)	Pervious Area (Ha)
1	548002	6124700	122.7	6.205	0.035	2.0		2	14.7	2.5	120.3
2	547021	6124672	72.7	5.811	0.032	3.7	1	3	15.9	2.7	70.0
3	546338	6124566	110.4	2.500	0.032	3.3	2	11	26.0	3.6	106.8
4	549858	6123457	133.3	8.666	0.035	2.0		7	22.5	2.7	130.6
5	549634	6121936	126.0	6.237	0.033	2.0		6	15.7	2.5	123.5
6	549300	6122572	156.9	8.814	0.035	4.2	5	7	11.7	6.6	150.3
7	548687	6123649	170.1	6.581	0.033	2.2	4	9	17.3	3.7	166.4
8	548184	6122006	134.2	5.345	0.031	3.1		9	31.8	4.2	130.0
9	547538	6123466	156.2	6.681	0.032	2.5	7	11	46.1	3.9	152.2
10	547022	6122331	98.1	6.614	0.032	2.9		11	38.7	2.9	95.2
11	546455	6123443	124.1	3.829	0.031	4.4	9	15	47.8	5.5	118.5
12	545212	6124531	144.8	2.984	0.030	2.0		13	10.8	2.9	141.9
13	544842	6123693	111.2	4.469	0.031	2.0	12	15	26.4	2.2	108.9
14	546063	6122235	124.1	4.582	0.031	3.1	10	17	72.1	3.9	120.2
15	545308	6122996	120.7	4.488	0.032	2.7	13	17	72.0	3.2	117.4
16	545575	6121370	160.9	4.368	0.046	2.0		17	50.1	3.3	157.6
17	544535	6121704	146.1	4.276	0.034	5.3	14	27	54.4	7.7	138.4
18	544450	6120708	96.2	3.489	0.032	3.3		27	45.1	3.2	93.0
19	546862	6121247	106.8	6.136	0.031	2.0		21	30.8	2.1	104.7
20	547528	6120530	253.8	5.685	0.034	2.0		21	31.1	5.1	248.7
21	545920	6119983	215.1	3.624	0.030	2.0	20	21	58.3	4.3	210.8
22	544401	6119823	182.1	2.772	0.030	2.0	21	27	37.6	3.6	178.5
23	543773	6123622	102.9	3.750	0.031	4.2		24	9.2	4.4	98.6
24	543837	6122739	91.3	4.660	0.032	4.0	23	36	49.6	3.7	87.7
25	543783	6121948	96.2	3.900	0.034	3.9		27	58.6	3.7	92.4

Id	Easting	Northing	Area (Ha)	Slope (%)	Catchment Roughness	Imper-vious (%)	U/S Node	D/S Node	Lag (min)	Impervious Area (Ha)	Pervious Area (Ha)
26	542134	6120744	89.0	1.486	0.034	2.0	27	55	22.0	1.8	87.2
27	543011	6120655	170.8	1.340	0.035	4.6	17	26	27.4	7.8	163.0
28	543060	6125705	157.2	2.791	0.033	9.0		30	9.6	14.1	143.1
29	543187	6124499	131.6	4.525	0.033	3.8		34	46.1	5.0	126.6
30	541963	6125392	151.7	2.989	0.031	5.6	28	31	23.1	8.5	143.3
31	541898	6124581	92.1	2.803	0.030	4.6	30	34	43.2	4.3	87.8
32	541027	6124603	89.5	2.377	0.030	5.5		33	16.3	4.9	84.5
33	541602	6123785	77.1	2.431	0.030	3.8	32	34	31.6	2.9	74.2
34	542761	6123366	128.7	4.056	0.033	3.7	31	36	13.9	4.8	123.8
35	541787	6122992	54.5	3.594	0.030	2.0		37	45.4	1.1	53.4
36	542538	6122526	73.6	1.877	0.030	3.4	24	37	45.4	2.5	71.1
37	542024	6121766	65.7	1.696	0.030	2.0	36	55	29.6	1.3	64.4
38	542761	6121849	61.9	2.204	0.029	5.5		37	17.9	3.4	58.5
39	540940	6123280	36.6	3.375	0.030	2.0		40	19.9	0.7	35.9
40	541361	6122711	54.7	2.997	0.030	2.0	39	37	16.2	1.1	53.6
41	539385	6121033	80.9	2.505	0.041	22.8		42	38.3	18.4	62.5
42	540313	6121214	52.8	2.006	0.036	5.5	41	75	24.8	2.9	49.9
43	540046	6120011	81.8	4.694	0.032	2.3		53	22.2	1.9	79.9
44	539106	6119957	56.6	2.749	0.036	14.0		46	9.1	7.9	48.7
45	539417	6118343	66.5	6.676	0.031	2.0		50	11.8	1.3	65.2
46	538949	6119258	53.6	4.132	0.031	2.9		48	18.6	1.6	52.0
47	539253	6118857	44.8	4.825	0.033	2.0		48	15.2	0.9	43.9
48	539961	6119431	50.6	4.567	0.031	5.4	46	49	34.4	2.7	47.9
49	540259	6118760	74.4	3.788	0.033	2.5	48	65	22.9	1.8	72.6
50	540215	6118046	49.1	4.918	0.033	2.7	45	65	23.4	1.3	47.8
51	538581	6117631	89.2	7.979	0.034	4.6		61	9.3	4.1	85.1

Id	Easting	Northing	Area (Ha)	Slope (%)	Catchment Roughness	Imper-vious (%)	U/S Node	D/S Node	Lag (min)	Impervious Area (Ha)	Pervious Area (Ha)
52	539674	6117473	111.7	5.037	0.034	4.4		65	15.4	4.9	106.8
53	540922	6119567	45.3	2.056	0.031	6.2	56	54	21.4	2.8	42.5
54	540840	6119012	26.5	1.856	0.033	6.1	53	66	31.3	1.6	24.9
55	541243	6120947	62.5	1.564	0.030	2.0	37	56	34.0	1.2	61.2
56	541100	6120230	59.7	1.257	0.030	2.0	55	53	22.2	1.2	58.5
57	541880	6119932	70.6	1.401	0.032	3.4	3	56	28.4	2.4	68.3
58	539757	6121993	94.7	1.955	0.040	17.0		42	24.9	16.1	78.7
59	541309	6121778	76.8	2.175	0.030	2.0		55	29.6	1.5	75.3
60	540356	6122691	100.0	3.264	0.031	2.3		74	36.5	2.3	97.7
61	538364	6116935	68.0	4.902	0.031	2.1	51	63	11.9	1.5	66.5
62	539419	6116769	59.5	0.615	0.030	4.4		64	41.3	2.6	56.8
63	538420	6116313	69.6	6.647	0.033	2.9		64	13.9	2.0	67.5
64	539057	6115999	58.2	0.545	0.031	6.5	63	999	25.1	3.8	54.4
65	540764	6117764	58.7	0.308	0.029	5.2	49	72	39.5	3.1	55.6
66	541205	6118431	49.4	1.708	0.030	2.8	54	72	39.5	1.4	48.0
67	541601	6119210	60.5	2.095	0.030	3.4		66	37.4	2.1	58.4
68	542503	6119286	79.6	1.860	0.034	4.9		71	22.2	3.9	75.7
69	543075	6119115	92.9	2.043	0.032	4.0		71	22.2	3.7	89.2
70	542713	6117611	74.9	3.937	0.037	4.2	71	73	20.6	3.1	71.8
71	542174	6118350	99.4	3.888	0.040	3.3	69	70	30.0	3.3	96.2
72	541632	6117513	106.9	0.798	0.037	2.0	66	73	17.8	2.1	104.8
73	542413	6116991	46.8	3.492	0.041	7.3	72	999	8.8	3.4	43.4
74	540613	6121839	54.3	1.952	0.035	2.2	60	55	12.7	1.2	53.1
75	540203	6120639	70.7	3.560	0.031	2.0		56	20.6	1.4	69.3
76	538122	6118164	45.2	5.236	0.045	26.4		77	14.4	11.9	33.3
77	537467	6117814	78.7	5.816	0.035	13.0	76	78	9.2	10.3	68.5

Id	Easting	Northing	Area (Ha)	Slope (%)	Catchment Roughness	Imper-vious (%)	U/S Node	D/S Node	Lag (min)	Impervious Area (Ha)	Pervious Area (Ha)
78	537343	6116998	75.6	5.918	0.032	5.8	77	81	12.3	4.4	71.3
79	536641	6116916	42.9	5.546	0.039	4.1		82	8.8	1.7	41.1
80	537669	6116017	60.8	6.941	0.044	3.9		83	10.7	2.4	58.5
81	537088	6116206	51.8	5.065	0.035	6.5		83	10.2	3.4	48.4
82	536477	6116196	38.3	1.911	0.035	11.6	79	83	12.0	4.4	33.8
83	537222	6115421	60.7	0.404	0.036	6.9	83	999	36.6	4.2	56.5
84	536346	6115619	37.4	0.408	0.029	7.8		83	25.3	2.9	34.4
85	536125	6118025	37.9	6.040	0.044	4.1		88	8.8	1.6	36.3
86	536533	6117649	78.4	4.521	0.031	4.6		87	10.9	3.6	74.9
87	535931	6117118	38.3	4.648	0.031	9.4	86	89	8.8	3.6	34.7
88	535506	6117989	39.5	2.529	0.043	6.1	85	90	9.2	2.4	37.0
89	535381	6117209	56.2	0.589	0.034	2.7	87	88	31.0	1.5	54.6
90	534793	6118091	49.8	0.554	0.047	4.5	88	91	25.4	2.3	47.5
91	533982	6118291	61.9	0.856	0.037	4.6	155	161	29.0	2.9	59.0
92	538404	6119666	24.8	3.511	0.030	16.6		106	5.0	4.1	20.7
93	538247	6119145	35.9	3.802	0.040	12.3		98	9.8	4.4	31.5
94	538271	6118630	46.0	4.752	0.034	3.8		98	9.0	1.7	44.3
95	537459	6118573	26.8	2.477	0.059	63.0		100	8.1	16.9	9.9
96	536762	6118362	17.8	3.349	0.038	3.0		97	6.3	0.5	17.2
97	536797	6118732	38.6	2.599	0.051	34.4	96	100	6.6	13.3	25.3
98	537641	6119092	27.5	2.737	0.062	76.4	93	99	7.8	21.0	6.5
99	537262	6119275	10.6	3.023	0.071	89.3	98	104	4.2	9.4	1.1
100	537216	6118986	8.5	2.014	0.066	91.1	97	101	5.0	7.8	0.8
101	536829	6119192	23.7	3.260	0.033	9.9	97	104	8.1	2.3	21.4
102	536516	6119576	22.8	3.348	0.032	8.1		151	6.9	1.8	20.9
103	538327	6120098	32.1	2.407	0.029	12.3		110	10.5	4.0	28.1

Id	Easting	Northing	Area (Ha)	Slope (%)	Catchment Roughness	Imper-vious (%)	U/S Node	D/S Node	Lag (min)	Impervious Area (Ha)	Pervious Area (Ha)
104	536906	6119699	21.5	2.521	0.035	2.0	99	148	10.6	0.4	21.0
105	537481	6119564	21.6	2.830	0.057	72.7	106	104	10.4	15.7	5.9
106	537970	6119642	14.6	3.117	0.036	26.5		105	4.6	3.9	10.8
107	537700	6119918	21.1	2.255	0.037	23.6		108	7.8	5.0	16.1
108	537191	6119920	12.9	3.205	0.031	6.0	107	118	9.0	0.8	12.2
109	537944	6120603	14.4	2.346	0.031	6.3		120	7.6	0.9	13.5
110	537750	6120335	16.5	2.550	0.035	10.6	103	120	6.1	1.8	14.8
111	538820	6120959	24.0	2.423	0.030	7.4		113	8.1	1.8	22.2
112	538749	6120461	22.4	2.530	0.030	7.4		113	7.5	1.7	20.7
113	538313	6120575	19.4	2.577	0.029	6.4	111	109	10.1	1.2	18.2
114	537482	6121376	20.6	2.020	0.029	10.6	131	121	7.4	2.2	18.4
115	537931	6121101	22.1	2.135	0.031	4.1		114	8.0	0.9	21.2
116	538376	6120977	17.0	3.860	0.030	2.0		109	6.3	0.3	16.7
117	537266	6120283	23.4	2.928	0.030	3.7		118	7.5	0.9	22.5
118	536804	6120219	20.4	2.656	0.030	7.2	117	148	9.2	1.5	18.9
119	536944	6120679	17.6	2.418	0.030	3.5		146	5.4	0.6	17.0
120	537499	6120764	28.7	1.932	0.031	3.5	110	121	6.3	1.0	27.7
121	537175	6121061	19.1	3.103	0.034	5.7	120	146	5.1	1.1	18.0
122	540397	6123934	94.5	3.127	0.030	7.6		123	11.7	7.1	87.3
123	539926	6123421	54.0	2.179	0.030	8.7	122	127	9.0	4.7	49.2
124	539907	6124867	106.7	2.658	0.032	2.0		173	15.7	2.2	104.5
125	538949	6124814	58.6	6.216	0.046	3.0		126	8.8	1.7	56.9
126	539048	6124215	23.7	2.767	0.031	2.7	125	173	6.3	0.6	23.1
127	539380	6123057	50.5	1.834	0.030	6.5	123	128	9.9	3.3	47.3
128	538969	6122652	35.7	2.398	0.030	5.0	127	129	5.7	1.8	34.0
129	538666	6122180	60.4	2.201	0.030	5.6	128	131	18.1	3.4	57.0

Id	Easting	Northing	Area (Ha)	Slope (%)	Catchment Roughness	Imper-vious (%)	U/S Node	D/S Node	Lag (min)	Impervious Area (Ha)	Pervious Area (Ha)
130	538847	6121578	30.7	2.377	0.030	9.5		129	9.4	2.9	27.7
131	537890	6121707	36.6	2.450	0.031	3.9	129	114	9.4	1.4	35.2
132	538423	6124278	66.1	5.273	0.034	4.8		133	9.4	3.2	62.9
133	538648	6123463	99.8	1.552	0.031	2.2	173	171	12.9	2.2	97.6
134	537689	6124063	83.9	5.071	0.045	8.8		170	12.4	7.4	76.6
135	537014	6124740	76.4	4.544	0.032	7.6		138	11.1	5.8	70.6
136	537629	6125332	93.5	2.694	0.032	2.6		139	16.0	2.4	91.1
137	538317	6125375	63.2	6.059	0.050	6.8		139	10.5	4.3	58.8
138	536456	6125561	123.7	3.244	0.033	4.0	135	999	16.8	4.9	118.8
139	537336	6126449	205.5	1.961	0.031	4.6	137	999	23.6	9.4	196.1
140	537299	6122221	65.3	1.725	0.031	5.0	175	114	18.0	3.2	62.0
141	535638	6123238	73.5	4.153	0.034	5.8		142	8.0	4.2	69.3
142	536423	6122547	75.6	1.759	0.030	5.5	174	143	8.9	4.2	71.4
143	536490	6121891	80.4	1.924	0.033	3.1	142	146	16.4	2.5	77.9
144	535534	6122259	67.3	5.890	0.033	2.8		143	6.8	1.9	65.4
145	535932	6121409	55.6	3.867	0.032	3.8		146	13.1	2.1	53.5
146	536598	6121086	66.0	5.054	0.031	3.4	143	148	11.4	2.2	63.7
147	535078	6120873	101.5	4.287	0.033	4.4		154	11.8	4.5	97.0
148	536255	6120212	59.0	3.158	0.032	3.1	146	151	16.7	1.8	57.2
149	535711	6120449	66.3	3.341	0.031	3.2		151	15.9	2.1	64.1
150	536196	6118733	38.2	4.236	0.041	3.8		153	7.4	1.5	36.7
151	535628	6119610	35.9	2.223	0.034	5.6	148	155	12.3	2.0	33.9
152	535940	6119290	33.4	2.493	0.034	5.8		155	15.6	2.0	31.5
153	535628	6118702	54.3	3.195	0.044	15.4	150	155	15.1	8.3	46.0
154	534823	6119861	102.3	4.112	0.035	5.2		155	12.6	5.3	96.9
155	534807	6118861	93.0	1.897	0.033	13.4	151	91	17.2	12.5	80.5

Id	Easting	Northing	Area (Ha)	Slope (%)	Catchment Roughness	Imper-vious (%)	U/S Node	D/S Node	Lag (min)	Impervious Area (Ha)	Pervious Area (Ha)
156	533771	6120918	189.8	3.989	0.034	5.5		157	15.1	10.4	179.4
157	533474	6119941	148.5	5.853	0.040	4.4	156	158	12.6	6.5	142.0
158	533553	6119097	107.9	3.221	0.062	36.6	157	161	16.9	39.5	68.4
159	532355	6119764	78.7	6.285	0.055	12.4		161	12.3	9.7	69.0
160	532230	6118989	62.4	2.761	0.079	66.3		161	11.9	41.4	21.0
161	532988	6118414	95.2	1.892	0.044	24.0	91	162	20.6	22.8	72.3
162	532103	6118076	101.9	4.206	0.053	36.2	161	999	11.1	36.9	64.9
163	540913	6117023	46.1	0.911	0.030	4.8		72	46.8	2.2	43.9
164	536507	6124312	49.6	4.628	0.032	3.1		165	6.0	1.5	48.1
165	535769	6124428	114.0	4.414	0.031	3.6	164	166	9.5	4.1	109.9
166	534936	6124068	88.7	1.587	0.032	2.2	165	168	22.5	2.0	86.7
167	535162	6124954	67.7	4.443	0.036	2.0		168	10.4	1.4	66.3
168	534171	6124869	71.6	2.875	0.030	2.0	166	999	17.4	1.4	70.2
169	538381	6121553	36.5	3.164	0.031	2.1		129	11.1	0.8	35.8
170	537708	6123079	29.9	1.976	0.033	8.2	134	172	10.3	2.5	27.4
171	538177	6122887	38.4	1.969	0.032	2.2	133	172	9.2	0.9	37.5
172	537885	6122415	36.5	1.187	0.030	5.0	171	140	25.3	1.8	34.7
173	539519	6124057	33.3	1.949	0.031	3.2	124	133	9.0	1.1	32.2
174	536428	6123371	74.1	2.950	0.030	2.6		142	14.3	2.0	72.1
175	537098	6123458	86.7	4.638	0.034	2.3		140	13.6	2.0	84.7

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