59916074/ 304600102 Final Flood Study Report

Rev I

Parramatta River Flood Study

59916074/ 304600102

Prepared for

City of Parramatta Council

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Contact Information

Stantec
ABN 17 007 820 322

Level 16
207 Kent St
Sydney NSW 2065
Australia

www.stantec.com
Phone +61 2 9496 7700
Fax +61 2 9439 5170

Author(s):

Venus Jofreh- Principal Water Resources Engineer

Eric Lin-Principal Drainage and Flooding Engineer

Approved By:

Anthony Densten
Group Leader, Water Resources

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Executive Summary

Introduction

Flood information in the City of Parramatta LGA has been developed through several previous flood studies undertaken at various times through the 1990's and 2000's. Due to changes in the catchment and advances in modelling software and techniques, Council decided to undertake an updated Parramatta River Flood Study to assist in floodplain management, structural works, planning, development control and emergency management in the Parramatta LGA.

City of Parramatta Council is responsible for local land use planning in its service area, including the Parramatta River (within its LGA) catchment and its floodplain.

Through its Floodplain Risk Management Committee, the City of Parramatta Council proposes to prepare a comprehensive Floodplain Risk Management Plan for the Study Area in accordance with the "Floodplain Development Manual: The Management of Flood Liable Land", April 2005 and as well as its updated counterpart, the NSW Government's 'Flood Risk Management Manual' from 2023.

This project relates to the "Data Collection" and "Flood Study" phases of the Floodplain Risk Management Process.

The subject of this Flood Study is both mainstream flooding and overland flow paths within the City of Parramatta Council former Local Government Area (LGA) prior to Council amalgamations in 2016.

The primary objective of the Flood Study is to model the flood behaviour in the Study Area under existing conditions and address possible future variations due to Climate Change. The development of a detailed flood model will help guide future development in the catchment.

The flood study outcomes provide the preparatory groundwork required to undertake the identification of emergency management measures and other critical flood information required by the State Emergency Services (SES) as part of flood response action.

The Flood Study will also provide the preparatory groundwork required to undertake a Floodplain Risk Management Study and a Floodplain Risk Management Plan with particular emphasis to implement potential flood mitigation solutions for the Westmead Biomedical Precinct and the Parramatta CBD and other areas within the flood study area. The Flood Study supports Council's intention to invest in innovative, cost-effective, long-term flood mitigation measures in the LGA.

Study Area

The Study Area includes the catchments of Parramatta River and adjoining tributaries within the City of Parramatta Council former Local Government Area (LGA) prior to Council amalgamations in 2016, excluding part of Duck Creek, Duck River and A'Beckett's Creek. The hydrology for the Study Area includes the Parramatta River, Toongabbie Creek and all tributary catchments upstream of Concord Road Bridge, and the upper portion of Terrys and Devlins Creeks catchments which flow to the Lane Cove River.

The hydraulic assessment for the S"udy 'rea Is limited to the former LGA boundary prior to Council boundary change in 2016. This includes Toongabbie Creek and Parramatta River and their tributaries as well as the upper portion of Terrys and Devlins Creeks within the Parramatta LGA. Duck Creek and Duck River have recently had flood models prepared and A'Beckett's Creek Flood Study & FRMS&P is currently in progress and scheduled for completion in 2024. As such, these tributaries are excluded from the current study. The Study Area is shown in **Figure 1-2**.

The Parramatta River Catchment stretches for over 212 square kilometres in area, with more than 20 major adjoining creek tributaries linking to the Parramatta River which discharges into the Sydney Harbour**. Figure 15-1** shows the catchment and the adjoining tributaries that flow into the Study Area.

The former Parramatta LGA area makes up 30% of the total Parramatta River Catchment and covers 61.4 square kilometres. The Study Area is 51 square kilometres and contains several areas of State or National importance, such as the Parramatta CBD and Westmead Biomedical Precinct, including the extended Clay Cliff catchment.

Approach and Methodology

The Parramatta River Flood Study was prepared using existing data provided by City of Parramatta Council as the basis for the hydrologic and hydraulic models. These models have been reviewed, amended and extended as appropriate to include additional collected data for this study or to refine the models to suit the objectives of the study.

A review of available information considered previous flood study models and reports, rainfall and streamflow gauge data, tide information, available survey, hydraulic structures and historical flood observations. Additional data collection was undertaken through stakeholder liaison, site visits, rainfall and streamflow gauge data acquisition, additional survey of bathymetry and hydraulic structures and community consultation to obtain community experiences of flooding.

These data were used to develop an XP-RAFTS hydrologic model of the Parramatta River catchment, and seven TUFLOW hydraulic models covering the Study Area.

The XP-RAFTS hydrologic model was developed firstly by combining existing hydrologic models into one large model representing the entire Parramatta River catchment and updating the model to reflect present day catchment conditions.

The hydrology model was then calibrated and validated to historic flood events that occurred in April 1988, April 2015, and June 2016. Once calibrated, the hydrology model is used to produce flow hydrographs for design flood events which are used as inputs for the hydraulic model.

The study also incorporates rainfall-on-grid 1% AEP and PMF modelling results for the purpose of validating hydrology inflows location, to best represent riverine flooding and its associated backwater effects, along with and significant overland flow paths. This comprehensive approach ensures a nuanced understanding of flood risk dynamics, encompassing both major and minor pathways of water movement.

The model flows were calculated in the hydrologic model in accordance with the Australian Rainfall & Runoff 2019 (ARR2019) Guidelines. The approach adopted is the ensemble in hydrology, mean in hydraulics approach as outlined in OEH *Floodplain Risk Management Guide: Incorporating 2016 Australian Rainfall and Runoff in studies* (NSW OEH, 2019).

The model flows were also validated against an updated Flood Frequency Analysis (FFA) of historical gauged peak flows at Marsden Street weir from 1889 to 2016 that includes 37 annual peak flows. Assessment also included a review of the rating curve as well as using the latest methods and additional years of data since the previous FFA. Review also considered adjustment to actual gauged flows to take into account changes in the catchment that have occurred (i.e. extra storage) and rating curve changes over the period of record to provide an estimated present day maximum flow expected. This revised annual maximum flow data was used for FFA assessment (refer Appendix B).

For the 1% AEP design storm event the modelled flows were calibrated to match expected FFA flows at Marsden Weir in the detailed hydraulic model and the calibrating was expanded to the main river and all tributary flows for the purposes of defining the Flood Planning Layer. No calibrating has been applied to the other design events.

The FFA provides a curve fitted to the gauged flow data to allow estimation of expected flows for a range of recurrence intervals. Current assessment has considered 2 options for statistically estimating flows based on the provided gauged data. It should be noted that the gauged data is provided over approximately 127yrs starting in 1889 with a large gap in the data from 1914 to 1956.

The “Adopted Fit” and Alternative Fit” were produced and following review the “Adopted Fit” was selected to define the 1% Design FFA calibrated flow at Marsden Weir. In general the ARR2019 design event flow estimates from XP-RAFTS and Flood Modelling generally correlate well with the FFA expected flows although for the 1% AEP design event there was a need to recalibrate the flows to match the FFA defined flood.

A 1D/2D TUFLOW hydraulic model was then created using existing data provided by City of Parramatta Council and incorporating additional data collected for this study. This included aerial photographs, ALS data, bathymetric survey, survey of hydraulic structures, and Council’s stormwater drainage network. The hydrologic model flows were input to the hydraulic model, which was also calibrated and validated to the three historic events.

Model setup for both the hydrology and hydraulic models have considered future use of the models and future stages of the floodplain risk management process. This includes the preparation of a separate Watershed Bounded Network Model (WBNM) hydrologic model to provide additional future backup to the current XP-RAFTS model used for this Study.

The Overland Flow assessment conducted for this study adopts a broad-based approach that may not fully account for minor terrain variations such as retaining walls, garden beds, or ground obstructions. However, its objective remains focused on using precise parameters akin to those employed in riverine flooding assessments.

The adopted overland flow modelling technique strikes a balance between capturing major flood pathways and identifying less obvious yet still pertinent flood risks. This approach, complemented by cross-referencing with rainfall-on-grid modelling, ensures a comprehensive understanding of flood risk dynamics.

Design Flood Events

The 1% AEP design event was recalibrated to match the FFA and is referred to as FFA-calibrated 1% AEP.

The calibrated and validated hydraulic model was used to simulate a range of design flood events (1% FFA calibrated, 2%, 5% and 20% Annual Exceedance Probability (AEP) events) and the Probable Maximum Flood (PMF) along the Parramatta River/Toongabbie Creek main channel and the tributaries and overland flow areas within the Study Area.

Current ARR2019 design event flow estimates correlate well with the FFA expected flows up until the 2% AEP event. Above this there appears to be a variation away from the design results and the FFA results for the 1%AEP event are higher than the standard ARR2019 design event outcomes.

Flows have been validated with a separate WBNM hydrologic model (undertaken by others during peer review) and show a close correlation.

Comparison with previous flood study results shows that the Current 2023 Study 1% AEP design flows (650 m^3/s in XP-Rafts and Tuflow) are approximately 15% lower at Marsden Street Weir when compared with the previous Upper Parramatta River Catchment Trust (UPRCT) XP-RAFTS model and “Adopted Fit” FFA calculated flows ($724m^3/s$).

To replicate the 1% AEP FFA defined flow rate in the Tuflow model a recalibration of the hydrological XP-RAFTS model ARR19 IFD was undertaken, and a defined temporal pattern was adopted that provided best fit to 1% AEP FFA design flow of $724m^3/s$ at Marsden Weir.

Based on these outcomes the recalibration was also applied to all tributary models to replicate the increased flow expected at the catchment outlets (i.e. 27%) for all flow durations. As expected at these larger flow rates there is a variation between the outcomes of XP-RAFTS and the detailed hydraulic model associated with increased storage and changed routing on the overbank areas. It was identified that hydrological modelling results needed to be increased by 27% in order to achieve the required 15% increase in the hydraulic model.

Model Results

Model calibration was undertaken to April 1988, April 2015, June 2016 at gauged locations where flow and flood depths were recorded. Outcomes are presented in Appendix C and generally indicate the following:

- In June 2016 event the modelled outcomes also show good correlation with recorded flow hydrographs and peak water levels at 5 locations along the catchment with a 0.5% increase in estimated flow at Marsden Weir but a 80mm water level difference potentially due to missed peak in data. Refer to Table C.1
- For the April 2015 event the modelled outcomes show good comparison with gauged flow and water level data at 5 locations with 4% flow difference and 30mm water level difference at Marsden Weir. Refer to Table C.2.
- Water Level comparison for the April 1988 within 0.7m of SKM 2005 reported water levels at 7 locations. Refer to Table C.3.

For design event assessment up to the FFA calibrated 1% AEP event, flooding is largely contained within the channel banks of the Parramatta River and its tributaries, with most of the flooding occurring through overland flow. Mainstream flooding largely affects some low-lying foreshore areas, but flood extents along the mainstream change dramatically when flow is out of bank in events rarer than the 1% AEP. The PMF affects large areas of the Parramatta River floodplain as well as overland flow areas.

Comparison with previous flood studies shows:

> Current Study flood levels for events up to the 2% AEP are generally lower than the UPRCT/SKM MIKE11 flood levels previously generated for the Upper Parramatta River;

> All areas downstream of Charles Street Weir are generally lower in the Current Study when compared to the Lower Parramatta River Flood Study (SKM, 2005) results. This is primarily due to the significant difference in flows and use of bathymetric data.

- For both the 1% AEP and PMF, substantial additional flood areas are observed in overland areas, which were not previously modelled, but have been included in the current TUFLOW model.

Differences between this Flood Study and the previous UPRCT model results are explained by differences in model inputs and modelling techniques including:

- two-dimensional modelling being used in this Flood Study which more accurately represents flow across floodplains and overland areas compared with one-dimensional modelling;
- buildings are blocked out in the current TUFLOW model, and this impacts flowpaths through overland flow areas;
- newly collected bathymetric survey of Toongabbie Creek between Old Windsor Road and the weir downstream of Cumberland Hospital and Domain Creek;
- newly acquired survey of numerous hydraulic structures throughout the study area which have been incorporated in the model;
- the inclusion of new structures which have been built since the previous modelling was undertaken such as Peter Parade levee;
- incorporation of the pedestrian portals through Lennox Bridge which were opened in late 2014. The effect of the portals is to lower water levels upstream of Lennox Bridge and allow more flow through the structure and hence increase flows and flood levels downstream of the bridge;
- incorporation of developments that have occurred since the previous flood studies and major infrastructure including the new Parramatta Stadium and the soon to be constructed Alfred Street bridge;
- adoption of a different tailwater level leading to influences on water levels downstream of Charles Street Weir (80mm lower at most downstream boundary in current study due to revised new methodology published by OEH; refer to Reference 13); and,
- Modelling and mapping of additional overland areas not previously modelled.

Overland Flow and Shallow Overland Flow

The prior assessment of overland flooding utilized the Rainfall on Grid (RoG) method as a provisional measure, in line with the guidelines established in ARR 1987. The findings from the RoG analysis have been integrated into our comprehensive Flood Study for the riverine model. The updated flood model for the Parramatta River Flood Study demonstrates a good correlation, indicating that the inflow nodes in the XP-RAFTS model have been effectively adjusted to accurately represent significant overland flow paths. Furthermore, theviiodellingg of pipe networks has been extended beyond the previously established DN600 diameter cutoff, enhancing the accuracy of overland flow representation.

The Overland Flow assessment conducted for this study adopts a broad-based approach that may not fully account for minor terrain variations such as retaining walls, garden beds, or ground obstructions. However, its objective remains focused on using precise parameters akin to those employed in riverine flooding assessments. The adopted overland flowviiodellingg technique strikes a balance between capturing major flood pathways and identifying less obvious yet still pertinent flood risks. This approach, complemented by cross-referencing with rainfall-on-grid vii odellingg, ensures a comprehensive understanding of flood risk dynamics. The study incorporates rainfall-on-grid 1% AEP and PMF modelling results to validate hydrology inflows location, to best represent riverine flooding and its associated backwater effects, along with significant overland flow paths. This comprehensive approach ensures a nuanced understanding of flood risk dynamics, encompassing both major and minor pathways of water movement. By fulfilling these requirements, the study provides insights to inform Section 10.7 (Formally Section 149, Private Certificate) planning regulations regarding flood risk assessment and management.

The flood mapping in Appendices F (Calibrated FFA 1% AEP flood depth) and L (Flood Planning Area) integrates two methods for local overland flow assessment. The First Method employs a 2m grid surface applied hydrograph in TUFLOW, considering factors like ground roughness, storm events, and model calibration. The Second Method utilizes Rain-on-Grid (ROG) on a 2m grid flood surface in TUFLOW, focusing on specific storm events and LiDAR data. Additionally, Local overland flow mapping in the upper catchments has been enhanced with ROG 1% AEP results (ARR 1987), representing broad-based shallow overland flow. This approach aligns with standard industry practice, providing a reliable depiction of flood-prone areas and overcome inherent difficulty of over-delineating catchments for a riverine flood study.

Climate Change

It is widely accepted that Climate Change will lead to increases in global temperatures which will lead to increases in the intensity of rainfall along with sea level rise. For this Study, Climate Change scenarios were assessed which coupled a low and a high carbon emissions scenario rainfall increase predictions with corresponding expected sea level rise for 2050, 2090 and 2150.

Consideration of the effects of Climate Change show that for a 6.4% increase in rainfall, FFA 1% AEP flood levels increase of approximately 400mm may be experienced at Marsden Street Weir. A 19.7% increase in rainfall intensity would elevate flood levels by over 0.51m. With consideration of the benchmark Sea Level Rise of 0.9m by 2100 and 1.5m by 2150, significant areas of the Lower Parramatta River foreshore would be impacted. However, impacts due to sea level rise are limited to areas downstream of the Charles Street Weir.

Conclusion

The Parramatta River Flood Study provides an update to the available flood information for the former Parramatta City Council LGA excluding Duck River, Duck Creek and A'Becketts Creek. The results of the Study describe the flood behaviour in the Study Area and will assist in raising community awareness of flooding and flood risk in their area. The study will be used by Council and various stakeholders to inform flood planning and emergency management in the Study Area.

The Study uses current industry standard methods and guidelines in flood estimation using Australian Rainfall and Runoff 2019 and a series of OEH floodplain management guidelines. The design event flood estimates were validated to a Flood Frequency Analysis of observed annual peak flood levels.

The overland approach used for this study is appropriate in that it utilises the most accurate parameters for significant overland paths whilst at the same time identifies shallow local upper catchment overland are which may not be significant in terms of depth.

The study provides insights to inform Section 10.7 (Private Certificate) planning regulations regarding flood risk assessment and management.

For flood planning levels a FFA calibrated 1% AEP design event and associated RCP8.5, 2150 Climate Change assessment was undertaken; however, standard ARR 2019 process was adopted for all other events. In accordance with ARR19 blockage of cross drainage structures was considered and the maximum water level envelope from the FFA 1% AEP calibrated design and Climate change scenario was considered for the proposed blockage and an unblocked scenario to ensure the flood planning layer and extents meets ARR 2019 requirements.

As part of this analysis, the Marsden Street Weir gauge (213004) level-flow relationship (rating curve) was reviewed and updated using the hydraulic model to inform the extrapolation to higher flows beyond the field gauging data. The modelling approach, model setup, parameters and results and the study outcomes have been peer reviewed by an independent consultant on behalf of Council.

The standard 1% AEP design flood levels out of this flood study are generally lower than previous MIKE 11 flood modelling levels that have been adopted by Council. However, the XP-RAFTS model flows for the FFA calibrated 1% AEP design event are larger so as to provide the best FFA calibrated outcome in the detailed hydraulic model. For the remaining events the reduction in flows are due to the design flow estimates being lower using updated methods along with and differences in model setup more up-to-date survey and catchment conditions. Probable Maximum Flood extents remain similar to previous modelling.

The models have been run for the FFA calibrated 1% AEP, standard ARR design 0.5%, 0.2%, 2%, 5%, 10%, 20%, 50% and 63% AEP Storms and half-PMF and PMF event. Flood levels, Depths, velocities, Hazard and Hydraulic Categories, Hazard Vulnerability Classification and Flood Risk Precincts have also been mapped for the FFA calibrated 1% AEP, standard ARR design 2%, 5%, 20% AEP Storms and PMF event.

Much of this proposed re-development activity will occur alongside the Parramatta River and adjoining tributaries which extend across over two thirds of the entire LGA. For this study, seven significant areas have been selected based on high flood planning constraints, using hazard mapping and emergency response planning. These areas pose the highest flood risk and by focusing on these areas, Council can allocate resources and respond effectively to mitigate flood impacts in the future. The significant areas outlined in this report include:

- Camellia.
- Parramatta CBD (whole of CBD);
- Parramatta CBD (river foreshore area);

> North Parramatta Urban Renewal Precinct;
> Westmead Biomedical Precinct;
> Knowledge Precinct Area (adjacent to and including parts of Western Sydney University);
> Rydalmere;

Other areas susceptible to high flood risk and sensitive to blockage and Climate Change include:

> Toongabbie – near Pendle Creek and Toongabbie Creek confluence
> Old Toongabbie – Bogalara Creek
> Westmead, Wentworthville and Constitution Hill - Finlaysons, Coopers and Milsons Creeks
> Harris Park and Rosehill – along Clay Cliff Creek
> Rydalmere and Ermington foreshore areas – Lower Parramatta River
> Shell Oil along Duck Creek and Duck River.

It should also be noted that large parts of Stage 1 of the Parramatta Light Rail are within the Parramatta River Floodplain, along with some of the stations for the forthcoming Metro West train line.

Flood Emergency Response Planning classification of communities and Flood Planning Constraints Categories have been assessed for Significant Areas to inform Council and SES regarding land-use planning and emergency management planning in future stages.

The updated Parramatta River Flood Study presents contemporary flood models and mapping for Council's use in planning decisions and to form the basis for the future stages of Floodplain Risk Management.

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Appendices

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Abbreviations

AEP	Annual Exceedance Probability
ALS	Aerial Laser Survey
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
ARR87	Australian Rainfall and Runoff 1987 edition
ARR2019	Australian Rainfall and Runoff 2019 edition
BoM	Bureau of Meteorology
CoP	City of Parramatta Council
DCP	Development Control Plan
FDM	Floodplain Development Manual
FFA	Flood Frequency Analysis
FPL	Flood Planning Levels
FRMM	Flood Risk Management Manual
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
GIS	Geographic Information System
ha	Hectare
IFD	Intensity Frequency Duration
km	Kilometres
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
m	Metre
m^2	Square metre
m^3	Cubic metre
m^3/s	Cubic metres per second (flow)
mAHD	Metres to Australian Height Datum
mm	Millimetre

m/s	Metres per second (velocity)
NSW	New South Wales
OEH	Office of Environment & Heritage
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
NSW SES	State Emergency Service
UPRCT	Upper Parramatta River Catchment Trust

Glossary

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded each year; it would occur quite frequent and would be relatively small. A 1%AEP flood has a low probability of occurrence or being exceeded each year; it would be fairly rare but it would be relatively large.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that periods between exceedances are generally random
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Creek Rehabilitation	Rehabilitating the natural 'biophysical' (i.e. geomorphic and ecological) functions of the creek.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events. E.g. some roads may be designed to have a 1% AEP flood immunity while other roads may be designed to be overtopped in the 20 year ARI or 5% AEP flood event.
Development	The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
Flood hazard	Potential risk to life and limb caused by flooding.
Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood-prone land, rather than being restricted to land subject to designated flood events.

Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain management measures	The full range of techniques available to floodplain managers.
Floodplain management options	The measures which might be feasible for the management of a particular area.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls.
Flood planning levels (FPLs)	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plains. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FPLs.
Flood storages	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always, aligned with naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas.
Geographical Information Systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hazard Vulnerability Classification	Hazard Vulnerability classification equivalent of Floodplain Manual flood hazard curve (H1-H6 category). Categorisation of Flooding threat that are most likely to have an impact on a and the surrounding area.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings.
Hydraulics	The term given to the study of water flow in a river, channel, or pipe, in particular the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety.

Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.
Overland Flow	The flow of water over the ground surface either along formal flow paths such as roads and formed channels, or informal flowpaths along topographic low points and through properties and open space areas. The term overland flow is used interchangeably in this report with “flooding”.
Peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The flood calculated to be the maximum that is likely to occur.
Provisional Flood Hazard	This is determined through a relationship developed between the depth and velocity of floodwaters and is based strictly on hydraulic considerations and refining the initial hazard categorisation to inform the safety of individuals using the low, intermediate, and high hazard categories.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Annual Exceedance Probability.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.
Upper Parramatta River Catchment Trust	A former organisation responsible for the previous hydrology and hydraulic modelling of the Upper Parramatta River.

Note * Terminology in this Glossary have been derived or adapted from the NSW Government Floodplain Development Manual, 2005, where available.

1 Introduction

Stantec (formally Cardno) was engaged by City of Parramatta Council (Council) to prepare the Parramatta River Flood Study in accordance with the NSW flood development manual and also its successor NSW Flood Risk Management Manual (2023). This Flood Study focuses on all mainstream flooding and overland flow paths within the City of Parramatta Council former Local Government Area (LGA) prior to Council amalgamations in 2016. This includes the Parramatta River and its tributaries, and a portion of Terrys and Devlins Creeks which flow to the Lane Cove River. Post amalgamations the model has been updated to include part of Duck River that is within the new LGA and does not include areas of Duck River outside the current LGA.

The primary objective of the New South Wales Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability for individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.

Through the Office of Environment and Heritage (OEH), the Department of Planning and Environment (DPE) and the State Emergency Service (SES), the NSW Government provides specialist technical assistance to Local Government Agencies on all flooding and land use planning matters. The Flood Risk Management Manual (NSW Government, 2023) is provided to assist Councils in meeting their obligations through the preparation of Floodplain Risk Management Plans. **Figure 1-1** was extracted from the Floodplain Risk Management Manual and highlights the process for plan preparation, implementation, and review.

The NSW Government has worked in partnership with councils to understand and manage flood risk to communities across New South Wales under the NSW Flood prone land policy (the policy) since 1984. The Flood risk management manual: the management of flood liable land (this manual) and its toolkit support policy implementation. This manual outlines a vision (see below) and general principles (see **Section 2**) for FRM in New South Wales. It also outlines how the NSW Government will work in partnership with councils to manage flood risk to communities and encourage councils in the same catchment to work cooperatively in flood risk management.

Note: Sections in Figure refer to sections of the Flood Risk Management Manual

Figure 1-1 Floodplain Risk Management Process (Figure 2.1, NSW Flood Risk Management Manual, 2023)

City of Parramatta Council is responsible for local land use planning in its service area, including the Parramatta River (within its LGA) catchment and its floodplain.

Through its Floodplain Risk Management Committee, the City of Parramatta Council proposes to prepare a comprehensive Floodplain Risk Management Plan for the Study Area in accordance with the NSW Government Department of Planning and Environment's "Flood Risk Management Manual", 2023 (The Manual).

This project relates to the "Data Collection" and "Flood Study" phases of the process.

1.1 Study Context

The City of Parramatta has been historically recognised as a vital local government area in metropolitan Sydney. The Parramatta CBD is the 2nd largest in Sydney and 6th largest in Australia, with tens of thousands of people working in the CBD and in the LGA. The Westmead Hospital in conjunction with affiliated medical institutes constitutes the largest biomedical precinct in the Southern Hemisphere.

Thousands of students attend the University of Western Sydney (UWS) at the CBD campus and the Rydalmere campus. Billions of dollars of redevelopment, including a new light rail system, has been planned to be built in the LGA over the next few years. The proposed rezoning of existing industrial lands will attract thousands of new residents to the LGA.

Much of this proposed re-development activity will occur alongside the Parramatta River and adjoining tributaries which extend across over two thirds of the entire LGA.

Significant areas within the catchment:

1. Camellia.
2. Parramatta CBD (whole of CBD);
3. Parramatta CBD (river foreshore area);
4. Knowledge Precinct Area which is adjacent to and includes part of University of Western Sydney Campus area;
5. North Parramatta Urban Renewal Precinct;
6. Westmead Biomedical Precinct;
7. Rydalmere;

It is vital for Council to have up-to-date flood information to inform the planning process for the significant development volume and to assist in managing current and future flood risk.

1.2 Study Objectives

The Flood Study is to provide City of Parramatta Council with a contemporary and advanced catchment wide Flood Model to assist in floodplain management, structural works, planning, development control and emergency management in the Parramatta LGA. The primary objective of the Flood Study is to model the flood behaviour in the Study Area under existing conditions, address possible future variations due to climate change and advise on future flood mitigation works. The development of a detailed flood model will help guide future development in the catchment.

The Flood Study provides the preparatory groundwork required to undertake the identification of emergency management measures and other critical flood information required by the State Emergency Services (SES) as part of flood response action.

The Flood Study will also provide the preparatory groundwork required to undertake a Floodplain Risk Management Study and a Floodplain Risk Management Plan with particular emphasis to implement potential flood mitigation solutions for the Westmead Biomedical Precinct and the Parramatta CBD and other areas within the flood study area. The Flood Study supports Council's intention to invest in innovative, cost-effective long-term flood mitigation measures in the LGA.

The flood study is also to provide council with better and more refined definition of a Flood Planning Layer (FPL) which has been defined as the maximum flood level envelope generated for the following event:

- FFA calibrated 1% AEP design event (for zero and ARR19 blockage) for the RCP8.5, Year 2150 Climate Change and including a 500mm freeboard.

The above events are run for both a structure blockage and unblocked scenario and the envelope of water level outcomes, hazards and depths are provided to define to FPL.

1.3 Study Area

The Study Area includes the catchments of Parramatta River and adjoining tributaries within the City of Parramatta Council former Local Government Area (LGA) prior to Council amalgamations in 2016. The Study Area is shown in **Figure 1-2**.

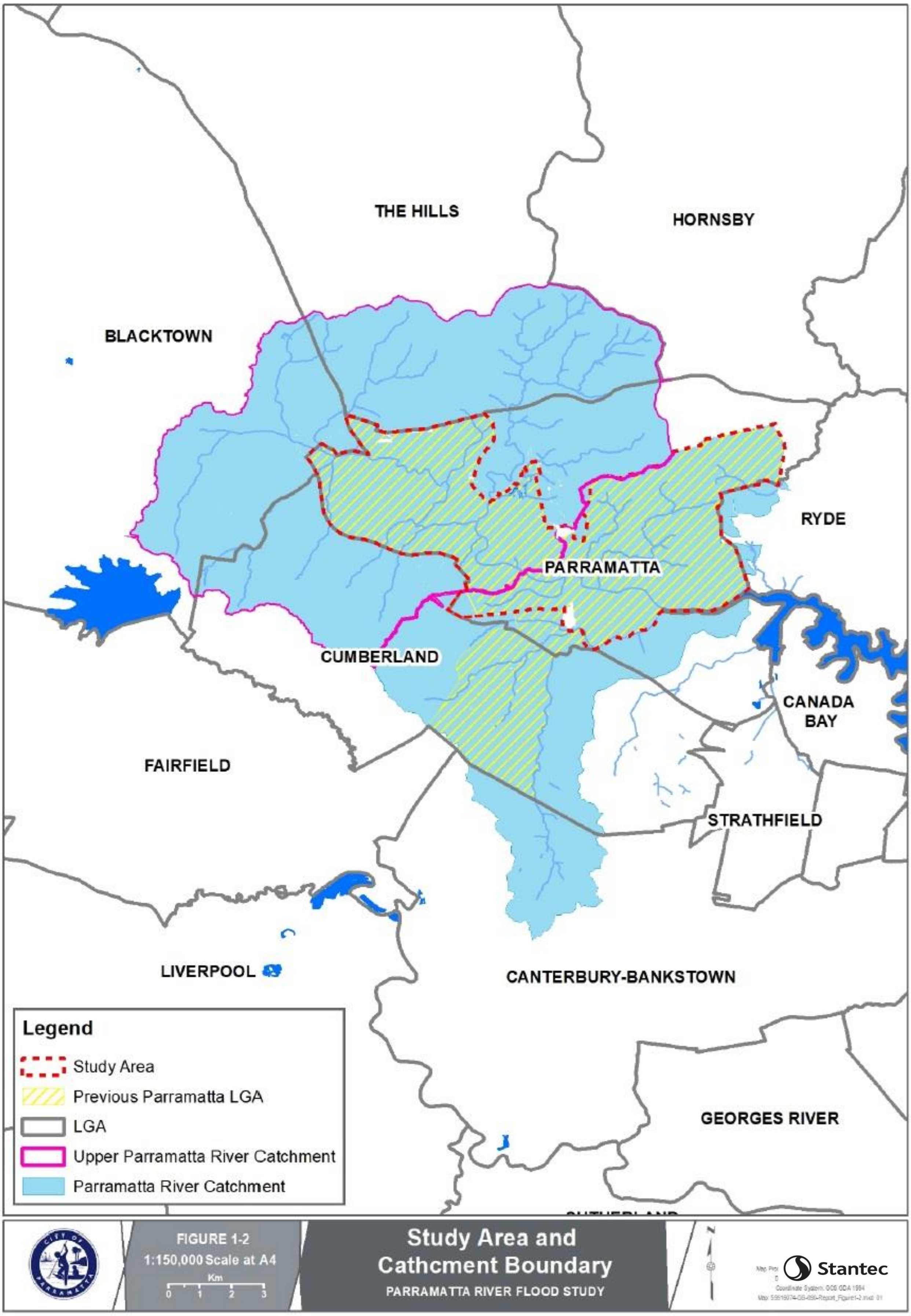

Figure 1-2 Parramatta River Flood Study – Study Area and catchment boundary (source: CoP Study Invitation to Tender)

The catchment was historically, strategically divided as the Upper Parramatta Catchment and the Lower Parramatta Catchment; however, these areas were combined for the purposes of this study. The combined catchment boundary (upper & lower Parramatta River Catchments) extends well beyond the former Parramatta LGA (and Study Area) and presently overlaps with eight other adjacent Council LGA boundaries (post amalgamation) as shown in **Figure 1-2**. Adjacent Councils (post amalgamation) including Parramatta River catchments are Ryde, Canada Bay, Strathfield, Burwood, Canterbury-Bankstown, Cumberland, Blacktown and The Hills.

The Parramatta River Catchment stretches for over 212 square kilometres in area, with more than 20 major adjoining creek tributaries linking to the Parramatta River which discharges into the Sydney Harbour apart from Devlins Creek and Terrys Creek catchments which discharge into the Lane Cove River)**.**

Additionally, **Figure 15-1**Error! Reference source not found. shows the catchment and the adjoining tributaries that flow into the Study Area in more detail.

The former Parramatta LGA area makes up 30% of the total Parramatta River Catchment and covers 61.4 square kilometres.

Duck Creek and Duck River have recently had flood models prepared and A’Beckett’s Creek Flood Study and FRMS&P is currently in progress and scheduled for completion in the near future. As such, these tributaries are excluded from this study and so the resulting Study Area for this assessment is 51 square kilometres.

2 Approach

The Parramatta River Flood Study was prepared using existing data provided by City of Parramatta Council as the basis for the hydrologic and hydraulic models. These models have been reviewed, amended and extended as appropriate to include additional collected data for this study or to refine the models to suit the objectives of the study.

A review of available information (**Section 3**) considered previous flood study models and reports, rainfall and streamflow gauge data, tide information, available survey, hydraulic structures and historical flood observations. Additional data collection was undertaken (**Section 4**) through stakeholder liaison, site visits, rainfall and streamflow gauge data acquisition, additional survey of bathymetry and hydraulic structures and community consultation to obtain community experiences of flooding.

This data was used to develop a detailed XP-RAFTS hydrologic model that covered the entire Parramatta River catchment, and the seven defined TUFLOW hydraulic models covering the Study Area. The Tuflow models developed have been based on modelling the Main Parramatta River Channel and an additional 6 major tributaries identified within the area highlighted in **Figure 1-2.**

The XP-RAFTS hydrologic model was developed firstly by rectifying several issues pertaining to the existing models provided by City of Parramatta Council and models updated to reflect present day catchment conditions. The existing hydrologic models were then consolidated into one large model representing the entire Parramatta River catchment.

The hydrology model was then calibrated and validated to the historic events that occurred in April 1988, April 2015, and June 2016. Once calibrated, the hydrology model is used to produce flow hydrographs for design flood events which are used as inputs for the hydraulic model. The development of the hydrologic model is detailed in **Section 5**.

The scope of the study included updating the hydrologic model in accordance with the Australian Rainfall & Runoff 2019 (ARR2019) Guidelines. The approach adopted is the ensemble in hydrology, mean in hydraulics approach as outlined in OEH *Floodplain Risk Management Guide: Incorporating 2016 Australian Rainfall and Runoff in studies* (NSW OEH, 2019). The model was run for an ensemble of 10 temporal patterns for each event and duration. The appropriate temporal pattern and critical duration for each AEP design event was determined. The ARR2019 hydrology methodology is detailed in **Section 6.1 and Appendix E**.

The model flows were also validated and further adjusted for the 1% AEP event against a Flood Frequency Analysis of historical gauged peak flows at Marsden Street weir described in **Section 5.4.3** and **Appendix B**. In general, ARR2019 design event flow estimates for 1% and 2% AEP are lower than estimated by the FFA and hence sensitivity testing was undertaken with differing IFDs and temporal pattern combinations to determine if alternate methods could lead to higher flow estimates. Following sensitivity testing, it was determined that a recalibration of the ARR19 IFD was required for the 1% AEP event to match the FFA outcomes and that this recalibration was to be further applied to both the 1% AEP and the Climate Change assessment (RCP8.5, 2150) to be adopted for flood planning level definition. Design flood estimation is detailed in **Section 6**.

A 1D/2D TUFLOW hydraulic model was then created using existing data provided by City of Parramatta Council and additional data collection. This included aerial photographs, ALS data, bathymetric survey, survey of hydraulic structures, and Council's stormwater drainage network. The hydrologic model flows were input to the hydraulic model, which was also calibrated and validated to the three historic events. The development of the hydraulic model is detailed in **Section 7**.

Model setup for both the hydrology and hydraulic models have considered future use of the models and future stages of the floodplain risk management process.

The calibrated and validated hydraulic model was then used to simulate a range of design flood events (FFA calibrated 1% AEP, standard ARR design 0.5%, 0.2%, 2%, 5%, 10%, 20%, 50% and 63% AEP Storms) and the Probable Maximum Flood (PMF) as well as half-PMF events along the Parramatta River/Toongabbie Creek main channel and the tributaries and overland flow areas within the Study Area. Sensitivity Analysis of input parameters and model scenarios along with Climate Change scenarios was also undertaken. Model Scenarios are outlined in **Section 9** with a summary of outcomes to be provided in Table 2-1.

Table 2-1 Models and Outcomes

Design Storms (AEP %)	Storms (ARI) Full Analysis		Model Results Only
	Full Analysis Storms – with Mapping	Full Analysis Storms – No Mapping	Results only Storms
FFA calibrated 1% (ARR19 Blockage)	X		
2		X	
5 (ARR19 Blockage)	X		
10			X
20		X	
50			X
63			X
0.5			X
0.2			X
50% of PMF			X
PMF	X		

Note that the concept of full analysis storms is expected to include assessment of all durations ranging from 15min to 36 hours for the required Design storms however current assessment has been done to review all storms and to select the critical durations that create the peak flood levels about the catchment. Mapping has been provided for the critical duration events as required.

Modelling was also undertaken to consider the blockage of key cross drainage structures and culverts (1D structures) within all models in accordance with ARR19 recommendations for the FFA calibrated 1% AEP and the climate change event required for FPL definition.

Results of the modelling have been processed and the following maps and outputs produced:

- Peak water level and depth
- Velocity
- Hazard Vulnerability Classification
- Hydraulic Categories
- Flood Risk Precincts
- Flood Profiles
- Flood Planning Areas
- Sensitivity Analysis
- Climate Change Scenarios
- Emergency Response Maps

The hydraulic modelling results and analysis of these results are presented in **Section 10**.

The modelling approach, model setup, parameters and results and the study outcomes have been peer reviewed by an independent consultant on behalf of Council.

3 Background and Review of Previous Information

This section outlines the information review of all background hydrologic and hydraulic data provided by City of Parramatta Council. The review collated information and determined its source, accuracy and suitability for use in this study as well as identifying data gaps. This includes previous Flood Studies, hydrologic models and hydraulic models. Any additional data required for the Flood Study was identified and obtained. This includes rainfall data, streamflow data, additional bathymetric survey and survey of hydraulic structures.

3.1 Existing Studies & Reports

3.1.1 Flood Studies and Floodplain Risk Management Studies & Plans

Several previous studies and assessments have been undertaken within the Parramatta River catchment. Some of these studies have been summarised and reviewed in a literature survey undertaken by Molino Stewart (February 2014). These studies are shown in **Table 3-1**. Other relevant studies that have not been specifically reviewed by Molino Stewart (February 2014) are identified in **Table 3-2**.

Table 3-1 Previous Studies Reviewed by Molino Stewart (2014)

	Study	Author	Date
1	Upper Parramatta River Catchment Floodplain Risk Management Study	Bewsher Consulting Pty Ltd	2003
2	Lower Parramatta River Floodplain Risk Management Study- Flood Study Review	SKM	2005
3	Lower Parramatta River Floodplain Risk Management Study and Plan- Volume 1- Main Report (2005)	SKM	2005
4	Lower Parramatta River Floodplain Risk Management Study and Plan- Volume 2- Planning (2005)	SKM	2005
5	Draft A'Becketts Creek Drainage Master Plan	GHD	2009
6	Duck River and Duck Creek Flood Study Review	WMA Water	2012
7	Duck River Catchment Floodplain Risk Management Study	Molino Stewart Pty Ltd	2012
8	Duck River Catchment Floodplain Risk Management Plan	Molino Stewart Pty Ltd	2012

Table 3-2 Other Relevant Studies (not mentioned in Molino Stewart, 2014)

	Study	Author	Date
1	A'Becketts Creek SWC No.46 Catchment Management Study – Volume 2	Bewsher Consulting Pty Ltd	1990
2	A'Becketts Creek- Revision of Flood Levels as a Consequence of the Duck Creek SWC No.35 Catchment Management Study	Water Board	1993
3	Terrys Creek Sub catchment Management Study	Cardno Willing	2005
4	Clay Cliff Creek Catchment Master Drainage Plan	Cardno Willing	2007
5	Eastwood and Terrys Creek Floodplain Risk Management Study and Plan (For Ryde Council)	Bewsher Consulting Pty Ltd	2008
6	Upper Devlins Creek Catchment Drainage Master Plan	Cardno Willing	2009
7	NSW Urban Flood Levee Review – Channel Street	Parramatta City Council	2013
8	NSW Urban Flood Levee Review – Edison Parade	Parramatta City Council	2013
9	NSW Urban Flood Levee Review – Peter Parade	Parramatta City Council	2013
10	Flood Control Study for Rosehill/Camellia	SKM	2013
11	Rydalmere Knowledge Precinct Flood and Development Control Study	SMEC	2013

These studies were reviewed in conjunction with their associated hydrologic and hydraulic models; a review of these models is outlined in **Section 3.2** and **Section 3.3**.

3.1.2 Tidal Levels

The following information regarding the tailwater level adopted in the *Lower Parramatta River Flood Study Review* (SKM, 2005) was found to be relevant to the this flood study.

> *"In this study, downstream boundary was defined by observed tides. The amplitude of the tide used in this study is about 0.6m. A higher amplitude tide was not used as it would have resulted in a joint probability that would have exceeded the probability of the flood flow being considered. However, in the DS parts of the Parramatta River, the Peak flood levels are controlled by the extreme flood level and not the flood flow level. To allow for this, the longitudinal profile of flood levels, from Charles Street Weir to Ryde Bridge was truncated when the flood level dropped to 1.42m AHD, about 3km US of Ryde Bridge. The High Tide of 1.42m was assessed as the 1% AEP using a frequency analysis. The level of 1.42, was assessed as the 1% AEP using a flood frequency analysis."*

A Frequency Analysis of High Tides undertaken by SKM (2005) at Fort Denison is shown in **Table 3-3**. A tide level of 1.42 mAHD was adopted for the 1% AEP event and was used as the downstream flood level in determining peak flood levels for the Lower Parramatta River.

Table 3-3 Frequency and Magnitude of High Tide at Fort Denison (SKM, 2005)

Exceedance Probability (% AEP)	Tide Level (mAHD)
20%	1.27
5%	1.34
2%	1.39
1%	1.42

NSW Floodplain Risk Management Guide - Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways (NSW OEH, 2015) provides advice on recommend boundary scenario that can be used to derive ocean boundary conditions and design flood levels for flood investigations in coastal waterways considering the interaction of catchment flooding and oceanic inundation for the various classes of estuary waterways found in NSW and likely corresponding ocean boundary conditions.

The guide provides design Ocean water level Boundary Scenario for Fort Denison in Sydney Harbour as shown in **Table 3-4**.

Table 3-4 OEH recommended Tidal Boundary Scenaio for Fort Denison (source Table 5.1 NSW OEH, 2015)

Catchment Flood Scenario Exceedance Probability (% AEP)	Ocean Water Level Boundary Scenario
1 Exceedance per year	HHWS(SS)
10 %	HHWS(SS)
2 %	5% AEP
1 %	5% AEP
PMF	1% AEP

A study for Sydney Coastal Councils & CSIRO (2012) provides design water levels at Fort Denison for a range of average recurrence intervals (ARI), as shown in **Table 3-5**. The source of data for the water levels for the Year 2010 is from Watson and Lord (2008), and the water levels for Year 2050 and Year 2100 was extracted from the NSW Coastal Risk Management Guide (NSW Government, 2010).

Table 3-5 Sydney Coastal Councils & CSIRO Design Still Water Levels for Sydney Harbour

ARI (years)	Water Level (mAHD)		
	Year 2010	Year 2050	Year 2100
0.02	0.97	1.31	1.81
0.05	1.05	1.39	1.89
0.10	1.1	1.44	1.94
1	1.24	1.58	2.08
5	1.32	1.66	2.16
10	1.35	1.69	2.19
20	1.38	-	-
50	1.42	1.75	2.25
100	1.44	1.78	2.28
200	1.46	-	-

The adopted tailwater levels for the study are discussed in Section 9.2.

3.2 Existing Hydrologic Model Data

Several hydrologic models were prepared for previous studies using XP-RAFTS modelling software. These hydrologic models were provided to Stantec, along with their associated studies where available (refer **Table 3-6**).

Table 3-6 Existing XP-RAFTS Models within the Parramatta River Catchment

	Catchment	Study	Author	Date
1	Upper Parramatta River (Draft 8 and Draft 9)	No report provided – LLS Report cannot be located	UPRCT	Approx. 2009-2010
2	Lower Parramatta River	Floodplain Risk Management Study – Flood Study Review	SKM	2005
3	Duck River	Duck River and Duck Creek – Flood Study Review	WMA Water	2012
4	Duck Creek			
5	A'Becketts Creek			
6	Vineyard Creek	Vineyard Creek Sub-Catchment Management Plan	SMEC	2004
7	Subiaco Creek	Subiaco Creek Sub-Catchment Management Plan	SKM	2006
8	Terrys Creek	Terrys Creek Sub-Catchment Management Study	Cardno	2005
9	Upper Devlins Creek	Upper Devlins Creek Catchment Drainage Master Plan	Cardno	2009

Prior to consolidating the separate models, a detailed review of each model and its adopted parameters was undertaken to determine their suitability for usage in the Parramatta River Flood Study.

3.2.2 Review of Hydrology Models

An initial data review of the abovementioned XP-RAFTS models was undertaken during Stage 1 of the Flood Study, and the following issues were identified in **Table 3-7**:

Table 3-7 Previous Hydrology Model Issues

Location	Issue Identified
Lower Parramatta River	• Subiaco Creek and Vineyard Creek models were not geo-referenced
Duck Creek, Duck River, Lower Parramatta River and Subiaco Creek	• Models required trimming such that only nodes representing the relevant watercourses were included
Duck Creek, Duck River, Lower Parramatta River and Vineyard Creek	• models had discrepancies between the sub-catchment areas as modelled in XP-RAFTS, and its associated GIS sub-catchment polygons;
Duck Creek and Duck River	• models had missing or overlapping sub-catchment areas

These issues were addressed as part of developing the consolidated hydrologic model, as outlined in **Section 5.2**.

3.2.3 Review of Rainfall Losses

The UPRCT Draft 8 and Draft 9 XP-RAFTS models adopt the Australian Representative Basins Model (ARBM) loss model to represent rainfall losses in the hydrologic model. All other hydrologic models had adopted the Initial Loss/Continuing Loss model.

Table 3-8 shows the key ARBM parameters adopted in the UPRCT Draft 8 model along with Typical ARBM Parameters for Canberra Catchments quoted in the XP-RAFTS Reference Manual. The only default parameters given are for Impervious Storage (CAPIMP): 0.6 – 1.2 mm for gentle to steep slopes and 1.2 – 1.5 mm for flat slopes. Parameters in bold are the most important, according to the Manual.

Table 3-8 ARBM Loss Model Parameters Adopted in the UPRCT Model (Draft 8)

Parameter	Typical Parameters*	UPRCT Model (Draft 8)
Impervious Storage Capacity (CAPIMP, mm)	0.5	1.2
Initial Impervious Storage (mm)	-	0
Interception Storage Capacity (ISC, mm)	**1.0**	**1.0**
Initial Interception Storage (mm)	-	0
Depression Storage Capacity (DSC, mm)	**1 - 5**	**1.0**
Initial Depression Storage (mm)	-	0
Upper Soil Storage Capacity (USC, mm)	**12.5**	**12.5**
Initial Upper Soil Storage (US, mm)	-	5.7
Lower Soil Storage Capacity (LSC, mm)	**12.5 - 200**	**60**
Initial Lower Soil Storage (mm)	-	34.7
Initial Groundwater Storage (mm)	-	0.055
Dry Sorptivity (S_0)	**4.5 - 10**	**15.85**
Saturated Hydraulic Conductivity (Ko, mm/min)	**0.42 – 1.18**	**1.223**
Lower Soil Drainage Factor (LDF)	0.05	0.05
Groundwater Recession Constant Rate (KG)	0.94	0.94
Groundwater Recession Variable Rate (GN)	1.0	1.0
Proportion Rainfall intercepted by Vegetation (IAR)	0.7	0.7
Max Evapotranspiration Upper Soil (UH, mm)	10	10

Max Evapotranspiration Lower Soil (LH, mm)	10	10
Proportion Evapotranspiration Upper Soil (ER)	0.7	0.7
Ratio potential Evaporation to A class pan	-	0.7

* Extracted from the XP-RAFTS Reference Manual

According to the UPRCT (2004) document:

> *"The loss module used in the Trust's Rafts model is the ARBM module. This module was adopted over the initial/continuing loss module as it allowed for recovery of loss parameters for continuous modelling. The parameters Dry Sorptivity (S_o) and Saturated Hydraulic Conductivity (A) were derived as the average from soil tests carried out at four locations by Jeffery and Katauskas Pty Ltd in the early 90's for the Trust. The report for these tests has since been misplaced. Currently, the adopted values of So and A are to remain unchanged, however, the Upper and Lower Soil Capacities can be adjusted for calibration purposes".*

Noting that $A = \frac{K_0}{2.8}$

The parameters from soil tests are reproduced below in **Table 3-9** :

Table 3-9 ARBM parameters – Results from Field Tests and values adopted in the UPRCT Draft 8 model

	Sorbtivity	Sorbtivity at Zero Moisture Content	Hydraulic Conductivity	Saturated Hydraulic Conductivity	Indicative Top Soil Depth	Indicative Root Zone Depth	Upper Storage Capacity	Indicative Initial Moisture Content	Indicative Lower Soil Zone Depth			Upper Storage Capacity	Lower Storage Capacity	Initial Upper Storage Capacity	Initial Lower Storage Capacity
	mm/ min^0.5	mm/ min^0.5	mm/ mm	mm/ mm	mm	mm	%	%	mm			mm	mm	mm	mm
	S	**So**	**Ko**	**A**		**USZD**	**USC %**	**US (int)**	**LSZD**	**A0**	**A1**	**USC**	**LSC**	**USC (int)**	**LSC (int)**
Cumberland State Forest	11 - 14 12.5	**14.20**	**4.9**	1.75	350	65	37.6	3 - 6 4.5	285	103.11	0.228	**24.44**	**107.2**	**1.1**	
Astoria Park	14 - 15 14.5	**16.71**	**5.0**	1.79	250	35	41.6	4 - 7 5.5	215	177.03	0.163	**14.56**	**89.4**	**0.8**	
Duncan Park	20 - 24 22.0	**26.82**	**2.0**	0.71	200	100	30.6	4 - 7 5.5	100	33.41	1.000	**30.60**	**30.6**	**1.7**	
Northmead Oval	2 - 6 4.0	**5.66**	**1.8**	0.64	80	50	22.2	5 - 8 6.5	30	83.03	1.657	**11.10**	**6.7**	**0.7**	
		63.39	13.7	4.89								80.70	233.9	4.3	
Mean Value		**15.85**	**3.4**	**1.22**								**20.20**	**58.5**	**1.08**	
Adopted Parameters		**15.85**	**3.43**	**1.22**								**12.50**	**60.0**	**7.5**	**40**
Rafts-XP Default		**10.00**		**0.3**								**12.50**	**50.0**	**0**	**0**
Rafts-XP Data Set (as per manual)															
Ref Set		**7.0**		**1.40**								**12.50**	**200.0**		
Dry Grass		**4.5**		**0.42**								**12.50**	**12.5**		
Residential Lawn		**10.0**		**0.84**								**12.50**	**25.0**		
Playing Fields		**10.0**		**1.18**								**12.50**	**25.0**		
Natural Forest		**10.0**		**0.42**								**12.50**	**100.0**		

(Source: Upper Parramatta River Catchment Trust, February 2004)

The UPRCT Draft 8 model parameters were selected to be used as the basis for the consolidated XP-RAFTS model. The ARBM loss parameters were then calibrated using the June 2016 historic event and validated with the April 1988 and April 2015 flood events, as detailed in **Section 5.3**.

3.2.4 Review of Surface Roughness & Impervious Areas

Different Manning's 'n' values were adopted in each of the separate models. A comparison of the Manning's 'n' values adopted for impervious and pervious areas in the separate models is shown in **Table 3-10**. Note that table has been ordered from upstream to downstream.

Table 3-10 Manning's 'n' Values Adopted in Previous Models

Model	Impervious Surface Roughness	Pervious Surface Roughness
UPRCT Model (Draft 8)	0.025	0.045
Lower Parramatta River	0.015	0.025
Duck River	0.015	0.015
Duck Creek	0.025	0.025
Vineyard Creek	0.02 to 0.025	0.025 to 0.15
Subiaco Creek	0.015	0.025
Terrys Creek	0.025	0.033
Upper Devlins Creek	0.025	0.033

A revision of the catchment delineation was undertaken for the consolidated hydrologic model (*refer* **Section 5.2.2**) to ensure that it provides a suitable resolution for defining overland flowpaths and to produce reliable results for the hydraulic model. The revision involved a finer discretisation of the Parramatta River catchment, and therefore was represented by more and smaller sub-catchments.

While the Manning's 'n' values and impervious areas adopted in the separate models were applicable to their respective catchment delineations, the smaller sub-catchments in the consolidated model required a revision of these parameters. This ensures that surface roughness and rainfall losses are modelled reliably.

As such, remote sensing techniques were used to revise the Manning' 'n' values and impervious areas adopted in the consolidated model, which is described in further detail in **Section 5.2.5**.

3.2.5 Review of Detention Basins

There are some 50 basins in the overall catchment of which 10 basins were significant in terms of detailed modelling and model data validation. A list of these basins (upstream to downstream) and their owners is shown in **Table 3-11** and the location of these basins is shown in **Figure 15-3**.

Table 3-11 List of the Significant Basins and Owners

Basin Name	Catchment	Owner
Clunies Ross Street Detention Basin	Greystanes Creek	Blacktown Council
CSIRO	Greystanes Creek	Cumberland Council (formerly Holroyd Council)
Darling Street Park	Pendle Hill Creek	Cumberland Council (formerly Holroyd Council)
Fox Hills	Greystanes Creek	Blacktown Council
Duncan Reserve	Grantham Creek	Blacktown Council
Sierra Place	Upper Toongabbie Creek	The Hills Council
McCoy Park	Toongabbie Creek	City of Parramatta
Loyalty Road	Darling Mills Creek	NSW Local Land Services
Lake Parramatta*	Hunts Creek	City of Parramatta
Brickfield Creek	Brickfield Creek	City of Parramatta (formerly owned by The Hills Council)
Ollie Webb Reserve	Clay Cliff Creek	City of Parramatta

*Lake Parramatta Dam is not a flood mitigation structure

While these significant basins were included in previous models, the model parameters needed to be validated against data to ensure the models appropriately represent these hydraulic control structures.

Survey data and/or 'as constructed' drawings were provided by City of Parramatta Council for three specific areas which provide flood attenuation/detention behaviour:

- Jubilee Park;
- McCoy Park Basin; and,
- Ollie Webb Reserve.

Stantec also used other sources of information to verify the existing basin characteristics in the model. All available data on the priority basins, including drawings, survey, previous reports and fact sheets were collected from related agencies and departments.

A validation exercise was carried out to confirm the stage-storage curves by developing stage-storage curves from ALS data and comparing with the stage-storage relationships in the XP-RAFTS model. The majority of these basins compared well, being within 5% and hence the XP-RAFTS relationships were adopted. Where there was a significant difference, the volumes needed to be confirmed through survey as described in Section 4.5.4.

Many of the basins were also setup using a stage-discharge relationship for the outlet and the dimensions of outlet pipes and spillways was not known.

Where the collected information was not sufficient, site visits and survey were undertaken to gather the required information. Additional survey was required to confirm the discharge characteristics for three basins.

This allowed the basin parameters to be checked and refined including: stage-storage (level-volume) data; outlet structure dimensions and discharge rating curves.

3.3 Existing Hydraulic Model Data

The following datasets were obtained from City of Parramatta Council for review:

- 1m Aerial Laser Survey, 2006;
- Bathymetric survey data;
- MIKE11 hydraulic model data;
- XP-SWMM hydraulic model data;
- TUFLOW hydraulic model data;
- Stormwater drainage network data;
- Drawings of hydraulic structures; and,
- Survey data of detention basins.

The above datasets are discussed in the following sections.

3.3.1 Review of ALS Data

Airborne Laser Scanning (ALS) survey data for the Parramatta River catchment was provided in 1-metre resolution. While the ALS data is generally suitable for hydraulic modelling within the study area, some channels were not represented accurately. The ALS data appears to have detected the standing water surface along some watercourses and would therefore cause an underestimation in flow conveyance capacity. For these areas, bathymetric survey or other channel bed data (such as cross-section data from the UPRCT MIKE11 model) is more suitable.

The ALS terrain is shown in **Figure 15-6**.

3.3.2 Review of Bathymetric Data

Stantec previously undertook a bathymetric survey of a portion of the Parramatta River for the *Sydney Harbour Ecological Response Model* (Cardno, 2015), which was prepared for the Greater Sydney Local Land Services (LLS). The extent of the bathymetric data relevant to this Flood Study spans from Cumberland Hospital to the downstream limits of the hydraulic model. The data has a point spacing of 8 meters longitudinally, and 4 metres perpendicular to the direction of river flow.

The Sydney Harbour Ecological Response Model Report (Cardno, 2015) states that:

> *"The bathymetric information was derived mainly from AUS Charts 201, 202 and 203. Other data provided by NSW government departments for previous investigations has also been included in the model system, namely: -*
>
> - *Bathymetric data on a 50m grid provided by Leichhardt Municipal Council (circa 2009)*
> - *LIDAR data of Parramatta River, creeks, Lane Cove River and Middle Harbour data provided by Hawkesbury-Nepean Catchment Management Authority (2012 & 2013).*
>
> *This data was combined to form a comprehensive Digital Elevation Model (DEM) of Sydney Harbour, Including Parramatta River. All data was converted to Australian Height Datum (AHD)."*

AUS charts and information gathered by depth sounding form the basis of level information in the river area. The level information in the 'dry' area (i.e. land areas) has been formed using LiDAR. To link the two datasets, survey was undertaken in the intertidal region.

AUS charts have been developed and are maintained by the Australian Hydrographic Service. The data source for the AUS charts associated with this study area are Maritime Services Board surveys to 1982 and R.A.N surveys to 1983. As survey data is supplied to the Australian Hydrographic Service, data is validated and any relevant information is included in the charts. It is difficult to ascertain exactly which survey data is included on the chart as it will have been combined with other sources.

The *Parramatta River Estuary, Data Compilation and Review Study* (Cardno Lawson Treloar, 2008) makes comment on a number of bathymetric surveys undertaken in the Parramatta River Estuary. These surveys are used in place of AUS chart where available as the data is more accurate. Depth soundings were undertaken in 2005 from the confluence with Duck River to Charles Street Weir with very high spatial resolution.

In addition to the 2005 bathymetry survey, a near shore bathymetry survey (river perimeter) was undertaken in 2013 from the Charles Street Weir to Cockatoo Island. For narrow streams (such as Duck River), bathymetry survey was undertaken as several long sections, not just the perimeter.

This component of the data was collected using a narrow beam echo sounder mounted to a kayak. The sounder can collect data at 50 mm resolution logging at intervals of 2 – 5 seconds. GPS coordinates were recorded concurrently to provide a three-dimensional data set.

In addition to the above data, a bathymetric survey produced by the RMS is also available. This data extends from the Church Street Weir to Duck River Outlet. The review of this dataset shows survey contained to the riverbed and does not contain any bank areas. A comparison against the LLS bathymetry data shows good agreement between bed levels, although the LLS dataset provides a more complete dataset.

Therefore, it was recommended the LLS bathymetry survey be used for hydraulic modelling, as it is available in a suitable, co-ordinated format and is in 2D, which will greatly improve stability and accuracy of the model. The 'dry' component of the bathymetry survey will not be used in this Study as this information is already available as part of the 2014 LiDAR.

Permission was granted by LLS to use the bathymetric survey data for this flood study.

3.3.3 Review of MIKE11 Models

As the bathymetric survey is only available for the lower reaches of the Parramatta River, the UPRCT Upper Parramatta River MIKE11 Cross sections were reviewed for suitability for use to model the river in the upper reaches. It is noted that many MIKE11 cross-sections were developed using ALS data, which may not be appropriate.

To determine the validity of the existing MIKE11 cross sections, the cross-section profiles were compared against NSW Land and Property Information (LPI) LiDAR provided by Council and bathymetric survey.

The review of cross-sections within the main channels (Parramatta River and Toongabbie Creek) show the cross-sections to be relatively accurate and suitable for use. Cross-sections for connecting tributaries do show some issues including not representing the channel area below the water surface within the in-bank area and/or a horizontal shift in the section. Some sections did not have appropriate geographic coordination and could not be represented in their correct location which created issues for comparison and would not be accurate for tying in to 2d terrain. Such sections had to be discounted from further use.

For cross sections that show a similar level within the in-bank area to LiDAR, and the watercourse was a dry channel, these sections were deemed suitable. Where the watercourse has water in it and the section matches the ALS, then it is likely the sections may in-fact be showing a water surface level rather than a river bed level. Such sections were noted as candidates for additional survey data collection.

Some locations, where the LiDAR and the MIKE11 cross section profile closely align, the river does contain a rock outcrop of naturally formed weir, suggesting the MIKE11 cross-section is likely to be accurate. This further increases the confidence of the accuracy of the MIKE11 cross-sections.

Where cross-sections appeared to not be suitable, did not extend below the water surface, or the section spacing was too sparse to represent hydraulic features, additional survey was collected.

The MIKE11 cross-sections extend for a significant width outside of the main river channel. Cross-sections have been trimmed to only represent the channel within the in-bank area and the 1% AEP flood extent. ALS is used outside of these locations.

3.3.4 Review of XP-SWMM Models

An XP-SWMM model of Clay Cliff Creek was prepared for the Clay Cliff Creek Catchment Master Drainage Plan (Cardno Willing, 2007). It has been assumed that there have been no changes to the Clay Cliff Creek channel since the preparation of this model as there is no documentation of any upgrades. Site investigation undertaken by Stantec did not identify any major changes to the Clay Cliff Creek channel since the preparation of this model. As such, data extracted from this model was used for the development of the hydraulic model for this Flood Study.

In addition to the above some changes have been observed around Jubilee Park in relation to re-development within the floodplain adjacent to the Sydney Water Channel. This has been reviewed and allowed for in the current model development.

3.3.5 Review of TUFLOW Models

A TUFLOW model of Upper Devlins Creek was prepared for the Upper Devlins Creek Catchment Drainage Master Plan (Cardno Willing, 2009). It has been assumed that there have been no changes to the Devlins Creek channel since the preparation of this model as there is no documentation of any upgrades. Site investigation undertaken by Stantec did not identify any major changes to the Devlins Creek channel since the preparation of this model. As such, data extracted from this model was used for the development of the hydraulic model for this Flood Study.

City of Parramatta Council also provided a TUFLOW model of the proposed Alfred Street Bridge. The new pedestrian bridge (which is being planned for construction, as of October 2019) crosses the Parramatta River, and is located approximately 480 metres upstream of James Ruse Drive Bridge. The Alfred Street Bridge was included in all design event hydraulic models for this Flood Study and was excluded from calibration event models. The updated mainstream flood model did not observe any adverse impacts caused by Alfred Bridge, which is consistent with Council's provided model.

3.3.6 Review of Stormwater Drainage Network

Data for the stormwater drainage network within the City of Parramatta Council LGA was provided. The data contained information about the size and invert levels of most pits and culverts.

For the pits and culverts with missing size and invert level data, an estimate was determined with reference to ALS and bathymetric survey data. The estimated invert level was determined by lowering culvert inverts to ensure that the depth of cover is not less than 450 mm along its entire length.

3.3.7 Review of Hydraulic Structures Data

Drawings for several hydraulic structures were provided by City of Parramatta Council. The drawings that were used in the preparation of this Flood Study include the following:

- Pedestrian bridge south of Elizabeth Street;
- Rings Bridge (O'Connell Street);
- Redbank Road Bridge; and,
- Weir 50m downstream of McCoy Park Basin Outlet.

In addition, some bridge information was sought from Roads and Maritime Services including:

- Silverwater Road Bridge;

- Old Windsor Road Bridge; and
- Briens Road Bridge;

For remaining bridges, additional survey was required to be obtained as discussed in **Section 4.4**.

3.4 Rainfall Data

A total of 88 rainfall gauges were identified within the Parramatta River catchment. This includes both open and closed gauges and pluviometers and daily read stations. A database was prepared to determine the type and range of data available for each rainfall gauge. Rainfall data for gauges that had available and relevant data was obtained for calibration and validation of the hydrologic and hydraulic models, as described in **Section 4.3**. A total of 33 pluviometers had data available for some or all the calibration events and details of these pluviometers are shown in **Table 4-1**. The location of these gauges is shown in **Figure 15-4.**

3.5 Water Level Data

There were 14 water level gauges identified within the Parramatta River catchment. Of these, 4 are water level gauges within basins and 10 are water level gauges on watercourses. A database was prepared to determine the type and range of data available for each gauge. Water level data for gauges that had available and relevant data was obtained, as described in **Section 4.4** and presented in **Figure 15-5** and **Table 4-2**.

3.6 Historic Flood Levels and Observations

Historic flood levels are available through assessment of annual peaks at the water level gauges discussed in Section 3.5, from previous reports and newspaper articles.

Historical flooding has occurred in 1898, 1914, 1956, 1961, 1967, 1969, 1974, 1975 (PWD, 1986). Since this report there has been major flooding in 1986, 1988, 1990, 1991, 1998 and more recently in 2015 and 2016.

Marsden Street Weir gauge (213004) provides the longest continuous data set of water level data and the annual maximum flood series is shown in the following **Table 3-12**. The annual maxima flow series shown is derived from the updated Marsden Street Weir gauge rating curve as discussed in **Appendix B**. Flows are those that occurred at the time of the event with the prevailing catchment conditions, detention basins and in-channel hydraulic structures that were present at the time of the event.

The largest event in the period of recorded water level occurred in April 1988.

The Lower Parramatta River Flood Study Review (SKM, 2005) noted peaks for five ungauged historic events which were of significance and for which there are documented records available, shown in **Table 3-13**. These were reported as estimated flood levels upstream of Lennox Street Bridge. Stantec have estimated the associated peak flood level upstream of Marsden Street Weir and then used a pre-1971 rating curve (prior to construction of Bernie Banton Bridge) to estimate the flow for the given event.

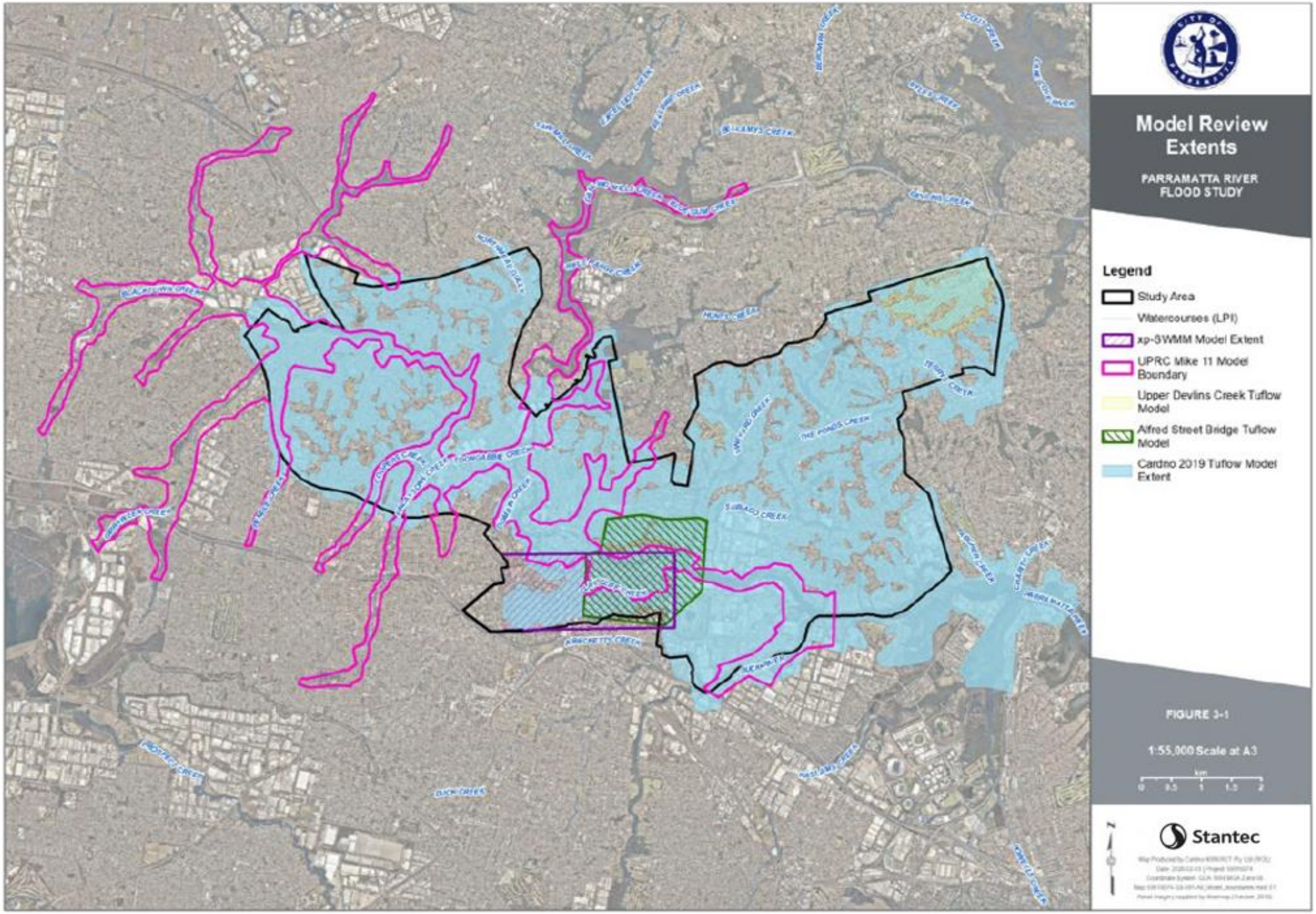

Figure 3-1 Overview of previous model extents reviewed for the Parramatta River Flood Study

Table 3-12 Annual Maximum Flood Series at Marsden Street Weir (gauge 213004)

Year	Gauged Flood Level (m AHD)	Gauged Peak Flow (m^3/s)	Rank (for period of record)
1979	4.794	52.5	31
1980	5.138	108.6	23
1981	5.036	90.8	25
1982	4.811	56.4	30
1983	5.173	114.8	21
1984	5.193	118.5	20
1985	5.304	140.2	17
1986	6.693	505.4	4
1987	5.512	185.1	12
1988	**7.866**	**688.5**	**1**
1989	5.639	215.5	9
1990	6.809	526.9	3
1991	6.943	549.8	2
1992	5.67	223.5	8
1993	5.26	131.3	18
1994	4.893	68.1	29
1995	5.499	182.1	14
1996*[1]	5.55	193.8	11
1997	5.211	122	19
1998	6.083	342.8	7
1999	5.51	184.6	13
2000	5.071	96.8	24
2001	4.704	40.4	34
2002	4.962	78.7	28
2003	5.011	86.6	27
2004*[2]	4.715	41.8	33
2005*[2]	-	-	-
2006*[2]	-	-	-
2007*[2]	-	-	-
2008*[2]	-	-	-
2009*[2]	4.741	45.4	32
2010	5.381	156.1	16
2011	5.021	88.3	26
2012	5.601	206.1	10
2013	5.401	160.3	15
2014	5.171	114.5	22
2015	6.151	362.7	5
2016	6.101	348.1	6

*[1]*Peak flow recorded January 1996, Loyalty Road Basin was commissioned mid 1996*

*[2]*Between 2004 and 2009 gauge not in operation for all or most of the year.*

Table 3-13 Historical Flood Level Observations

Year	Estimated Gauge Height (m)	Estimated Peak Flood Level @ Marsden Street Weir (mAHD)	Estimated Peak Flow @ Marsden Street Weir (m^3/s)
1889	7.9 (US Lennox Bridge, Newspaper)	~ 8.19	~ 747
1914	7.3 (US Lennox Bridge, Newspaper)	~ 7.60	~ 655
1956	6.34 (US Lennox Bridge, PCC)	~ 6.75	~ 516
1961	5.80 (US Lennox Bridge, PCC photos)	~ 6.43	~ 445
1967	6.10 (US Lennox Bridge, PCC)	~ 6.60	~ 487

Observations of flooding documented through photographs and videos were also provided by CoP. Many of these photographs and video documented flooding during the April 1988 and June 2016 events (8 locations), with 3 locations for the June 2016 event as shown in **Figure 15-7**.

These photographs and video were used for model validation as presented in Section 5.3 and **Appendix C**.

4 Additional Data Collection

Additional data was collected where the existing hydrologic and hydraulic data was found to be unsuitable for the preparation of hydrologic or hydraulic models for this Flood Study. Site inspections, bathymetric survey and survey of hydraulic structures were undertaken to ensure reliable information was adopted.

New developments were identified and considered at the time of model development with building outlines reflecting the status of development in the catchment and do include several in progress developments such as Parramatta stadium.

4.1 Site Inspections

Several site inspections have been carried out during the study. These are described below with a selection of photographs from site visits presented in **Appendix A**.

4.1.1 Inception Site Inspection

A site inspection at various locations across the Parramatta River catchment was conducted at the commencement of the project. The site inspection was undertaken on 3 February 2016 to make observations of hydraulic structures and watercourses. The following locations where inspected:

- Parramatta River through the CBD;
- Lennox Bridge;
- Marsden Street Weir;
- Barry Wilde Bridge;
- Ollie Webb Reserve;
- Jubilee Park;
- Various locations along Clay Cliff Creek; and,
- Various locations along Vineyard Creek.

Notable observations at these areas included a low level pipe crossing near the confluence of Brickfield Creek and Parramatta River, immediately downstream of Barry Wilde Bridge. This was not represented in previous models and could create an obstruction to flows and influence flood behaviour.

4.1.2 CBD Bridges Inspections

A further site inspection was undertaken on 17 November 2016 to capture more detail of the bridges and weirs in the vicinity of Parramatta CBD. Inspections of the following bridges and weirs were undertaken:

- Barry Wilde Bridge;
- Charles Street Weir;
- Elizabeth Street Footbridge;
- Gasworks Bridge;
- Lennox Bridge; and,
- O'Connell Street Bridge.

4.1.3 Mainstream Structures and Fences Inspections

On 16 February 2017 Cardno engineers attended a site inspection within the mainstream model boundary to observe features that may impact hydraulic modelling. Fences and obstructions that were derived from aerial imagery were checked to determine if the assumptions made are correct. The determination was made that it would be very difficult to determine if a fence acted as a blockage from aerial imagery.

The following locations were attended:

- Camellia Precinct;
- Harris Park;

- Parramatta Park;
- Westmead;
- Northmead; and,
- Toongabbie.

Key features observed at the above locations were:

- Bridge structures;
- Detention Basins;
- Channel conditions to estimate roughness; and,
- Fences.

Key features and locations are shown in **Figure 4-1.**

4.1.3.1 Camellia Precinct

The Camellia precinct was observed to understand how hydraulic behaviour may be influenced between lots by fences. It was observed that many fences within the precinct are wire / cyclone fences. These will likely have minimal influence on flow other than the potential for partial blockage.

Locations that do contain fences that could influence hydraulic behaviour were recorded.

4.1.3.2 Harris Park

Within the Harris Park suburb fences were observed as mostly either brick fences or wire fence. In some cases, these can appear to be identical when observed from aerial imagery. Where possible, fence types observed on site were adjusted in the model, however, not all areas could be inspected and general assumptions on fence types had to be made for some areas.

4.1.3.3 Wentworthville

Building fences along Hopkins Street in this area were inspected. It was noticed that almost all back fences as well as the side fences between two properties are 1.8m wooden lapped paling fences. Front fences were mostly wire fences which do not need to be modelled as an obstruction. A few low height brick front walls were observed, and in these cases the modelled fences were modified to suit the observations. Generally, the observations were matching the fences set up in the model based on the aerial image.

4.1.3.4 Northmead

Building fences along Northmead Road (within the model boundary) were inspected. Many properties have no front fence but high back and side fences. The observations were matching the fences setup assumptions in the model.

4.1.3.5 Constitution Hill

Building fences along Portadown Road, Keady Way and Charlemont Way were inspected. Almost all back and side fences were high which was matching the fences setup assumptions in the model.

4.1.3.6 Parramatta Park

The main channel through Parramatta Park was observed to record bridge structures. Two structures were identified and made note of.

4.1.3.7 Westmead

Access to Toongabbie Creek was possible at the Briens Road Bridge and at a location approximately 500 m downstream. Observations of the creek informed the adopted channel roughness for the hydraulic model.

Three sample locations were observed to validate the adopted roughness. These locations were:

- Parramatta Marist High;
- Adjacent to Picasso Crescent; and
- Adjacent to Westmead Private Hospital.

It was noted that the location had significant tree canopy cover but minimal undergrowth on the channel banks and within the channel. As such, the roughness values adopted for these locations were adjusted to suit the observations on site, rather than aerial imagery which would assume a much higher value.

A review of fence assumptions was also undertaken at Westmead. Similar to Harris Park, it was observed that the assumptions made for fences from the aerial did not align with site observations in all cases. Fences were updated based on site observations wherever possible, however, not every fence could be inspected.

4.1.3.8 Bridges

The following bridges were observed to understand key features that may influence hydraulic modelling and to validate the existing information held on bridges.

> Briens Road
> Hammers Road
> Fitzwilliam Road (Pendle Creek)
> Station Road (Girraween Creek)
> Wisteria Gardens (Domain Creek)
> Oakes Road
> Thackeray Street Pipe/Pedestrian Bridge

4.1.3.9 Basins & Levees

The following detention basins were observed:

> McCoy Park Basin; and,
> Peter Parade Levee.

4.1.4 Finlaysons Creek and Basin Outlet Inspections

Further site inspections were undertaken particularly at Finlaysons Creek on 19 September 2018, to confirm channel roughness, particularly where the concrete section ends, and hydraulic controls, including weirs.

The basin outlets at Loyalty Road Basin and Brickfield Basin were also inspected. The sizes of outlet culverts and openings were measured, along with the confirmation of gauge zero levels. This data was included in the hydrologic and hydraulic models.

4.1.5 Ground-Truthing

Ground-truthing site inspection was carried out with Council staff on 2 May 2019, shown in **Figure 4-1**, to review the flood study model results to confirm hydraulic behaviour at a few locations across the catchment. The areas inspected were:

> Claycliff Creek - including flow paths around Rosehill Woolworths and Results Laser Clinic at River Road W Camellia;
> Parramatta CBD – including Riverbank carpark (closed Feb 2021), Parking in Wentworth Street and Justice Precinct Carpark in Hunter Street. In addition, the status of construction of new developments was inspected;
> Westmead – including Westmead Private Hospital trunk drainage under hospital and Westmead Children's Hospital flow paths;
> Peter Parade Levee;
> Toongabbie – to confirm wall arrangements;
> Old Windsor Road Winston Hills – check pipe and flow path alignment;
> Thomas Williams Reserve – check culvert sizing.

The inspections allowed confirmation of the presence of flow paths under buildings, hydraulic controls that are critical for the model and structures or areas where information needed to be confirmed. The extent and locations of the inspections is shown in **Figure 4-1.**

The model setup was updated as appropriate to reflect the information collected to ensure the model more accurately represented the on-ground features and hydraulic behaviour.

4.2 Bathymetric Survey

The review of bathymetric data discussed in **Section 3.3** indicated that the existing hydraulic data is generally suitable for hydraulic modelling within the study area. However, some channel reaches were identified as having poor quality data and these channels are not accurately represented. The sub-standard data had the potential to underestimate the flow conveyance capacity of these channel reaches such as described in **Section 3.3**. Therefore, additional bathymetric survey was undertaken for portions of the following watercourses:

- Parramatta River;
- Greystanes Creek;
- Milsons Creek;
- Pendle Hill Creek;
- The Ponds Creek;
- Subiaco Creek;
- Terrys Creek; and,
- Vineyard Creek.

This was undertaken as a combination of detailed bathymetric survey in some reaches and cross-section survey. The surveyed extents are shown in **Figure 15-8**.

4.3 Rainfall Data

Rainfall data was required for the historic events that occurred in April 1988, April 2015 and June 2016 in order to calibrate and validate the hydrologic and hydraulic models. A total of 33 pluviometers had data available for some or all of these events. Data for these pluviometers were obtained from Bureau of Meteorology, Manly Hydraulics Laboratory and Sydney Water Corporation. Details of these pluviometers are shown in **Table 4-1**.

Table 4-1 Summary of Rainfall Gauge Pluviometers in the Parramatta River Catchment

Gauge Name	Gauge ID	Latitude	Longitude	Owner	Years of Operation
AUBURN RSL BOWLING CLUB	566082	-33.8602	151.019	SWC	1990-
Baulkham Hills (Eucalyptus CT) (Balcombie Heights)	67109	-33.7678	150.9814	GS LLS	1992-
BAULKHAM HILLS (SWIMMING POOL)	567050	-33.7458	150.991	GS LLS	1990-
BAULKHAM HILLS RESERVOIR	567145	-33.744	150.9871	SWC	Unknown
BLACKTOWN (DOG POUND)	567053	-33.8025	150.901	CMA	1990-
BLACKTOWN BOWLING CLUB	567157	-33.7756	150.9131	SWC	Unknown
CARLINGFORD BOWLING CLUB	566081	-33.7831	151.049	MHL	2001-
CHESTER HILL BOWLING CLUB	566169	-33.8773	150.9963	MHL	2003-
CONDELL PARK RESERVOIR	566096	-33.9189	151.0108	MHL	2001-
CUMBERLAND STATE FOREST (IBM)	567149	-33.7476	151.036	UPRCT	1990-
GREYSTANES (CUMBERLAND GOLF CLUB)	567146	-33.8231	150.941	SWC (UPRCT)	1990-
GUILDFORD	67008	-33.8667	150.9833	BoM	1959-1977
GUILDFORD (PIPEHEAD)	567079	-33.8468	150.9693	MHL	2001-
GUILDFORD (WOODVILLE GOLF CLUB)	566060	-33.8694	150.995	SWC	1999-
HOMEBUSH SP0041 FORMERLY KNOWN AS HOMEBUSH BC	566022	-33.857	151.0812	MHL	2001-
KINGS LANGLEY (NSW SOCCER FEDERATION)	567148	-33.7421	150.945	SWC	1990-
LAKE PARRAMATTA	Unknown	Unknown	Unknown	CoP	Unknown
MERRYLANDS WEST (CANAL ROAD)	567064	-33.8384	150.956	GS LLS	1990-
NORTH EPPING BOWLING CLUB (COMPOSITE)	566083	-33.7537	151.0924	MHL	1990-
North Parramatta (Burnside Homes)	567112	-33.7917	151.018	SWC (UPRCT)	<1992-
NORTH PARRAMATTA (Masons Drive)	567112	-33.7917	151.018	BOM	1984-1992
North Rocks (Muirfield Golf Club)	567111	-33.7672	151.0186	GS LLS	1992-
NORTHMEAD BOWLING CLUB	567104	-33.7822	150.9963	SWC	<1992-
PARRAMATTA (MASONIC CLUB)	566086	-33.8167	151.0142	MHL	1990-
PARRAMATTA REPEATER	566000	-33.8208	151.0056	CMA	<1997-
POTTS HILL RESERVOIR	566036	-33.89358904	151.032667	SWC	1895-
PROSPECT RESERVOIR	567083	-33.8192	150.9127	SWC, BOM	1887-
RYDE PUMPING STATION	566037	-33.8085	151.0907	SWC	1948-
SEVEN HILLS (RADIO FM 103.2)	67110	-33.7861	150.924	GS LLS	1994-
SP0098 AUBURN	566140	-33.8454	151.017	MHL	2001-
TOONGABBIE BOWLING CLUB	567151	-33.7856	150.95	SWC (UPRCT)	1990-
WESTMEAD HOSPITAL REDBANK RD	567111	-33.7997	150.9894	MHL, GS LLS	2001-
WS201 SEVEN HILLS	567171	-33.7612	150.959	MHL	2001-

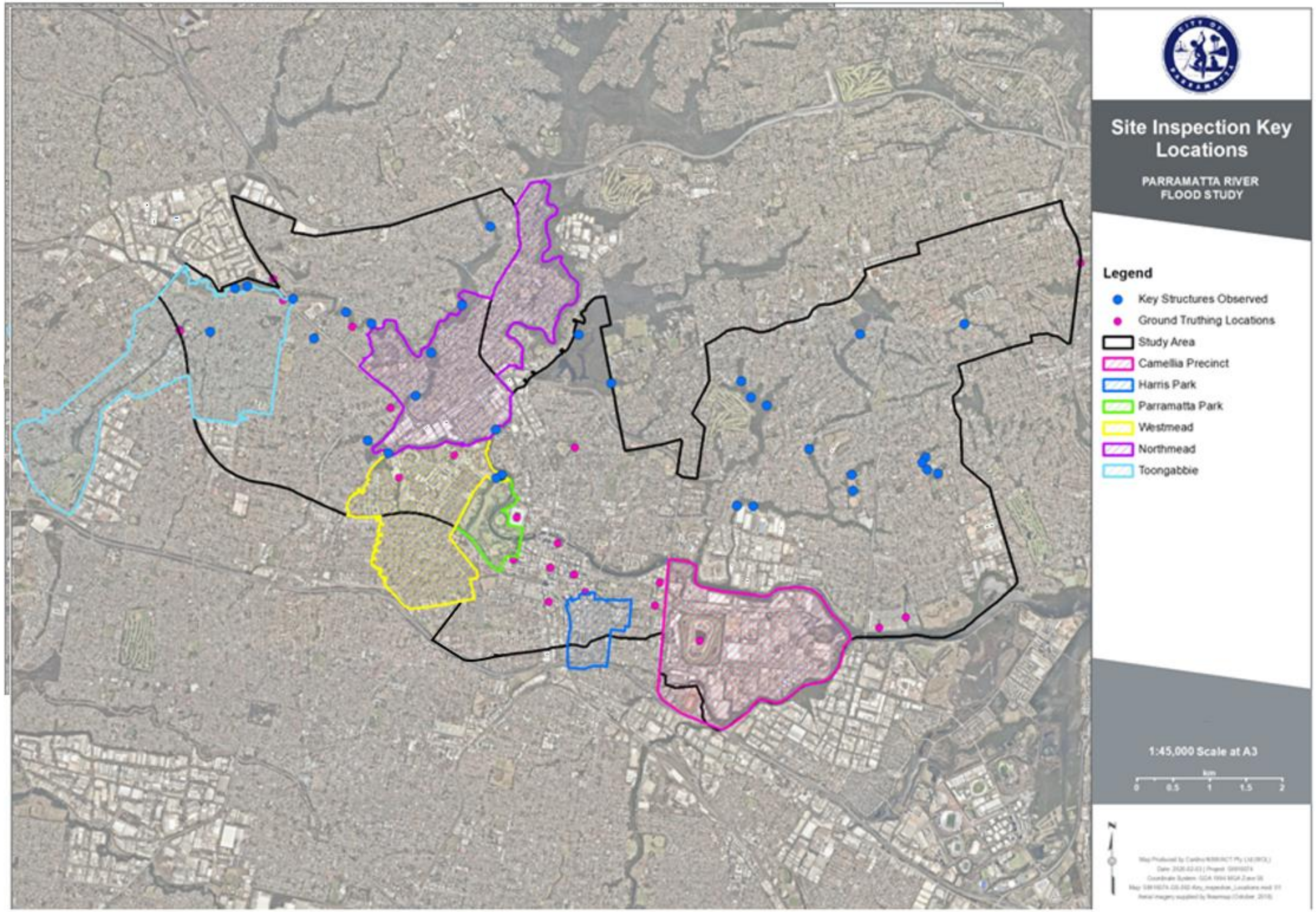

Figure 4-1 Site Visit and Ground Truthing Key Locations

4.4 Water Level and Streamflow Data

A total of 15 water level and streamflow gauges were identified to be relevant to this Flood Study. Historic water level data for these gauges was acquired from their respective owners, as well as rating curves where available. Details of these gauges are shown below in **Table 4-2**.

Table 4-2 Summary of Water Level and Streamflow Gauges in the Parramatta River Catchment

Gauge Name	Gauge ID	Latitude	Longitude	Owner	Years of Operation
Blacktown Creek at Int. Peace Park	567109	150.93	-33.77	BCC	2011-
Darling Mills Creek at Loyalty Road Basin	567072	151	-33.78	CMA	2000-
Darling Mills Creek at Nth Parramatta Viaduct	567057	151	-33.8	CMA	1990-
Duck River at the Steps	213209	151.02	-33.84	SWC/CoP	2011-2012
Hunts Creek at Lake Parramatta	-	-	-	CoP	Approx. 2008 -
Model Farms Creek at Sierra Place Basin	567094	150.96	-33.75	CMA	2004-2012
Parramatta River - Riverside Theatre	2134120	151	-33.81	CoP/MHL	Approx. 2014 -
Parramatta River at Cumberland Hospital	213282	151	-33.81	AWT/SWC	1992-2005
Parramatta River at Marsden Street Weir (at Parramatta Hospital)	213004	151	-33.81	NOW (To 2004) CMA (to present)	1979-
Parramatta River at Silverwater Road Bridge	213435	151.05	-33.81	MHL	2012-
Toongabbie Creek at Briens Road, Northmead	567074	150.98	-33.8	NOW	1979-present
Toongabbie Creek at Johnstons Bridge	567058	150.98	-33.78	CMA	1992-
Toongabbie Creek at McCoy Park Basin	-	150.95	-33.77	CoP	approx. 2013 -
Toongabbie Creek at Redbank Road	567056	150.99	-33.8	CMA	1990-

4.5 Survey of Hydraulic Structures

The existing data provided by City of Parramatta Council included the stormwater drainage network and design or 'as constructed' drawings of some hydraulic structures. However, there was limited data available and some of this data was found to be unsuitable or had missing information. Therefore, additional survey was undertaken for structures where dimensions and levels could not be verified and were used in the preparation of the hydrologic and hydraulic models.

There are many bridges and culverts located within the Parramatta River catchment and many were modelled in previous MIKE11 models provided to Stantec by Council. Bridge data from the MIKE11 model was extracted and, where suitable, converted for usage in the hydraulic model.

An additional 190 hydraulic structures were surveyed for this study to March 2018. The types of surveyed structures are shown in **Table 4-3**. The location of the surveyed hydraulic structures is shown in **Figure 15-9**.

Table 4-3 Additional Survey of Hydraulic Structures

Structure Type	Quantity of Structures Surveyed
Bridges	109
Culverts	64
Detention Basins	3
Weirs	14
TOTAL	**190**

4.5.2 Bridges

Where MIKE11 bridge information was not suitable for usage, a detailed on-site survey was taken by surveyors from Stantec and OPUS. The bridge survey data included all footbridges, above-ground pipe crossings and road bridges that were relevant to the hydraulic behaviour.

4.5.3 Culverts

Detailed ground survey was conducted by OPUS and Stantec to obtain reliable data for some of the outdated culverts in the model where data was missing or could not be verified.

4.5.4 Detention Basins

Additional survey was undertaken for three detention basins to confirm their storage volume and outlet configuration:

- Brickfield Creek Basin (topography and outlet structures);
- Darling Street Basin (topography and outlet structures); and,
- Loyalty Road Flood Retarding Basin (embankment and outlet only).

The location of the surveyed structures is shown in **Figure 15-9**.

4.5.5 Weirs

Additional survey was undertaken for the following weirs:

- Charles Street Weir;
- Marsden Street Weir;
- Kiosk Weir;
- Flat Stones Weir;
- Weir at Blacktown Creek, upstream of McCoy Park Basin;
- Weir at Toongabbie Creek, near Blackhousia Bushland Reserve;
- Redbank Road Weir;
- Weir at Toongabbie Creek, upstream of Briens Road Bridge;
- Weir at Toongabbie Creek, downstream of Briens Road Bridge;
- Weir at Toongabbie Creek, 500m downstream of Hammers Road Bridge;
- Two weirs at Domain Creek, in Wisteria Gardens; and,
- Weir at an unnamed tributary of Vineyard Creek, north-west of the Oatlands Golf Club.

The location of the surveyed structures is shown in **Figure 15-9**.

4.6 Community Consultation

Community and stakeholder engagement were conducted to obtain information about historical flooding events that the community have experienced and to gauge the level of flood awareness within the community. A newsletter containing information about the Parramatta River Flood Study and details of the online survey were distributed to the community via mail or electronically.

Stakeholder consultation was conducted through letters sent to multiple agencies, councils, and engineering consultancies, seeking their input and requesting relevant information. This extensive outreach included engagement with eight state agencies, namely OEH, BoM, SES, Sydney Waters, TfNSW, NSW Office of Water, and NSW Public Works. Additionally, communication was initiated with 14 councils and eight engineering consultancies. These stakeholders were specifically targeted due to their expertise and involvement in areas related to the project. The purpose of this consultation was to gather valuable insights, data, and perspectives from a diverse range of stakeholders to inform the decision-making process and ensure comprehensive analysis and planning.

The community survey was made available via an online survey platform between 17 September 2018 and 18 January 2019, and data was collated and analysed by ORIMA Research. The survey relied on households and businesses voluntarily accessing the survey via the City of Parramatta Council's website.

At the end of the consultation period, a total of 264 responses to the community survey were received. Based on an approximate 23,000 flood affected properties in the LGA, this reflects an approximately 1% response rate from the community. Of the response received, a total of 190 flood experiences were recorded. There were also 90 photographs that were submitted.

The community recalled April 2015 and June 2016 as the most severe flood events experienced in the City of Parramatta. Responses of flood experiences were focussed around:

- Parramatta CBD and Parramatta CBD Foreshore area;
- Toongabbie - behind Chanel Street levee at Pendle Creek and Toongabbie Creek confluence downstream of McCoy Park Basin;
- Vineyard Creek catchment - Oatlands and Dundas near Kissing Point Road;
- The Ponds Creek catchment - Dundas near Bennetts Road

Other areas which also had flood observations include:

- Constitution Hill – Coopers Creek catchment
- Westmead – Finlaysons Creek
- Rosehill – Clay Cliff Creek
- Winston Hills – Northmead Gully catchment

The common issues raised by the community in their responses were:

- Flood impacts disrupting daily household routine and work;
- Concerns about over development of home units from developers;
- Concerns about a lack of stormwater management; and
- Concerns that debris is blocking waterways at creeks and stormwater drainages.

Furthermore, there were only 4% of respondents who have implemented Flood Plans for their properties and businesses. It is recommended that further education, consultation and flood advice are required in order to continue to raise flood awareness to the community.

The report documenting the community consultation process, questionnaire and community responses are provided in **Appendix P**.

4.7 Public Exhibition

The City of Parramatta conducted a six-week public exhibition of the Draft Parramatta River Flood Study, which concluded on October 30, 2023. The study elicited a total of 264 responses from the community survey. Certain feedback from individual responses necessitate thorough analysis and will be issued to each resident by Council separately. In the meantime, please consult the table below for frequently asked questions (FAQs) in **Table 4-4**.

Table 4-4 Draft PRFS Public Exhibition FAQs and Response

FAQs Item	Community Consultation Questions	STANTEC Responses
1	I have observed flooding on my property before, but the current study does not show any flood extents at my property.	Please be aware that flood management necessitates a nuanced approach, considering various types of flow and their implications. It involves defining different flood types, their severity levels, and identifying appropriate flood control measures tailored to specific sites. The draft PRFS results only depicts creek/riverine mainstream floods and overland areas affected by mainstream backwater and significant overland flow water way. These are subject to comprehensive flood planning controls. Conversely, residents may encounter shallow local overland flow scenarios characterised by rapid rise and swift movement of water, followed by quick recession. These scenarios necessitate setting minimum standards for residential floor heights and integrating freeboard considerations into developments to mitigate flooding impacts on adjacent properties, but these type of flood may not meet the criteria for inclusion in the Flood Planning Level (FPL) flood mapping, thus not make into the flood mapping. Please review the updated FPL plot, which illustrates the shallow depth of localized overland flow, aligning closely with the observations, which are subjected to different flooding control requirements.
2	I have been living at my property for a long time, during 1% AEP events and have never observed flooding at my property. Why does the study show flood extents within my property?	Please note that a 1% Annual Exceedance Probability (AEP) does not directly translate to residents experiencing a flood once every 100 years. In the updated flood model for the Parramatta River Flood Study, Stantec has achieved a significant improvement in accuracy. This is evidenced by a strong correlation between the inflow nodes in the XP-RAFTS model and significant overland flow paths, with rainfall on grid assessment conducted separately. Additionally, Stantec expanded the modelling of pipe networks beyond the previously established DN600 diameter cutoff, thereby enhancing the representation of overland flow. Furthermore, the adjustments made to inflow have undergone external verification by the external reviewer, WMA Water, and have received approval from the Council, confirming the credibility of our study's findings. The draft PRFS results indicate the categorization of floods into two main types: creek/riverine mainstream floods and overland areas affected by mainstream backwater and significant overland flow waterways. These are subject to comprehensive flood planning controls. The depth of the 1% AEP flooding near the upstream catchment properties is shallow, which may be experienced by residents but recognized as different from conventional riverine flood behavior. Please note that the Flood Planning Level (FPL) has not applied any depth filter and study does not cover the full LGA.

FAQs Item	Community Consultation Questions	STANTEC Responses
3	What causes a property to be identified as flood tagged?	Properties are identified as flood tagged based on their location within areas susceptible to flooding, as defined by flood planning regulations. Floods are categorized into two main types: creek/riverine mainstream floods and overland areas affected by mainstream backwater and significant overland flow waterways. These categories are subject to comprehensive flood planning controls. Specifically, properties are tagged as flood prone if they fall within the Flood Planning Level (FPL). The FPL is determined by various factors, including the 1% Annual Exceedance Probability (AEP) Flood Level, adjustments for blockage according to Australian Rainfall and Runoff (ARR) 2019 guidelines, projections for climate change effects such as an increase in rainfall intensity by 2150, and the addition of a 0.5-meter freeboard.
4	My property was not within the flood extents in the previous study, what has changed since then? (properties at the lower extents of the model)	The new flood study area now encompasses a larger region compared to the previous study, driven primarily by advancements in technology and modelling techniques. In the updated Parramatta study conducted by Stantec, there was a transition from the previous quasi 2D Mike model with 1D sections to a more sophisticated 2D Tuflow model. The previous model's limitations, notably its inability to adequately consider overland flow paths, may have led to some areas being overlooked in terms of flood risk assessment. Additionally, the application of the 2D Tuflow model allowed for a more comprehensive understanding of flood dynamics, including flood storage and overland flow pathways. This enhanced model enabled us to capture a broader range of flood scenarios, resulting in a more accurate depiction of flood extents and potential impacts on properties previously not accounted for. Furthermore, the incorporation of climate change considerations and blockage factors as per the new Australian Rainfall and Runoff (ARR) 2019 guidelines further expanded the scope of the study. These factors were likely not accounted for in previous assessments, contributing to the broader flood extents observed in this flood study.
5	What is the Probable Maximum Flood (PMF), and why is it considered in this study?	The Probable Maximum Flood (PMF) represents the most severe flood event theoretically possible under extreme weather conditions, factoring in precipitation intensity, storm duration, and topographical features to calculate maximum potential flood discharge. Considering the PMF in this study is essential as it serves as a pivotal benchmark for evaluating flood risk and designing resilient flood mitigation measures. By comprehending the potential magnitude of the worst-case flood scenario, planners and engineers can develop infrastructure and policies capable of withstanding such extreme events. Incorporating the PMF into the study enables a comprehensive assessment of flood risk, ensuring robust and effective flood management strategies are implemented to safeguard communities and infrastructure against the most severe flooding events. Additionally, the PMF maintains consistency with the previous study for comparison and

FAQs Item	Community Consultation Questions	STANTEC Responses
		findings and forms the basis for the subsequent Flood Risk Management Study and Plan. Despite its rarity, the catastrophic nature of a PMF underscores its critical importance in flood risk assessment and management.
6	What are the changes in the modelling methods and assumptions since the previous study?	Since the previous study, there have been significant changes in the modelling methods and assumptions. These modifications have resulted in larger flood extents observed in this flood study. The key changes include: The application of blockages as per the Australian Rainfall and Runoff (2019) guidelines: This incorporation of updated guidelines for blockages has influenced the modelling process, potentially resulting in more extensive flood extents. Projection of climate change to meet the current New South Wales Office of Environment and Heritage (OEH) requirements: Climate change projections have been integrated into the modelling process to align with current regulatory standards. These projections may have contributed to the expansion of flood extents. Inclusion of overland flows not considered in the previous study: The current study has expanded its scope to include overland flows, which were not adequately accounted for in the previous modelling. This addition has likely led to the identification of additional flood depths and subsequently larger flood extents. For more detailed information, please refer to the flood study report.
7	Why are the flood extents now wider compared to the previous study?	The wider flood extents observed in the current study compared to the previous one are primarily attributed to the necessity to adhere to the latest guidelines and standards. Several key changes have contributed to this expansion: Firstly, application of blockages as per the Australian Rainfall and Runoff (2019) guidelines has influenced the modelling process, potentially resulting in more extensive surface flood extents. Secondly, the projection of climate change to 2150 RCP 8.5 to meet the current New South Wales Office of Environment and Heritage (OEH) recommendation has been integrated into the modelling process. . Lastly, the inclusion of significant overland flows that were not considered in the previous study has expanded the scope of the current study. As a result of these recent updates, it is possible that your property may now be identified as flood-

FAQs Item	Community Consultation Questions	STANTEC Responses
		affected due to the inclusion of additional flood depths not previously observed.
8	What are the next steps after the flood study? What mitigations will Council be undertaking/what can we do during a flood?	This Flood Study forms the basis for the next stage, which is a Flood Risk Management Study and Plan. This next stage assesses the following in detail; flood damages, high risk hotspot areas (with respect to low/high flood islands, trapped perimeters and other risk criteria), emergency evacuation routes and structural/non-structural mitigation options (property modifications and emergency management). The Flood Risk Management Study and Plan will include these assessments for specific locations throughout the study area.
9	What impacts to future development/my current DA are there now that my property is flood impacted?	Once the flood model is officially adopted, the Flood Planning Level (FPL) will be extracted from the latest model. Affected DAs should be verified and advised with Council's development engineer.
10	Various similar questions about properties outside of the study area (does that mean they are not flood affected, does that mean they are not being considered when they should be, etc)	Properties located outside of the current study area should refer to the currently adopted Council Flood Study for their corresponding location. Council may want to consider combining all models in the future to have a centralised source of information across the LGA.
11	Some general questions around depth/H1-H6 hazard categories, why are low depth areas high hazard, etc	H1-H6 flood hazard categories are a function of depth and velocity outlined in the Flood Risk Management Manual (2023), based on the risk to safe passage of children/the elderly, pedestrians and vehicles. Areas with low flood depth may still be considered as high hazard if the flood velocity is relatively high.
12	What is the flood level for my property?	Once the Flood Study is formally adopted, S10.7 flood certificates may be requested from Council. If related to an affected DA, flood levels should be verified and advised with Council's development engineer.
13	How are the flood levels estimated? How are the flood maps generated?	To estimate flood levels and generate flood maps, a combination of hydrodynamic and hydrological modelling is used, TUFLOW for 2D floodplain and river system simulations with 1D models for urban drainage networks. This approach is refined with hydrological data from XP RAFTS, which simulates how rainfall translates into runoff, feeding into TUFLOW to model various flooding scenarios. The results from these simulations are then imported into GIS software, such as QGIS or ArcGIS, Tuflow model result are merged with other tributary models and spatial data to visualise the potential impact of flooding. This process culminates in the creation of detailed flood maps that illustrate extents, depths, and areas at risk under various conditions.

FAQs Item	Community Consultation Questions	STANTEC Responses
14	The drainage network near my property has been recently improved, why my property is affected on flood maps?	Despite recent improvements to the drainage network near your property, it's essential to note that drainage systems are typically designed for minor storm events. While these enhancements may have improved overall drainage, they may not fully prevent flooding, particularly during significant rainfall or instances of overland flow. Flood maps reflect various factors such as topography and historical data, which can indicate vulnerability to flooding despite drainage improvements. Therefore, the property may still be depicted as flood-affected on flood maps
15	Why are properties on higher ground, including those on steep land, above road levels, or with elevated structures, considered flood-affected, while adjacent or nearby lower-level areas may not be?	Properties situated on higher ground, even those atop steep terrain, above road levels, or featuring elevated structures, may still confront flood-related issues due to several factors such as runoff patterns, inadequate drainage systems, and the overall dynamics of floodplains. Despite their elevated positioning, these properties can remain susceptible to flooding owing to their location along runoff pathways or proximity to rising water bodies. Residents' confusion between river flooding and overland flow flooding underscores the critical need for a clear understanding of flood dynamics. In some instances, properties may experience flooding from upstream overland flow rather than directly from adjacent water bodies, resulting in extremely shallow flooding depths. Despite their elevated nature, these properties could still be at risk due to their positioning within a floodplain, proximity to water bodies, or specific landscape features rendering them vulnerable to flooding. Conversely, lower-lying areas might avoid such designation through effective drainage systems, historical data indicating low risk, or protective landscaping, highlighting the intricate interplay of topographical, hydrological, and infrastructural elements in flood risk assessment. The Overland Flow assessment conducted for this study adopts a broad-based approach that may not fully account for minor terrain variations such as retaining walls, garden beds, or ground obstructions. However, its objective remains focused on using precise parameters akin to those employed in riverine flooding assessments. The adopted overland flow modelling technique strikes a balance between capturing major flood pathways and identifying less obvious yet still pertinent flood risks. This approach, complemented by cross-referencing with rainfall-on-grid modelling, ensures a comprehensive understanding of flood risk dynamics. The study incorporates rainfall-on-grid 1% AEP and PMF modelling results to validate hydrology inflows location, to best represent riverine flooding and its associated backwater effects, along with significant overland flow paths.. This comprehensive approach ensures a nuanced understanding of flood risk dynamics, encompassing both major and minor pathways of water movement. By fulfilling these requirements, the study provides insights to inform Section 10.7 (Private Certificate) planning regulations regarding flood risk assessment and management. While broad-based LOF mapping fulfills fundamental

FAQs Item	Community Consultation Questions	STANTEC Responses
		certification requirements, a more detailed, site-specific flood study may be indispensable for accurately assessing flood risks and addressing specific planning concerns for a DA application. Properties with distinctive features or specific concerns may warrant further targeted flood studies, either as part of future development application processes or updates to flood risk modelling protocols, to proficiently manage flood risk in these areas.
16	How were site levels/contours determined and what determined mapped areas?	Site levels and contours were determined by generating GIS contours using flood results from the Tuflow model, depicting the elevation of the land surface. These contours map the actual extent of flooding within the flood-prone area, encompassing areas affected by riverine floods, overland flow impacted by riverine backwater, and significant overland paths derived from flood simulation results. It is important to note that the flood contour excludes the most upper catchment local depth of flow and only includes results as a broad-based approach to meet the requirements of Section 10.7 (Property Certificate). For detailed information on specific areas, please refer to Appendix L - FPL for polygonised areas.
17	Are flood levels available?	Flood levels within the Parramatta River catchment study area can be determined by interpreting flood contour maps and depth data from the Parramatta River Flood Study (PRFS) report, specifically within its flood depth mapping appendices. Upon formal adoption of these levels by the Council, residents can then officially request specific flood data through the acquisition of a flood certificate.
18	How were hazard levels/ratings determined and what are the thresholds for respective levels?	Hazard levels and ratings were determined according to the Flood Risk Management Manual 2023. The manual's Flood Hazard Category Chart sets thresholds for different hazard levels based on factors like flood depth, velocity. Ratings range from H1 - H6, indicating the severity of flooding. These are generally related to the risks associated with a flood depth and a corresponding flood velocity. Hazard commences with risk to people, children and progresses up to risk to traffic and building structures.
19	Is the street drainage network considered in the model?	Yes Street Drainage have been include in the modelling, however drainage system blockage have been applied in accordance to ARR2019 recommendation

5 Hydrology

The XP-RAFTS hydrologic model for the Flood Study was developed based on the existing UPRCT Draft 8 model along with various tributary hydrologic models. These models were reviewed and any identified issues in the existing hydrologic models were rectified as well as being updated to reflect the current catchment conditions. These hydrologic models were then consolidated into one large model representing the Parramatta River catchment. Further refinements to the catchment delineation were undertaken to ensure that the hydrologic model had an appropriate level of detail, and therefore be suitable for producing inputs for the hydraulic model.

5.1 Existing Models

5.1.1 Existing Hydrologic Models Adopted

A selection of seven hydrologic models was used to develop the consolidated XP-RAFTS hydrologic model of the Parramatta River catchment. Where there was an overlap of the models, data from the latest or most accurate models was used, this sub-catchment delineation can be seen in **Figure 15-2**. The selected hydrologic models are as follows:

- Duck River & Duck Creek Model;
- Lower Parramatta River Model;
- Terrys Creek Model;
- Upper Devlins Creek Model;
- Upper Parramatta River Catchment Trust (UPRCT) Draft 8 Model;
- Subiaco Creek Model; and,
- Vineyard Creek Model.

Further information on the hydrologic models is detailed in **Table 3-6**.

5.1.2 Geo-Referencing Models

Some of the XP-RAFTS hydrologic models provided by City of Parramatta Council were not geo-referenced. Accordingly, all were geo-referenced using the MGA Zone 56 projection to ensure that the separate models could be consolidated accurately.

The A'Becketts Creek XP-RAFTS hydrologic model could not be adopted as it could not be geo-referenced. A GIS layer associated with the model was not provided, and therefore, it was not possible to verify the sub-catchments areas or locations. Data from the UPRCT Draft 8 Upper Parramatta River Model was used to represent A'Becketts Creek catchments instead.

5.2 Model Consolidation

5.2.1 Model Consolidation

The UPRCT Draft 8 Upper Parramatta River model was selected by Council to be used as a basis for the consolidated model. However, some parts of Greystanes Creek, downstream of the CSIRO Basin, were amended in the Draft 9 model using more detailed data and Lidar information. As such, this portion of the Draft 8 Upper Parramatta River model was updated using data from the Draft 9 model.

Unique identifiers were assigned to model nodes and its key parameters to ensure that the model consolidation would not overwrite data. The separate models were then consolidated into a single model of the Parramatta River catchment. **Figure 15-10** shows the sub-catchment boundaries and XP-RAFTS node names of the consolidated model.

5.2.2 Revised Catchment Delineation

The catchment delineation was extensively revised in the consolidated hydrologic model to ensure that its outputs would be suitable for use in the TUFLOW hydraulic model.

In some areas, sub-catchments from two separate models overlapped when combined. These sub-catchment boundaries were modified to ensure that these areas would not be duplicated in the consolidated model. Sub-catchment boundaries in the vicinity of hydraulic structures were also realigned, ensuring the accuracy of flows through hydraulic structures in the hydraulic model.

ALS data with a 1-metre grid resolution was used with the CatchmentSIM software to refine the catchment delineation for the consolidated hydrologic model. The catchments were discretised to a finer resolution (i.e., more and smaller sub-catchments) and then checked against the base survey data to confirm size, shape and location of catchments was appropriate.

The consolidated XP-RAFTS model with the refined delineation of the Parramatta River catchment consists of a total number of 1,426 nodes. This includes nodes representing sub-catchments as well as dummy nodes to combine the flow hydrographs where multiple nodes discharge into a single location.

5.2.3 Vectored Slopes

The CatchmentSIM software uses ALS data to map flow paths every 100 metres around the sub-catchment boundary to the sub-catchment outlet and calculates the average vectored slope. These vectored slopes were then used as input for the consolidated model.

5.2.4 Link Lagging

Hydrograph lagging between sub-catchment nodes in the consolidated XP-RAFTS model was determined using results from a direct-rainfall TUFLOW model of the entire Parramatta River catchment. The direct-rainfall model was developed using the 1% AEP design rainfall derived using ARR87 methods.

The 2-metre resolution ALS terrain data and Council land use maps were used to determine the surface roughness and rainfall losses in the model. The model uses a 2-metre grid cell resolution to accurately represent channels within the Parramatta River catchment.

The average flow velocity along mainstreams within each sub-catchment were extracted from the direct-rainfall TUFLOW modelling results. These average velocities were then used to calculate the lag times for each link in the consolidated XP-RAFTS model.

5.2.5 Surface Roughness & Impervious Areas

Remote sensing techniques were used to delineate land use within the Parramatta River catchment. Each land use was assigned with a Manning's 'n' and impervious area, as shown in **Table 5-1**. The remote sensing data produces a raster grid as shown in **Figure 15-12**, which was used to determine the pervious and impervious areas within each sub-catchment.

For pervious sub-areas within each sub-catchment, all land use data was used to calculate the weighted average Manning's 'n' in each sub-catchment. A Manning's 'n' of 0.015 was adopted for all impervious sub-areas, since the surface roughness of impervious areas (e.g., concrete, asphalt) is unlikely to vary greatly.

Table 5-1 Land Uses and Adopted Manning's 'n'

Land Use ID	Description	Manning's 'n'
1	Buildings	0.025
2	Water	0.030
3	Trees	0.100
4	Grass	0.035
5	Road/Concrete	0.015

5.2.6 Rainfall Losses

The ARBM loss model was adopted as a base for the consolidated XP-RAFTS model. The parameters used in the UPRCT Draft 8 Model were calibrated to the June 2016 event and is detailed in **Section 5.3**.

As mentioned in **Section 3.2.3**, ARR2019 Guidelines have suggested initial/continuing losses and does not specifically support the ARBM loss model. However, due to the history of the hydrology model and the timing of release of ARR2019 guidance, it was decided to continue with using the ARBM loss model.

5.2.7 Detention Basins and Levees

A total of 60 structures (basins, levees, and flood mitigation structures) are represented as retarding basin nodes in the current consolidated XP-RAFTS model.

There are some 50 basins in the overall catchment of which 10 were significant in terms of detailed modelling and model data validation. Three levees were significant in terms of detailed modelling and model data validation. A list of these basins and their owners is shown previously in **Table 3-11**, and the location of these basins and levees is shown in **Figure 15-3**.

While these significant basins were included in previous models, Stantec also used other sources of information to verify the existing basin characteristics in the model. All available data on the priority basins, including drawings, survey, previous reports, and fact sheets were collected from related agencies and departments. This allowed the basin parameters to be checked and refined including stage-storage (level-volume) data; outlet structure dimensions and discharge rating curves; and initial water levels where appropriate.

Where the collected information was not sufficient, site visits and survey were undertaken to gather the required information. Detailed surveys were undertaken during November and December 2017, and were used to define stage-storage relationships, basin outlet details and basin spillway details in the XP-RAFTS model.

5.3 Calibration & Validation

The XP-RAFTS hydrologic model was calibrated and validated using three historic flood events that occurred in April 1988, April 2015 and June 2016, to ensure the reliability of the model layout and its adopted hydrologic parameters.

The model parameters were calibrated to the June 2016 event and validated against the April 2015 and April 1988 events.

5.3.1 Historic Storm Events

The historic storms selected for calibration were determined by firstly collecting rainfall data from the Marsden Weir Gauge. This data was gathered to identify significant historical storm events that occurred in the Parramatta River catchment. The largest storm recorded at this gauge occurred in April 1988, and was in the order of a 1% to 2% AEP event. The storm events that occurred during April 2015 and June 2016 were in the order of a 10% AEP event. Other significant rainfall events were recorded in 1986, 1990 and 1991 and prior to installation of the gauge.

Two events were selected to represent smaller and recent events with present day catchment conditions, and one larger event was selected to ensure the hydrologic model is reliable for a range of storm magnitudes. The selected storms and recorded total rainfall are as follows:

- April 1988 – 341 mm in 48 hours;
- April 2015 – 230 mm in 48 hours; and,
- June 2016 – 264 mm in 48 hours.

The hyetograph for the April 1988 event was extracted from UPRCT data at the Marsden Street Weir gauge (Station 7299, as of April 1988) and is presented in **Figure 15-13**. The hyetographs for the April 2015 and June 2016 events were extracted from Sydney Water at the Northmead Bowling Club (Station 567104) and are presented in **Figure 15-14** and **Figure 15-15**.

5.3.2 Rainfall Gauges & Model Setup

Data for the rainfall gauges that are located within the Parramatta River catchment were collected and reviewed. For each event, all gauge data was reviewed to ensure its suitability and reliability. Some gauges were found to have missing data for some or all of the duration of the historic events, and some gauges did not have data available from data authorities (e.g. Sydney Water). The final set of appropriate gauges were selected and applied for each hydrologic calibration model, as shown in **Table 5-3**. The location of these gauges is shown in **Figure 15-4.**

Thiessen polygons were generated using the gauge locations for each historic event. Rainfall data for each gauge was allocated to catchments nearest to that gauge as determined using Thiessen Polygons which draw polygons with sides equidistant from adjacent gauges. The areas of the model within each of the Thiessen Polygons are therefore closest to the gauge in the centre of the polygon and assumed to have experienced rainfall like that gauge. Hydrology model nodes within each of the Thiessen polygons were assigned with the rainfall data that was associated with its respective rainfall gauge.

The present-day catchment model setup was used as the basis of the calibration and validation events. The hydrology model setup was then adjusted to remove features such as basins which were known to have been constructed after each event to represent the catchment conditions at the time of each event as accurately as possible. All other hydrology parameters were not modified including catchment imperviousness. The XP-RAFTS hydrology model setup with regards to catchment conditions and basins active for each of the calibration events is provided in **Appendix B**.

For the June 2016 and April 2015 events, the current XP-RAFTS model setup is largely representative of these events as these are recent events.

It is to be noted that the following basins were constructed after 1988:

- Loyalty Road Basin was completed in 1996;
- Fox Hills Basin was completed in 1990; and
- Sierra Place Basin was completed in 1990 (and its enlargement in 2001).

As such, the relevant retarding basin nodes in the hydrologic model were switched off in the April 1988 validation model. McCoy Park detention basin was completed in 1984 and was maintained in the model for the April 1988 event. Impervious areas were not adjusted to reflect the catchment conditions in 1988.

5.3.3 Calibration of ARBM Rainfall Losses

5.3.3.1 UPRCT Draft 8 ARBM Loss Values

Since the consolidated hydrologic model was based on the UPRCT Draft 8 XP-RAFTS model, its associated ARBM loss values were used as a starting point for calibration (with the exception of baseflow, which was not switched on for both first or second sub-catchments). These UPRCT Draft 8 ARBM loss values are shown in **Table 5-4**.

The three historic events were simulated using these loss values, and the models produced results that were inconsistent with gauged streamflow and water level data.

Stantec also undertook sensitivity testing of various hydrology model parameters and ARBM parameters to determine the impacts of varying the parameters on peak flows at Marsden Street Weir. This was to determine if the influence of each parameter in matching the peak flow at Marsden Street Weir and the timing and response of the hydrograph including initial losses. This included varying the catchment lag parameter (B), the impervious and pervious area PERN, and the various ARBM loss values.

An analysis of these modelling results showed that inaccurate data was being used at some detention basins which was refined accordingly. As a result, the model was refined and updated and a better match to the calibration events was achieved.

5.3.3.2 UPRCT Draft 9h ARBM Loss Values

Following the testing of the UPRCT Draft 8 ARBM loss values, an unpublished report of the calibration of the UPRCT XP-RAFTS hydrologic model (UPRCT, 2004) was reviewed to determine a suitable set of ARBM rainfall loss values to adopt. From this report, the Draft 9h ARBM loss parameters were selected for modelling, as they had been previously calibrated and adopted (refer Updated Table 12, UPRCT, 2004).

The hydrologic modelling results using the UPRCT Draft 9h loss values were compared against streamflow and water level gauge data for the three historic events, as well as being used as input in the TUFLOW hydraulic model for testing.

5.3.3.3 ARBM Loss Sensitivity Analysis

Using the Draft 9h ARBM loss values as a basis, a sensitivity test was then undertaken to determine the impact of varying values of individual ARBM loss parameters. The values for the following ARBM loss parameters were varied, and the results that it produced are described below:

- Initial upper and lower soil storage – affects the shape of the early portion of the hydrograph, but does not affect the peak flow for the three historic events;
- Dry sorptivity – had insignificant impact on hydrograph shape or peak flows;
- Hydraulic conductivity – had insignificant impact on hydrograph shape or peak flows;
- Constant groundwater recession – insignificant to minimal impact on peak flows; and,
- Baseflow – contributed to significantly larger flow volumes and higher peak flows.

5.4 XP-RAFTS and WBNM Flow Comparison

XP-RAFTS and WBNM are both widely used rainfall runoff models that have been shown to reproduce observed flood events on numerous Australian catchments. There are differences between how some of the processes are represented between the models, but both are just different simplifications of real processes and produce similar results with standard parameters.

During the peer review stage, the independent reviewer constructed a WBNM model which allows for the temporal pattern from different pluviographs to be adaptive assigned to different subcatchments. XP- RAFTS ARR2019 Median TP flows at Marsden Weir have been validated with a separate WBNM hydrologic model and results in Table 5-2, show a close correlation.

Table 5-2 Comparison of FFA, WBNM and XP-RAFTS results

AEP (%)	Adopted FFA Fit - Flow (m^3/s)	WBNM Flow (m^3/s)	XP-RAFTS Flow (m^3/s)
20	263	294	330
10	354	363	397
5	453	454	446
2	598	548	568
1	719	616	610

Table 5-3 Rainfall Gauges Used in Hydrologic Calibration Models for historic flood events

Rainfall Gauge	Gauge Number	April 1988 Model	April 2015 Model	June 2016 Model	Comment
AUBURN RSL BOWLING CLUB	566082	-	✓	-	Missing data for a portion of the June 2016 event
Baulkham Hills (Eucalyptus CT) (Balcombie Heights)	67109	✓	✓	✓	
BAULKHAM HILLS (SWIMMING POOL)	567050	✓	-	-	Data not available for April 2015 or June 2016 events
BAULKHAM HILLS RESERVOIR	567145	-	✓	✓	Data not available for April 1988 event
BLACKTOWN (DOG POUND)	567053	✓	-	-	Data not available for April 2015 or June 2016 events
BLACKTOWN BOWLING CLUB	567157	-	✓	✓	Data not available for April 1988 event
CARLINGFORD BOWLING CLUB	566081	-	✓	✓	Data not available for April 1988 event
CHESTER HILL BOWLING CLUB	566169	-	-	-	All gauge data not available
CONDELL PARK RESERVOIR	566096	-	-	-	All gauge data not available
CUMBERLAND STATE FOREST (IBM)	567149	✓	✓	✓	
GREYSTANES (CUMBERLAND GOLF CLUB)	567146	✓	✓	✓	
GUILDFORD (PIPEHEAD)	567079	-	✓	-	Gauge not operational during April 1988 or June 2016 event
HOMEBUSH SP0041 FORMERLY KNOWN AS HOMEBUSH BC	566022	-	✓	✓	Data not available for April 1988 event
KINGS LANGLEY (NSW SOCCER FEDERATION)	567148	✓	✓	✓	
MERRYLANDS WEST (CANAL ROAD)	567064	✓	-	-	Data not available for April 2015 or June 2016
NORTH EPPING BOWLING CLUB (COMPOSITE)	566083	-	✓	✓	Data not available for April 1988 event
North Parramatta (Burnside Homes)	567112	✓	✓	✓	
NORTH PARRAMATTA (Masons Drive)					
North Rocks (Muirfield Golf Club)	567111	✓	✓	✓	
NORTHMEAD BOWLING CLUB	567104	✓	✓	✓	
PARRAMATTA (MASONIC CLUB)	566086	-	-	-	Gauge not operational during all three historic events
PARRAMATTA REPEATER	566000	✓	-	-	Data not available for April 2015 or June 2016
POTTS HILL RESERVOIR	566036	-	✓	✓	Data not available for April 1988 event
PROSPECT RESERVOIR	567083	-	✓	✓	Data not available for April 1988 event
RYDE PUMPING STATION	566037	-	✓	✓	Data not available for April 1988 event
SEVEN HILLS (RADIO FM 103.2)	67110	✓	✓	✓	
SP0098 AUBURN	566140	-	-	-	All gauge data not available
TOONGABBIE BOWLING CLUB	567151	✓	✓	✓	
WESTMEAD HOSPITAL REDBANK ROAD	567111	✓	-	-	Data not available for April 2015 or June 2016
WS201 SEVEN HILLS	567171	-	✓	✓	Data not available for April 1988 event

5.4.1.2 Calibrated ARBM Loss Values

Following a review of the initial hydrologic and hydraulic calibration modelling results, minor adjustments to the UPRCT Draft 8 and Draft 9h parameters were made to improve hydrograph response and peak flood levels in the XP-RAFTS model. The ARBM loss parameters and other catchment parameters adopted in the UPRCT Draft 8 and Draft 9h Model and for this Flood Study are compared in **Table 5-4** and **Table 5-5**.

Table 5-4 Adopted ARBM Loss Model Parameters for the 2018 Parramatta River Flood Study

Parameter	Typical Parameters	UPRCT Model (Draft 8)	UPRCT Model (Draft 9h)	Parramatta River FS Model (2019)
Impervious Storage Capacity (mm)	0.5	1.2	1.2	1.5
Interception Storage Capacity (mm)	1.0	1.0	1.0	1.0
Depression Storage Capacity (mm)	1 - 5	1.0	1.0	1.0
Upper Soil Storage Capacity (mm)	12.5	12.5	15	12.5
Lower Soil Storage Capacity (mm)	12.5 - 200	60	75	75
Initial Groundwater Storage (mm)	-	0.055	0.1	0.1
Dry Sorptivity	4.5 - 10	15.85	15.85	15.85
Hydraulic Conductivity (mm/min)	0.42 – 1.18	1.223	1.223	1.223
Lower Soil Drainage Factor	0.05	0.05	0.05	0.05
Groundwater Recession Constant Rate	0.94	0.94	0.94	0.94
Groundwater Recession Variable Rate	1.0	1.0	1.0	1.0
Proportion Rainfall intercepted by Vegetation	0.7	0.7	0.7	0.7
Max Evapotranspiration Upper Soil (mm)	10	10	10	10
Max Evapotranspiration Lower Soil (mm)	10	10	10	10
Proportion Evapotranspiration Upper Soil	0.7	0.7	0.7	0.7
Ratio potential Evaporation to A class pan	-	0.7	0.7	0.9
First Sub-catchment Baseflow Multiplier	-	1	0.65	0.65
Second Sub-catchment Baseflow Multiplier	-	Switched off	Switched on; set to zero	Switched on; set to zero

Table 5-5 Adopted Catchment Parameters for the 2018 Parramatta River Flood Study

Parameter	Default Parameter	UPRCT Model (Draft 8 & 9h)	Parramatta River FS Model (2018)
B Factor	1.0	1.0	1.0
Manning's n Impervious	0.025	0.015 - 0.025	0.015 – 0.025
Manning's n Pervious	0.045	0.025 - 0.070	0.025 – 0.1

5.4.2 Calibration & Validation Modelling Results

The hydrologic modelling results are shown in **Appendix C** plotted against the gauged water level data in basins and streamflow gauges for the following events:

- June 2016 event
- April 2015 event; and,
- April 1988 event.

In all three historic events, there is generally a consistent hydrograph shape when comparing the modelled hydrograph and gauged data. This indicates a good catchment response in the hydrologic model. Outcome of model calibration are presented in Appendix C with summary details provided below in **Table 5-6, Table 5-7** and **Table 5-8**

Table 5-6 Calibration results – June 2016 Storm

GAUGE STATION	Gauged Peak WL (mAHD)	TUFLOW Modelled Peak WL (mAHD)	WL Difference (mAHD)	Gauged Flow (m³/s)	TUFLOW Modelled Flow (m³/s)	Percentage (%) Flow Differences	COMMENTS
Toongabbie Creek (JOHNSTONS BRIDGE)	23.59	23.52	-0.06	209.94	195.31	-6.97%	
Toongabbie Creek (BRIENS ROAD)	13.00	13.26	0.26	220.48	195.74	-11.2%	
Toongabbie Creek (REDBANK ROAD)	10.58	10.51	-0.07	262.47	239.05	-8.92%	Gauge data may not be reliable
MARSDEN ST WEIR	6.10	6.18	0.08	349.06	367.17	5.2%	Water level is unstable, may have missed the peak water level.
RIVERSIDE THEATRE	4.80	5.01	0.22	380.72	367.15	-3.56%	

Table 5-7 Calibration results – April 2015 Storm

Gauge Station	Gauged Peak WL (mAHD)	TUFLOW Modelled Peak WL (mAHD)	WL Difference (mAHD)	Gauged Flow (m³/s)	TUFLOW Modelled Flow (m³/s)	Percentage (%) Flow Difference	COMMENTS
Toongabbie Creek (JOHNSTONS BRIDGE)	20.52	23.51	3.00	29.29	222.44	NA	Gauge data not reliable
Toongabbie Creek (BRIENS ROAD)	9.73	13.63	3.90	287.62	221.94	-22.8%	Gauge data for water level not be reliable
Toongabbie Creek (REDBANK ROAD)	11.03	11.17	0.14	262.47	267.81	2.04%	Gauge data may not be reliable
MARSDEN ST WEIR	6.15	6.18	0.03	363.5	377.50	3.9%	Gauge data was adjusted
RIVERSIDE THEATRE	4.94	4.97	0.03	403.89	363.80	-9.93%	

Table 5-8 Calibration results – April 1988 Storm

Ref No.	Storm	Location of Measurement	SKM 2005 Report 1988 Historical Water Levels (note 1) (mAHD)	Cardno 2019 1988 Calibration Model (mAHD)	Difference (m)
6	Apr-88	Parramatta River at Charles Street	5.00	5.31	0.31
7	Apr-88	Parramatta River at Morton Street	4.00	4.45	0.45
8	Apr-88	Parramatta River at Confluence with Vineyard Creek	3.50	3.73	0.23
9	Apr-88	Parramatta River at Pike Street	3.60	3.64	0.04
10	Apr-88	Parramatta River at Thackeray Street	3.00	3.29	0.29
11	Apr-88	Parramatta River at Silverwater Road	2.00	2.69	0.69
21	Apr-88	Claycliff Creek at 130 Alfred Street, across Road cnr Oak and Alfred	4.80	4.81	0.01

5.4.2.2 Rating curve review

Initial calibration showed a reasonable correlation with gauge data for 2015 and 2016 events, however, was underestimating the peak flows for the 1988 event. Following an initial validation for design events with a Flood Frequency Analysis (FFA) using gauged flow data, it was decided that a review of the Marsden Street Weir Rating Curve was required to confirm whether the gauged flow estimates derived from the PINEENA Rating curve were accurate. The rating curve review process is described in **Appendix B**.

The objective of the review was to obtain a defensible flow relationship by using the hydraulic model results rather than the extrapolation beyond the gauging zone applied to the available PINEENA rating curve. The need for the review became apparent due to challenges in determining an appropriate flow adjustment relationship in converting historical flows to present day catchment conditions. This conversion is necessary to develop a homogenous annual maxima time series for use in the FFA.

The review included a comparison with the PINEENA rating curve, PINEENA field gauging's and the Council adopted Draft 8 MIKE11 model results. It was noted that rating curve within the PINEENA field gauging was a good fit, however, the extrapolation appears to overestimate flows for a given flood level. This is due to the complex interaction of Lennox Bridge and Marsden Street Weir where water becomes stored behind Lennox Bridge and this backs up to Marsden Street Weir. This has the effect of reducing flows for a given flood level than would otherwise be experienced if the flow was unimpeded by Lennox Bridge. A similar impact is observed due to Bernie Banton bridge at higher flood levels. As such, it was deemed appropriate to revise the rating curve using the hydraulic model for larger flows.

The TUFLOW model was reviewed and refined in the vicinity of Marsden Street Weir and Lennox Bridge to ensure flow is modelled accurately.

The revised rating curve was derived from the TUFLOW modelling results and compared with the existing PINEENA rating curve, PINEENA field gaugings, and the UPRCT Draft 9 MIKE11 Probable Maximum Flood (PMF) modelling results. The rating curve was also validated against weir equations derived using Bentley FlowMaster software to ensure its reliability. The MIKE 11 setup was also reviewed to identify and explain differences in the hydraulic model results.

The revised rating curve was used to adjust historical flows and select historical calibration events compared with both hydrology and hydraulic modelling to further validate the revised rating curve. An updated homogenous annual maxima series was also developed using the TUFLOW revised rating curve. The updated annual maxima series was then used as input for an updated FFA at Marsden Street Weir.

Results of the calibration outcomes described below at Marsden Street Weir use the revised Marsden Street Weir rating curve information.

5.4.2.3 June 2016 Event

In the June 2016 hydrologic calibration model, there is a reasonably good match to most gauges along Toongabbie Creek and Parramatta River. The following observations are made:

- There is a good correlation between the modelled and gauged flows seen at Marsden Street Weir and Riverside Theatre to within a few percent.
- There is also a good match with the gauged peak water levels in Lake Parramatta, Loyalty Road Basin and McCoy Park.
- This demonstrates that the volumes flowing into and out of these basins is being replicated well in the model. It is noted that the McCoy Park gauge is in the upper part of the basin and hence shows different water levels to the XP-RAFTS model as the water is storing in the lower part of the basin towards the spillway outlet. It is not until larger events that a level water surface is seen in the basin which will begin to occur above an approximate RL of 26.3 mAHD.
- There is a tendency that the modelled flows are underestimated by up to 11.2% in the upper reaches at Toongabbie Creek (Redbank Road), Toongabbie Creek (Briens Road) and Toongabbie Creek (Johnstons Bridge) gauges, when compared to gauged data. However, it is not known how reliable the rating curves are for these gauges.
- The Toongabbie Creek (Redbank Road) gauge is likely unreliable when compared with other gauges, the flows are at times higher than downstream gauges and the water levels appear to show some drift possibly due to instrument error.

- The model overestimates flows on Darling Mills Creek by some 30%, however, it is unknown whether the rating curve is reliable. Water levels in Loyalty Road Basin show a good correlation which is upstream of Darling Mills Creek gauge and hence it is believed that the modelled outflows from the basin should be reliable.

5.4.2.4 April 2015 Event

For the April 2015 event, the following observations are made:

- There is a good correlation between the modelled and gauged flows seen at Marsden Street Weir and Riverside Theatre to within a few percent.
- In the calibration model, flows at most gauges tend to be slightly lower than that of gauged flows, which could be explained by the above unreliability of gauges.
- However, the Darling Mills Creek and Loyalty Road Basin gauges show that the peak flows or water levels are slightly overestimated in the hydrologic model. This indicates potentially additional rainfall being assigned to these catchments that did not occur (due to rainfall gauge limitations).
- The Toongabbie Creek (Redbank Road) and Toongabbie Creek (Johnstons Bridge) gauges were deemed to be unreliable for the April 2015 event due to poor data for either flow or level being provided, indicating error with these gauges during the event.

5.4.2.5 April 1988 Event

In the April 1988 event hydrologic calibration model, only two gauges are available for calibration – Marsden Street Weir and Toongabbie Creek (Briens Road). The following observations are made:

- There is a relatively good fit between the modelled and gauged flows at Marsden Street Weir in terms of timing and volume along with peak flow and level estimates.
- The lower modelled flows could be related to the different catchment conditions than represented in the model such as new roads (M2 and M4) which weren’t present in 1988 that create an informal detention of flows and are included in the hydrology model. There are also less rainfall gauge data available for use in the model and hence, some rainfall may not have been included in the model or certain catchments assigned to an unrepresentative rainfall gauge.
- The calibration model shows significantly higher flows than the gauge at Toongabbie Creek (Briens Road). The Briens Road rating curve is not considered reliable for large flow rates beyond an approximate 10% AEP event. When flows were large enough, water spills into a flood-runner at Toongabbie Creek (Briens Road) and bypasses the streamflow gauge, making the low level gaugings and extrapolation unreliable for higher flows. Hence, peak flows are underestimated by the Briens Road rating curve for higher flows.

5.4.3 Comparison with Flood Frequency Analysis

A Flood Frequency Analysis (FFA) was undertaken for the gauge at Marsden Street Weir (213004) and is detailed in a report enclosed in **Appendix B**. The catchment has undergone a number of changes over the period of the gauge record and it was necessary to adjust the gauged flow data to present day conditions to have a homogenous Annual Maximum Series of flow data to perform the FFA. This was done through correlation of hydrology model results for different catchment conditions over time that represented periods after major changes to the catchment, primarily the construction of detention basins within the catchment.

Analysis of gauge data shows that the April 1988 event was the largest event in the gauged data set. Correlation of observed historic flood levels upstream of Lennox Bridge to Marsden Street Weir (**Table 3-13**) indicates that only the 1889 event appears to have exceeded the 1988 event (largest event in the gauged period for 1979 – present).

The FFA estimates that the peak flow for the 1% AEP at Marsden Street Weir should be approximately 719 m^3/s under current conditions using the standard Log-Pearson III fit to the entire data set. However, it is noted that there is a distinct jump in the AMS record with no records between 220 and 340m^3/s, with the data showing a relatively smooth relationship above and below this transition. This distinct jump makes fitting the FFA difficult as these points are near or outside the 90% confidence limits. An alternative FFA was carried out with a threshold where a distribution was only fitted to the data above this transition. This provided a better fit the data with an alternate 1% AEP flow value of 656m^3/s.

Utilising standard ARR2019 methods, flow estimates were derived for 20%, 10%, 5%, 2% and 1% AEP events with a 90th percentile pre-burst rainfall applied.

The results were compared with the FFA to determine their suitability as estimates of design events. The results are documented in **Appendix E**.

Estimated flows from the FFA are provided in **Table 5-9**.

Table 5-9 Design Flood Estimates from Flood Frequency Analysis at Marsden Street Weir

ARI (years)	AEP	Flow – Adopted Fit (m^3/s)	Flow – Alternate Fit (m^3/s)	ARR2019 Design*1 Event Flow (m^3/s)
100	1%	719	651	610
50	2%	598	580	532
20	5%	453	469	446
9.49	10%	354	373	397
1.44	20%	263	265	330

Note: *1- Based on ARR19 IFD and Median R6 TP selection

The previous UPRCT FFA verification is shown in **Table 5-10** below for comparison. The current FFA estimates are lower than the previous UPRCT assessment which is explained by the different FFA methods and different annual maximum flow estimates from updating the rating curve and adjusting flows for current catchment conditions.

Table 5-10 Flood Frequency Analysis from previous UPRCT assessment and models (source: UPRCT, 2004)

Marsden Weir (Mike-11 Ch 2201.0)						
ARI	AEP	Flood Frequency Analysis	Mike-11 Draft 9g	Mike-11 Draft 9e	Mike-11 Draft 9e (no LRB)	Mike-11 Draft 8
		m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
500y	0.2%	825	911	903	-	1008
200y	0.5%	804	803	798	-	907
100y	1%	778	730	721	852	820
50y	2%	728	629	642	-	749
20y	5%	606	539	540	-	659
10y	10%	469	-	-	-	-
5y	20%	293	364	369	-	563
2y	50%	130	130	225	-	415
	80%	64.9	-	-	-	-
	90%	47.1	-	-	-	-
	95%	36.9	-	-	-	-
	99%	24.6	-	-	-	-

Table 9: Summary of Adopted Design Discharges comparing Draft 9g with the statistical analysis, Draft 9eand Draft 8.

A summary plot of all of the above outcomes is presented in Figure 5-1.

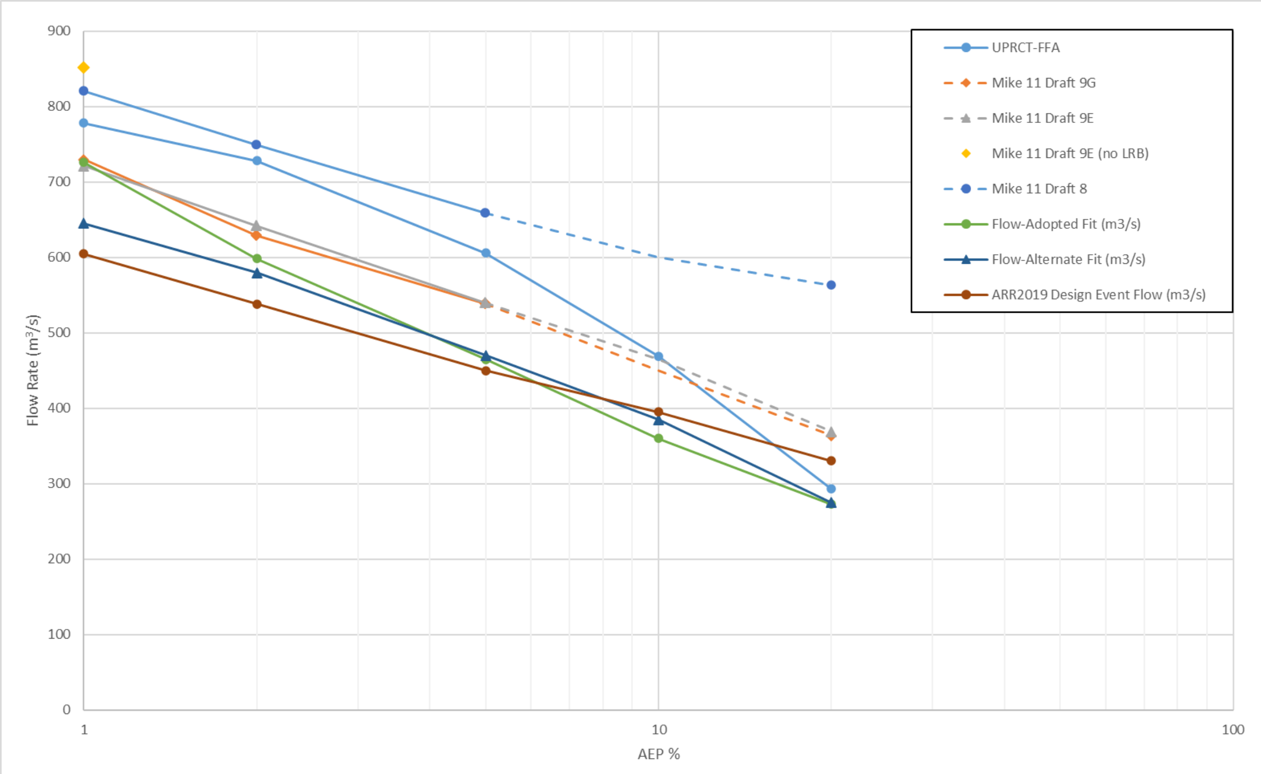

Figure 5-1 Current FFA and Design Outcomes and Previous UPRCT Mike Outcomes (Marsden Weir)

Review of the above generally indicates a changed slope in the outcomes for the current hydrologically assessed design outcomes when using standard ARR19 process (ARR IFD and Median TP) when compared to the most recent "Adopted Fit" FFA and all previous UPRCT outcomes. This generally indicates potential issues with the current adopted ARR19 IFD for the region and suggests future updates using all available data to better define the local IFD outcomes.

The design "upper median" peak flow at Marsden Street Weir estimated using standard ARR2019 methods is 610 m^3/s (using 90th percentile pre-burst depths) which is lower than the estimated 1% AEP peak flow from the current "Adopted Fit" flood frequency analysis (724m^3/s).

Although the ARR2019 Design flood events are generally lower than the FFA estimate for events greater than the 5% AEP, the model is well calibrated to the June 2016 historical event and as such this suggests further potential issues in adopting the current ARR19 IFD process.

On this basis CoP has indicated a preference to create a 1% AEP event that is calibrated to the "Adopted Fit" FFA for use in Flood Planning Layer definition and we expect that this would generally involve the following:

- Increases to the existing ARR19 IFD's for the region to increase 1%AEP design flows to calibrate to FFA outcomes;
- Potential to select an alternative (not median) temporal pattern that matched historical flood behaviour in the hydrology.

Note that this adjustment has been identified and processed only for the 1% AEP event and the corresponding Climate Change scenario required for Flood Planning (RCP8.5, Year 2150) with a method applied for assigning this increase to the tributary models for additional storm durations. The remaining outcomes have continued to use the standard ARR19 process.

5.4.4 Comparison of ARR19 against ARR87 IFD data

Based on the identification of potential issues with the current ARR19 IFD an assessment has been undertaken to review the outcomes of the current ARR19 IFD compared against the older ARR87.

The IFD data for the current modelling has been determined based on 5 zones as outlined in **Figure 15-11**.

Assessment has been undertaken to identify the range of potential variation in IFD data that may be acceptable for FFA calibrating of the 1% AEP event as historically the ARR87 IFD has been used for design flow estimates. Outcomes of comparison of ARR19 against ARR87 is presented below in Figure 5-2.

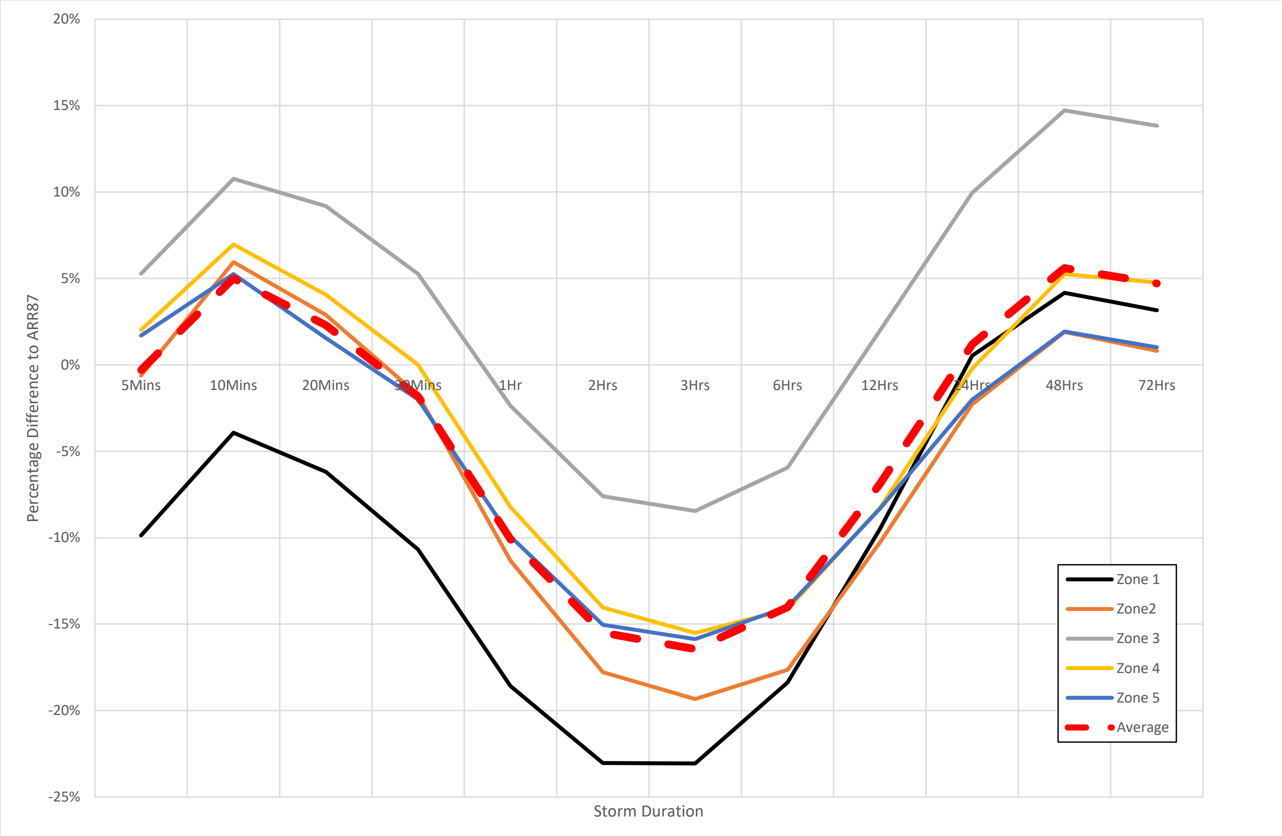

Figure 5-2 ARR19 IFD comparison against ARR87

Review of the above generally indicates that for the IFD data generated for the current modelling there is a significant variation that appears to be storm duration dependent and geographically dependent. Review of the IFD zones in **Figure 15-11** indicates the majority of the catchment to the Marsden Weir is contained within Zone 2, 3 and 4 of the model and as such there appears to be a significant reduction in rainfall for storm event between 1hr and 12hr. For these storm events the rainfall can vary between 8% to 22% in the different zones. This potential variation in the IFD has been used to assess and review the potential IFD changes adopted for the FFA calibrated 1% AEP design event.

5.5 PROVISIONAL ARR87 RAINFALL ON GRID OVERLAND FLOW ASSESSMENT

At the conclusion of the mainstream modelling in earlier phases, an assessment of overland flooding was conducted using the Rainfall on Grid (ROG) method as a provisional measure, in accordance with the guidelines outlined in ARR1987. The insights gleaned from the ROG analysis have been seamlessly integrated into our comprehensive Flood Study for the mainstream. The updated flood model for the Parramatta River Flood Study demonstrates a strong correlation, indicating the effective adjustment of inflow nodes in the XP-RAFTS model to accurately depict significant overland flow routes. Additionally, we have expanded the modelling of pipe networks beyond the previously established DN600 diameter cutoff, thereby improving the precision of overland flow representation. This approach ensures a thorough understanding of flood risk dynamics. The study incorporates rainfall-on-grid modelling results for 1% AEP and PMF scenarios to validate the location of hydrology inflows, ensuring the optimal representation of riverine flooding, its associated backwater effects, and significant overland flow paths.

Our efforts to upscale the Flood Frequency Analysis (FFA) also show a strong correlation with the ARR 1987 guidelines, confirming the reliability of the RoG methodology from 1987 for capturing shallow overland flows in upstream catchment areas. Additionally, the inflow adjustments have been externally verified by WMA Water and approved by the Council, reinforcing the credibility of our study’s findings.

6 Hydrology - Design Flood Estimation

6.1 Hydrology – ARR2019 Update

The hydrology modelling of the Parramatta River catchment for determining design flood event flows has been undertaken in accordance with the new Australian Rainfall and Runoff 2019 (ARR2019) Guidelines. The new ARR2019 Guidelines includes updated Intensity-Frequency-Duration (IFD) data, areal reduction factors (ARFs), and has introduced ensemble modelling methods to account for the variability in rainfall temporal patterns.

The methods employed are described in detail in **Appendix E**.

6.1.1 Intensity-Frequency-Duration Data

It was determined that due to the size of the catchment and from assessment of gridded rainfall depth data obtained from BoM that there is sufficient variability in rainfall depth/intensity across the catchment that multiple IFD zones would be required to appropriately represent the expected rainfall in the catchment. Five (5) IFD zones were chosen as representative of the areas surrounding the centroid of each zone. These are shown in **Figure 15-11**.

6.1.2 Temporal Pattern Data

Ensemble modelling methods were employed in accordance with the ARR2019 Guidelines. Ensemble modelling involves modelling a set of 10 different temporal patterns for each design event and storm duration. The Parramatta River catchment is within the *East Coast South* zone for selecting temporal patterns from the ARR Data Hub.

Design storms are sorted into three temporal pattern bins as shown in **Figure 6-1**. A different set of 10 temporal patterns are associated with each temporal pattern bin. The 1% AEP event, for example, falls within the 'Rare' temporal pattern bin.

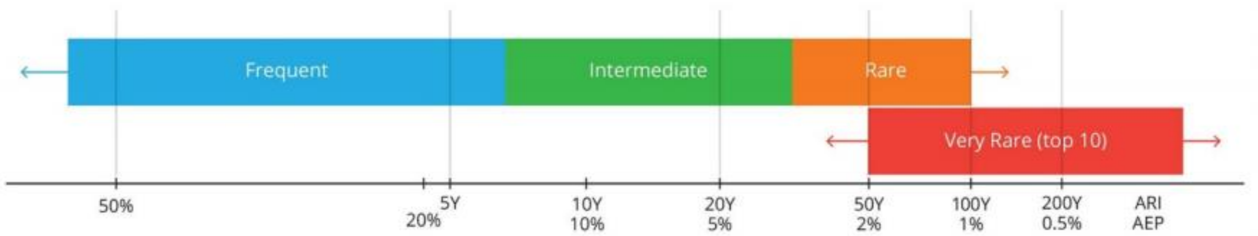

Figure 6-1 Bins for temporal patterns versus AEP (source: ARR Figure 2.5.12)

The temporal pattern that produces the flow above the mean flow of all temporal patterns is then selected to represent that particular design event and storm duration.

6.1.3 Areal Reduction Factors (ARFs)

ARR states that flood estimates are required for catchments that are sufficiently large. Design rainfall intensities at a point are not representative of the areal average rainfall intensity across the catchment. The ratio between the design values of areal average rainfall and point rainfall, computed for the same duration and Annual Exceedance Probability (AEP), is called the Areal Reduction Factor (ARF). This allows for the fact that larger catchments are less likely than smaller catchments to experience high intensity storms simultaneously over the whole of the catchment area.

It should be noted that the ARF provides a correction factor between the catchment rainfall depth (for a given combination of AEP and duration) and the mean of the point rainfall depths across a catchment (for the same AEP and duration combination). Applying an ARF is a necessary input to computation of design flood estimates from a catchment model that preserves a probability neutral transition between the design rainfall and the design flood characteristics. The ARF merely influences the average depth of rainfall across the catchment, it does not account for variability in the spatial and/or space-time patterns of its occurrence over the catchment.

6.1.3.1 Mainstream model

Based on complexity and size of the catchments in Parramatta, areal reduction factors are required to provide an accurate representation of rainfall intensity across the catchments and the resulting flows for the mainstream watercourses.

Areal reduction factor calculations for the Parramatta River catchment to Marsden Street Weir were automated using XP-RAFTS software. This location was chosen as it is central to the study area and is appropriate for the calibration at Marsden Street weir.

6.1.3.2 Tributary & Overland Flow models

The average catchment size was assessed to determine the local rainfall and flood peak. As shown in **Table 6-1** the majority of the tributary catchments are between 2 – 6 km^2, with the exception of Hunts Creek and the entire Darling Mills Creek catchment. Their sub-catchments related to overland flow are smaller again. Guidance in ARR recommends that the point rainfalls are valid for catchments up to 4km^2. As such, given most catchments are around 4 km^2 or less, it was deemed appropriate that no ARF be applied to the rainfall in determining the 1% AEP flows for the Tributary and Overland Flow models.

Table 6-1 Catchment Size for Tributary Catchments

Creek Catchment Name	Area (km^2)
Brickfield Creek	3.18
Clay Cliff Creek	1.96
Coopers Creek	4.26
Darling Mills Creek	22.53
Domain Creek	1.49
Devlins Creek	1.81
Finlaysons Creek	6.13
Greystanes (Girraween) Creek	0.24
Hunts Creek	7.83
Milsons Creek	0.92
Quarry Branch Creek (Northmead Gully)	3.22
Pendle Hill Creek	5.50
The Ponds Creek	4.71
Subiaco Creek	3.73
Terrys Creek	2.34

6.2 Probable Maximum Flood Estimation

The Generalised Short Duration Method (BoM, 2003) was used to estimate the rainfall intensity of the Probable Maximum Precipitation for the Parramatta River catchment. The method of applying rainfall intensities for the Mainstream model and for the Tributary & Overland Flow models are as follows. The methodology is also further described in **Appendix E**.

6.2.1 Mainstream PMF Rainfall Intensity

A spatially distributed PMF rainfall intensity was adopted for the Mainstream model according to the GSDM. The GSDM ellipses were generated in the XP-RAFTS model for the Parramatta River catchment, oriented to align with the catchment and centred over the CBD area which is approximately in the middle of the Study Area. Each sub-catchment node in the hydrology model was then assigned a rainfall intensity that corresponded to its respective GSDM ellipse that it was located within.

6.3 Design Event Modelling

6.3.1 Model Scenarios

The hydrologic model was used to simulate ensembles for a range of design events and durations. The design events modelled for the Final Flood Study include the:

- PMF;
- 1% AEP event;
- 2% AEP event;
- 5% AEP event; and,
- 20% AEP event.

Different sets of pre-burst rainfall, areal reduction factors, ARBM initial stores values and PMF ellipses were selected for application to the Mainstream and Tributary & Overland Flow hydraulic models. These parameters are shown in **Table 6-2** for design events up to the 1% AEP event, and in **Table 6-3** for the PMF.

Table 6-2 Adopted Parameters for Hydrologic Model for design events up to the 1% AEP

Hydraulic Model Application	Pre-Burst Rainfall	Areal Reduction Factor	ARBM Initial Stores
Mainstream	90th Percentile	For area upstream of Marsden Street Weir	20%
Tributary & Overland Flow	75th Percentile	Not Applied	20%

Table 6-3 Adopted Parameters for Hydrologic Model for the PMF

Hydraulic Model Application	Ellipse Method	Areal Reduction Factor	ARBM Initial Stores
Mainstream	All ellipses used	N/A	90%
Tributary & Overland Flow	B-ellipse used only	N/A	90%

6.3.2 Tributary and Overland Flow PMF Rainfall Intensity

The rainfall intensity for the GSDM B-ellipse was applied for all Tributary & Overland Flow models. This provides a representative estimate of PMF rainfall intensity for each Tributary & Overland Flow model without the complexity of applying GSDM ellipses for every catchment.

While using the A-Ellipse may be more appropriate for the small overland flow catchments to obtain peak flows, due to the size of the models, this would tend to overestimate volumes and produce spurious results in the low parts of the catchments/tributaries.

6.3.3 Critical Duration

The critical durations for each temporal pattern bin were determined by simulating a range of durations in the hydraulic model. The hydrologic model was simulated for all durations for application to the Mainstream and Tributary & Overland Flow hydraulic models and assessment undertaken to identify the critical durations at key focal point locations within the modelled area.

6.3.4 Design Event Flows

Table 6-4 shows design event flows calculated in the XP-RAFTS hydrology model at key locations within the model Study Area.

Table 6-4 Design Event flows and critical duration from XP-RAFTS Hydrology Models at Key Locations

Model Stage	Location	XP-RAFTS Node	FFA 1% AEP*1		2% AEP		5% AEP		20% AEP		PMF	
			Critical Duration	Flow (m^3/s)	Critical Duration	Flow (m^3/s)	Critical Duration	Flow (m^3/s)	Critical Duration	Flow (m^3/s)	Critical Duration	Flow (m^3/s)
Mainstream	Marsden St Weir	UPP1.33 0L	12hr	787.2	12hr	535.7	6hr	468.9	4.5hr	337.6	2hr	3329.8
Trib & OF	Pendle Creek	UPP64.0 2a	6hr	67.7	30min	48.1	30min	42.4	1.5hr	38.2	1hr	442.3
Trib & OF	Oakes Road Bridge	UPP1.19 0n	6hr	23.1	30min	18.2	30min	15.3	1.5hr	12.7	45min	160.0
Trib & OF	Finlaysons Creek	UPP4.09 0c	3hr	80.4	25min	65.3	20min	58.9	45min	49.2	1hr	509.3
Trib & OF	Coopers Creek	UPP5.11 0b	3hr	51.0	30min	46.1	30min	43.3	45min	39.1	45min	439.7
Trib & OF	Quarry Creek	UPP13.0 7b	6hr	51.0	12hr	36.5	3hr	30.8	1.5hr	29.4	45min	313.1
Trib & OF	Lake Parramatt a Outlet	UPP3.09 0a1	12hr	110.6	12hr	79.4	3hr	60.8	1.5hr	51.5	1hr	628.1

Trib & OF	Brickfield Creek	UPP45.13b	12hr	49.6	12hr	35.2	20min	30.4	1.5hr	28.3	45min	338.6
Trib & OF	Vineyard Creek	VINN14b	12hr	60.3	12hr	41.9	3hr	37.5	1.5hr	33.2	1hr	408.6
Trib & OF	Darling Mills Creek	UPP2.190d	12hr	224.3	12hr	154.8	6hr	131.5	3hr	107.5	1.5hr	1524.1
Trib & OF	Subiaco Creek	SUBS1.10bb	4.5hr	108.8	12hr	79.5	3hr	67.1	2hr	61.6	1hr	698.4
Trib & OF	Terrys Creek	Terrout	2hr	77.5	45min	49.9	2hr	43.4	20min	29.0	45min	336.8
Trib & OF	Devlins Creek	Out2	2hr	42.4	20min	24.8	20min	21.1	1hr	38.1	45min	191.6
Trib & OF	Claycliff Creek	LPP1bc	12hr	42.7	12hr	27.9	3hr	24.6	1.5hr	21.7	1.5hr	224.6

Note: *1 – 1% AEP Event recalibrated to match FFA in hydraulic assessment

7 FFA Calibrated 1% AEP Design Flows

7.1 Marsden Weir FFA recalibration

CoP has indicated that for Flood Planning Assessment the hydraulic modelling is required to calibrate the 1% AEP flow to the FFA assessed $724m^3/s$. Current design estimates are significantly lower than this value at $610m^3/s$ and Stantec has undertaken recalibration assessment to revise all flows in Main Channel and Tributary models to allow for this recalibration.

In undertaking assessment, it was identified that although there had previously been a good match between hydrological and hydraulic outcomes for design events, this trend did not continue when considering the recalibrated 1% AEP flow. A recalibrated hydrology model that aimed to replicate the FFA defined $724m^3/s$ flow did not replicate the same flow in the developed hydraulic model (set up described in the following sections).

There are several reasons for this however the main explanation appears to be the additional storage and routing offered in a hydraulic model within the main channel is larger than that modelled in the current hydrological model for all events at flood levels for flows > approximately $650m^3/s$. Additional floodplain storage appears to be activated at these levels and starts to create a deviance between the existing hydrology and developed hydraulics model for the main channel. Preliminary assessment has identified that XP-RAFTS hydrological flows of 780m3/s is required to match the 1% AEP FFA flows in the developed hydraulics model.

Accordingly, to calibrate to the FFA flow at the Marsden Weir in the hydraulic model the ARR19 IFD has been adjusted and outcomes assessed for all potential temporal patterns to find the best fit to provide the required 780m3/s XP-RAFTS flow and the associated $724m^3/s$ hydraulic model flow.

Initial testing considered review of the standard temporal patterns and if required increasing the ARR19 IFD to levels that would provide the required flow with outcomes presented in Table 7-1.

Table 7-1 FFA recalibration assessment

Testing Scenario	1% AEP 12hour Temporal Pattern*	RAFTS Flow at UPP 1.330L (TP)	Tuflow Q at Marsden Weir Gauge (TP-existing IFD)	XP-RAFTS Flow at UPP 1.330L (UTP-Recalibrated IFD)	Tuflow Q at Marsden Weir Gauge (UTP – recalibrated IFD)	Approx IFD Recalibration %
TP5	Intermediate TP, R8	719.5	662	780	Approx 720*	15%+
TP8	Median TP. R5	610	595	780	Approx 720*	36%+
TP9	Highest TP, R9	753	702	780	Approx 720*	8%+

Note TP Ranking from R0-R9

Assessment has identified that using an alternative temporal pattern (i.e. highest) was not able to provide the recalibration required. Accordingly, an increase to the ARR19 IFD was assessed for the identified range of TP to achieve the required hydrological flow.

To match the 1% AEP FFA flow rate in the hydraulic model, a 15%, 36% and 8% recalibration has been applied to the selected 1% AEP 12hr event for TP5, TP8 and TP9 respectively. Stantec generated the corresponding hydrographs and applied it to preliminary PRFS mainstream TUFLOW model to simulate the flooding process at the Marsden Street weir.

Outcomes of hydraulic model outcomes against the historical flood record (April 1988) are presented in Figure 7-1, Figure 7-2 and Figure 7-3. All three recalibrated TPs show a similar shape to the recorded data, where recalibrated TP9 is identified as the recommended TP due to the comparison with record data among the other two TPs. As it captures the low point between the peaks prior to the rare event coming through. Note that comparing a design TP outcome against actual recorded storm is not expected to provide a perfect replication in any way between both event types but has been used to provide guidance in regard to best TP to adopt going forward.

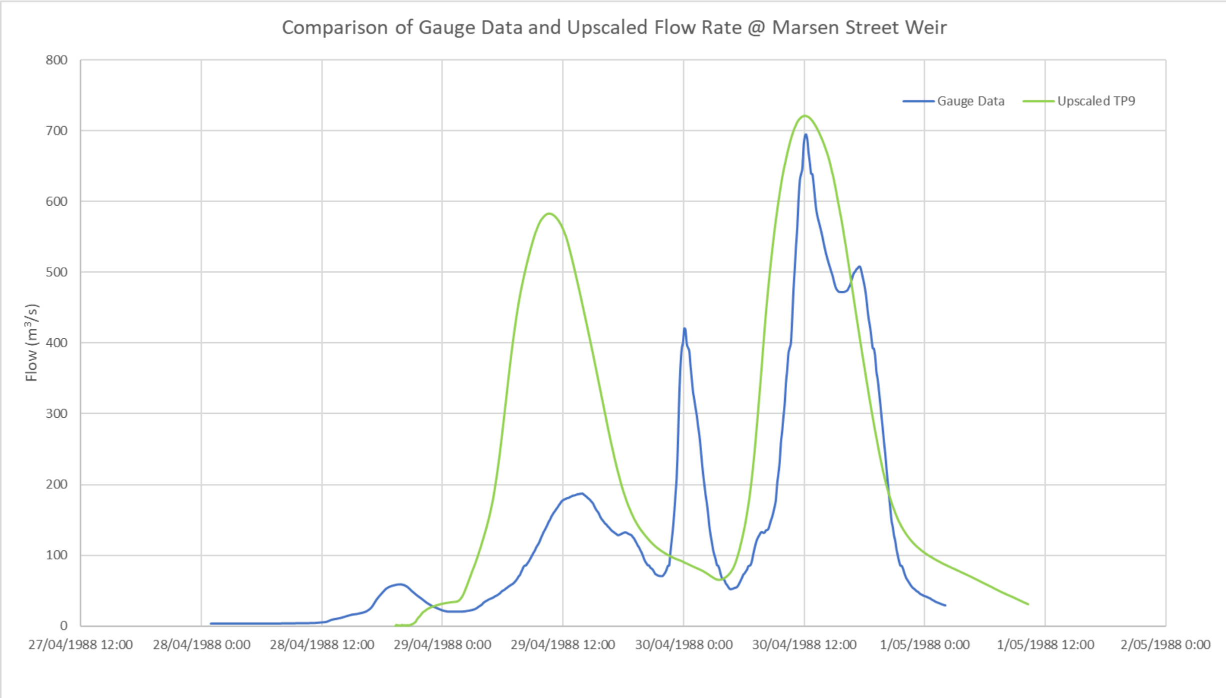

Figure 7-1 Comparison of gauge data and recalibrated 1% AEP 12hr TP9 TUFLOW result at Marsden Street weir (8%+)

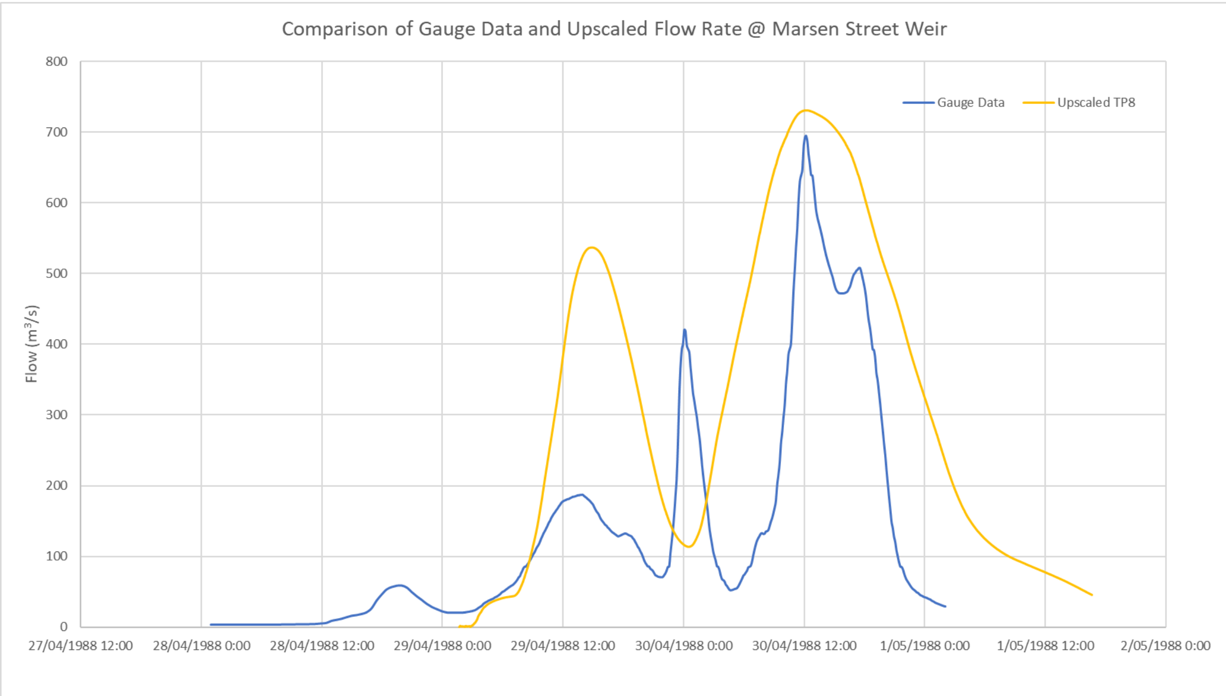

Figure 7-2 Comparison of gauge data and recalibrated 1% AEP 12hr TP8 TUFLOW result at Marsden Street weir (36%+)

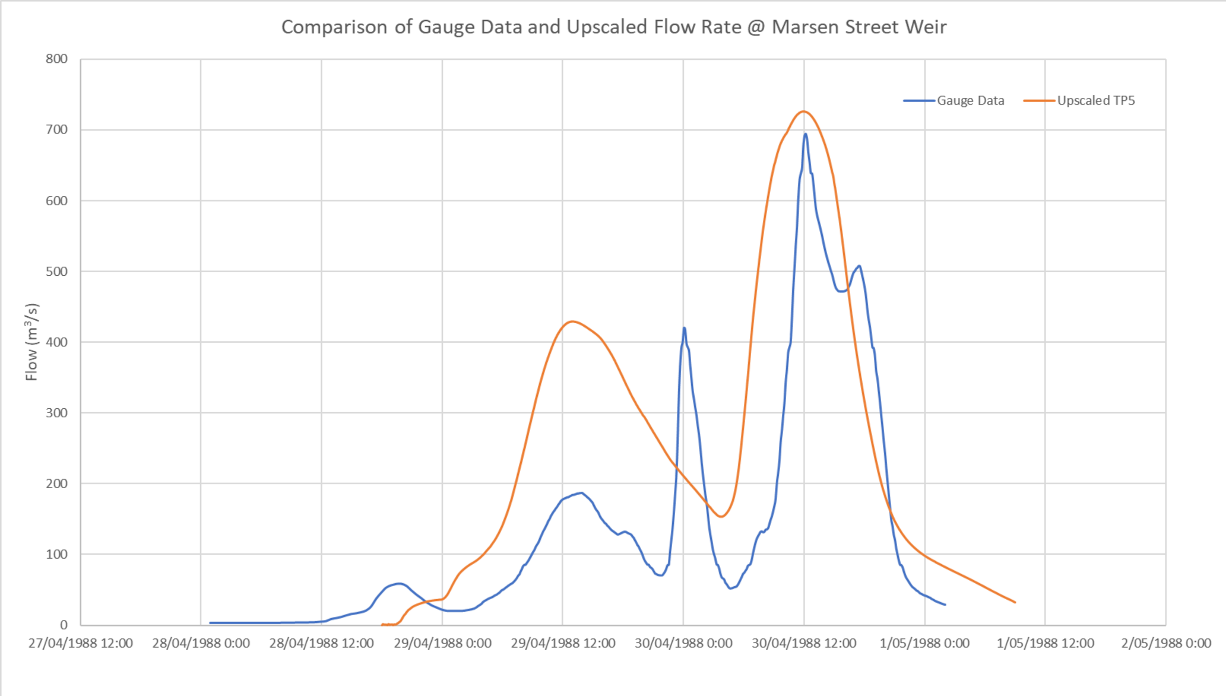

Figure 7-3 Comparison of gauge data and recalibrated 1% AEP 12hr TP5 TUFLOW result at Marsden Street weir (15%+)

Review of the above indicates the following:

- The recalibrated TP9 result best resemblance to the 1988 hydrograph with a similar timing, volume and overall flow increase to peak flood levels.
- The recalibration required for this event (8%) matches well with the average difference between the ARR87 and ARR19 IFD differences.

Stantec has adopted the 8% recalibrated 1% AEP 12hr TP9 for ongoing assessment of main channel performance to match the FFA flow at Marsden Weir and that the other identified critical durations (2hr and 6hr) also be recalibrated in the same manner for assessment.

Stantec do not recommend proceeding further testing TP5 and TP8 as the percentage of recalibration exceed the range compared to the ARR87 IFD.

7.2 Tributary Recalibration

7.2.1 Method for Recalibration

Based on the requirement for recalibration of flows for the 1% AEP event to match FFA outcomes, Stantec has developed and applied a method for recalibration the associated tributary flows. Note that as there is no significant gauged data at the end of all tributary models the method applied to the Main Channel cannot be replicated for each tributary.

The method for recalibration the tributary models has been defined as follows:

- Review total recalibration required in hydrology model outcomes for main channel and compare to standard ARR2019, median TP outcomes.
- Consider the requirement to recalibration the outflows from all tributaries by the same factor regardless of the critical storm duration adopted (i.e. % increase applied to all flows at outlets).
- Assessment of potential additional ARR2019 IFD recalibration required to match the target outflows.
- Identify any consistent temporal pattern outcomes that provides a consistent recalibration to the outlet flows for all identified durations.

7.2.2 Recalibration Required

Review of recalibration requirement for Main Channel at Marsden Weir has identified the following:

- Standard ARR2019 1% AEP flow rate of 610m3/s (median TP).
- Recalibrated requirement (8% ARR2019 IFD, TP9) flow rate of 780m3/s.

Based on the above the nominal total 1% AEP recalibration required to flows at Marsden Weir appears to be 28% when compared to the standard ARR2019 approach outcomes which was achieved with the 8% ARR2019 IFD increase of TP9. This recalibration has been considered and applied to all tributary outflow locations for all critical durations for on-going assessment.

For all tributaries a detailed assessment of the critical storm durations reporting to the local drainage outlets has been undertaken and review of the existing standard ARR2019 results and recalibrated results has been developed. A summary of the outcomes of recalibration flows to tributary outlets by 28% is presented below in **Table 7-2.**

Table 7-2 Tributary Outlet Recalibration Requirements for 1% AEP FFA calibrated

Model	Creek	XP-RAFTS Node	Critical Duration Outlet	Critical Duration (Upstream)	Median TP (R5)	R5 Flow (m3/s)	Target Flow *1(m3/s)
Pendle	Pendle Creek	UPP64.02a	6hr		TP5	54.2	68.9
				15min	TP10	46.5	59.1
	Oaks Street Bridge	UPP1.190n	6hr		TP2	17.8	22.6
				15min	TP7	17.2	21.9
FinCoo	Finlaysons Creek	UPP4.090c	3hr		TP7	65.2	82.8
	Coopers Creek	UPP5.110b	3hr		TP4	50.8	64.5
Quarry	Quarry Creek	UPP13.07b	6hr		TP3	40.2	51.1
DarSub	Lake Parramatta Outlet	UPP3.090a1	12hr		TP1	80.4	102.1
				20min	TP4	27.5	34.9
				4.5hr	TP5	73.3	93.1
	Brickfield Creek	UPP45.13b	12hr		TP1	39.9	50.7
				20min	TP6	37.9	48.1
				4.5hr	TP10	38.2	48.5
	Vineyard Creek	VINN14b	12hr		TP1	47.6	60.5
				20min	TP10	32.0	40.6
				4.5hr	TP10	46.9	59.6
	Darling Mills Creek	UPP2.190d	12hr		TP1	173.8	220.7
				20min	TP3	53.8	68.4
				4.5hr	TP9	161.8	205.5
	Subiaco Creek	SUBS1.10bb	12hr		TP1	90.4	114.8
				20min	TP8	50.3	63.8
				4.5hr	TP9	86.7	110.1
ClayCliff	Claycliff Creek	LPP1bc	12hr		TP1	31.7	40.2
TerDev	Terrys Creek	Terrout	2hr		TP6	63.2	80.3
	Devlins Creek	Out2	2hr		TP6	30.4	38.6

Note: *1 – Based on 28% increase requirement

Review of the above s a range of critical durations for the Tributary model outlets with the predominant events limited to 15min, 2hr, 3hr, 6hr and 12hr events. Previous review of modelled outcomes has also identified additional critical storm durations usually associated with upstream areas and target flows for these events at the outlet have also been assigned.

Further assessment (similar to Main Channel Review) has been undertaken to identify the required ARR2019 IFD recalibration required and the selected TP to provide flow increases that match the required Target Flows for the outlets. This arrangement would then be applied to all Tributary model critical events. Outcomes of assessment has developed the following approach for recalibration of all Tributary models:

- For critical durations up to and including the 6hr event the ARR19 IFD has been increased by 19%
- For critical durations of 12hr the ARR19 IFD has been recalibrated by 9%.

Note that both of these outcomes remain consistent and within the range of variation between the ARR87 and ARR19 IFD for these critical storm events.

Further assessment has been undertaken to identify the flows associated with all TP's and a TP selected that best matches the overall required target flow and total flow across all tributary models.

Outcomes of assessment and selected TP for both recalibrated scenarios is presented in Table 7-3 and Table 7-4.

The flows generated from the selected recalibration and TP have been used for hydraulic modelling of all tributary models to generate the FFA calibrated 1% AEP design levels. Note that this process has also been applied to the Climate change scenario required for FPL definition.

Table 7-3 Recalibration Assessment – 12hr Storm Events (9% ARR19 IFD recalibration) and selected TP

Model	Creek	XP-RAFTS Node	Critical Duration	Target Flow	TP1		TP2		TP3		TP4		TP5		TP6		TP7		TP8		TP9		TP10	
					Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)
DarSub	Lake Parramatta Outlet	UPP3.090a1	12hr	102.1	88.2	-14%	80.6	-21%	110.6	8%	58.5	-43%	124.7	22%	115.2	13%	54.8	-46%	81.8	-20%	124.9	22%	67.8	-34%
	Brickfield Creek	UPP45.13b	12hr	50.7	43.6	-14%	36.4	-28%	49.6	-2%	25.6	-49%	61.3	21%	59.3	17%	24.5	-52%	37.6	-26%	56.7	12%	30.9	-39%
	Vineyard Creek	VINN14b	12hr	60.5	52.1	-14%	43.4	-28%	60.3	0%	32.1	-47%	74.6	23%	73.8	22%	28.6	-53%	44.2	-27%	69.7	15%	38.3	-37%
	Darling Mills Creek	UPP2.190d	12hr	220.7	188.0	-15%	183.0	-17%	224.3	2%	159.8	-28%	229.4	4%	196.2	-11%	150.8	-32%	185.9	-16%	234.8	6%	167.7	-24%
	Subiaco Creek	SUBS1.10bb	12hr	114.8	98.9	-14%	83.7	-27%	114.1	-1%	62.1	-46%	140.2	22%	136.6	19%	57.5	-50%	86.5	-25%	133.3	16%	73.3	-36%
Claycliff	Claycliff Creek	LPP1bc	12hr	40.2	34.5	-14%	31.2	-23%	42.7	6%	24.0	-40%	48.4	20%	45.4	13%	21.4	-47%	31.9	-21%	49.5	23%	27.9	-31%
Total Flow			12hr	589.1	505.3	-14%	458.2	-22%	601.6	2%	362.2	-39%	678.6	15%	626.5	6%	337.5	-43%	467.9	-21%	668.9	14%	405.9	-31%

Table 7-4 Recalibration Assessment – 15min to 6hr Storm Events (19% ARR19 IFD recalibration) and selected TP

Model	Creek	Node	Critical Duration	Target Flow	TP1		TP2		TP3		TP4		TP5		TP6		TP7		TP8		TP9		TP10	
					Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)	Flow	Diff (%)
Pendle	Pendle Creek	UPP64.02a	15min	59.1	54.9	-7%	56.0	-5%	55.6	-6%	54.3	-8%	55.3	-6%	53.4	-10%	55.1	-7%	55.4	-6%	57.5	-3%	56.1	-5%
			6hr	68.9	54.7	-21%	63.4	-8%	65.0	-6%	43.3	-37%	63.7	-7%	71.0	3%	51.0	-26%	48.3	-30%	68.5	-1%	67.7	-2%
	Oaks Street Bridge	UPP1.190n	15min	22.6	20.7	-8%	21.8	-3%	21.6	-4%	20.7	-8%	21.6	-4%	20.9	-7%	21.2	-6%	21.7	-4%	21.3	-6%	20.4	-10%
			6hr	22.0	19.6	-11%	21.1	-4%	21.7	-1%	13.0	-41%	20.1	-9%	24.1	10%	16.6	-25%	15.8	-28%	21.4	-2%	23.1	5%
DarSub	Lake Parramatta Outlet	UPP3.090a1	20min	34.9	48.6	39%	49.2	41%	40.0	15%	43.6	25%	43.8	26%	42.9	23%	43.5	25%	44.9	29%	52.0	49%	42.6	22%
			4.5hr	93.1	74.6	-20%	106.3	14%	78.2	-16%	105.7	14%	91.7	-1%	103.2	11%	75.6	-19%	84.4	-9%	88.6	-5%	102.9	11%
	Brickfield Creek	UPP45.13b	20min	48.1	42.8	-11%	48.5	1%	48.2	0%	44.4	-8%	46.2	-4%	44.9	-7%	44.2	-8%	44.5	-8%	45.7	-5%	45.7	-5%
			4.5hr	48.5	31.5	-35%	50.1	3%	35.4	-27%	51.7	7%	43.2	-11%	49.1	1%	32.5	-33%	42.5	-12%	49.9	3%	45.5	-6%
	Vineyard Creek	VINN14b	20min	40.6	38.4	-5%	41.4	2%	40.8	0%	38.0	-6%	39.8	-2%	37.9	-7%	37.9	-7%	38.1	-6%	40.1	-1%	38.5	-5%
			4.5hr	59.6	37.1	-38%	61.1	3%	42.3	-29%	71.1	19%	55.1	-7%	64.0	7%	38.8	-35%	53.7	-10%	62.8	5%	56.3	-6%
	Darling Mills Creek	UPP2.190d	20min	68.4	70.9	4%	73.3	7%	63.9	-7%	64.1	-6%	67.4	-1%	63.6	-7%	63.6	-7%	66.9	-2%	77.6	14%	63.8	-7%
			4.5hr	205.5	188.5	-8%	212.2	3%	181.6	-12%	179.8	-13%	176.2	-14%	198.6	-3%	185.9	-10%	184.6	-10%	186.9	-9%	217.6	6%
	Subiaco Creek	SUBS1.10bb	20min	63.8	62.3	-2%	60.3	-6%	61.4	-4%	58.2	-9%	63.3	-1%	58.1	-9%	58.1	-9%	59.9	-6%	71.3	12%	59.7	-6%
			4.5hr	110.1	74.1	-33%	111.5	1%	82.1	-26%	126.2	15%	100.8	-8%	117.2	6%	77.5	-30%	95.0	-14%	111.2	1%	108.8	-1%
TerDev	Terrys Creek	Terrout	2hr	80.3	68.3	-15%	79.1	-1%	52.4	-35%	97.2	21%	80.2	0%	85.7	7%	49.6	-38%	80.3	0%	65.0	-19%	77.5	-4%
	Devlins Creek	Out2	2hr	38.6	32.2	-17%	39.7	3%	27.6	-28%	43.8	13%	33.3	-14%	42.9	11%	25.5	-34%	40.1	4%	33.5	-13%	42.4	10%
FinCoo	Finlaysons Creek	UPP4.090c	3hr	82.8	61.4	-26%	79.5	-4%	76.4	-8%	74.0	-11%	57.3	-31%	67.2	-19%	76.1	-8%	75.3	-9%	73.4	-11%	80.4	-3%
	Coopers Creek	UPP5.110b	3hr	64.5	52.1	-19%	61.5	-5%	67.0	4%	65.4	1%	43.5	-33%	47.9	-26%	63.5	-2%	61.9	-4%	54.9	-15%	63.7	-1%
Quarry	Quarry Creek	UPP13.07b	6hr	51.1	43.8	-14%	47.5	-7%	49.1	-4%	30.2	-41%	45.9	-10%	53.1	4%	40.7	-20%	38.2	-25%	51.3	0%	51.0	0%
Total Flow			15min-6hr	1262.3	1076.5	-15%	1283.7	2%	1110.1	-12%	1224.7	-3%	1148.3	-9%	1245.7	-1%	1057.0	-16%	1151.5	-9%	1232.8	-2%	1263.6	0.105%

8 Hydraulics

8.1 Hydraulic Model Setup

The hydraulic models have been developed as 1D/2D linked models using the TUFLOW software.

In general, some channels, pipe networks, culverts and some bridges are setup in the 1-dimensional domain, while other channels, bridges, topography and floodplains are established in the 2-dimensional domain. The 1D and 2D domains are dynamically linked to allow exchange of flow between them.

The entire study area, which is modelled in TUFLOW, covers an area of 51 km^2. Due to the large study area, a staged approached was undertaken when developing the TUFLOW hydraulic models (refer **Table 8-1**). The TUFLOW HPC GPU engine was used to undertake all simulations (version 2020-10-AA_iSP_w64).

The models were divided into the following stages:

> Stage 1 – Mainstream Parramatta River and Toongabbie Creek
> Stage 2 – Tributary models
> Stage 3 – Overland Flow

It was agreed with Council to consolidate the Tributary & Overland Flow models to avoid discrepancies at the boundary which can be experienced in model staging. The models have been setup with overlap of the Mainstream extent and the Tributary extent to ensure that the envelope of peak levels from different flooding mechanisms is covered appropriately.

Table 8-1 TUFLOW Model Staging

Stage	TUFLOW Model
Mainstream	• Model 1 – Parramatta River and Toongabbie Creek
Tributary & Overland Flow	• Model 2 – Clay Cliff Creek • Model 3 – Darling Mills, The Ponds, Subiaco, Vineyard and Brickfield Creeks • Model 4 – Finlaysons, Coopers and Milsons Creeks • Model 5 – Pendle Hill and Greystanes Creek • Model 6 – Quarry Branch Creek • Model 7 – Terrys and Devlins Creeks

8.1.2 Model Extents

The extents of the TUFLOW models are shown in **Figure 15-16**.

The Mainstream model covers the Parramatta River and Toongabbie Creek mainstream channels and their floodplains, while Stage 2 models cover Parramatta River tributaries and overland flow paths within the Study Area. The downstream limits of each Stage 2 model is at the confluence of each tributary with Toongabbie Creek/Parramatta River.

8.1.2.1 Model 1 – Parramatta River and Toongabbie Creek

The Mainstream Parramatta River Model consists of the main Toongabbie Creek and Parramatta River channels, and their floodplains throughout the Study Area. The upstream limit of Model 1 is upstream of McCoy Park Basin on Toongabbie Creek. The downstream boundary of the model is at Concord Bridge at Ryde, where the river is tidally dominated.

The model has been widened to ensure that it encompasses the expected PMF flood extents. This was based on the previous PMF GIS layer provided by CoP with a suitable buffer applied to ensure that the PMF was captured if there was a change to the flows or flood level predictions.

8.1.2.2 Model 2 – Clay Cliff Creek

The Clay Cliff Creek model covers the entire Creek's course through the study area. On the upstream end, it begins in the Ollie Webb Reserve on Pitt Street and progresses through the Parramatta CBD and Harris Park.

The model ends at the banks of the Parramatta River and includes the overland areas between Charles Street Weir to Camellia.

8.1.2.3 Model 3 – Darling Mills, Hunts, The Ponds, Subiaco, Vineyard and Brickfield Creeks

Model 3 includes the following watercourses (and their catchments to the study area boundary):

> Darling Mills Creek – the model boundary was extended north of Parramatta LGA including James Ruse Drive upstream to Hazel Ryan Oval to capture a greater extent of the creek;

> Hunts Creek – from William Place, North Rocks, to its confluence with Darling Mills Creek;

> The Ponds Creek – completely included within the model;

> Subiaco Creek – completely included within the model;

> Vineyard Creek – completely included within the model; and,

> Brickfield Creek – from Brickfield Basin north of James Ruse Drive, to its confluence with Parramatta River.

Where the creeks within the model extended upstream of the study area, the model boundary was located a short distance outside the study area and a total inflow was inserted at this location.

The model boundary ends at Parramatta River starting at O'Connell Street Bridge and ending downstream at Waratah Street, Melrose.

Overland flow areas for all catchments within the LGA boundary down to the Parramatta River are included. The model extents were clipped to an expected PMF extent derived from a buffered rain on grid model PMF extent. The Rain on Grid PMF model was initially developed to for the primary definition of overland flowpaths and model extents.

8.1.2.4 Model 4 – Finlaysons, Coopers and Milsons Creeks

Model 4 includes the following watercourses (and their catchments):

> Coopers Creek – from the T1 Western Rail Line crossing to its confluence with Toongabbie Creek;

> Finlaysons Creek – from the T1 Western Rail Line crossing to its confluence with Toongabbie Creek; and,

> Milsons Creek – completely included within the model.

The model spans from the southern boundary of the Study Area, upstream of the T1 Western Rail Line to Toongabbie Creek on the downstream end. The downstream model boundary runs along the edge of the Toongabbie Creek channel and extends from Hammers Road down to Redbank Road.

8.1.2.5 Model 5 – Pendle Hill and Bogalara Creek

Model 5 includes Pendle Hill Creek, from the T1 Western Rail Line crossing to a point approximately 250 metres upstream of the Barangaroo Road crossing. It also includes Bogalara Creek and overland flow paths between the two creeks.

8.1.2.6 Model 6 – Quarry Branch Creek

Model 6 covers overland flow areas in the region encompassed by the M2 Motorway, Windsor Road, Toongabbie Creek and Old Windsor Road. Quarry Branch Creek (Northmead Gully) is included in the model, from its M2 Motorway crossing to its confluence with Toongabbie Creek.

8.1.2.7 Model 7 – Terrys and Devlins Creek

Model 7 extends across the North-East corner of the Study Area and covers the area bounded by Carlingford Road, T1 Main Northern Train line, Marsden Road and the Eastwood Train Station.

This model contains two watercourses:

> Terrys Creek – from the top of its catchment to a point just downstream of the Blaxland Road Crossing; and,

> Devlins Creek – from the top of its catchment to a point downstream of the Carlingford Road crossing.

8.1.3 Digital Elevation Model

A combination of the following sources was used to develop the 2D digital elevation model used in all TUFLOW models:

- 1-metre resolution Aerial Laser Survey;
- Digital elevation model of the Parramatta CBD provided by Council; and,
- Bathymetric survey.

8.1.4 1D and 2D Domains

The majority of the hydraulic models are modelled in the 2D domain. A model grid size of 2 x 2 metres was adopted in the 2D domains in all hydraulic models. This resolution was selected to ensure a balance of an accurate representation of the terrain and flood behaviour, while maintaining reasonable model simulation times.

Some channels within the Study Area are too narrow to be accurately modelled in the 2D domain due to grid size resolution. As such, these channels were represented by 1D channels (refer **Figure 15-18**) to ensure that its flow conveyance is accurately modelled. Typically to represent the detail of a channel in the 2D domain and maintain the flow area, the channel needs to be greater than 5 cells in width. In general, channels less than 12 metres in width were represented by 1D channels.

8.1.5 Materials Roughness Layer

The materials layer used to define the Manning's 'n' roughness in the TUFLOW models were based on land uses in the City of Parramatta Council cadastre shown in Council's Local Environment Plan. The TUFLOW materials layer is shown in **Figure 15-17** and corresponds to the following Manning's 'n' values are summarised in **Table 8-2**:

Table 8-2 TUFLOW Materials Roughness

TUFLOW Material Type	Manning's 'n'	Material Description	Corresponding Council LEP Zoning
1	0.02	Watercourse	-
2	0.08	Low Density Industrial	General Industrial IN1
3	0.1	Moderate Density Industrial, substantial building with little permeability	General Industrial IN2
4	0.2	High Density Industrial, substantial building with almost no permeability	General Industrial IN3
5	0.06	Channel banks, moderate vegetation	-
6	0.08	Channel banks, dense vegetation	-
7	0.04	Low Density Residential	Low Density Residential R2
8	0.04	Medium Density Residential	Medium Density Residential R3
9	0.04	High Density Residential	High Density Residential R4
10	0.1	High Density Development	Neighbourhood Centre B1
11	0.1	High Density Development	Local Centre B3
12	0.1	High Density Development	No Description B3
13	0.1	High Density Development	Mixed Use B4
14	0.1	High Density Development	Business Development B5
15	0.1	High Density Development	Enterprise Corridor B6
16	0.04	Parks, grass and some trees	Public Recreation RE1 & RE2
17	0.015	Concrete channel	-
18	0.1	High Density Development	Special Activities SP1

TUFLOW Material Type	Manning's 'n'	Material Description	Corresponding Council LEP Zoning
19	0.1	High Density Development	Infrastructures SP2
22	0.02	Roads	-
23	0.03	Smooth paved ground, carparks	-
24	0.1	Industrial site – paved ground with low density structures	-
25	0.045	Grass with medium density trees	-
26	0.035	Grass only	-
27	0.07	Dense Trees with under brushes	-

8.1.6 Inflows

Inflow hydrographs were extracted from the hydrologic model and applied in the hydraulic model as inflow polygons. Adopting this approach assumes that runoff from a sub-catchment is concentrated into a small area within the sub-catchment, typically at the catchment outlet.

At the upstream boundaries, flows are input as a total flow from the hydrologic model derived for the upstream catchments. These are input as either a 1d inflow for 1d channels or as a rectangular 2d_SA polygon for 2d areas to distribute flow behaviour. For sub-catchments within a model, a local flow from that sub-catchment is applied to the hydraulic model.

In general, flows are applied at the downstream low points of each sub catchment, except for the most upstream sub-catchments where a flow is applied at the centroid of the sub-catchment along the main drainage line. The study incorporates rainfall-on-grid 1% AEP and PMF modelling results to validate hydrology inflows location, to best represent riverine flooding and its associated backwater effects, along with significant overland flow paths where flow depths are greater than 50mm. The outlet or centroid node points were converted into circular 2d_SA inflow polygons with a diameter of 40 metres. In general, the inflows in the model are input as local catchment inflows except where there are upstream areas outside the Study Area, and at these locations total flows are input.

In areas where the Mainstream and Tributary models overlap, the inflow locations in the tributary model have been adjusted to match the Mainstream locations. In the mainstream model the inflows from the local tributaries have been adjusted to ensure the inflow is applied within the flood extent of the main stream so that total flows from the hydrology model that haven't been routed in the Tributary Tuflow aren't applied and create issues at the convergence of the model domains.

8.1.7 Downstream Boundary & Tailwater Conditions

The tailwater water condition adopted at the downstream boundary of all hydraulic models were determined based on flood storm events selected in accordance with the *NSW Floodplain Risk Management Guide – Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (NSW OEH, 2015). Refer to **Section 9.2** for details.

The downstream boundary of the Mainstream model is at Concord Road Bridge at Ryde, which was selected as it is understood to be consistent with the Sydney Harbour tidal levels. It is also a location far enough downstream of the Study Area boundary to not influence flood model results because water levels are controlled by ocean tide and not by the channel geometry, which is sufficiently deep and wide at this location.

Fixed tide levels for the Mainstream model were extracted from the *Lower Parramatta River Flood Study Review* (SKM, 2005), which is outlined in **Section 3.1.2**.

The downstream boundary of each Tributary & Overland Flow model is at the confluence of each tributary with Toongabbie Creek/ Parramatta River. This applies to all creek channels, drainage lines and overland flow paths. The models have a boundary at all drainage path outlets (creeks, drainage lines, overland flow paths) to the mainstream Parramatta River or Toongabbie Creek.

A fixed tailwater level is applied based on the relevant design event Mainstream model results at each identified inflow location. This allows each inflow to have a varied TW level associated with the gradient in the mainstream. For all events less than the 2% AEP all tributary outflows have been set as HQ boundaries so flow just progresses into the river area.

A summary of the adopted tailwater levels for Mainstream and Overland Flow hydraulic models is shown in **Table 9-5.**

8.1.8 Buildings

Aerial photographs and ALS data classes were used to generate building outline polygons in GIS. This was to model buildings as “block-outs”. Building “block-outs” remove cells from the hydraulic model and assumes that flow cannot pass through or have storage within buildings.

All structures that are main buildings that would have solid walls are included. Structures where flow can pass through, such as carports or awnings, have been excluded where they were able to be clearly identified on aerial photographs.

Assessment has also considered some locations where flow can pass through buildings or car parks and in these locations the structure blockages have been removed or amended to allow for flow. e.g; Woolworths Rosehill and other buildings along Clay Cliff Creek.

The Parramatta Stadium and surrounding grading has also been included in the Mainstream model, according to the Issued for Construction Bulk Earthworks & In-Ground Stormwater Plan design drawings (WSS_CD_1.01.008 to WSS_CD_1.01.014 dated 30 May 2017), for all design event and sensitivity analysis models. The stadium has been excluded from calibration event models as it was not constructed at the time of these events.

8.1.9 Proposed Structural Changes

As part of the proposed flood study, several structural changes were considered, including the incorporation of PLR (Parramatta Light Rail) updates. The PLR updates encompassed modifications to structures such as Bankwest Stadium, RSL upgrades, the Parramatta River Escarpment Boardwalk, and Alfred Bridge. These changes were integrated into the Tuflow model to assess their impact on flood dynamics. However, for more specific details on these structural changes, it is necessary to refer to a separate study that specifically addresses those aspects.

Basement carparking is not included as there is no database to know where they all are, their size and any driveway threshold levels. This is beyond the scope of the study.

8.1.10 Fences

Fences have been included where they cross all major flowpaths or are deemed to potentially influence flooding through either directing flows or storing water behind them. Fences were modelled as layered flow constrictions in the TUFLOW model. The blockage factor and form loss coefficients were determined based on the type of fence (e.g., solid brick or sandstone, mesh or paling fence), as identified from desktop analyses using aerial photographs.

In general, fences were identified as either a low retaining wall, a high wooden or colourbond panel fence or a solid high wall.

A ground-truthing site visit showed that there is difficulty in identifying the correct fence type from aerial photography and some inferences must be made. It is not possible to include all fence types accurately without a detailed survey of all fences, which is an extensive exercise and beyond the scope of this study (refer to Section 4.1.3).

8.1.11 Stormwater Pits and Pipes

The stormwater pit and pipe network adopted in the hydraulic model was developed from the following sources of data:

- Council stormwater pits and pipes GIS database;
- Previous XP-SWMM model data;
- Previous MIKE11 model data; and,
- Survey data.

As agreed with Council, all pipes less than 600 mm in diameter were removed from the hydraulic model. The stormwater pit and pipe network included in the TUFLOW Models is shown in **Figure 15-18**.

Council's GIS database of drainage infrastructure includes most assets owned by other agencies such as Sydney Water, RMS, Railways and other Councils within the LGA. In addition, site inspections were undertaken to ensure that all drainage infrastructure required for flood modelling was included.

8.1.12 Structures and Form Losses

8.1.12.1 Bridges

Bridges along the river represent significant hydraulic features affecting flood levels due to contraction and expansion of flows and losses associated with flow area bridge piers and flow interaction with the bridge's superstructure (deck, beams and railings/barriers). Calculation of the bridge hydraulic efficiency and parameterisation of the efficiency in the TUFLOW flood model is important to ensure the bridges are appropriately represented in the flood model.

The bridges were modelled as 2D layered flow constriction shapes (2d_lfcsh) and are shown in **Figure 15-19**, bridges were also represented as closed cross-sections in the 1D domain. Bridges in the 2d domain allowed the bridge structure to be represented through application of form losses and blockages at specific levels corresponding with the piers, soffit, deck and parapet. The total head loss across a bridge structure is caused by two major components:

- Losses due to the contraction and expansion of the floodplain flow through the bridge opening; and,
- Losses due to the drag and turbulence caused by the piers and bridge deck.

Since the abutments are represented in the 2d hydraulic model topography, the form loss due to the contraction and expansion of flow is already accounted for in the model. Therefore, it is only necessary to include an allowance for reduction in waterway area due to piers and the form losses caused by the pier drag and turbulence and the deck and railings.

This allows a hydraulic loss and blockage to be applied to different layers that relate to the piers, deck and railings. For all bridges, the graphs in the 1994 AustRoads publication "Hydraulic Design of Bridges, Culverts and Floodways" which uses "Bradley's Method" was adopted to parameterise the energy losses (form loss coefficient-FLC) of the bridge sub-structure. It is noted that the layered flow constriction has been included as a polygon in the model to represent changes in cross fall in the bridge and the loss values entered into the model are applied per metre of bridge width.

The following parameters primarily drive the calculation:

- Calculation of waterway area for the design event;
- Calculation of waterway area removed by the pier columns; and
- Pier number, shape and configuration.

Figure 15-20 is interpreted for backwater coefficient (FLC/backwater coefficient is read from y-axis) based on ratio of projected pier blockage area to total unblocked waterway area.

Table 8-3 Existing Bridge Loss and Blockage Parameters

Layer	Blockage	Hydraulic Loss	Comment
Piers	Variable depending on pier number and size	As calculated for each bridge	The piers obstruct a % of the waterway area under the bridge, which for a given pier shape/configuration relates to a hydraulic loss value of k read from **Figure 15-20** and divided per metre width of bridge.
Deck	100%	1.56	Corresponding to a submerged deck (Cd = 0.8)
Railing	50%, 80% or 100%	For 50% and 80% - 0.5 For 100% - 1.56	Allowing for blockage by debris: • 50% for railings or open barriers • 80% for wire mesh fences • 100% for solid walls or concrete barriers

Refer **Appendix Q** for complete bridge structure FLC calculations and parameters applied in the TUFLOW model. Existing Bridge Loss and Blockage Parameters are summarised in **Table 8-3**.

The Alfred Street Bridge was included in all design event hydraulic models for this Flood Study and was excluded from calibration event models.

8.1.12.2 Stormwater Pits and Culverts

Pit inlets have been modelled as 1D nodes with rectangular inlets with a width and height extracted from Council's stormwater pit and pipe database or from survey.

The stormwater pits are linked to culverts, which have been setup as 1D elements and use a standard 0.5 entry loss and 1.0 exit loss. All pipes have been assigned a Manning's 'n' of 0.015.

8.1.12.3 ARR 2019 Blockage

ARR19 indicates that for flood planning levels and extents some consideration needs to be given to the blockage of structures within the planning area flood extents.

In general blockages of structures tend to result in higher upstream water levels and extents however hydraulic modelling of blockage also reduces the downstream flow rates as upstream storage acts to route and reduce flows as they progress down the catchment.

To fully assess water level impacts because of blockage, the blockages need to be applied incrementally (one blockage per model run) as you progress down the catchment to model all potential blockage scenarios. This was not undertaken as part of current scope of works however can be considered in future revised assessments.

Current modelling has considered blockage in accordance with ARR19 requirements and both CoP and Stantec have reviewed ARR19 and recommend the L10 = 1.5m approach to blockage. The requirements for this blockage scenario are presented below:

- For all cross drainage structures with a horizontal width of less than 1.5m a 50% blockage is applied (ARR Table 6.6.6).
- For structures with horizontal width between 1.5 to 4.5m a 10% blockage is applied (ARR Table 6.6.6)
- Sag or on-grade pit blockages to stormwater network:

  - 20% for On-grade pit

  - 50% for Sag Pits

The above blockages are to be applied to both the mainstream and tributary models in the 5% and FFA calibrated 1% AEP assessments. The pit types are as defined in the most up to date 1D network information (which includes pipe data corrections undertaken in 2021 by Stantec).

The outcomes of blockage assessment are expected to have impacts upstream for the first few crossings and that the flows may potentially be routed by the blockage and reduce flows downstream to rates less than defined in the no blockage scenario.

CoP has identified that the FFA calibrated 1% AEP and 5% AEP events are required to consider blockage and outcomes of these modelled events have been provided as an envelope for both the blockage and no blockage scenario.

Further work on incremental blockage is recommended to ensure potential upstream water levels in downstream blocked structures are captured for both events.

For flood planning assessment the FFA calibrated 1% AEP event was modelled for the full blockage and no blockage scenario and outcomes presented as an envelope of water level extents and levels. ARR19 Blockage are applied as baseline case for all climate changes and non-blockage related sensitivity scenarios.

8.1.12.4 Zero Blockage Scenario

One additional scenario with zero blockage, in conjunction with applied blockage, was applied to derive an envelope to both the mainstream and tributary models. This is further discussed in section 10.8.

8.2 Calibration & Validation

The Parramatta River model was calibrated using the June 2016 event. The model was also run for two validation events of April 2015 and April 1988 and the results plotted against recorded water level and streamflow data at each gauge location that had data available during each event.

The XP-RAFTS hydrology model setup with regards to catchment conditions and basins active for each of the calibration events is described in Section 5.3.2 and provided in **Appendix B**.

Similarly, the TUFLOW hydraulic model was then adjusted to remove hydraulic structures or features that were known to not be present at the time of each calibration event. For the June 2016 and April 2015 events, the current TUFLOW model setup is largely representative of these events as these are recent events. However, for all calibration events the Peter Parade levee upgrade was not included as this was constructed in 2017 and other recent infrastructure including Alfred Street Bridge and the Northern Foreshore boardwalk were also not included. For the 1988 validation event, the hydraulic model has been modified to remove the pedestrian portals through Lennox Bridge as these were constructed in 2014 and the Briens Road flood relief culverts which were constructed in 2006.

Hydrographs at selected locations are shown in **Appendix C**.

8.2.1 Water Level and Streamflow Gauges

Data for the water level and streamflow gauges that are located within the Study Area were collected and reviewed. For each event, all gauge data was reviewed to ensure its suitability and reliability. Some gauges were found to have missing data for some or all the duration of the historic events, and some gauges did not have data available from data authorities.

The final set of appropriate gauges were selected and applied for each hydraulic calibration model, as shown in **Table 8-4**. A figure of these gauge locations is shown in **Figure 15-5**.

8.2.2 Calibration & Validation Modelling Results

The hydraulic modelling results are shown in **Appendix C** plotted against the gauged water level data in basins and streamflow gauges for the following events:

- June 2016 event
- April 2015 event; and,
- April 1988 event.

In all three historic events, there is generally a consistent hydrograph shape when comparing the modelled hydrograph and gauged data. This indicates a good catchment response in the hydrologic model.

8.2.2.1 June 2016 Event

In the June 2016 hydraulic calibration model, there is a good match to most gauges along Toongabbie Creek and Parramatta River. The following observations are made:

> There is a good correlation between the modelled and gauged flows seen at Marsden Street Weir and Riverside Theatre to within 5%.

> Flood levels are overestimated by 110mm at Marsden Street weir, however, it is noted that there appears to be quite a lot of noise and instability in the gauged water levels and flow values at the peak of the event. As such, the accuracy of the gauge data is questionable and the peak value could be slightly higher. Water levels and flows at Riverside Theatre show a strong correlation.

> There is a tendency that the modelled flows are lower in the upper reaches at Toongabbie Creek (Redbank Road), Toongabbie Creek (Briens Road) and Toongabbie Creek (Johnstons Bridge) gauges, when compared to gauged data.

> The difference in flows is most pronounced at Briens Road where the modelled flows are 11% lower than gauged flow data. This is believed to be due to storage in the area upstream of the bridge which reduces flowrates for a given level when compared with the rating curve. This storage is also not modelled in the hydrology model which shows a good correlation with the gauged data.

> Water levels show a reasonable correlation to within +/- 400mm. The differences at Johnstons Bridge are even less significant, with the estimated levels only 60mm lower than gauge levels.

Validation of flood extents against historic photographs and videos is presented in **Appendix C**. This shows that for the available locations of documented flood extents, the model shows a similar behaviour to that observed and documented.

8.2.2.2 April 2015 Event

For the April 2015 validation event, the following observations are made:

- There is a good correlation between the modelled and gauged flows seen at Marsden Street Weir and Riverside Theatre.
- Flood levels at Marsden Street Weir show a strong correlation, while water levels at Riverside Theatre are slightly underestimated.
- The Toongabbie Creek (Redbank Road) and Toongabbie Creek (Briens Road) gauges were deemed to be unreliable for the April 2015 event due to poor data for flow or water level being provided, indicating a possible error with the gauge during the event.
- The Toongabbie Creek (Redbank Road) gauge is likely unreliable when compared with other gauges, the flows are at times higher than downstream gauges and the water levels appear to show some drift possibly due to instrument error.
- In the calibration model, flows and water levels at most gauges tend to be slightly lower than that of gauged levels.
- However, the Darling Mills Creek and Loyalty Road Basin gauges show that the peak flows or water levels are slightly overestimated in the hydrologic model. This indicates potentially additional rainfall being assigned to these catchments that did not occur (due to rainfall gauge limitations).

Validation of flood extents against historic photographs and videos is presented in **Appendix C**. This shows that for the available locations of documented flood extents, the model shows a similar behaviour to that observed and documented.

Table 8-4 Water Level and Streamflow Gauges Used in Hydraulic Calibration Models

Water Level Gauge	Gauge Number	April 1988 Model	April 2015 Model	June 2016 Model	Comment
Blacktown Creek (International Peace Park)	567109	-	✓	✓	Water level data only
Model Farms Creek (Sierra Place Basin)	567094	-	-	-	Gauge not used for calibration (unreliable or no data available)
Toongabbie Creek (McCoy Park Basin)	Unknown	-	✓	✓	Water level data only
Toongabbie Creek (Johnstons Bridge)	567058	-	✓	✓	Water level data only (rating curve not reliable)
Toongabbie Creek (Briens Road)	567074	✓	✓	✓	Stream flow data used in calibration
Toongabbie Creek (Redbank Road)	567056	-	✓	✓	Stream flow data used in calibration
Darling Mills Creek (Loyalty Road Basin)	567072	-	✓	✓	Water level data only
Lake Parramatta	Unknown	-	✓	✓	Water level data only
Darling Mills Creek (North Parramatta Viaduct)	567057	-	✓	✓	Stream flow data used in calibration
Parramatta River at Cumberland Hospital	213282	-	-	-	Gauge not used for calibration (unreliable or no data available)
Parramatta River (Marsden Weir)	567107	✓	✓	✓	Stream flow data used in calibration
Riverside Theatre	567112	-	✓	✓	Stream flow data used in calibration
Duck River (The Steps)	213209	-	-	-	Gauge not used for calibration (unreliable or no data available)
Lower Parramatta River (Silverwater Bridge)	213435	-	✓	-	Water level data only

8.2.2.3 April 1988 Event

In the April 1988 event hydrologic calibration model, only two gauges are available for validation – Marsden Street Weir and Toongabbie Creek (Briens Road). The following observations are made:

- There is a good fit between the modelled and gauged flows at Marsden Street Weir for timing volume while peak flows and peak levels are very close to the gauged values.
- The calibration model shows significantly higher flows than the gauge at Toongabbie Creek (Briens Road). It was likely that flows were large enough that water spilled into a flood-runner at Toongabbie Creek (Briens Road) and bypassing the streamflow gauge, hence peak flows are underestimated by the Briens Road rating curve for higher flows. This likely inaccuracy of the Briens Road rating curve is noted in Molino Stewart (2014, pg. 42)

In addition to the above, historical observations provided in the Lower Parramatta River Flood Study (SKM, 2005) have been used to validate the current model.

This comparison is shown in **Appendix C**. This shows that flood level estimates are a reasonable match to the historical flood level between Charles Street Weir and Vineyard Creek confluence and at Silverwater Road Bridge, while differences of 290-450mm are observed alongside Camelia at Morton Street and Thackeray St. SKM note that the presented historical flood levels are either surveyed or estimated, but do not indicate which have been estimated. The two reported values alongside Camellia may be low quality, particularly as one value is higher than the upstream value at Vineyard Creek confluence. There is also no significant hydraulic control in this area other than the Thackeray Street pipe bridge, which may have had some blockage due to debris during the flood event, which is not represented in the calibration model setup.

Validation of flood extents against historic photographs and videos is presented in **Appendix C**. This shows that for the available locations of documented flood extents, the model shows a similar behaviour to that observed and documented, however, the model appears to have generally lower flood levels. This would be explained by the lower flows calculated by the hydrology model. It is likely also related to changes in the catchment and infrastructure which the current model does not represent for 1988 conditions leading to differences in flood behaviour.

For example, at Lennox Bridge, the hydraulic model has two pedestrian portals on either side of the bridge, however, these were not present in 1988 and hence, water levels would be expected to be higher with only the central arch of the bridge available for flow conveyance.

8.3 Validation of Head Loss at Bridge Structures

In order to confirm that the loss parameters used in the TUFLOW model are appropriate, an assessment was undertaken using the 1-dimensional HEC-RAS software at a selection of bridges. This assessment is provided in a summary report in **Appendix D**. The assessment shows a good correlation at the bridges assessed and hence it is deemed that the loss parameters being used in the TUFLOW models are appropriate and provide a good representation of hydraulics at bridge structures.

9 Model Scenarios

The following sections describe the model scenarios undertaken for the Parramatta River Flood Study.

9.1 Design Events and Durations

All mainstream and tributary models have been run for the 0.2%, 0.5%, 1%, 2%, 5%, 10%, 20%, 50%, 63% AEP Storms and half-PMF and PMF event.

The following tables show the storm durations modelled for the different stage models. The critical durations determined for flow from the hydrology model at key locations were used as a guide for the durations which would be required to be modelled with the hydraulic model.

For the Mainstream model, given the critical duration of 12 hours in the hydrology model, the longer durations from 1 hour to 36 hours were simulated.

For Tributary & Overland Flow models, critical durations ranged from short 15min up to the 12hr event and given the overland flow within these models, it was deemed appropriate to model the shorter durations up to 2 hours. There are some catchments where there are basins upstream and hence the critical durations are longer than 2 hours and were also modelled.

The critical durations initially considered for modelling the FFA calibrated 1%AEP, Design 2%, 5%, 20% AEP described in **Table 9-1** and PMF are described in **Table 9-2**.

Table 9-1 Modelled Durations for the FFA Calibrated 1%, Design 2%, 5%, 20% AEP Storms

Storm Durations	Mainstream Model	Tributary and Overland Flow Models
15 min	-	✓
20 min	-	✓
25 min	-	✓
30 min	✓	✓
45 min	-	✓
1 hour	✓	✓
1.5 hour	✓	✓
2 hour	✓	✓
3 hour	✓	✓*
6 hour	✓	✓*
9 hour	✓	✓*
12 hour	✓	✓*
18 hour	✓	-
24 hour	✓	-
30 hour	✓	-
36 hour	✓	-

* Longer durations were selectively run for the following models based on critical durations from the hydrology:

- Model 2 – Clay Cliff Creek
- Model 3 – Darling Mills, The Ponds, Subiaco, Vineyard and Brickfield Creeks
- Model 4 – Finlaysons, Coopers and Milsons Creeks
- Model 5 – Pendle Hill and Greystanes Creek

With reference to the historic events, it was found applying the pre-burst rainfall over a duration of 30 hours across all events and durations would be appropriate. This allows for a consistent method of pre-burst rainfall application across all events and durations, as well as achieving a pre-burst rainfall intensity that is similar to that of the historic events.

Pre-burst rainfall has been applied over 30 hours in the hydrology model with corresponding preburst depth, based on the historical storms preburst analysis of regional rainfall gauges. As part of the rainfall event, this preburst depth is temporal distributed as input time series to simulate the inflow hydrograph for Tuflow model. ARBM was applied instead of initial loss(IL)/continue loss(CL) to maintain consistency with the UPRCT models. To achieve a base flow from the pre-burst rainfall prior to the burst, the TUFLOW model durations include 2 hours of pre-burst rainfall before the burst hydrograph is applied. As such the model simulations start at hour 28 of the hydrograph. The starting would storage parameters in ARBM (the initial losses effectively) were chosen from calibration to historical events, however, with the preburst applied, the soil is saturated when the burst storm event happens, so all the initial loss is taken up and there is limited impact on flows.

Table 9-2 Modelled Storm Durations for the PMF

Storm Durations	Mainstream Model	Tributary and Overland Flow Models
15 min	✓	✓
30 min	✓	✓
45 min	✓	✓
1 hour	✓	✓
1.5 hour	✓	✓
2 hour	✓	✓
3 hour	✓	✓
4 hour	✓	
5 hour	✓	
6 hour	✓	

Outcomes of the initial model runs have been processed and summarised in order to identify for each event the actual critical durations that provide the highest flows and associated water levels within all models. Outcomes for duration modelling is presented in **Figure 15-21** to **Figure 15-25**.

Review of outcomes has provided a list of critical durations with a summary of the durations progressing to sensitivity and final design assessment provide below in **Table 9-3**. Note that for all additional events (i.e. 0.2%, 0.5%, 10%, 50% and 63% AEP) the critical durations have been defined from the output of the XP-Rafts hydrological models.

Table 9-3 Modelled Critical Durations for AEP events

Event	Source	Model						
		Mainstream	ClayCliff	DarSub	FinCoo	Pendel	Quarry	TerDev
PMF	Tuflow	3hr and 4hr	45min , 2hr	45min , 3hr	45min	15min and 1hr	30min	30min , 1hr
0.5 PMF	Tuflow	3hr and 4hr	45min , 2hr	45min , 3hr	45min	15min and 1hr	30min	30min , 1hr
0.2% AEP	XP-RAFTS	3hr and 4.5hr	20min , 1hr	45min , 1.5hr	20min, 45min	20min and 30min	30min	30min
0.5% AEP	XP-RAFTS	12 hours	20min, 1hr	45min and 6hr	20min and 45min	20min and 30min	20min, 30min	30min
FFA calibrated 1%AEP	Tuflow	2hr, 6hr and 12hr	12hr	20min, 4.5hr, 12hr	3hr	15min and 6hr	6hr	2hr

2%AEP	Tuflow	2hr and 12hr	12hr	15min and 12hr	25min	20min	20min and 12hr	15min and 2hr
5%AEP	Tuflow	2hr and 6hr	3hr	15min and 6hr	25min	20min	3hr	30min
10% AEP	XP-RAFTS	2hr and 9hr	30min,1hr	45min,2hr	30min	30min	30min	30min
20%AEP	Tuflow	3hr, 4.5hr	2hr	1.5hr	45min	20min and 1.5hr	1.5hr	1hr
50% AEP	XP-RAFTS	2hr and 12hr	1hr	45min, 1.5hr	45min	45min	45min	1hr
63%AEP	XP-RAFTS	1hr and 3hr	1hr	45min,2hr	45min	45min	45min	30min

The above list represents the extent of Tuflow modelled outcomes that have been used to generate peak water level, hazard and outcomes for each AEP event.

9.2 Tailwater Conditions

The adopted water levels at the downstream boundary of all hydraulic models were selected in accordance with the *NSW Floodplain Risk Management Guide - Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (NSW OEH, 2015) replicated in **Table 9-4**.

Table 9-4 Combinations of Catchment Flooding and Oceanic Inundation Scenarios (source: Table 8.1 OEH, 2015)

Design AEP for peak levels/velocities	Catchment Flood Scenario	Ocean Water Level Boundary Scenario	Comment/ Reference
50% AEP	50% AEP	HHWS(SS)	Dynamic hydrograph can be taken from Appendix C with peak flood to coincide with HHWS(SS) highest peak for highest water levels Peak HHWS(SS) 1.25m AHD
20%	20% AEP	HHWS(SS)	
10%	10% AEP	HHWS(SS)	
5%	5% AEP	HHWS(SS)	
2%	2% AEP	5% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
1% Envelope level	5% AEP	1% AEP	Envelope provides 1% AEP design flood estimate
1% Envelope level	1% AEP	5% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
1% Envelope velocity	1% AEP	ISLW	Dynamic hydrograph can be taken from Appendix C with peak flood to coincide with ISLW lowest trough for peak velocities in entrance. Fixed ISLW approx. -0.95m AHD
0.5%	0.5% AEP	1% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
0.2%	0.2% AEP	1% AEP	
PMF	PMF	1% AEP	
1% Catchment	1%	HHWS(SS)	Suggested envelopes for analysis of catchment flooding only
PMF Catchment	PMF	HHWS(SS)	

The proposed recommended Higher High-Water Springs (HWSS) level of 1.25m AHD exceeds the Highest Astronomical Tide (HAT) level, which stands at approximately 1.2m AHD and represents the highest tidal level in Sydney Harbour. To provide a more accurate benchmark, the annual average Higher High-Water Springs (HHWS) level of 0.995m AHD was adopted.

This data was extracted from the OEH NSW Tidal Planes Analysis - 1990-2010 Harmonic Analysis (Table A17, MHL, 2012) for the Sydney Port Jackson at the HMAS Penguin gauge. That is (Annual Average HHWSS) is 1.920 (HA) - 0.925 (Conversion to m AHD).

Fixed tide levels for the Mainstream model were extracted from the *Lower Parramatta River Flood Study Review* (SKM, 2005), which is outlined in **Section 3.1.2**. .

A summary of the adopted tailwater levels for Mainstream and Overland Flow Climate Change hydraulic models is shown in **Table 9-5.**

Table 9-5 Hydraulic Model Tailwater Levels for Design Events

Event	Mainstream Tailwater Level	Tributary & Overland Flow Tailwater Level
PMF 0.5PMF	Fixed 1% AEP Tide = 1.42m AHD	Fixed Mainstream Peak FFA- calibrated 1% AEP Flood Levels
0.2% AEP 0.5% AEP FFA-calibrated 1% AEP 2% AEP	Fixed 5% AEP Tide = 1.34m AHD	Fixed Mainstream Peak 5% AEP Flood Levels
5% AEP 10% AEP 20% AEP 50% AEP 63% AEP	Fixed Annual Average HWSS Level = 0.995 mAHD	Normal Depth Outflow. TW has been set to HQ (normal depth) for tributary creeks

9.3 Sensitivity Analysis

Sensitivity Analysis is undertaken to examine the effect that varying parameters in the model has on results such as changing model inputs or boundary conditions or to investigate potential future scenarios for prevailing catchment conditions.

Table 9-6 shows the Sensitivity Analysis Scenarios that were investigated for the Mainstream model for the Flood Study. Each analysis has been run for the critical duration events to capture the envelope of peak flood level results for comparison with the adopted model setup for the FFA Calibrated 1% AEP event using ARR2019 Blockage as base event.

Table 9-6 Sensitivity Analysis Scenarios

ID	Sensitivity Scenario	Description	Base Event
SS1	+20% Mannings Roughness	Increase in the roughness value applied to the materials layer by 20% of adopted values	1% FFA-calibrated AEP with ARR 19 Blockage
SS2	-20% Mannings Roughness	Decrease in the roughness value applied to the materials layer by 20% of adopted values	1% FFA-calibrated AEP with ARR 19 Blockage
SS3	ARR87 – IFD and methods	ARR87 IFD data and temporal patterns used. ARBM with 90% initial stores and no pre-burst applied.	ARR87 IFD
SS4	50% Blockage	50% blockage applied to all pits, pipe culverts, and bridge and culvert structures	1% FFA-calibrated AEP

ID	Sensitivity Scenario	Description	Base Event
SS5	Blockage – Critical Structures	80% blockage applied to all pits, and 100% blockage applied to all pipe culverts, and bridge and culvert structures along tributaries.	1% FFA-calibrated AEP
SS6	Tailwater - 5% AEP +0.3m	Addition of 0.3m to the adopted 5% AEP tide level	1% FFA-calibrated AEP with ARR 19 Blockage
SS7	Impact of Basin Removal	Removal of regional detention systems – McCoy Park and Loyalty Road Basin from the models	1% FFA-calibrated AEP with ARR 19 Blockage

For SS3, models were run using the critical durations from previous models as a guide. A range of critical durations were run for each model to obtain the envelope of peak levels at all areas within the model.

For SS4, only culverts and bridges within the study area were blocked. Major structures under railway lines at the upstream of models were left unblocked to allow flows to enter the study area. This allows assessment of the impact of blockage of structures within the study area. Due to the limited number of small diameter structures in the mainstream model, and the focus on the relative impacts of blockage along tributaries adjacent to significant areas, this scenario was run only for the Tributary and Overland Flow models.

For SS6, only models with a tidal boundary have been simulated. This includes the mainstream model, Vineyard and Subiaco Creeks and Clay Cliff Creek.

For SS7, impact of basin removal has been modelled by removing the McCoy Park Basin and Loyalty Road Basins from the hydrology model and the revised inflows input the mainstream model. The mainstream model topography was revised to remove the McCoy Park basin embankment to flatten the terrain to connect to the adjacent Pendle Hill Creek. All other parameters in the model were unchanged. Note that this is not a Dam Break assessment but an assessment of expected flood level if the basins were not constructed.

9.4 Climate Change

It is widely accepted that Climate Change will lead to increases in global temperatures which will lead to increases in the intensity of rainfall along with sea level rise. The NSW Government's Flood Risk Management Manual (NSW Department of Planning and Environment, 2023) requires that flood studies and floodplain risk management studies consider the impact of climate change (rainfall increase and sea level rise) on flood behaviour. This Study has assessed the impacts on flooding of both climate change induced rainfall increases and sea level rise using current industry guidelines.

Climate Change scenarios tested have been adopted from ARR2019 along with consideration of the OEH Floodplain Risk Management Guides: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways OEH (2015) and Practical Consideration of Climate Change (DECC, 2007).

Recognizing the significance of accounting for potential climate change impacts, the consideration of design criteria for flood risk management becomes crucial. The climate change scenario has been incorporated into the analysis of the 1% AEP event, ensuring the resilience and adaptability of our flood risk management strategies.

It is important to note, however, that the extension of the climate change scenario to other AEP events has not been included in this study. The primary focus has been to assess and address the potential impact of climate change for the flood planning purposes, ensuring adequate protection for identified flood risk areas.

9.4.1 Rainfall Increase

Climate change predictions are made based on modelling changes to temperature and rainfall in global climate models for various Representative Concentration Pathways (RCPs), which consider projected increases in greenhouse gas concentrations. Temperature and rainfall for low, medium and high carbon emissions scenarios for years up to 2090 for the Parramatta River catchment are shown in **Table 9-7**.

ARR2019 (Ball et al., 2019) recommends the use of RCP 4.5 and RCP 8.5 values. These values are available as a percentage that the rainfall should be factored by from the ARR Data Hub.

Table 9-7 ARR Data Hub recommended Climate Change Data

Year	RCP 4.5		RCP6.5		RCP 8.5	
	Temperature Increase (ºC)	Rainfall Increase	Temperature Increase (ºC)	Rainfall Increase	Temperature Increase (ºC)	Rainfall Increase
2030	0.869	4.30%	0.783	3.90%	0.983	4.90%
2040	1.057	5.30%	1.014	5.10%	1.349	6.80%
2050	1.272	6.40%	1.236	6.20%	1.773	9.00%
2060	1.488	7.50%	1.458	7.40%	2.237	11.50%
2070	1.676	8.50%	1.691	8.60%	2.722	14.20%
2080	1.81	9.20%	1.944	9.90%	3.209	16.90%
2090	1.862	9.50%	2.227	11.50%	3.679	19.70%
2150*	-	11.50%	-	-	-	28.5%

Note: * Sourced from Ocean and Cryosphere in a Changing Climate - Summary for Policy Makers, IPCC WGI and LL Sept provided by DPIE

9.4.2 Climate Change Sea Level Rise

Flood Risk Management Guide – Incorporating sea level rise benchmarks in flood risk assessments (DECCW, 2010) references the NSW sea level rise planning benchmarks in the *NSW Sea Level Rise Policy Statement* (2009).

The NSW sea level rise planning benchmarks are an increase above 1990 mean sea levels of 40cm by 2050, 90cm by 2100 and by 150cm by 2150. These benchmark figures were established by considering the most credible national and international projections of sea level rise for the NSW coast and take into consideration the uncertainty associated with sea level rise projections.

9.4.3 Climate Change Tidal Inundation

The 1% AEP design still water level of 1.45m AHD at Fort Denison as recommended in *NSW Floodplain Risk Management Guide - Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* (NSW OEH, 2015) has been adopted for mapping the 1% tidal inundation envelope.

The impacts of sea level rise (in the absence of any catchment flooding event) for 2050 (1.85m AHD), 2100 (2.35m AHD) and 2150 (2.95m AHD) have also been mapped by adding the sea level rise planning benchmark values to the 1% AEP tide level. This has been undertaken through mapping of areas below the see level rise levels for each of these scenarios.

9.4.4 Climate Change Scenarios

Based on the above considerations, it was decided to run both the rainfall increase and expected corresponding sea level rise into each scenario for two future scenarios. Sea level rise affects the tidal areas within the Study Area, which are limited to those areas downstream of Charles Street Weir.

Climate Change Scenarios assessed are provided in Table 9-8. Refer to Table 3-4, Table 3-5, Table 9-4 and Table 9-5 for the derivation tailwater of climate Change Scenarios.

Table 9-8 Climate Change Scenarios

ID	Scenario	Catchment Event	Adopted Mainstream Ocean Tide	Rainfall Increase	Sea Level Rise (SLR)	Adopted Boundary Water Surface Level	Base Case
CC1	RCP4.5 – 2050	FFA-calibrated 1% AEP	5% AEP – 1.34m AHD	6.4%	2050 (+0.4m)	Mainstream: 1.74m AHD Tributaries: Mainstream 5% TWL	1% FFA-calibrated AEP with ARR 19 Blockage
CC2	RCP8.5 – 2050	FFA-calibrated 1% AEP	5% AEP – 1.34m AHD	9.0%	2050 (+0.4m)	Mainstream: 1.74m AHD Tributaries: Mainstream 5% TWL	1% FFA-calibrated AEP with ARR 19 Blockage
CC3	RCP4.5 – 2090	FFA-calibrated 1% AEP	5% AEP – 1.34m AHD	9.5%	2100 (+0.9m)	Mainstream: 2.24m AHD Tributaries: Mainstream 5% TWL	1% FFA-calibrated AEP with ARR 19 Blockage
CC4	RCP8.5 – 2090	FFA-calibrated 1% AEP	5% AEP – 1.34m AHD	19.7%	2100 (+0.9m)	Mainstream: 2.24m AHD Tributaries: Mainstream 5% TWL	1% FFA-calibrated AEP with ARR 19 Blockage
CC5*	Tidal Inundation + 2050 SLR	N/A	1% AEP – 1.45m AHD	N/A	2050 (+0.4m)	1.85m AHD	-
CC6*	Tidal Inundation + 2100 SLR	N/A	1% AEP – 1.45m AHD	N/A	2100 (+0.9m)	2.35m AHD	-
CC7	RCP4.5 – 2150 + Tidal Inundation + 2150 SLR	FFA-calibrated 1% AEP	5% AEP – 1.34m AHD	11.5%	2150 (+1.5m)	Mainstream: 2.84m AHD Tributaries: Mainstream 5% TWL	1% FFA-calibrated AEP with ARR 19 Blockage
CC8	RCP8.5 – 2150 + Tidal Inundation + 2150 SLR	FFA-calibrated 1% AEP	5% AEP – 1.34m AHD	28.5%	2150 (+1.5m)	Mainstream: 2.84m AHD Tributaries: Mainstream 5% TWL	1% FFA-calibrated AEP with ARR 19 Blockage and Zero Blockage
CC9*	Tidal Inundation + 2150 SLR	N/A	1% AEP – 1.45m AHD	N/A	2150 (+1.5m)	2.95m AHD	-

* indicates “Mapping Only” events, no Tuflow modelling has been undertaken for these scenarios

For Tributary & Overland Flow models the increased rainfall scenarios were adopted in combination with the 5% AEP levels from mainstream model as the downstream tailwater level. Since for each climate change scenario, the tributaries and mainstream models results are enveloped this approach is considered reasonable.

Each mainstream FFA calibrated 1% AEP CC scenario accounted for the correct SRL condition and the water level profile extends sufficiently into the tributary area and is above the affected region that will experience mainstream backwater. The enveloped result, which represents the maximum potential impact, would be accurate in this case. Hence, whether adopting a 5% AEP or climate change 5% AEP tailwater conditions, there would be no significant difference in the overall outcomes. Both scenarios would yield comparable results, indicating that the chosen approach accounts for the anticipated flood conditions adequately.

10 Modelling Outcomes

The following sections describe the results and processing of results for determining various flood behaviour parameters.

All flood results are presented in the Appendices on a series of maps with an Index Sheet showing the Map reference number for different areas of the catchment. The index sheet and map reference is consistent for each flood parameter plotted.

10.1 Critical Duration

The hydraulic model was run for the durations outlined in Section 8 above and the critical duration for peak flood levels at all locations within the models was determined. The critical durations are shown in **Figure 15-21** to **Figure 15-25** for each event up to the PMF event. The results indicate that:

For the 1% and 2% AEP:

- the 2 hour, 6 hour and 12 hour durations are critical for Parramatta River and Toongabbie Creek;
- A range of durations are critical for the tributaries and overland flow areas (refer Table 9-3);
- isolated areas in the Lower Parramatta River area exhibit a 36 hr critical duration. This includes areas of Shell Oil in Camellia Peninsula and Wanngal Wetlands. This is likely due to water ponding in these areas as there are no outlet structures connecting to downstream areas.

For the PMF:

- the 3, 4 and 5 hr durations are critical for Parramatta River and Toongabbie Creek;
- 45 mins to 2hrs is critical for the lower end of most tributaries; and,
- 15 mins or 30 mins is the critical duration for most overland flow areas and upper tributary areas.

10.2 Peak Flood Levels, Extents and Depths

Flood extent maps showing peak flood level contours and peak flood depths for the 20%, 5%, 2%, 1% AEP and PMF design flood events are provided in **Appendix F**. The representative water levels are summarised in the **Table 10-1.** For events up to the 1% AEP, flooding is largely contained within the channel banks of the Parramatta River and its tributaries, with the majority of flooding occurring through overland flow. Mainstream flooding largely affects some low-lying foreshore areas, but flood extents along the mainstream change dramatically when flow is out of bank in events rarer than the 2% AEP. The PMF affects large areas of the Parramatta River floodplain as well as overland flow areas.

Table 10-1 Peak Flood Levels at Key Locations

Location	20% AEP	5% AEP	2% AEP	FFA-calibrated 1% AEP	PMF
	WL (m AHD)	WL (m AHD)	WL (m AHD)	WL (m AHD)	WL (m AHD)
McCoy Park Basin	26.14	26.71	27.27	28.19	30.25
Toongabbie Creek (Johnstons Bridge)	23.48	24.26	24.67	25.33	29.55
Toongabbie Creek (Briens Road)	12.53	13.20	13.47	14.98	19.76
Toongabbie Creek (Redbank Road)	10.45	11.08	11.29	12.20	18.72
Marsden Street Weir	6.10	6.55	6.70	7.95	14.66
Riverside Theatre	4.91	5.69	5.92	7.41	14.01
D/S Silverwater Bridge	1.30	1.58	1.85	2.27	5.63

Each mainstream scenario was carefully calibrated to incorporate the accurate Tidal conditions. Moreover, the water level profiles were extended well into the tributary areas, rising above the regions anticipated to experience the effects of mainstream backwater and tidal influences. It is important to highlight that the impact on tributaries within the backwater influence zone was not be considered in isolation. Instead, an encompassing approach was adopted, where the results are integrated to represent the maximum potential impact. This comprehensive method ensures the accuracy of the assessment in capturing the full extent of the effects.

10.2.2 Mainstream Flood Behaviour

Flooding during events up to and including the 2% AEP event is generally contained within the channel banks of the Toongabbie Creek/Parramatta River and its tributaries. Increased areas are expected to experience overbank flooding in the FFA calibrated 1% AEP event, including but not limited to the following locations:

- Pendle Hill Creek, immediately upstream of the Fitzwilliam Road crossing –depth of over-bank flooding upstream of the Fitzwilliam Road crossing and also at the crossing reach up to 1.1 metres.
- Toongabbie, immediately downstream of McCoy Park Basin – flood 0.2 to 1.2 meters in the roadways, with some localised areas of more than 1.5 metre at sag-points.
- Bogalara Creek, upstream of its Old Windsor Road crossing – flows are stored behind the Old Windsor Road embankment and causes flood depths of 0.1 to 1.1 metres at neighbouring properties depending on its proximity to the Creek.
- Clay Cliff Creek, in the vicinity of the Hassall Street and James Ruse Drive intersection – flows from Clay Cliff Creek are expected to spill onto roadways and properties in the area. Localised peak flood depths of 2.1 metres are expected on James Ruse Drive, and 2.3 metres on Oak Street. Some properties immediately adjacent to Clay Cliff Creek are expected to be inundated up to 2.3 metres.
- Camellia – flood depths are generally less than 0.6 meters within Camellia.

A significant amount of flow is expected to spill into the Parramatta River floodplain in the Probable Maximum Flood, affecting a large number of properties. Flood depths along the Parramatta River floodplain are expected to be less than 2.5 metres at most locations. Areas where flood depths are greater include, but are not limited to, the following:

- Toongabbie Creek, immediately downstream of McCoy Park Basin – flood depths in the residential area south of Toongabbie Creek, behind Chanel St levee are expected to be approximately 5.0 metres.
- Finlaysons Creek and Coopers Creek confluences with Parramatta River – flood depths in this residential area in the vicinity of these confluences are expected to reach approximately 5.3 metres.
- Parramatta CBD – flood depths within Parramatta CBD are expected to reach up to 6.0 metres.
- Clay Cliff Creek, in the vicinity of Hassall Street and James Ruse Drive intersection – a large area in the vicinity of this road intersection is expected to be inundated to a depth of more than 5.5 metres.
- The Camellia peninsula industrial area bounded by Duck River and Parramatta River – this area is expected to be generally inundated to depths of more than 2.5 metres.
- Ermington Naval Storage Depot Site – this redeveloped residential site is expected to be completely inundated, with flood depths expected to reach more than 3.0 metres.

10.2.3 Tributaries and Overland Flood Behaviour

10.2.3.1 Greystanes (Girraween) Creek and Pendle Hill Creek

Flows are largely contained within the Pendle Creek channel in the 5% AEP event with overtopping of banks occurring during rare events, downstream of the railway and around Fitzwilliam Road/Station Road and the confluence with Greystanes Creek including residences in Woodlawn Drive and Piquet Place.

Extensive inundation is seen throughout the Toongabbie residential area between Fitzwilliam Road and Chanel St levee for all modelled events.

There are various overland flow paths through the suburbs of Toongabbie, Old Toongabbie, Pendle Hill and Constitution Hill (Appendix Sheet F5.6 and F5.14).

In a PMF event, significant flood depths would be experienced through the Toongabbie area adjacent to Toongabbie Creek.

10.2.3.2 Coopers, Finlaysons and Milsons Creeks

In frequent events (less than the 5% AEP), flows are largely contained to the channels, with some flood impact to adjacent properties and shallow overland flow paths upstream of Cumberland Highway on Coopers Creek and between Wentworth Avenue and Darcy Road on all creeks.

For intermediate to rare events up to the FFA calibrated 1% AEP event, additional depths of flooding are experienced, with slightly larger areas are inundated.

During the PMF, the whole area becomes inundated to great depths from the Parramatta River to the railway.

10.2.3.3 Domain Creek

Inundation along Domain Creek is limited to parkland with no impact to surrounding properties. During the PMF, flood levels are expected to begin impacting adjacent properties to the west.

10.2.3.4 Clay Cliff Creek

Clay Cliff Creek catchment will experience extensive flooding through streets and properties through Parramatta CBD, Harris Park and Rosehill, largely due to the large number of road crossings which do not have 1% AEP capacity and due to backwater from the Parramatta River.

Even in the 20% AEP, many roads are affected, in particular James Ruse Drive near Hassall St and Oaks St.

During the PMF, the entire area is inundated.

10.2.3.5 Subiaco Creek, The Ponds Creek and Vineyard Creek

Flows are generally contained within the banks of the creeks, with some impact to adjacent properties which back onto the creeks, particularly the industrial areas at the downstream of Subiaco and Vineyard Creeks.

Various overland flow paths exist through Dundas, Rydalmere and Ermington.

Victoria Road and Kissing Point Road would be overtopped in a 1% AEP with high flood depths upstream of Kissing Point Road near Larnook Close.

Flows in the PMF are deeper and wider along existing flowpaths. Some additional storage is seen upstream of Kissing Point Road and Silverwater Road. Widespread flooding is observed in the Rydalmere industrial area between Railway St and Clyde St between Victoria Road and the Paramatta River.

10.2.3.6 Brickfield Creek

Flooding is experienced in streets and through properties in North Parramatta for all events including Brickfield St, Mason St, Isabella St and Fennell St. With rarer events, more streets and properties become inundated with widespread inundation during the PMF.

10.2.3.7 Hunts Creek and Darling Mills Creek

The industrial area including Board Street, Church Street, Boundary Street and up to James Ruse Drive are impacted by flooding in the 20% AEP event and rarer.

During a PMF, the backwater from Parramatta River results in large flood depths through this area.

10.2.3.8 Quarry Branch Creek

This area is largely characterised by overland flows through Winston Hills, some flowing into Toongabbie Creek, Northmead Gully and Quarry Branch Creek and some flowing north to James Ruse Drive. For frequent events, overland flows are confined to the streets except in Baulkham Hills where flowpaths through properties exist.

During the 1% AEP and PMF, flow depths can become quite deep within properties due to water ponding up against buildings where flowpaths transverse streets.

10.2.3.9 Upper Devlins and Terrys Creeks

Overland flowpaths occur through the rear of properties in Epping from Hermington Street and Edenlee Street through Boronia Park to Carlingford Road. In the 1% AEP flood depths of greater than 0.5 meters occur on Carlingford Road.

Along Terrys Creek, in a 20% AEP, flows largely follow the urban drainage channel/waterway with overland flow occurring through residential areas along the following flowpaths:

- from Mobbs Lane, Marook Street to Raimonde Road and Valley Road;
- Cottee Drive, Lomax Street and Ferntree Place;
- Midson Road, Cavan Drive, Skenes Avenue and Holway Street.

Depths increase for rarer events with depths greater than 1.5m experienced along the flowpaths in a PMF.

10.3 Comparison with Previous MIKE 11 Model Results

There are two main studies for comparison of flood levels with previous studies. The UPRCT Upper Parramatta River MIKE11 modelling work, which is largely undocumented, and the Lower Parramatta River Flood Study (SKM, 2005). Available MIKE11 results are a composite of the UPRCT Draft 9 MIKE 11 model upstream of Charles Street Weir and the SKM Lower Parramatta River Flood Study MIKE 11 model downstream of Charles Street Weir. Flood extents for the 1% AEP event and the PMF event from this TUFLOW Flood Study compared with previous MIKE 11 modelling are shown in **Figure 15-26** and **Figure 15-27**, respectively.

Peak flood levels have been extracted from the TUFLOW model at MIKE11 cross-section locations along the mainstream channels. The peak water level for previous MIKE11 results, 2019 TUFLOW results and water level differences are provided in **Figure C1 to Figure C19** and tabulated in **Table C7** in **Appendix C**. **Table C7** provides water level differences for each design event as well as a comparison with the 2019 TUFLOW model using ARR87 flows.

10.3.1 Flow Rates

A comparison of flow rates at key locations along the mainstream channels is shown in **Table 10-2**.

Table 10-2 Comparison of flow rates 2019 TUFLOW vs MIKE 11

Event	Model	MIKE 11 (ARR87)	This Study (ARR2019)	This Study (ARR87)
	Location	Flow (m^3/s)		
PMF	Marsden Street Weir	2063	3080	-
	D/S Silverwater Bridge	3150	4251	-
FFA-calibrated 1% AEP	Marsden Street Weir	729	724	595
	D/S Silverwater Bridge	1344	1205	1004
2% AEP	Marsden Street Weir	665	508	-
	D/S Silverwater Bridge	1224	828	-
5% AEP	Marsden Street Weir	534	469	-
	D/S Silverwater Bridge	1070	742	-
20% AEP	Marsden Street Weir	418	335	-
	D/S Silverwater Bridge	862	520	-

NB: Values at Marsden Street are extracted from UPRCT Draft 9 MIKE 11 model values for downstream Silverwater Road Bridge are extracted from the SKM Lower Parramatta River Flood Study MIKE 11 model

The table shows the differences in design flood event flow estimates derived from the two different Australian Rainfall and Runoff versions i.e. ARR87 compared with ARR2019. Flows have reduced for all events except the PMF (PMF methodology is unchanged between ARR2019 and ARR1987 and is in accordance with the Generalised Short Duration Method – BoM, 2003) and the FFA adjusted 1% AEP event. Increases in the PMF are attributable to a correction in the setup of Sierra Place Basin.

10.3.2 Current Flood Study vs Previous MIKE 11 Flood Studies

The comparison of flood levels in **Table C7** shows that for flows up to and including the 2% AEP event, 2019 TUFLOW model results are generally lower than the UPRCT/SKM MIKE11 flood levels by for the Upper Parramatta River, however, the extents are generally consistent within the mainstream channels. The 2019

TUFLOW model 1% AEP levels for the Upper Parramatta River are generally higher than UPRCT/SKM MIKE11 flood levels due to the application of FFA matching.

All areas downstream of Charles Street Weir are typically lower in this Flood Study when compared to the Lower Parramatta River Flood Study (SKM, 2005) results. This is primarily due to the significant difference in flows.

There are localised water levels that are significantly lower than MIKE11 (more than 2m) as well as localised increases (up to a few meters) at some locations, particularly upstream of structures that have either been updated with new survey or new structures included since the previous modelling. For example, large decreases are observed upstream of Hammers Road, due to new bathymetric survey data while increases are observed upstream of Peter Parade levee, which was not included in the MIKE 11 models.

Notable flood extent reductions in the 1% AEP are observed in Clay Cliff Creek, Brickfield Creek, Vineyard Creek, Subiaco Creek and The Ponds Creek catchments as well as along Duck River.

Comparison of PMF results with previous MIKE 11 modelling shows lower flood levels predicted in the current study for most areas upstream of Marsden Street Weir, despite PMF flow estimates being higher than UPRCT estimates. This is largely attributable to changes in model setup with additional survey and revised structure representation as per the reasons listed below. The PMF results demonstrate that increased accuracy of the TUFLOW model (over the MIKE 11 model) produces overall lower water levels despite higher PMF peak flows.

Further, the previous MIKE11 model used cross-sections to model the river and these sections did not all extend far enough laterally to represent the full cross-sectional topography and flood width accurately. Hence, the MIKE11 model would tend to provide walls at the side of each cross-section, artificially reducing the cross-sectional flow area and thereby increasing flow depths for a given flow. The 1d model also did not necessarily represent all break out flow paths and in some areas forced flow to be directed according to the 1d model setup rather than bypassing to other areas which occurs in the 2d model.

For both the FFA calibrated 1% AEP and PMF, substantial additional flood areas are observed in overland areas, which were not previously modelled, but have been included in the current TUFLOW model. The PMF was also previously not mapped in Vineyard Creek, Subiaco Creek and The Ponds Creek catchments.

Differences between this Flood Study and the previous UPRCT model results are explained by differences in model inputs and modelling techniques including:

- Design flood event flow estimates using ARR2019 are lower than those previously adopted by Council (ARR87) for events up to and including the 2% AEP leading to lower flood extents and depths;
- two-dimensional modelling being used in this Flood Study which more accurately represents flow across floodplains and overland areas compared with one-dimensional modelling;
- the Inclusion of building footprints in the current model;
- newly collected bathymetric survey of Toongabbie Creek between Old Windsor Road and the weir downstream of Cumberland Hospital and Domain Creek;
- newly acquired survey of numerous hydraulic structures throughout the study area which have been incorporated in the model;
- the inclusion of new structures which have been built since the previous modelling was undertaken such as Peter Parade levee, Chanel St and Edison Pde;
- incorporation of the pedestrian portals through Lennox Bridge which were opened in late 2014. The effect of the portals is to lower water levels upstream of Lennox Bridge and allow more flow through the structure and hence increase flows and flood levels downstream of the bridge;
- incorporation of developments that have occurred since the previous Flood Study and major infrastructure including the new Parramatta Stadium and the soon to be constructed Alfred St bridge;
- Adoption of a different tailwater level leading to influences on water levels downstream of Charles Street Weir; and,
- Modelling and mapping of additional overland areas not previously modelled.

10.3.3 Model Setup Comparison

To demonstrate the flood level differences that are related to changes in model setup between the previous MIKE11 models and this TUFLOW model, comparisons using ARR87 flow estimates in each model are made. It is not possible to use the previous flood study model inflows due to the differences in techniques across the different models and changes to the hydraulic model inflow locations. Stantec have run the current hydrology model using ARR87 techniques and estimated the ARR87 1% AEP flow as 692m^3/s at Marsden Street Weir which is comparable to the UPRCT MIKE 11 1% AEP flow of 729m^3/s to within 5%.

When the TUFLOW model was run using ARR87 flows, results (**Table C7**) show that with similar (within 5%) flows to the MIKE 11 model, the TUFLOW model predicts generally similar levels and extents to the MIKE 11 model. However, there are localised differences which can be explained at each location by a change in the model setup. Areas where increases in flood level are observed along the mainstream channels compared with MIKE11 results, despite the slightly lower flows, include:

> Higher flood levels of between 0-0.4 m between McCoy Park Basin outlet and Peter Parade Levee – this is due to the natural constriction of the river channel near the levee causing a backwater upstream. This constriction was not represented in the MIKE11 model due to the constriction lying between two cross-sections;

> Higher flood levels of up to 1.9 m along Toongabbie Creek upstream of Old Windsor crossing new survey and revised bridge setup

Areas where decreases in flood level are observed along the mainstream channel compared with MIKE11 results include:

> Lower levels within McCoy Park basin using new survey data;

> Lower flood levels upstream of Briens Road Bridge using new survey and revised bridge setup; and

> Lower levels upstream of Lennox Bridge and Marsden Street Weir due to changes to model setup and use of more accurate bathymetry information, new survey of Marsden Street Weir and Lennox Bridge.

> Lower flood levels of up to 0.6 m between Briens Road and Cumberland Hospital due to new bathymetric survey data and also likely due to storage upstream of Briens Road;

> Lower flood levels upstream of Lennox Bridge due to the inclusion of the pedestrian portals constructed in 2014; and

> Lower flood levels downstream of Lennox Bridge, due to the lower flows compared with those used in Lower Parramatta River Flood Study MIKE 11 model (SKM, 2005).

10.3.4 Comparison of Hydrology Methods

Comparing results for ARR87 and FFA-calibrated ARR2019 using the TUFLOW model (**Table C7**) shows that just due to changes in flows, flood levels are on average 0.64m higher using ARR87 flows in the Upper Parramatta River. The difference is variable as larger flows are often constricted more at bridges and other hydraulic controls, hence have a higher localised flood level. Through the Lower Parramatta River, the FFA-calibrated ARR2019 flood levels are on average 0.56m higher compared to ARR87 levels.

10.4 Flow Velocities

Flow velocity maps are provided in **Appendix G**.

Flow velocities in the 1% AEP event are generally between 2 to 4 m/s within the Parramatta River and between 2 to 3 m/s within tributaries. Overland flow velocities across the Study Area are generally limited to less than 1 m/s, with some localised kerbside flows of up to 2 m/s at some locations.

Flow velocities in the Probable Maximum Flood generally vary from 2 to 4 m/s Upper Parramatta River from 4 to 6 m/s in the Lower Parramatta River. Flow velocities within tributaries generally vary from 3 to 6 m/s. Most overland flow velocities are expected to be limited to less than 2 m/s, with few localised roadway flows that exceed 6 m/s.

10.5 Flooding at Major Hydraulic Controls

Flood Profiles showing peak flood levels along the Toongabbie Creek and Parramatta River mainstream channels and all named tributaries are provided in **Appendix K**.

10.5.1 Mainstream

Observation of the flood profiles shows that the major hydraulic controls along Parramatta River and Toongabbie Creek in the FFA calibrated 1% AEP include:

> Natural channel constriction near Wharf Road, Melrose Park, downstream of Wanngal Wetlands
> Duck River confluence and Silverwater Road Bridge;
> Charles Street Weir;
> Barry Wilde Bridge;
> Lennox Bridge;
> Marsden Street Weir and Bernie Banton Bridge;
> Weir south of Cumberland Hospital;
> Natural Channel constriction downstream of Mons Road Bridge;
> Briens Road Bridge and Finlaysons Creek confluence;
> Old Windsor Road Bridge/NW Transitway;
> Quarry Branch Creek Confluence;
> natural channel constriction near Peter Parade Levee;
> Johnstons Bridge; and,
> McCoy Park Basin outlet/Pendle Creek confluence.

In the PMF, additional hydraulic controls are observed at:

> Channel morphology adjacent to Melrose Park and downstream of Wanngal Wetlands where the channel narrows; and,
> Between Thackeray Street pedestrian bridge and Subiaco Creek confluence.

10.5.2 Tributary and Overland Flow

Major hydraulic controls along each tributary are shown in **Table 10-3.**

Table 10-3 Major hydraulic controls along tributaries

Tributary	Major Hydraulic Control
Greystanes (Girraween) Creek	– Station Road Culvert – Railway Line and Portico Parade
Pendle Hill Creek	– Fitzwilliam Road Culvert – Barangaroo Road Bridge – Culvert under industrial area at rear of 120 Bellendella Road – Wentworth Ave and Railway Culverts
Bogalara Creek	– Old Windsor Road and NW Transitway bridges
Coopers Creek	– Fulton Avenue Bridge – Cumberland Highway Culverts – Darcy Road Bridge – Wentworth Avenue and Railway Culverts

Tributary	Major Hydraulic Control
Finlaysons Creek	– Milsons Creek Confluence/Briens Road High Flow Culverts – Darcy Road Bridge – Wentworth Avenue and Railway Culverts
Milsons Creek	– Darcy Road Bridge/Westmead Private Hospital undercroft grated inlet – Wentworth Avenue and Railway Culverts
Domain Creek	– Weirs upstream of confluence with Paramatta River – Internal Access Road Crossing – near Jessie Street
Clay Cliff Creek	– Arthur Street Culvert – Alfred Street Culvert – Harris Street Bridge – Wigram Street Bridge – Parkes Street to Station Street connector culvert – Anderson Street to Jubilee Street connector culvert – Church Street to Anderson Street connector culvert – Inkerman Street Bridge – Marsden Street Bridge
Subiaco Creek	– Cycleway footbridge – Park Road Bridge – Ellimatta Street Footbridge – Kirby Street Bridge and Footbridge – Silverwater Road Bridge (PMF) – Cross Street
The Ponds Creek	– Bennetts Road West footbridge – Kissing Point Road Bridge – Sturt Street Bridge – Ponds Creek Reserve Footbridge
Vineyard Creek	– Victoria Road Bridge – Robert Street – Carlingford Railway Bridge (PMF) – Kissing Point Road (PMF) – Tulong Avenue footbridge and sewer pipeline (PMF)
Brickfield Creek	– Wilde Avenue Culverts – Ross Street to Victoria Road trunk drainage culvert – Doyle Ground/Fennell Street – James Ruse Drive bridge

Tributary	Major Hydraulic Control
Hunts Creek	– James Ruse Drive bridge – Lake Parramatta Dam
Darling Mills Creek	– Pipe Crossing near Board Street – Church St/Windsor Road
Quarry Branch Creek	– Moxhams Road Bridge – Churchill Drive Bridge
Devlins Creek	– Carlingford Road – Kent Street Bridge – Midson Road
Terrys Creek	– Terry Road – Holway Street – Valley Road Culvert – Mobbs Lane Bridge

10.6 Hazard and Hydraulic Categories

10.6.1 Hazard Vulnerability Classification (formally FDM Flood Hazard)

Flood Hazard Vulnerability Classification is determined through a relationship developed between the depth and velocity of floodwaters and is based strictly on hydraulic considerations.

Historically, the criteria for these relationships have been taken from the NSW Floodplain Development Manual (FMD, NSW Government, 2005) The FDM hazard curves are shown in **Figure 10-1**.

However, FDM 2005 has been superseded by (1) Flood Risk Management Guide FB03 -Flood Hazard and (2) Flood Risk Management Manual and (3) Flood Risk Management Measures-MM01 (4) Flood Risk Management Guide FB02 -Flood Function (5) Flood Risk Management Guide FB01 -Understanding and Managing Flood Risk (6) Flood Risk Management Guide - Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways

Recently, a new method of hazard categorisation has been developed by the revised ARR 2019 manual (Book 6: Flood Hydraulics, Section 7.2.7) and Flood Risk Management Guide 2023. The classification is still based on depth and velocity but utilises six categories based on the stability of children, adults, the elderly and vehicles in flood waters.

The ARR2019 hazard curves are shown in **Figure 10-2**, this figure identify thresholds that enable categorisation of flood hazard across the floodplain and for flood events of different scales using information readily derived from hydraulic models into 6 categories. These are H1 to H6, which range from least to most hazardous conditions.

In addition, **Figure 10-3** presents separate curves of thresholds for the stability of people. **Figure 10-4** and Figure 10-5 provide separate curves for vehicles and buildings, which may be useful when looking at these individual aspects more closely.

The results based on the hazard mapping for the ARR19 Hazard Vulnerability Classification (Hazard curves) are provided in **Appendix H**.

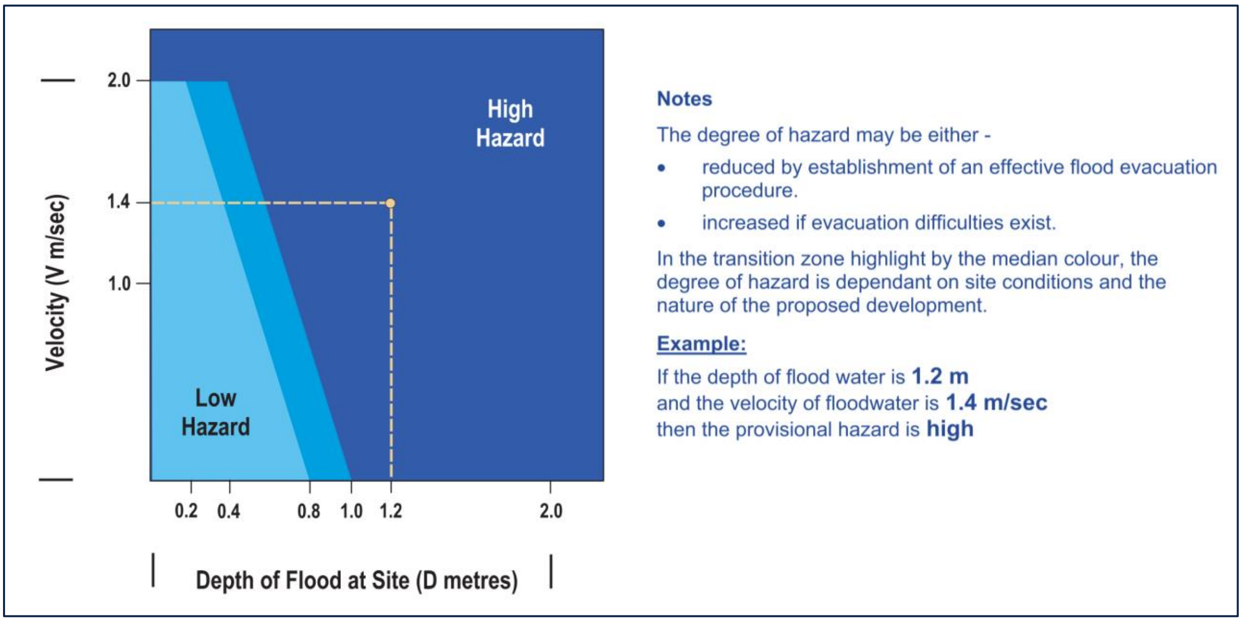

Figure 10-1 Hazard Categories from Appendix L of the Floodplain Development Manual 2005

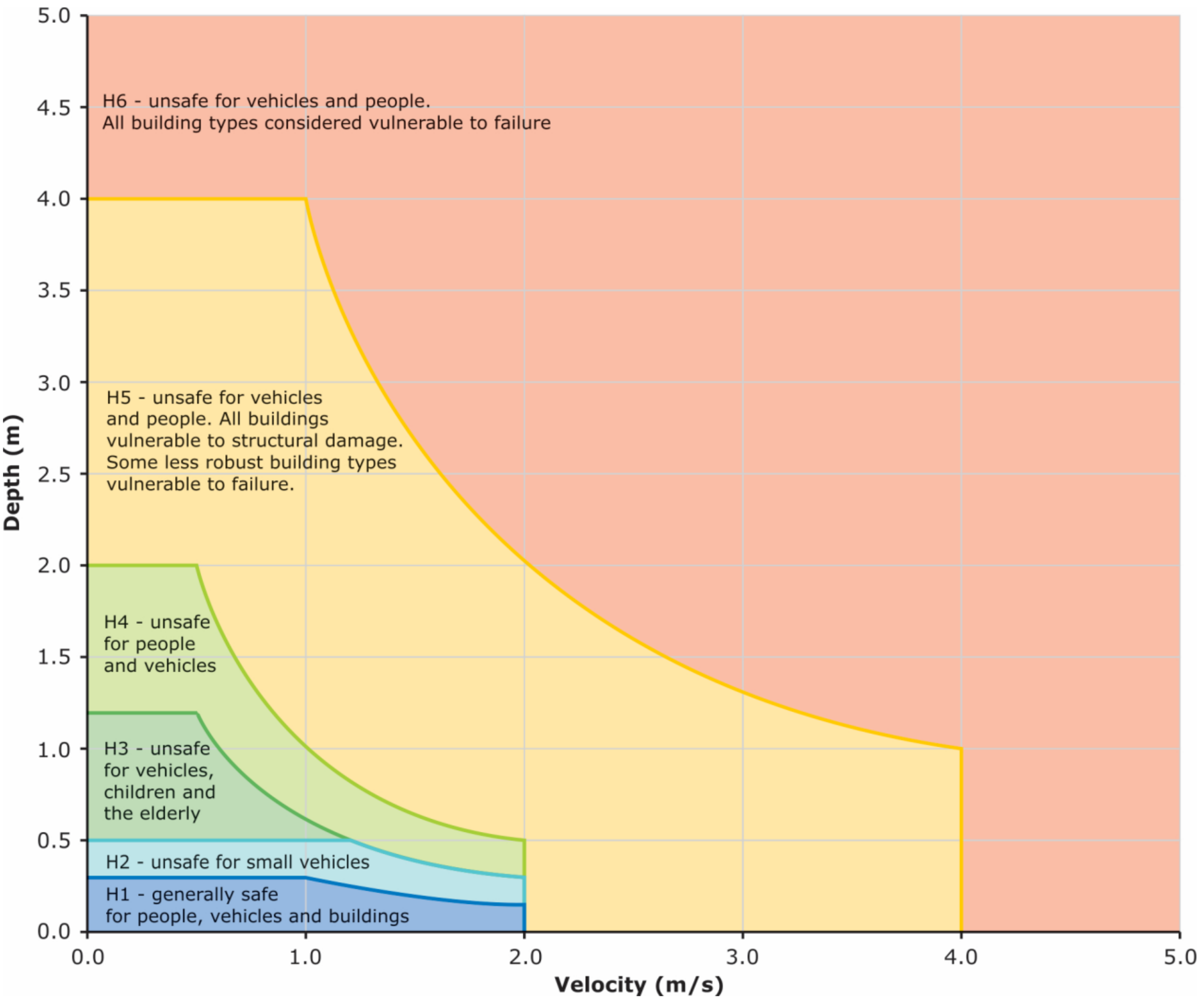

Figure 10-2 General flood hazard vulnerability curve

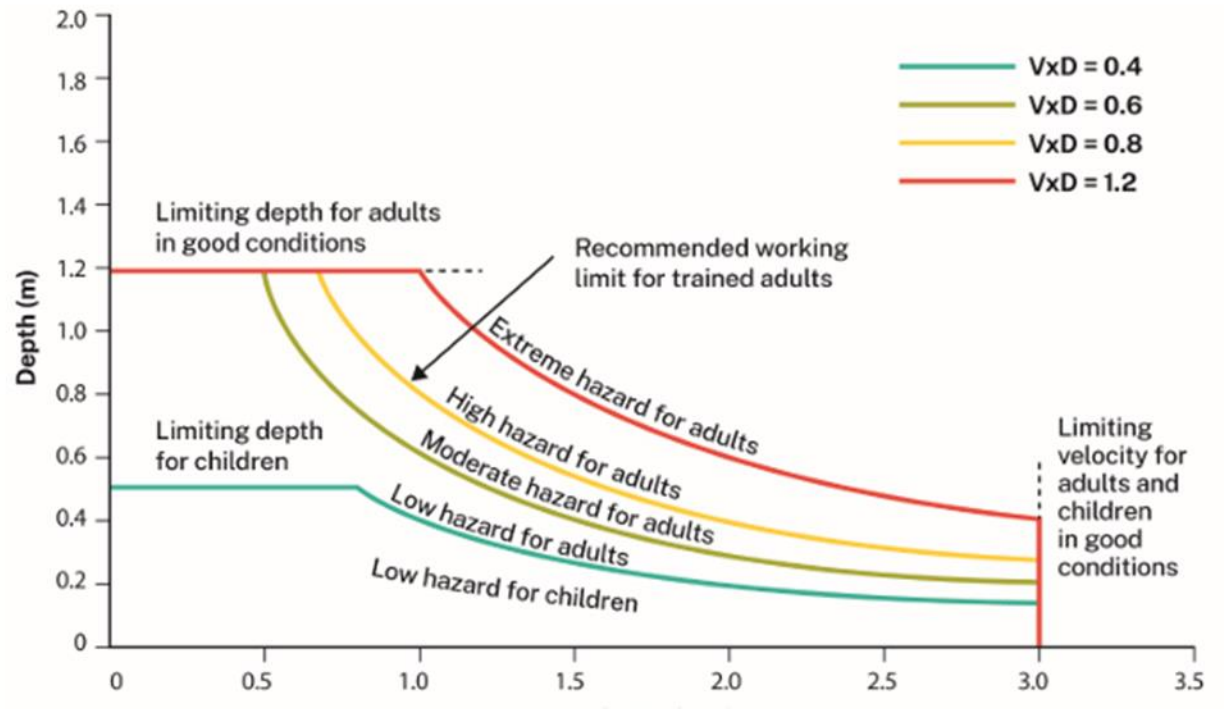

Figure 10-3 Threshold For the Stability of People In Floods

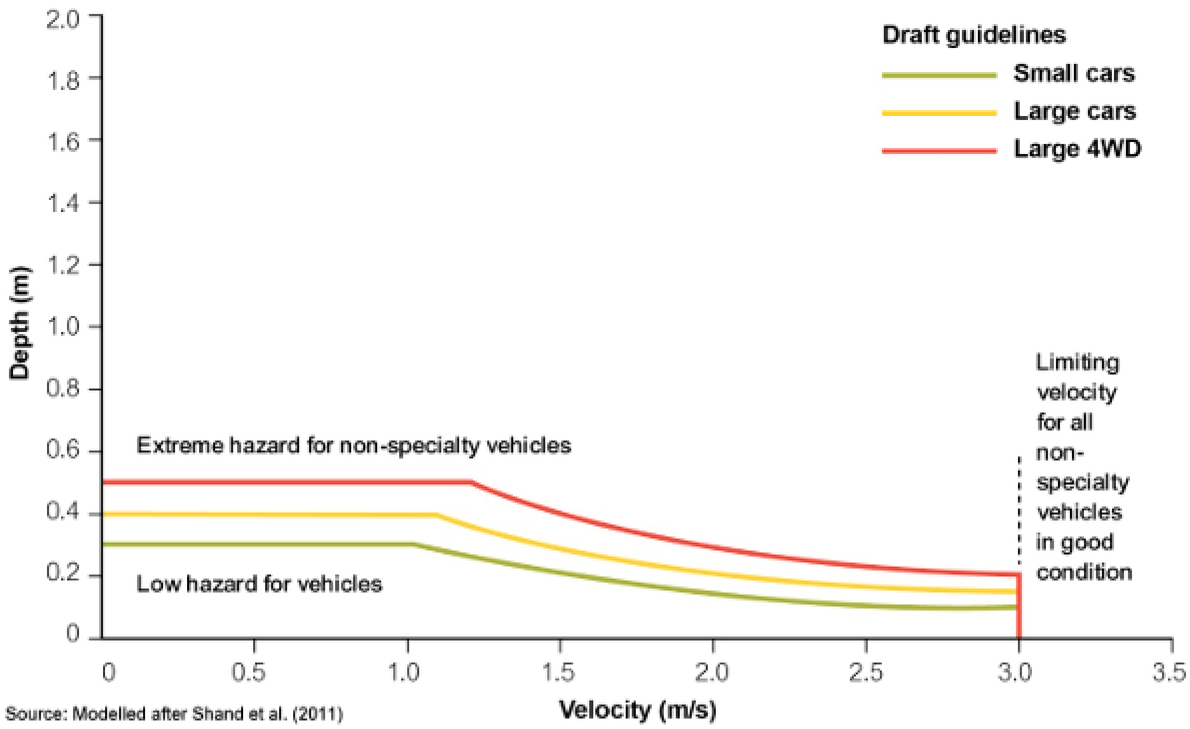

Figure 10-4 Threshold for Vehicle Stability in Floods

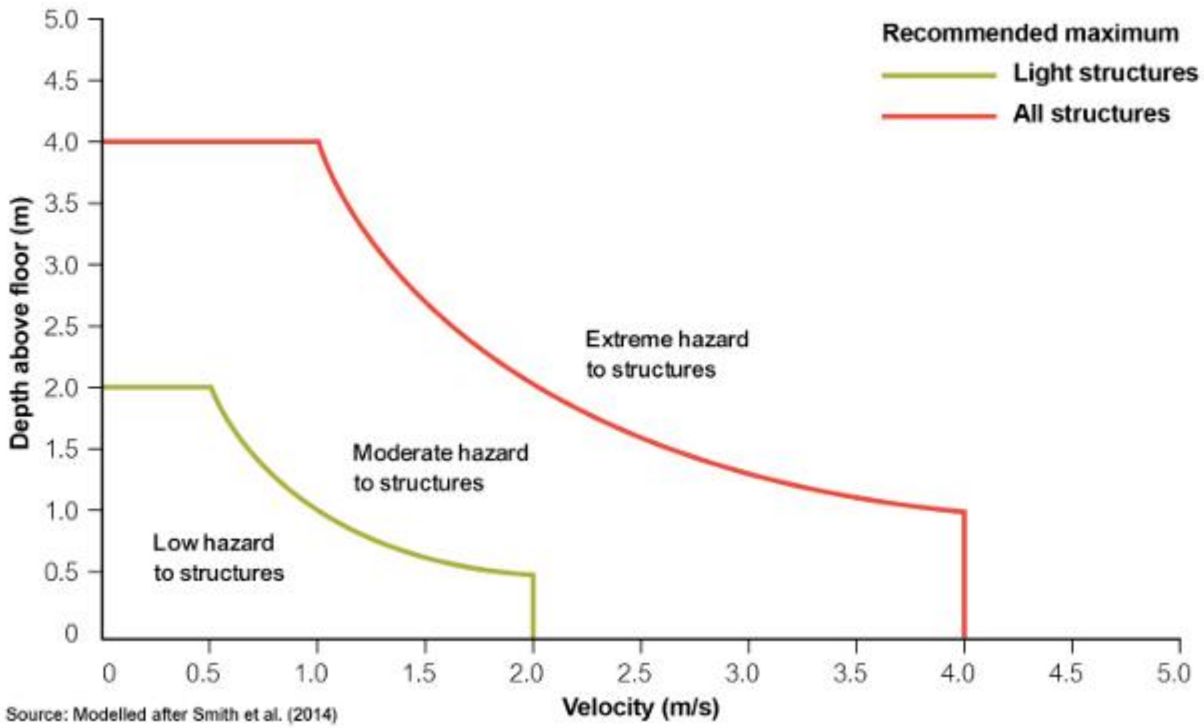

Figure 10-5 Thresholds for building stability in floods

Within the Parramatta River, the FFA-calibrated 1% AEP flood hazard is predominately classed as H6, as a result of the significant depths that occur not just within the river channel but also on some of the overbank areas. The depths and velocity make mainstream Parramatta River flooding hazardous for both pedestrians and vehicles. As a result of the relatively steep banks along the River, the fringe of lower hazards are relatively small. That is, the transition from H6 hazard to flood-free occurs very quickly, with little lower hazard flooding occurring in between.

For the tributaries, the hazard mapping shows that FFA-calibrated 1% AEP H6 hazard areas are largely contained within creek and river systems. Most tributaries are fairly incised, and hence have overbank areas that are classified as H3 hazard or lower. However, H5 hazard is expected in overbank areas along Hunts Creek, Darling Mills Creek and Duck Creek. James Ruse Drive near Hassall St and the surrounding roads are subject to H4 and H5 Hazard in the FFA-calibrated 1% AEP event. Some parts of the River Road W is subject to H6 Hazard.

For most overland flow paths, a H1 to H2 hazard is expected, and are generally safe for people, larger vehicles and buildings, based on the ARR2019 hazard categories. There are some localised areas of H3 Hazard along some roads in the FFA-calibrated 1% AEP event which is unsafe for vehicles and people,

In the PMF, H3 to H6 hazard regions dominate the flood extent, with only the outer flood fringe classed as H1 to H2 hazard. These H5 to H6 hazard regions may impact properties along Toongabbie Creek, Parramatta River, Pendle Hill Creek, Bogalara Creek, Coopers Creek, and Finlaysons Creek. Other significant areas that are greatly affected by H5 to H6 hazards in the PMF include Parramatta CBD, Western Sydney University (adjacent to Parramatta River), Westmead Hospital, and Camellia. Property flooding is classed between H1 to H2 hazard further away from major watercourses, as is the PMF flooding occurring across properties along overland flow areas.

10.6.2 Hydraulic Categories

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The Flood Risk Management Manual (2023) defines flood prone land to be one of the following three hydraulic categories:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage -** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe -** Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

Floodways were determined for the FFA calibrated 1% AEP event by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2003).

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

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

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

To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2m (Howells et al, 2003). Thus, the criteria used to determine the flood storage is:

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

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

Hydraulic Categories as determined by the above methods are provided in **Appendix I**.

10.7 Flood Risk Precincts

Flood Risk Precincts for the Study Area were prepared according to the classification provided by City of Parramatta, as shown in **Table 10-4**. Flood Risk Precincts maps are provided in **Appendix J**.

Table 10-4 City of Parramatta Council Flood Risk Precincts

Flood Risk Precinct	Common Description	Technical Description
High Risk Area	▪ Frequent flooding is common ▪ Near the main river and creeks where water flows during a flood, including overflow from drainage ▪ This area will see the fastest flowing and deepest water and cause a significant risk to life	High hazard flood area within the FFA-calibrated 1% annual exceedance probability (AEP) (1:100)
Medium Risk Area	▪ Frequent flooding will be rare ▪ Where the flood water goes once the creek/river areas overflow ▪ In rare floods these areas have the potential for deep and fast flowing water	Medium and low hazard area in the FFA-calibrated 1% AEP (1:100)

Flood Risk Precinct	Common Description	Technical Description
Low Risk Area	▪ Flooding is extremely rare ▪ Generally, away from the river or creek and higher up ▪ If a flood affects these areas it will cover a large area with dangerous water in many places	Area from the FFA-calibrated 1% AEP (1:100) up to the Probable Maximum Flood
Everywhere Else	Not expected to flood but there still could be local incidents of water running off the land and of street drainage not coping with rainfall amounts.	Area outside the Probable Maximum Flood. There may still be isolated impacts from local overland flow.

High Flood Risk Precincts are generally limited to areas within the Parramatta River channels and its tributaries. Some overbank areas are classified as High Flood Risk Precincts, which include (but are not limited to):

- Clay Cliff Creek, in the vicinity of the Hassall Street and James Ruse Drive intersection; and,
- Finlaysons Creek; in the vicinity of its confluence with Parramatta River.

Isolated High Flood Risk occurs in local overland flowpaths including the following areas:

- Baulkham Hills and Winston Hills (Map 3)
- Carlingford (Map 5)
- Toongabbie (Map 6)
- Winston Hills, Old Toongabbie and Constitution Hill (Map 7)
- Westmead (Map 15, 16, 22 and 23)
- Dundas, Oatlands and Rydalmere (Map 25)
- Harris Park and Rosehill (Map 29)

Medium Flood Risk covers large parts of the Study Area and Low Flood Risk also affects a significant number of properties related to the PMF extent.

All other areas can be seen in more detail in the Flood Risk Precinct maps in **Appendix J.**

Flood Risk in relation to planning and emergency responses is further discussed in **Section 11**.

10.8 Flood Planning Area

Parramatta Development Control Plan 2011 (CoP, 2011) provides a matrix of flood planning controls that set the Flood Planning Level (FPL) depending on the land use type and the flood risk. The Flood Planning Level (FPL) is typically defined as the 1% AEP FFA Calibrated flood plus with 2150 Climate change and SLR plus with 500mm. Freeboard for most residential and commercial developments in high and medium flood risk zones.

Climate Change considerations show that flood levels may be expected to increase by up to 500mm for 2050 scenarios and approximately 600mm for 2090 scenarios in the Upper Parramatta River areas. Lower Parramatta River areas may expect increases of up to 1100mm for the 2150 scenario. On this basis, a 500mm freeboard on FFA calibrated 1% AEP flood levels predicted in the revised Parramatta River Flood Study is appropriate to account for uncertainties and Climate Change, albeit not both. Therefore, this study considered adopting a 1% AEP with Climate Change for 2150 scenario (28.5% rainfall increase +1.5m SLR) as the base flood level with 500mm freeboard added to form the flood planning level. This will then account for longer term Climate Change as well as potential blockage impacts.

The Flood Planning Area (FPA) has been determined by adding 500mm freeboard to the envelope of the following scenarios and extending the surface laterally to intersect with the adjacent terrain to define the area within the FPL:

- FFA-calibrated 1% AEP with no drainage blockage applied;

- FFA-calibrated 1% AEP with ARR2019 drainage blockage applied;
- CC8 (RCP8.5 – 2150 + Tidal Inundation + 2150 SLR) with no drainage blockage applied;
- CC8 (RCP8.5 – 2150 + Tidal Inundation + 2150 SLR) with ARR2019 drainage blockage applied.

In particular for overland flow areas with shallower depths, the FPA has been clipped to the PMF extent as this is defined as the credible limit of flood affectation.

The listed TUFLOW result set used to generate FPL and FPA follows the industry standard approach by applying no depth filter to the results generated using the flow inflow method. However, it's important to note that the polygon area depicting upstream shallow depths of flow obtained from the rainfall on grid model were applied with 50mm depth filters. The polygon area identified on the FPL does not fall under flood planning control and therefore is not inclusive of the required 500mm freeboard.

Further consideration may be given to filtering shallow depth overland flows and ensuring areas sensitive to blockage and Climate Change impacts are fully considered in the Flood Planning Area.

Flood Planning Areas maps are provided in **Appendix L**.

10.9 Sensitivity Analysis

Results of Sensitivity Analysis scenarios are presented in **Appendix M** as peak water level and depth maps, along with water level difference plots compared with the adopted FFA calibrated 1% AEP event peak water levels. Difference maps have been derived by subtracting the FFA calibrated 1% AEP event water surface level (presented in **Appendix F**) from the Sensitivity Scenario water surface level. Areas that were dry in the FFA calibrated 1% AEP, but experience flooding in the Sensitivity Scenario are indicated as "Was dry, now wet". Areas that were flooded in the FFA calibrated 1% AEP event, but are no longer flooded in the Sensitivity Scenario are indicated as "Was wet, now dry".

Peak water levels for each Sensitivity Analysis scenario are shown in **Table 10-5** at the water level gauging stations along Toongabbie Creek and Parramatta River and in **Table 10-6** at reference locations along tributaries. The tables also show water level difference compared to the FFA Calibrated 1% AEP peak water levels. Reference locations are shown in **Figure 15-28**.

The below sections describe the impacts on flood levels through varying parameters as part of the analysis.

10.9.1 Manning's Roughness

Maps **M2** and **M4** in **Appendix M** show the peak water levels and depth for the 20% increase and 20% decrease in roughness respectively. Water level difference plots for the 20% increase and 20% decrease in roughness are provided in Maps **M3** and **M5** in **Appendix M** respectively.
Table 10-5 and **Table 10-6** provides peak water levels and water level difference for +/- 20% Manning Roughness values for the FFA calibrated 1% AEP design event.

For increased Mannings Roughness:

- Flood levels increase generally by 100-200mm along Parramatta River and its tributaries with minimal increase in flood extents.
- Localised higher increases of around 250mm occur in upper Toongabbie Creek between Hammers Road Bridge and McCoy Park Basin. This is likely due to a narrower and shallower channel through this reach, along with having a more vegetated channel in this area.
- Sensitivity to increased roughness tapers off at Homebush Bay where the channel widens.
- Most overland flow areas in Parramatta CBD, Camellia, Westmead, North Parramatta Urban Renewal Areas are not significantly sensitive to increased roughness with increases typically in the range of 10-30mm. Exceptions are:
  - James Ruse Drive, Hassall Street, Arthur Street, Grand Avenue and Tramway Avenue in Harris Park/Rosehill which experience 50-100mm increase in flood level (Map 29).
  - Tucks Road, Chanel Street, Chanel Street and Rausch Street in Toongabbie (Map 6) which is likely due to ponding behind Chanel Street levee with elevated Toongabbie Creek water levels

For decreased Mannings Roughness:

- Flood levels decrease generally by 100-200mm along Parramatta River and its tributaries.
- Sensitivity to decreased roughness tapers off where the channel widens.
- Increased flood levels are observed in flood storage areas and at locations where water ponds behind a hydraulic control such as a bridge or building. This is likely due to flood waters arriving more quickly from upstream areas due to decreased roughness, thereby contributing more volume or higher flow rates to the bottom of the catchment at each location.

10.9.2 Blockage

Table 10-5 and **Table 10-6** provides peak water levels and water level difference for blockage sensitivity for the FFA-calibrated 1% AEP design event.

Maps **M8** and **M9 series** in **Appendix M** show the results for the 50% Blockage Scenario. The 50% blockage scenario involves applying 50% blockage to pits, pipe culverts, and bridge and culvert structures. As the majority of bridges over Toongabbie Creek and Parramatta River are large with large spans, blockage sensitivity does not apply at these structures. This is reflected in the results, where there are minor increases observed along the mainstream channel of up to 40mm. Areas with the greatest sensitivity to blockage are areas with a drainage network or culverts under roads. This is observed in the following areas:

- Toongabbie – behind Chanel Street Levee (Appendix M8 and M9 Map 6)
- Toongabbie, along Pendle Creek behind Station Road (Map 6)
- Harris Park and Rosehill along Clay Cliff Creek (Map 29)
- Coopers Creek – behind Fulton Avenue Bridge (Map 15)

Maps **M10** and **M11** in **Appendix M** show the results for the selected 80% Blockage Scenario. The select blockage scenario applies 80% blockage to pits and 100% blockage pipe culverts, and bridge and culvert structures along tributaries. Impacts are generally seen locally upstream and adjacent to culvert and bridge structures which have been blocked. Decreases under blockage scenarios are observed downstream of structures as water is stored upstream of blocked structures.

Areas with the greatest sensitivity to the 100% blockage scenario include:

- Eastwood – upstream of Carlingford Road (Appendix M10 and M11 Map 5)
- Toongabbie – behind Chanel Street Levee (Map 6)
- Toongabbie – along Pendle Creek behind Station Road (Map 6)
- Darling Mills Creek – behind the North Rock Road Bridge (Map 16)
- Old Toongabbie – Bogalara Creek upstream of Windsor Road Bridge (Map 7)
- Eastwood – along Terrys Creek (Map 12)
- Wentworthville – along Coopers Creek upstream of Fulton Avenue and Cumberland Highway (Map 15), and near Strickland Place and Fryer Avenue (Map 21)
- Westmead – along Finlaysons Creek upstream of Darcy Road and upstream of Westmead Private Hospital (Map M8-22 and M9-22)
- North Parramatta – Brickfield Creek between Victoria Road and Isabella Street (Map 24)
- Ermington and Dundas – upstream of Silverwater Road (Map 26)
- Harris Park and Rosehill – along Clay Cliff Creek (Map 29)

10.9.3 Tailwater Level

Maps **M12** and **M13** in **Appendix M** show the results for the Tailwater Level sensitivity Scenario including 0.3m increase in the tailwater level. **Table 10-5** and **Table 10-6** provides peak water levels and water level difference for tailwater sensitivity for the FFA-calibrated1% AEP design event. The results show that.

- There are no significant difference in flood levels upstream of Charles Street Weir as flows have not changed and tidal influence does not propagate upstream of Charles Street Weir.

- There is a minor increase (up to 20mm) upstream chain of Charles Street Weir between Lennox Bridge and Cumberland Hospital Weir.
- Starting from Charles Street Weir, flood level increases ramp up to 450 mm towards the downstream boundary, due to the elevated tailwater level.
- As most flows are contained within channels, flood extents are not significantly increased, with minor impacts to foreshore areas of Rydalmere, Camellia, Ermington and Melrose Park.
- No impact is seen upstream of Clay Cliff Creek, Subiaco Creek or Vineyard Creek as the channel capacity is the hydraulic control and the tailwater increase does not cause a backwater up the channels.

10.9.4 ARR87 IFD and Temporal Patterns

Maps **M6** and **M7** in **Appendix M** show the results of ARR87 IFD sensitivity analysis. **Table 10-5** and **Table 10-6** provides peak water levels and water level difference for ARR87 sensitivity for the 1% AEP design event.

Flood levels are significantly lower (up to 1m) using ARR87 hydrology data and methods to determine the design flood flows. At Marsden Street Weir, the ARR2019 FFA-calibrated 1% AEP flow is 727m^3/s, while for the ARR87 1% AEP flow is 595m^3/s, which is some 18% lower. This is due to application of FFA calibrating.

The mainstream channels generally experience flood levels that are typically 300-600mm lower, resulting in reduced flood extents across the Study Area. Some of the areas with the most significant reduction in flood extents or levels are:

- Epping (Appendix M6 and M7 - Map 5)
- Toongabbie (Map 6)
- Eastwood (Maps 12 and 13)
- Wentworthville and Constitution Hill (Maps 15 and 21)
- Westmead (Maps 15, 22 and 23)
- Parramatta CBD foreshore (Map 23)
- North Parramatta (Map 24)
- Harris Park and Rosehill (Map 29)
- Rydalmere and Ermington foreshore areas (Maps 30, 31 and 32)
- Shell Oil along Duck Creek and Duck River (Map 33 and 34)

10.9.5 Basin Removal

Maps **M14** and **M15** in **Appendix M** show the results of Basin removal (McCoy Park and Loyalty Road Basin) sensitivity analysis. **Table 10-5** and **Table 10-6** provides peak water levels and water level difference for Basin Removal sensitivity for the FFA-calibrated 1% AEP design event. The results show that:

- Flood levels increases generally by 100-1000mm along the mainstream channels and lead to minor difference in flood extents compared with design FFA-calibrated 1% AEP results.
- Localised higher increases of around 400mm occur in downstream of Darling Mills Creek. This is likely due to the removal of Loyalty Road Basin at the far upstream of Darling Mills Creek (Map 16).

Table 10-5 Sensitivity Analysis – water level difference at gauge locations along Mainstream

Location	FFA-calibrated 1% AEP	ARR87		+ 20% Roughness		- 20% Roughness		50% Blockage		Select Blockage		TWL +0.3m		Basin Removal	
	WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
McCoy Park Basin	28.19	27.61	-0.58	28.21	0.02	28.16	-0.03	28.20	0.01	28.20	0.01	28.19	0.00	26.79	-1.40
Toongabbie Creek (Johnstons Bridge)	25.33	24.77	-0.56	25.55	0.22	25.07	-0.26	25.33	0.00	25.34	0.01	25.33	0.00	25.34	0.01
Toongabbie Creek (Briens Road)	14.98	14.20	-0.78	15.01	0.03	14.94	-0.04	15.02	0.03	15.08	0.10	14.98	0.00	15.15	0.17
Toongabbie Creek (Redbank Road)	12.20	11.49	-0.71	12.32	0.12	12.00	-0.20	12.19	-0.01	12.18	-0.02	12.26	0.06	12.93	0.73
Marsden Street Weir	7.95	7.13	-0.82	7.90	-0.06	8.04	0.09	7.96	0.01	7.98	0.03	7.97	0.02	9.16	1.21
Riverside Theatre	7.41	6.55	-0.86	7.34	-0.07	7.52	0.11	7.42	0.01	7.45	0.04	7.62	0.21	8.51	1.10
Silverwater Bridge	2.27	2.05	-0.22	2.43	0.16	2.10	-0.17	2.27	0.00	2.42	0.15	2.42	0.15	2.38	0.11

Refer to **Figure 15-28** for reference locations.

Table 10-6 Sensitivity Analysis - water level difference at reference locations along Tributaries

Reference ID	Location	FFA-calibrated 1% AEP	ARR87		+ 20% Roughness		- 20% Roughness		50% Blockage		Select Blockage		TWL +0.3m		Basin Removal	
		WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
Grey_01	**Greystanes (Girraween) Creek**	28.11	28.08	-0.03	28.12	0.00	28.07	-0.05	28.22	0.10	28.42	0.31	28.11	0.00	28.11	0.00
Grey_02	**Greystanes (Girraween) Creek**	26.37	25.93	-0.44	26.55	0.18	26.18	-0.19	26.37	0.00	26.39	0.02	26.37	0.00	26.60	0.23
Pen_01	**Pendle Creek**	26.83	26.82	-0.01	26.84	0.02	26.81	-0.02	26.84	0.01	26.87	0.05	26.83	0.00	26.83	0.00
Pen_02	**Pendle Creek**	30.68	30.70	0.02	30.69	0.01	30.67	-0.01	30.68	0.00	30.75	0.07	30.68	0.00	30.68	0.00
Bog_01	**Bogalara Creek**	24.60	24.58	-0.02	24.56	-0.04	24.53	-0.07	25.53	0.92	25.71	1.11	24.60	0.00	24.60	0.00
Coo_01	**Coopers Creek**	18.89	15.98	-2.91	18.87	-0.02	18.90	0.00	19.96	1.07	20.29	1.40	18.89	0.00	18.89	0.00
Coo_02	**Coopers Creek**	16.87	16.86	-0.02	16.89	0.02	16.86	-0.01	16.85	-0.02	16.85	-0.02	16.92	0.05	16.82	-0.05
Coo_03	**Coopers Creek**	15.47	14.74	-0.72	15.46	-0.01	15.46	-0.01	15.54	0.07	15.73	0.26	15.48	0.01	15.61	0.14
Fin_01	**Finlaysons Creek**	15.53	15.45	-0.08	15.54	0.01	15.49	-0.04	15.61	0.08	15.76	0.23	15.53	0.00	15.53	0.01
Fin_02	**Finlaysons Creek**	14.66	13.80	-0.86	14.70	0.05	14.62	-0.03	14.69	0.04	14.53	-0.12	14.65	0.00	14.85	0.20
Mil_01	**Milsons Creek**	16.76	16.79	0.03	16.76	0.00	16.75	-0.01	16.75	0.00	16.75	-0.01	16.81	0.05	16.73	-0.02
Mil_02	**Milsons Creek**	14.67	13.81	-0.86	14.71	0.05	14.63	-0.04	14.70	0.03	14.54	-0.13	14.70	0.03	14.87	0.21
Dom_01	**Domain Creek**	10.42	10.38	-0.04	10.44	0.02	10.39	-0.02	10.42	0.00	10.42	0.00	10.42	0.00	10.54	0.12
Clay_01	**Claycliff Creek**	12.21	8.98	-3.23	12.22	0.01	12.19	-0.02	12.21	0.00	12.20	-0.02	12.21	0.00	12.21	0.00
Clay_02	**Claycliff Creek**	6.47	6.04	-0.43	6.49	0.02	6.40	-0.07	6.54	0.07	6.62	0.15	6.51	0.04	6.13	-0.34
Clay_03	**Claycliff Creek**	5.57	3.71	-1.85	5.63	0.06	4.58	-0.98	6.17	0.61	7.05	1.48	5.59	0.02	5.73	0.16
Sub_01	**Subiaco Creek**	14.40	13.27	-1.13	14.25	-0.15	14.25	-0.15	14.35	-0.05	14.40	0.00	14.40	0.00	14.40	0.00
Sub_02	**Subiaco Creek**	9.38	7.24	-2.13	9.23	-0.15	9.21	-0.17	9.32	-0.06	9.42	0.04	9.38	0.00	9.38	0.00
Sub_03	**Subiaco Creek**	3.50	2.51	-0.99	3.38	-0.11	3.39	-0.11	3.44	-0.05	3.54	0.04	3.50	0.00	3.50	0.00

Reference ID	Location	FFA-calibrated 1% AEP	ARR87		+ 20% Roughness		- 20% Roughness		50% Blockage		Select Blockage		TWL +0.3m		Basin Removal	
		WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
Pon_01	**Ponds Creek**	23.24	21.16	-2.08	23.24	0.01	23.22	-0.02	23.23	-0.01	23.21	-0.03	23.24	0.00	23.24	0.00
Pon_02	**Ponds Creek**	12.00	9.30	-2.70	12.05	0.05	12.00	0.00	12.00	0.00	12.08	0.08	12.00	0.00	12.00	0.00
Vin_01	**Vineyard Creek**	38.18	33.40	-4.78	34.71	-3.47	34.70	-3.48	38.18	0.00	38.69	0.52	38.18	0.00	38.18	0.00
Vin_02	**Vineyard Creek**	12.62	10.04	-2.58	12.39	-0.23	12.36	-0.26	12.62	0.00	14.77	2.15	12.62	0.00	12.62	0.00
Vin_03	**Vineyard Creek**	9.38	6.72	-2.67	9.40	0.02	9.37	-0.01	9.37	-0.02	9.44	0.06	9.38	0.00	9.38	0.00
Bri_01	**Brickfield Creek**	11.09	10.31	-0.78	10.95	-0.14	10.93	-0.16	11.13	0.04	11.23	0.13	11.09	0.00	11.09	0.00
Bri_02	**Brickfield Creek**	8.89	8.50	-0.39	8.81	-0.09	8.79	-0.10	9.05	0.16	9.37	0.48	8.89	0.00	8.89	0.00
Dar_01	**Darling Mills Creek**	14.05	13.63	-0.42	14.18	0.13	13.93	-0.12	14.05	0.00	14.05	0.00	14.05	0.00	14.83	0.79
Ter_01	**Terrys Creek**	77.39	74.91	-2.47	77.41	0.02	77.37	-0.02	77.48	0.09	77.56	0.17	77.39	0.00	77.39	0.00
Ter_02	**Terrys Creek**	73.16	69.70	-3.47	73.18	0.02	73.15	-0.01	73.28	0.12	73.38	0.22	73.16	0.00	73.16	0.00
Dev_01	**Devlins Creek**	90.07	87.88	-2.19	90.11	0.04	90.04	-0.02	90.10	0.03	90.14	0.07	90.07	0.00	90.07	0.00
Dev_02	**Devlins Creek**	83.77	81.91	-1.86	83.80	0.02	83.74	-0.03	83.77	0.00	83.80	0.03	83.77	0.00	83.77	0.00
Qua_01	**Quarry Branch Creek**	33.47	33.23	-0.23	33.01	-0.46	32.81	-0.66	35.56	2.10	35.78	2.32	33.47	0.00	33.47	0.00
Qua_02	**Quarry Branch Creek**	19.59	19.64	0.04	19.67	0.08	19.52	-0.07	19.57	-0.02	19.42	-0.17	19.59	0.00	19.59	0.00

Note* Cell at Critical location is dry, WL information extracted from adjacent water bodies
Refer to **Figure 15-28** for reference locations

10.10 Climate Change Scenarios

Results of Climate Change scenarios are presented in **Appendix N** as peak water level and depth maps, along with water level difference plots compared with the adopted FFA calibrated 1% AEP event peak water levels. Difference maps have been derived by subtracting the baseline FFA 1% calibrated 1% AEP event water surface level (presented in **Appendix F**) from the Climate Change Scenario water surface level. Areas that were dry in the baseline FFA 1% AEP, but experience flooding in the Climate Change Scenario are indicated as “Was dry, now wet”. Areas that were flooded in the baseline FFA 1% AEP event, but are no longer flooded in the Climate Change Scenario are indicated as “Was wet, now dry”.

10.10.1 Tidal Inundation

Maps in **Appendix N** show the 1% AEP design still water level of 1.45 mAHD along with the extents related to 0.4m sea level rise (2050 – 1.85m AHD), 0.9m sea level rise (2100 – 2.35m AHD)and (2150 – 2.95m AHD) . The following comments are made regarding the impacts of sea level rise on tidal inundation in the Lower Parramatta River:

- Tidal inundation affects the Lower Parramatta River downstream of Marsden Street Weir. Charles Street Weir is a physical barrier that forms the tidal limit of the River under normal tidal cycles. However, the culverts under the deck are at approx. RL 1.17m AHD, and so the 1% AEP tide level and both 2050 and 2090 SLR scenarios will penetrate upstream of Charles Street Weir to Marsden Street Weir, which is the next physical barrier to the tide.
- under a 2050 and 2090 SLR scenarios, additional areas of tidal inundation are expected along foreshore areas, particularly in the lower reaches of the Parramatta River and Duck Creek. This is most notable is low lying foreshore areas including:
  - The northern and southern foreshore areas of the Parramatta River between Marsden Street Weir and Charles Street Weir adjacent to the Parramatta CBD;
  - The northern foreshore areas of the Parramatta River between Charles Street Weir and James Ruse Drive including Rangihou Reserve, properties on Rangihou Crescent, Baludarri Drive and the Baludarri Wetlands (Map 29);
  - Properties along Subiaco Creek on Bridge Street in Rydalmere between Victoria Road and the Parramatta River (Map 25);
  - Reid Park and industrial properties and lots along Pike Street, Rydalmere (Map 30);
  - Eric Primrose Reserve and properties on Antoine Street and John St, Rydalmere (Map 31);
  - Properties on Allambie St, Yarramona St, Haleyman St, Bundara St, Korinne St, Arista Way and Broadoaks St, Ermington (Maps 31 and 32);
  - The wetland at the end of Grand Avenue at the eastern end of Camellia peninsula (Map 31);
  - Boat ramp and public toilets on Wharf Road, Melrose Park (Map 32);
  - Areas along the edge of Shell Oil along Duck River (Maps 33 and 34); and
  - Properties along Tennyson Street in Clyde adjacent to Duck Creek (Map 33).

10.10.2 Increased Rainfall and SLR Scenarios

Peak water levels for each Climate Change Scenario are shown in **Table 10-7** at the water level gauging stations along Toongabbie Creek and Parramatta River and in **Table 10-7** and **Table 10-8** at reference locations along Tributaries. The tables also shows water level difference compared to the FFA Calibrated 1% AEP peak water levels. Reference locations are shown in **Figure 15-28**.

Table 10-7 Climate Change Scenarios – water level difference at reference locations along Mainstream

Location	FFA-calibrated 1% AEP	RCP4.5 2050 (CC1)		RCP4.5 2090 (CC3)		RCP4.5 2150 (CC7)		RCP8.5 2050 (CC2)		RCP8.5 2090 (CC4)		RCP8.5 2150 (CC8)	
	WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
McCoy Park Basin	28.19	28.26	0.07	28.29	0.10	28.30	0.11	28.29	0.09	28.36	0.17	28.42	0.23
Toongabbie Creek (Johnstons Bridge)	25.33	25.49	0.16	25.56	0.23	25.60	0.28	25.55	0.22	25.79	0.46	25.95	0.62
Toongabbie Creek (Briens Road)	14.98	15.37	0.39	15.45	0.47	15.44	0.46	15.41	0.43	15.68	0.70	15.91	0.93
Toongabbie Creek (Redbank Road)	12.20	12.50	0.30	12.57	0.37	12.59	0.39	12.54	0.34	12.78	0.58	13.05	0.85
Marsden Street Weir	7.95	8.35	0.40	8.51	0.55	8.56	0.61	8.46	0.51	8.83	0.87	9.14	1.19
Riverside Theatre	7.41	7.78	0.37	7.91	0.50	7.97	0.55	7.87	0.46	8.20	0.78	8.47	1.06
Silverwater Bridge	2.27	2.55	0.28	2.90	0.63	3.38	1.11	2.58	0.31	2.99	0.72	3.54	1.27

Refer to **Figure 15-28** for reference locations

Table 10-8 Climate Change Scenarios – water level difference at reference locations along Tributaries

Ref ID	Location	FFA-calibrated 1% AEP	RCP4.5 2050 (CC1)		RCP4.5 2090 (CC3)		RCP4.5 2150 (CC7)		RCP8.5 2050 (CC2)		RCP8.5 2090 (CC4)		RCP8.5 2150 (CC8)	
		WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
Grey_01	Greystanes (Girraween) Creek	28.11	28.13	0.02	28.14	0.03	28.15	0.04	28.14	0.03	28.17	0.06	28.19	0.08
Grey_02	Greystanes (Girraween) Creek	26.37	26.59	0.22	26.67	0.30	26.72	0.35	26.65	0.29	26.92	0.55	27.14	0.77
Pen_01	Pendle Creek	26.83	26.85	0.02	26.89	0.06	26.91	0.09	26.88	0.05	27.05	0.22	27.23	0.40
Pen_02	Pendle Creek	30.68	30.71	0.03	30.73	0.05	30.74	0.06	30.73	0.05	30.79	0.11	30.85	0.17
Bog_01	Bogalara Creek	24.60	24.70	0.10	24.75	0.15	24.78	0.18	24.74	0.14	24.91	0.31	25.02	0.42
Coo_01	Coopers Creek	18.89	19.01	0.12	19.06	0.17	19.10	0.20	19.05	0.16	19.23	0.34	19.42	0.53
Coo_02	Coopers Creek	16.87	17.02	0.15	17.20	0.33	17.27	0.40	17.18	0.31	17.44	0.57	17.55	0.67
Coo_03	Coopers Creek	15.47	15.80	0.33	15.89	0.42	15.89	0.43	15.86	0.39	16.11	0.64	16.35	0.88
Fin_01	Finlaysons Creek	15.53	15.57	0.04	15.59	0.06	15.60	0.07	15.59	0.06	15.64	0.12	15.70	0.17
Fin_02	Finlaysons Creek	14.66	15.09	0.44	15.12	0.47	15.10	0.45	15.09	0.43	15.29	0.64	15.50	0.84

Ref ID	Location	FFA-calibrated 1% AEP	RCP4.5 2050 (CC1)		RCP4.5 2090 (CC3)		RCP4.5 2150 (CC7)		RCP8.5 2050 (CC2)		RCP8.5 2090 (CC4)		RCP8.5 2150 (CC8)	
		WL (mAHD)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)	WL (mAHD)	Diff (m)
Mil_01	Milsons Creek	16.76	16.77	0.01	16.78	0.02	16.79	0.03	16.78	0.02	16.82	0.06	16.90	0.14
Mil_02	Milsons Creek	14.67	15.11	0.44	15.14	0.47	15.11	0.45	15.12	0.45	15.31	0.64	15.52	0.86
Dom_01	Domain Creek	10.42	10.45	0.03	10.47	0.05	10.48	0.06	10.47	0.05	10.53	0.12	10.59	0.17
Clay_01	Claycliff Creek	12.21	12.24	0.03	12.29	0.08	12.30	0.09	12.28	0.07	12.35	0.14	12.40	0.19
Clay_02	Claycliff Creek	6.47	6.50	0.03	6.52	0.05	6.53	0.06	6.52	0.05	6.56	0.09	6.60	0.13
Clay_03	Claycliff Creek	5.57	5.75	0.19	5.92	0.35	6.09	0.52	5.82	0.26	6.05	0.48	6.25	0.68
Sub_01	Subiaco Creek	14.40	14.45	0.05	14.44	0.04	14.48	0.08	14.46	0.06	14.56	0.16	14.64	0.24
Sub_02	Subiaco Creek	9.38	9.50	0.12	9.50	0.12	9.57	0.20	9.54	0.16	9.68	0.30	9.78	0.40
Sub_03	Subiaco Creek	3.50	3.60	0.10	3.60	0.10	3.68	0.18	3.64	0.14	3.78	0.28	3.88	0.38
Pon_01	Ponds Creek	23.24	23.25	0.01	23.25	0.01	23.26	0.02	23.26	0.02	23.31	0.07	23.34	0.11
Pon_02	Ponds Creek	12.00	12.12	0.12	12.12	0.12	12.16	0.16	12.15	0.15	12.20	0.21	12.26	0.26
Vin_01	Vineyard Creek	38.18	38.41	0.24	38.41	0.24	38.47	0.29	38.45	0.27	38.51	0.33	38.54	0.36
Vin_02	Vineyard Creek	12.62	12.73	0.11	12.73	0.11	12.81	0.19	12.78	0.16	12.99	0.37	13.18	0.57
Vin_03	Vineyard Creek	9.38	9.39	0.00	9.39	0.00	9.40	0.02	9.39	0.01	9.43	0.04	9.47	0.09
Bri_01	Brickfield Creek	11.09	11.13	0.03	11.13	0.03	11.15	0.05	11.14	0.04	11.18	0.09	11.21	0.12
Bri_02	Brickfield Creek	8.89	8.93	0.04	8.93	0.04	8.97	0.07	8.95	0.06	9.02	0.13	9.07	0.18
Dar_01	Darling Mills Creek	14.05	14.13	0.08	14.17	0.13	14.20	0.16	14.17	0.12	14.32	0.28	14.48	0.43
Ter_01	Terrys Creek	77.39	77.42	0.04	77.44	0.05	77.45	0.06	77.48	0.10	77.48	0.10	77.52	0.13
Ter_02	Terrys Creek	73.16	73.20	0.03	73.21	0.05	73.22	0.05	73.25	0.08	73.25	0.08	73.28	0.12
Dev_01	**Devlins Creek**	83.77	83.81	0.03	83.82	0.05	83.83	0.06	83.87	0.10	83.87	0.10	83.91	0.14
Dev_02	**Devlins Creek**	90.07	90.10	0.04	90.12	0.05	90.13	0.06	90.17	0.10	90.17	0.10	90.20	0.14
Qua_02	Quarry Branch Creek	19.59	19.61	0.02	19.63	0.03	19.64	0.05	19.62	0.03	19.69	0.10	19.77	0.18
Qua_01	Quarry Branch Creek	33.47	33.80	0.34	33.99	0.53	34.12	0.65	33.96	0.49	34.64	1.18	35.17	1.71

Refer to **Figure 15-28** for reference locations

The following comments are made regarding Climate Change scenarios:

> Due to rainfall increases under Climate Change scenarios, flood level increases are observed along Toongabbie Creek, Parramatta River and the lower reaches of the tributaries.

> More significant localised increases are observed, typically at hydraulic structures where the increased flows mean the flow behaviour can change regime e.g. from flowing under a bridge structure to impacting the bridge deck. This can be seen upstream of Briens Road, Cumberland Hospital weir and Lennox Bridge.

Rainfall Increase:

- For the RCP4.5 2050 Scenario (6.4% rainfall increase), **Appendix N1 and N2**:
  - The mainstream flooding is still largely contained within the banks but results in small areas of newly flood affected land along the edges of the watercourses.
  - Increases in overland flow areas are typically 20-600mm and predominantly less than 70mm. Areas experiencing greater than 50mm increase include:
    - Epping – residential areas from Ryde Street and The Boulevarde through Boronia Park to Carlingford Road (Map 5)
    - Toongabbie – along Pendle Creek and behind Chanel Street Levee (Map 6)
    - Old Toongabbie – along Bogalara Creek south of Old Windsor Road (Map 7)
    - Eastwood – along Terrys Creek (Map 12)
    - Wentworthville – along Coopers Creek upstream of Fulton Ave and Cumberland Highway (Map 15), and near Strickland Place and Fryer Ave (Map 21)
    - Westmead – along Finlaysons Creek (Map 22)
    - Rydalmere – industrial areas along Subiaco Creek including Crowgey Street, Bridge Street and Clyde Street (Map 25)
    - Harris Park and Rosehill - locations along Clay Cliff Creek (Map 29)
- For the RCP8.5 2150 Scenario (28.5% rainfall increase) **Appendix N12 and N13**:
  - Due to the significantly increased flows (approx. 20%), flood extent increases are seen along the entire mainstream channels. The mainstream flooding is still largely contained within the banks but results in areas of newly flood affected land along the edges of the watercourses, particularly near Pendle Creek, Finlaysons and Coopers Creeks, Parramatta CBD Foreshore and most significantly in the Lower Parramatta River foreshore areas around Rydalmere, Camellia, Ermington and Melrose Park.
  - Increases in overland flow areas are typically less than 100mm. Areas experiencing greater than 100mm increase include:
    - Epping – residential areas from Ryde Street and The Boulevarde through Boronia Park to Carlingford Road (Map 5)
    - Toongabbie – along Pendle Creek and behind Chanel Street Levee (Map 6)
    - Old Toongabbie – along Bogalara Creek south of Old Windsor Road (Map 7)
    - Eastwood – along Terrys Creek (Map 12)
    - Wentworthville – along Coopers Creek upstream of Fulton Avenue and Cumberland Highway (Map 15), and near Strickland Place and Fryer Avenue (Map 21)
    - Westmead – along Finlaysons Creek (Map 22)
    - Dundas – along Vineyard Creek upstream of Victoria Road and Kissing Point Road (Map 25)
    - Rydalmere – industrial areas along Subiaco Creek including Crowgey Street, Bridge Street and Clyde Street (Map 25)
    - Harris Park and Rosehill - locations along Clay Cliff Creek (Map 29)

11 Discussion

11.1 Revised Flood Levels

The updated 2019 Parramatta River Flood Study provides revised flood level estimates for a range of design flood events. These revised flood levels are generally lower than those currently adopted by City of Parramatta Council for use in flood planning for events less than and including the 2% AEP. This has been discussed in Section 10.3.

Differences between this Flood Study and the previous UPRCT model results are explained by differences in model inputs and modelling techniques including:

> Flooding during events up to and including the 2% AEP event is generally contained within the channel banks of the Toongabbie Creek/Parramatta River and its tributaries.

> Design flood event flow estimates are lower for events less than and including the 2% AEP than those previously adopted by Council due to the use of the latest ARR2019 data and methods. Lower flows provide lower flood extents and flood depths;

> The updated flood modelling uses two-dimensional modelling which more accurately represents flow across floodplains and overland areas compared with one-dimensional modelling which was used in the previous study;

> Interpolation techniques for determining flood levels between 1D model cross section results used in the previous model mapping. This Flood Study models all areas on a 2D grid and does not use interpolation;

> Buildings are blocked out in the current model, and this impacts flowpaths through overland flow areas;

> Newly collected bathymetric survey of Toongabbie Creek between Old Windsor Road and the weir downstream of Cumberland Hospital and Domain Creek. This affects the flow cross-sectional areas and can lead to lower flood levels;

> Newly acquired survey of numerous hydraulic structures throughout the study area which have been incorporated in the model representation of these structures;

> The inclusion of new structures which have been built since the previous modelling was undertaken;

> Incorporation of the pedestrian portals through Lennox Bridge which were opened in late 2014. The effect of the portals is to lower water levels upstream of Lennox Bridge and allow more flow through and hence increase flood levels downstream of the bridge;

> Incorporation of developments that have occurred since the previous Flood Study and major infrastructure including the new Parramatta Stadium and the soon to be constructed Alfred Street Bridge and northern foreshore boardwalk;

> Adoption of a different tailwater levels; and,

> Modelling and mapping of additional overland areas not previously modelled.

11.2 Flow Rates

The adopted FFA calibrated 1% AEP flow rates using ARR2019 data and methods for the Parramatta River at Marsden Street Weir are 724m^3/s, which is consistent with the 730m^3/s adopted in the UPRCT Draft 8 and Draft 9 MIKE 11 models. The current design flood estimates using ARR2019 are based on current industry standards with the most up-to-date available data and methods and correlate with the revised Flood Frequency Analysis, noting that the 1% AEP flow has been recalibrated to match the FFA.

It is noted that the validation to the FFA is only available at Marsden Street Weir. There are no other suitable gauges to provide a validation in other tributaries or overland flow areas and there is no guidance on whether to apply a similar adjustment to other areas of the model.

As the Flood Study is calculating flow and levels across the Study Area, there are multiple points of interest and one technique cannot be applied to all areas. There is variability in the flood producing storm events across the catchment and this is accounted for by employing different procedures for the Mainstream and Overland Flow areas.

11.3 Flood Planning Area

The Flood Planning Area (FPA) has been determined by adding 500mm freeboard to the envelope of the following scenarios:

- FFA-calibrated 1% AEP with no drainage blockage applied;
- FFA-calibrated 1% AEP with ARR2019 drainage blockage applied;
- CC8 (RCP8.5 – 2150 + Tidal Inundation + 2150 SLR) with no drainage blockage applied;
- CC8 (RCP8.5 – 2150 + Tidal Inundation + 2150 SLR) with ARR2019 drainage blockage applied.

The flood planning areas developed for this study differ from those currently adopted by CoP for flood planning. This is to be expected given the differences in the estimation of design flood levels and also the change in the definition of Flood Planning Levels criteria. The Flood Study uses current industry standard guidelines along with up-to-date data, modelling software and methods and the resulting flood level in the Parramatta River Flood Study are considered to be accurate and appropriate.

Sensitivity analysis has provided the magnitude of flood level differences that can be expected through uncertainty of input parameters or changes to tailwater conditions, or if structures were to become blocked.

The flood mapping in Appendices F (Calibrated FFA 1% AEP flood depth) and L (Flood Planning Area) utilizes 1% AEP Rainfall on Grid to supplement shallow local upstream overland flow, following two distinct methods. The First Method, predominantly used, employs a 2m grid surface applied hydrograph in TUFLOW, considering ground roughness based on satellite imagery, building block-outs, ARR 2019 storm events, FFA calibrated 1% AEP storm, climate change and sensitivity testing, pre-burst storms, infiltration loss, model calibration, pipe drainage from diameter 600mm and larger, smaller pipe drainage for significant flow paths, and incorporation of 1D channels and overflows. Additionally, 2014 LiDAR data contributes to building the flood surface. In contrast, the Second Method utilises Rain-on-Grid (ROG) on a 2m grid flood surface in TUFLOW, mainly considering ARR 1987 1% AEP Storm, broad roughness areas, 2014 LiDAR data, and significant simplifications such as no losses or pre-burst conditions. While both methods have their specific applications and considerations, they collectively contribute to a comprehensive understanding of flood risk dynamics, aligning with industry practices and ensuring reliability in depicting flood-prone areas.

11.4 Flood Emergency Assessment – SES Requirements

11.4.1 Background

When determining the flood risk to life, the flood hazard for an area does not directly imply the danger posed to people in the floodplain. This is due to the capacity for people to respond and react to flooding, ensuring they do not enter floodwaters. This concept is referred to as flood emergency response.

To assist in the planning and implementation of response strategies the State Emergency Service (SES) classifies communities according to their flood impact. Flood affected communities are those in which the normal functioning of services is altered either directly or indirectly because a flood results in the need for external assistance. This impact relates directly to the operational issues of evacuation, resupply and rescue. The classifications adopted by the SES (2007c) are:

- **Flood Islands.** These are inhabited or potentially habitable areas of high ground within a floodplain linked to the flood free valley sides by a road across the floodplain and with no alternative overland access. The road can be cut by floodwater, closing the only evacuation route and creating an island. Flood islands can be further classified as:
  - High Flood Island - the flood island contains enough flood free land to cope with the number of people in the area or there is opportunity for people to retreat to higher ground; and
  - Low Flood Island - the flood island does not have enough flood-free land to cope with the number of people in the area or the island will eventually become inundated by floodwaters.

- **Trapped Perimeter Areas.** These would generally be inhabited or potentially habitable areas at the fringe of the floodplain where the only practical road or overland access is through flood prone land and unavailable during a flood event. The ability to retreat to higher ground does not exist due to topography or impassable structures. Trapped Perimeter Areas are further classified according to their evacuation route:
  - High Trapped Perimeter - the area contains enough flood-free land to cope with the number of people in the area or there is opportunity for people to retreat to higher ground; and
  - Low Trapped Perimeter - the area does not have enough flood-free land to cope with the number of people in the area or the island will eventually become inundated by floodwaters.
- **Areas Able to be Evacuated.** These are inhabited areas on flood prone ridges jutting into the floodplain or on the valley side that are able to be evacuated.
  - Areas with Overland Escape Route - access roads to flood free land cross lower lying flood prone land; and
  - Areas with Rising Road Access - access roads rise steadily uphill and away from the rising floodwaters.
- **Indirectly Affected Areas.** These are areas that are outside the limit of flooding and therefore will not be inundated nor will they lose road access. However, they may be indirectly affected as a result of flood-damaged infrastructure or due to the loss of transport links, electricity supply, water supply, sewerage or telecommunications services and they may therefore require resupply or in the worst case, evacuation.
- **Overland Refuge Areas**. These are location that other areas of the floodplain may be evacuated to, at least temporarily, but which are isolated from the edge of the floodplain by floodwaters and are therefore effectively flood islands or trapped perimeter areas.

11.4.2 Flood Emergency Response Classification

The Flood Emergency Response Planning (FERP) classifications in a 1% AEP and PMF event has been undertaken and mapped for all the Significant Areas in accordance with the OEH guideline: *Flood Emergency Response Planning Classification of Communities* (OEH, 2016). These are provided in **Appendix O** and the series of figures are shown in **Table 11-1**.

Table 11-1 FERP Figure Numbers

Significant Areas	FFA-calibrated 1% AEP Event	PMF Event
Camellia	Figure O1.1	Figure O1.2
Parramatta CBD (river foreshore area)	Figure O2.1	Figure O2.2
Knowledge Precinct Area	Figure O3.1	Figure O3.2
North Parramatta Urban Renewal Precinct	Figure O4.1	Figure O4.2
Parramatta CBD (whole of CBD)	Figure O5.1	Figure O5.2
Rydalmere	Figure O6.1	Figure O6.2
Westmead Biomedical Precinct	Figure 07.1	Figure 07.2

In the FFA-calibrated 1% AEP event, Camellia, Parramatta CBD (whole of CBD), North Parramatta Urban Renewal Precinct, Parramatta CBD (river foreshore area), Rydalmere, and Westmead Biomedical Precinct are predominantly flood free or classified as “Areas Able to be Evacuated”, either as areas with overland escape routes or areas with rising road access. A portion of the Knowledge Precinct Area which lies south of Victoria

Road, between James Ruse Drive and Railway Street is classified as “Trapped Perimeter Area”. The rest of the Precinct is not flood affected.

In the PMF event, Camellia, Parramatta CBD (whole of CBD), North Parramatta Urban Renewal Precinct, Parramatta CBD (river foreshore area), and Westmead Biomedical Precinct are predominantly classified as “Flood Islands”, either as low flood or high flood islands where road evacuation must be completed before access road cut-off. Portion of the Knowledge Precinct Area which lies south of Victoria Road, between James Ruse Drive and Railway Street is classified as “Trapped Perimeter Area”. Rydalmere is predominantly classified as “Areas Able to be Evacuated” with overland escape route, and “Flood Islands” where road evacuation must be completed before access road cut-off.

Table 11-2 outlines the response required for different flood emergency response planning classifications. Due to the predominant classification of the Significant Areas floodplain as areas with rising road access and overland escape routes, the emergency response requirement will most likely be evacuation to local refuge centres if the residents cannot take stock in their property.

Table 11-2 Emergency Response Requirements

Classification	Response Required		
	Resupply	Rescue / Medivac	Evacuation
High Flood Island	Yes	Possibly	Possibly
Low Flood Island	No	Yes	Yes
Area with Rising Road Access	No	Possibly	Yes
Area with Overland Escape Routes	No	Possibly	Yes
Low Trapped Perimeter	No	Yes	Yes
High Trapped Perimeter	Yes	Possibly	Possibly
Indirectly Affected Areas	Possibly	Possibly	Possibly

11.4.3 Access and Movement

Any flood response suggested for the Study Area must take into account the availability of flood free access, and the ease with which movement may be accomplished. Movement may be evacuation of residents from flood affected areas, medical personnel attempting to provide aid, or NSW SES personnel installing flood defences.

A summary of road flooding for the Significant Areas are summarised in **Table 11-3** with locations shown in the FERP maps provided in **Appendix O**.

Access roads for which access is lost are highlighted. Access is considered lost when depths exceed 0.2m. The table highlights that most of the major roads experience loss of access in the PMF event with overtopping depths ranging from 0.5m to 5.2m.

The results demonstrate that evacuation of the floodplain using major roads may not be a safe emergency management strategy for the FFA calibrated 1% AEP flood event for the Knowledge Precinct Area and for the PMF flood event for all the significant areas.

Table 11-3 Access Road Flood Depths (m)

ID	Location	FFA-calibrated 1% AEP Flood Depth (m)	PMF Flood Depth (m)
Parramatta CBD (whole of CBD)			
A	Intersection of O'Connell Street and Macquarie Street	0.55	5.67
B	Intersection of Church Street and Macquarie Street	-	3.50
C	Intersection of Church Street and George Street	-	3.52
D	Intersection of George Street and Smith Street	0.04	3.72
E	Intersection of Macquarie Street and Smith Street	-	1.81
F	Intersection of Charles Street and George Street	0.07	4.12
G	Intersection of Charles Street and Macquarie Street	0.16	3.75
H	Intersection of Darcy Street and Church Street	0.14	3.47
I	Intersection of Hassall Street and Wigram Street	0.07	1.64
J	Intersection of Hassall Street and Harris Street	0.80	3.89
Parramatta CBD (river foreshore area)			
A	Intersection of Wilde Avenue and Lamont Street	0.27	5.00
B	Intersection of Victoria Road and Sorrell Street	-	2.55
C	Intersection of Victoria Road and Marist Place	-	1.36
Knowledge Precinct Area			
A	Victoria Road	0.97	2.07
B	Victoria Road	0.72	1.77
C	Intersection of Bridge Street and Victoria Road	0.76	1.77
North Parramatta Urban Renewal Precinct			
A	Intersection of Fleet Street and Albert Street	0.19	1.83
B	Eels Place	0.36	3.55
C	Intersection of Fleet Street and Fennel Street	0.02	2.00
D	Intersection of New Street and Dunlop Street	0.33	0.58
E	O'Connell Street	0.00	3.95
Westmead Biomedical Precinct			
A	Intersection of Darcy Road and Bridge Road	-	2.11
B	Intersection of Darcy Road, Institute Road and Mons Road	0.06	2.64
C	Institute Road	-	2.46
D	Intersection of Hawkesbury Road and Hainsworth Street	0.53	2.26
Rydalmere			
A	Intersection of Bridge Street and Victoria Road	-	2.70
Camellia			
A	Intersection of James Ruse Drive and Grand Avenue	1.84	5.91
B	Grand Avenue	-	1.66

11.4.4 Flood Evacuation Considerations

Evacuation involves the movement of people from a flood affected location to one that is flood free. Evacuation may occur by car, foot, boat, helicopter or other method. The key limitations to evacuation are flood free access, mobility of people being evacuated and time available to evacuate.

The two key considerations for evacuation – sufficient prior warning to allow evacuation, and a safe refuge in an evacuation centre. Potential evacuation routes to flood free areas have been identified for the Significant Areas. These routes have been mapped in the FERP figures in **Appendix O**. It is recommended that detailed evacuation assessment and planning including identifying potential evacuation centres is undertaken during the Floodplain Risk Management Study and Plan process.

11.4.5 Flood Planning Constraints Category

The *Australian Disaster Resilience Guideline 7-5 Flood Information to Support Land Use Planning Activities* (AIDR, 2017) has identified four Flood Planning Constraints Categories (FPCC) to better inform land-use planning activities. Details on these categories are provided in **Table 11-4**.

These categories have been defined based on the frequency of exposure to flooding, flood function, flood hazard, flood range, and isolation from safety. It provides the basis for providing advice on the flood related constraints that need to be considered to effectively manage flooding and its impacts in different areas of the floodplain.

Table 11-4 Flood Planning Constraints Categorisation

FPCC	Constraint
1	This category includes: > Design flood event flow (typically FFA calibrated 1% AEP) conveyance and storage areas; and > Design flood event H6 hazard areas.
2	This category includes: > Flow conveyance for floods larger than the design flood event (typically the PMF event); > Design flood event H5 hazard areas; > Flood hazard H6 areas for floods larger than the design flood event (typically the PMF event); > Areas that have been identified as isolated and submerged through the FERP classification; and > Areas that have been identified as isolated and elevated through the FERP classification.
3	This category includes the areas that are outside the FPCC 2 category and below the design flood event plus freeboard.
4	This category includes the areas that are outside the FPCC 3 category but within the extreme event such as the PMF.

The areas classified as FPCC 1 and FPCC 2 have been identified as the worst affected / critical locations with significant risk of flooding within the Significant Areas. These categories have been mapped. The maps are provided in **Appendix O** and the series of figures are shown in **Table 11-5**.

Table 11-5 FPCC Figure Numbers

Significant Areas	Figure Number
Camellia	Figure O1.3
Parramatta CBD (river foreshore area)	Figure O2.3
Knowledge Precinct Area	Figure O3.3
North Parramatta Urban Renewal Precinct	Figure O4.3
Parramatta CBD (whole of CBD)	Figure O5.3
Rydalmere	Figure O6.3
Westmead Biomedical Precinct	Figure O7.3

11.4.6 Recommendation

It is recommended that flood emergency response planning for these areas, to be undertaken during the Floodplain Risk Management Study and Plan process, includes the following key considerations:

> Cut-off of external access isolating an area;
> Key internal roads being cut-off;
> Transport infrastructure being shut down or unable to operate at maximum efficiency;
> Flooding of key response infrastructure such as hospitals, evacuation centres, emergency services sites;
> Risk of flooding to critical and vulnerable developments;
> Evacuation centres, routes and timelines;
> Flood warning systems; and
> Potential for shelter-in-place.

11.5 Flood Damages Assessment

Various flood events may cause damage to property with significant costs to property owners and insurers. The damage may occur due to floodwaters affecting the building interior (façade, contents), building structure (weatherproofing, electrical wiring) and other property outside the building (vehicles, contents of sheds and garages).

Estimating the cost of flooding helps identify the magnitude of impact of the event to a community, and subsequently provides a benchmark for the viability of potential measures for mitigating the impacts of flooding.

Flood modelling undertaken as part of this study includes provision of the following, which will allow flood damages assessment to be undertaken during the Floodplain Risk Management Study and Plan process:

> Properties affected by inundation for the nominated flood events;
> Properties and infrastructure affected by flood hazard;
> Locations of critical water related infrastructure such as dams, detention basins; and
> Identification of residential, commercial and industrial properties.

It is recommended that Council consider floor level survey for all properties within the 1% AEP extent and areas of high risk and the identified Significant Areas that are impacted by flooding in the PMF flood events.

11.6 Flood Emergency Response

The progression of flood for the FFA calibrated 1% AEP event has been investigated and mapped in **Appendix O** and the series of figures are shown in **Table 11-6**. A time step of 30 mins has been considered suitable since there are minimal to no changes in flood behaviour for smaller timesteps. The critical duration for the Significant Areas vary, as shown in **Table 11-6**, after which the flood waters start to recede.

Table 11-6 Flood Progression Figure Numbers

Significant Areas	Critical Duration	Figure Number
Camellia	12 hour	Figure O1.4
Parramatta CBD (river foreshore area)	12 hour	Figure O2.4
Knowledge Precinct Area	3 hour	Figure O3.4
North Parramatta Urban Renewal Precinct	3 hour	Figure O4.4
Parramatta CBD (whole of CBD)	2 hour	Figure O5.4
Rydalmere	3 hour	Figure O6.4
Westmead Biomedical Precinct	2 hour	Figure O7.4

It is recommended that the thematic representation of the flood behaviour provided is used at the basis to inform the evacuation routes and timelines assessed as part of the emergency response planning.

12 Limitations

12.1 Limitations and Future modelling opportunity

The study has used the current industry standard practice and guidelines in determining flood behaviour in the Study Area. The study has developed on existing information and updated the models to reflect changes in the catchment, including incorporation of changes to impervious areas in the catchment, new developments, new hydraulic structures and updated pit and pipe information. The study has utilised all existing information available and undertook survey where there was no information available. New survey of bathymetry, bridges, culverts and weirs has been incorporated in the models and the latest software provides the most accurate representation of terrain and hydraulic structures. The models have been calibrated to historic events and show a good correlation.

While the models are deemed an accurate representation of the flood behaviour in the catchment, the following limitations are acknowledged and will need to:

> Models are a representation of the real world and use mathematical calculations to approximately replicate actual flood behaviour within a certain acceptable tolerance;

> The accuracy of ALS survey information used to define the terrain and for mapping flood levels and depths;

> Accuracy of all bridge, weir, culvert, pit and pipe data and detention basin data that was not surveyed in detailed;

> Accuracy of information outside the Study Area which may affect the flows arriving at the Study Area boundary;

> Inconsistencies at the interface between mainstream and Tributary and Overland Flow model results due to differences in inflows for the different scale models;

> Climate Change scenarios as based on current guidance;

> The functionality of XP-RAFTS software to automate ARR2019 methods for spatially-varied IFD is limited and may be better suited to other models in future;

> ARR2019 Culvert to be assessed individually and test scenario iterations . Blockage % will be derived from the ARR2019 blockage risk assessment in a form of a spreadsheet and will be created for each tributary. Summarising debris L10 assumption, critical information, assumptions and recommend individual blockage percentages.

> A ground-truthing site visit showed that there is difficulty in identifying the correct pit and fence type from aerial photography and some inferences must be made. It is not possible to include all pit, and fence types as well as culvert sizes accurately without a detailed survey, which is an extensive exercise and beyond the scope of this study. It is recommended that detailed survey of existing drainage network and fence type to be conducted, and incorporated in the future flood model update.

> It is further recommended that assessment be undertaken by Council to assess the potential change to ARR19 IFD based on the inclusion of all Council recorded storm data throughout the area. Review may indicate a potential change to IFD data for events more frequent than the 2% AEP and may justify the Adopted Fit FFA approach.

> Some observed local and minor flooding which will not affect the outcome of the study. Recommendations are provided in the peer review register spreadsheets to improve the model in the future studies.

> It is reported that Redbank Road and Briens Road gauges were deemed to be unreliable for the April 2015 event. future flood model improvement may consider check with another flood event where the data is available should be used to check model. Information used in the Darling Mills Creek and Loyalty Road Basin gauges need to be checked again with basin model set up if model results show inconsistencies with recorded gauge information.

> There are only 3 water level gauges on Tributary Creeks in the LGA. Council is recommended to install additional water level gauges on tributary creeks to aid calibration and validation of future flood events. Minimum one for each of the tributary Tuflow model study area. At least one that is not influenced by downstream tailwater conditions to be able to truly gauge the catchment behaviour.

- The Flood emergency assessment conducted in this study addressed the critical components outlined in the flood risk management framework. However, it fell short in its coverage, failing to encompass the entirety of the LGAs. Moreover, a comprehensive evaluation of damage costs and loss of life was lacking. This underscores the necessity to delve deeper into these aspects in the subsequent stages of analysis
- The overland flow approach utilized in this study is deemed appropriate because it incorporates the most accurate parameters for significant overland paths. Furthermore, it effectively addresses the planning requirements outlined in Section 10.7 (Private Certificate), offering a broad-based analysis that captures major flood pathways. However, it does not account for minor terrain features such as street furniture, kerbs, gutters, and retaining walls. For future updates of the Flood Study Models, it is recommended to conduct a more detailed overland study in the upper catchment. This enhanced study should consider implementing the following measures:
  - Utilization of a finer grid resolution for increased accuracy.
  - Incorporation of advanced TUFLOW tools such as SGS and QUADTREE.
  - Adjustment of Council pipe network sizes down to 375mm for improved representation.
  - Inclusion of smaller ground formations like retaining walls, street furniture, and large trees.
  - Assessment of gutter flow obstructions to better understand drainage dynamics.
  - Consideration of the potential impacts of climate change on flood patterns and intensities.

The following items are identified as project risks moving forward based on the current status of the project and models:

- Usability of the XP-RAFTS model for future phases of the floodplain risk management process and for issue to consultants/developers for assessments in individual catchments;

12.2 Next Steps

The next steps for the project are as follows:

- The Final Parramatta River Flood Study to be scheduled for formal adoption by the Council, with the objective of endorsing the Flood Study results.
- Extended PMF Duration Analysis: Conduct an analysis to extend the Probable Maximum Flood (PMF) duration, providing vital information for flood emergency management strategies and estimating periods of isolation due to flooding. Consideration should be given to potential sheltering-in-place scenarios during the PMF.
- Formal Commencement of the Next Phase: Begin the next phase of the project, officially initiating the Flood Risk Management process. This phase involves developing a comprehensive assessment and strategic plan to mitigate flooding impacts on communities and infrastructure (inclusive of utilities). Prioritize actions based on their effectiveness and feasibility to reduce flood risk effectively.
- Incorporation of Additional Improvement Works: Integrate any identified improvement works into the flood model study to enhance its accuracy and effectiveness. This may involve adjustments based on new data or stakeholder input to ensure the model reflects the latest understanding of flood dynamics.

13 Conclusion and Recommendations

13.1 Conclusion

The Parramatta River Flood Study provides an update to the available flood information for the former Parramatta City Council LGA excluding Duck River, Duck Creek and A'Becketts Creek. The results of the Study describe the flood behaviour in the Study Area and will assist in raising community awareness of flooding and flood risk in their area. The study will be used by Council and various stakeholders to inform flood planning and emergency management in the Study Area.

The report provides a description of the Parramatta River Flood Study: project objectives; data collection and review; additional data collection; hydrology and hydraulic model setup, calibration and validation; model scenarios; design event model results, sensitivity analysis and Climate Change Scenarios. The report also provides guidance on the adoption of Flood Planning Levels and Emergency Response parameters for use in planning and by the NSW SES.

A number of previous hydrology models were reviewed, updated and combined into a single XP-RAFTS model for the Parramatta River catchment to Ryde Bridge. The model was calibrated and validated against six historical flooding events including April 2016, June 2015, June 1991, February 1990, April 1988, and August 1986 using recorded gauge data. The hydraulic model was developed using TUFLOW 2-dimensional modelling software and was calibrated against the April 2016 flood event and validated against the April 2015 and April 1988 events.

The model showed a good correlation to all events with respect to timing of catchment response and modelled flood peak levels and flows. The model was also validated against photographic records provided by Council and the community through a community consultation survey.

The overland flow assessment for this study employed a comprehensive strategy, albeit with limitations in capturing minor terrain features like retaining walls, garden beds, and other obstructions. Its focus is on leveraging precise parameters similar to those used in riverine flood analyses, balancing the identification of primary flood routes with the recognition of subtler yet relevant flood risks. The adopted overland flow result strikes a balance between capturing major flood pathways and identifying less obvious yet still pertinent flood risks. This approach, complemented by cross-referencing with rainfall-on-grid modelling, ensures a comprehensive understanding of flood risk dynamics. The study incorporates rainfall-on-grid 1% AEP and PMF modelling results to validate hydrology inflows location, to best represent riverine flooding and its associated backwater effects, along with significant overland flow paths. This thorough approach afforded a deep insight into the complexities of flood risk, addressing both prominent and secondary water movement channels. Achieving these objectives, the study delivers essential data to guide Section 10.7 (Property Certificate) planning regulations for flood risk evaluation and management.

The Study uses current industry standard methods and guidelines in flood estimation using Australian Rainfall and Runoff 2019 and a series of OEH floodplain management guidelines. The design event flood estimates were validated to a Flood Frequency Analysis of observed annual peak flood levels. As part of this analysis, the Marsden Street Weir gauge (213004) level-flow relationship (rating curve) was reviewed and updated using the hydraulic model to inform the extrapolation to higher flows beyond the gauging data. The modelling approach, model setup, parameters and results and the study outcomes have been peer reviewed by an independent consultant on behalf of Council.

The 1% AEP design flood levels in this Flood study are generally higher than UPRCT/SKM MIKE11 flood levels due to the application of FFA. New areas of overland flow have been mapped as part of this study which were not previously mapped. Probable Maximum Flood (PMF) extents remain similar to previous modelling. The PMF was not previously mapped in Subiaco, Vineyard and The Ponds Creek catchments.

An assessment of sensitivity to blockage indicates that the mainstream channels of Toongabbie Creek and Parramatta River mainly consist of large bridge crossing that are not susceptible to significant blockage. Impacts of blockage is more substantial in areas with pit and pipe networks or urban drainage channels with small culverts under road crossings or buildings.

Consideration of the affects of Climate Change show that for a 6.4% increase in rainfall, flood level increases of approximately 150mm may be experienced at Marsden Street Weir. Minor increases are observed in overland flow areas, with localised larger increases upstream of hydraulic structures. A 19.7% increase in rainfall intensity would elevate flood levels by over 0.5m along the mainstream channels and some tributaries. Increases of up to 100mm are expected to be experienced in overland flow areas, with localised areas to experience greater impacts. A significant expansion of the flood-affected area has been identified throughout the study area under 28.5% increase of rainfall intensity. It is anticipated that the flood levels in the mainstream, tributaries, and overland flow areas will rise by more than 0.8m, 0.5m, and 0.3m, respectively. Similar to blockage scenarios, this is largely observed along urban waterways where the increased flow exceeds the capacity of culvert or bridge structures. With benchmark SLR of 0.9m by 2100, significant areas of the Lower Parramatta River foreshore would be impacted.

The models have been run for the 0.2%, 0.5%, FFA-calibrated 1%, 2%, 5%, 10%, 20%, 50% and 63% AEP storms and Probable Maximum Flood (PMF) and half-PMF event and flood levels, depths and velocities mapped. Hazard and hydraulic categories, Hazard Vulnerability Classification, Hydraulic Categories and Flood Risk Precincts have also been mapped.

Areas with the highest flood risk include the Significant Areas outlined in this report including:

- Parramatta CBD (whole of CBD);
- Parramatta CBD (river foreshore area);
- North Parramatta Urban Renewal Precinct;
- Westmead Biomedical Precinct;
- Knowledge Precinct Area (adjacent to and including parts of Western Sydney University);
- Rydalmere;
- Camellia.

Other areas susceptible to high flood risk and sensitive to blockage and Climate Change include:

- Toongabbie – near Pendle Creek and Toongabbie Creek confluence
- Old Toongabbie – Bogalara Creek
- Westmead, Wentworthville and Constitution Hill - Finlaysons, Coopers and Milsons Creeks
- Harris Park and Rosehill – along Clay Cliff Creek
- Rydalmere and Ermington foreshore areas – Lower Parramatta River
- Shell Oil along Duck Creek and Duck River.

Flood Emergency Response Planning classification of communities and Flood Planning Constraints Categories have been assessed for Significant Areas to inform Council and SES regarding land-use planning and emergency management planning in future stages.

The updated Parramatta River Flood Study presents contemporary flood models and mapping for Council's use in planning decisions and to form the basis for the future stages of floodplain risk management.

The final draft of the Flood Study report and its results underwent review and public exhibition. This final report incorporates feedback from all relevant stakeholders, ensuring that all comments were duly considered. The study outcomes were presented for formal adoption by the Council, with the aim of endorsing the Flood Study results.

13.2 Recommendations

13.2.1 General

Stantec recommends the following updates to be considered for future model updates:

- If computing power permits, it is recommended to merge multiple 2D domain layers and tributary models within the Local Government Area (LGA) into a single TUFLOW HPC/Quadtree model.
- Update the model with detailed survey information to improve the accuracy of the captured data. Additionally, reassess assumptions made for existing bridges, basins, pits & pipes, and fences.
- Based on the limitations mentioned in the WSL gauges, it is recommended that the Council installs rain gauges at strategic locations to enhance calibration accuracy, especially for the tributary models.
- Incorporate any additional elements that have been identified as limitations and consider any modelling comments that do not impact the quality of the current flood results.

- In accordance with the recommendation from the Department of Planning and Environment (DPE) for flood risk management, modal consider longer duration Probable Maximum Floods (PMFs) where the peak is less than the critical duration but the isolation persists for a longer period, primarily for evacuation purposes.
- Continue to improve FFA curve by incorporating data from recent rarer storm events. This will enhance the accuracy of the flood modelling and provide a more comprehensive understanding of the flood risk within the area.

13.2.2 Hydrology model

The Hydrology model developed for this study used XP-RAFTS software. Unfortunately, the software developers are no longer providing software updates to ensure functionality of the software with current industry standard methods in Australian Rainfall and Runoff 2019. As such, the models developed, while suitable for defining flood behaviour for this study, are cumbersome to use and not practical for use in future phases of the floodplain risk management process or for issue to developers/community for assessments in individual catchments.

Council, through discussions with the Department of Planning, Industry and Environment (DPIE), commissioned WMAWater to develop an alternate hydrology model using the Watershed Bounded Network Model (WBNM) software. This model is a simplified model, it is free software, making it more accessible and has been calibrated to historic events and shows good correlation with the XP-RAFTS model design flow estimates. It is recommended that the alternate WBNM hydrology model be used for any additional event or scenario modelling and in future for the Floodplain Risk Management Study and Plan phase.

For developments requiring use of Council's flood models, other than for major infrastructure development or urban development Precinct planning, it is not anticipated that individual developments will have major alteration to design flows, especially if compliant on-site detention is provided for new developments. As such, it may not be necessary for Council to release the hydrology model and the developer can use the inflows in the hydraulic model as is. Release of hydrology models will only be required if the subject of flood modelling will require alteration of sub-catchments within the hydrology model to appropriately define changes to flows.

13.2.3 Hydraulic Models

The hydraulic models have been divided into seven models to simulate flood behaviour across the Study Area (described in Section 8.1). The models have been run using the GPU version of the TUFLOW software. Models should be run using GPU and the same model version of the TUFLOW software as used in this study (version 2020-10-AA_iSP_w64) to ensure replication of the documented results.

There is an overlap between the Mainstream model and the Tributary and Overland Flow models. The appropriate model to use for an area of interest should consider both mechanisms of flooding and determine which is critical for the design event of interest. For Example, in Constitution Hill, Wentworthville and Westmead area, two models are relevant: Model 1: Mainstream; and Model 4: Finlaysons, Coopers and Milsons Creeks. For events up to the 1% AEP event, local catchment flooding is dominant and Model 4 should be used for most areas. However, for the PMF, mainstream flooding is dominant and Model 1 should be used.

14 References

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3. Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) (2019), Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2019.
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5. Cardno Willing (2007), Clay Cliff Creek Catchment Master Drainage Plan
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11. Molino Stewart (February 2014), Literature Survey of Parramatta River Catchment within Parramatta LGA – Final Report, prepared for Parramatta City Council.
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13. OEH (2015), Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways, Office of Environment and Heritage, Sydney, November 2015, Document No. OEH 2015/0769.
14. OEH (2016), Floodplain Risk Management Guide: Flood Emergency Response Planning Classification of Communities, NSW Government, Document No. OEH 2016/0732.
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16. Sydney Coastal Councils & CSIRO (2012), Mapping & Responding to Coastal Inundation, Sydney Coastal Councils & CSIRO, Sydney, February 2012.
17. Ryan C, (2013), Using LiDAR Survey for Land Use Classification, 2013 Floodplain Management Association.
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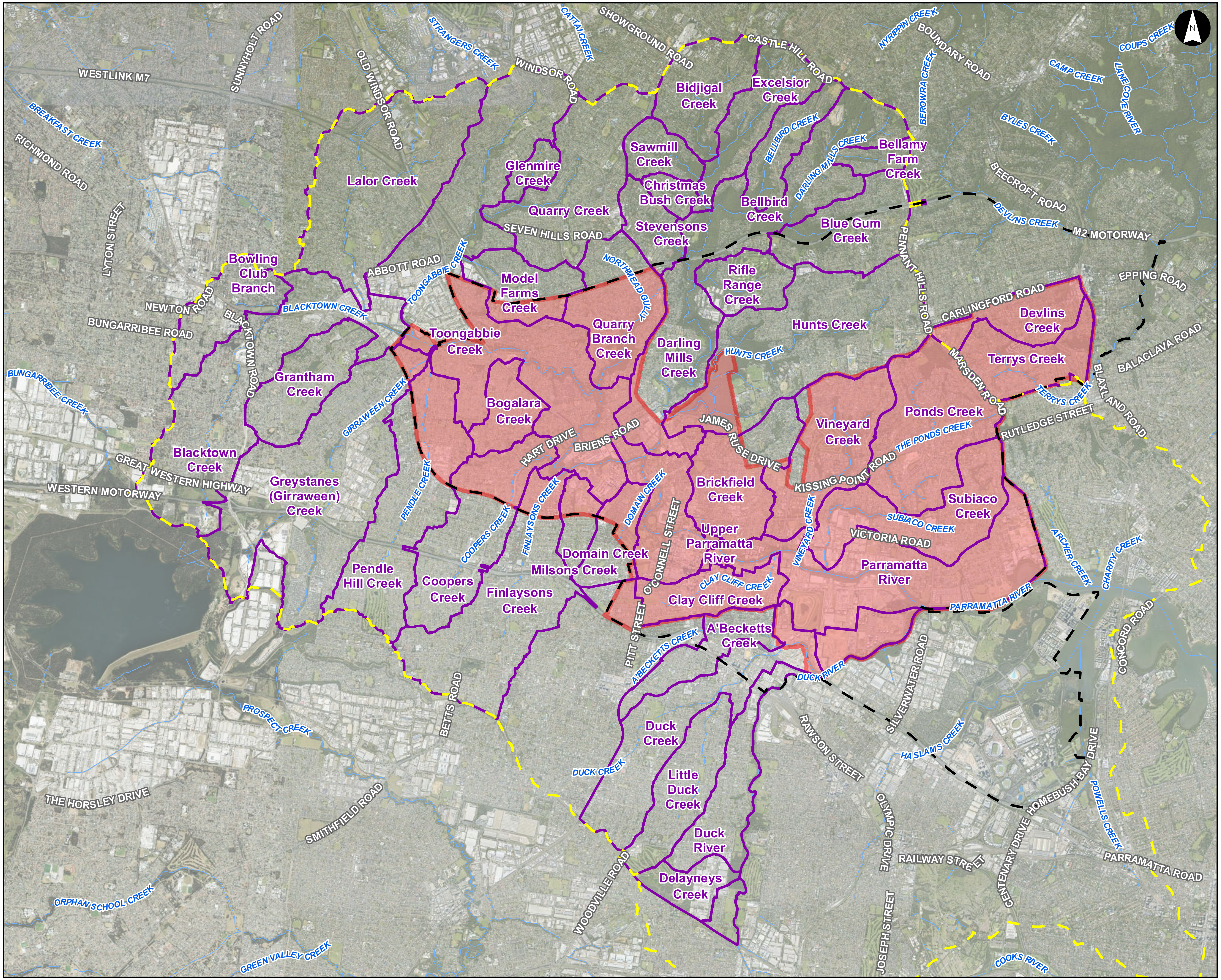
15 Figures



Study Area

Parramatta River Flood Study

Project Code: 59916074 / 304600102
Drawn By: ANK, Checked By: AS
Map: 59916074-GS-011-StudyArea.mxd
Rev: 05
Date: 2024-04-11

Legend

- Study Area
- Watercourse
- Tributary Catchments
- Flood Study Catchment Boundary for Parramatta River
- LGA Boundary

Figure 15.1

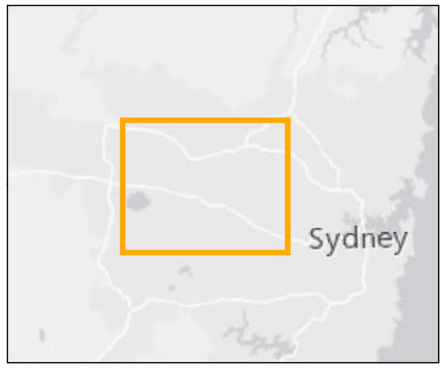
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

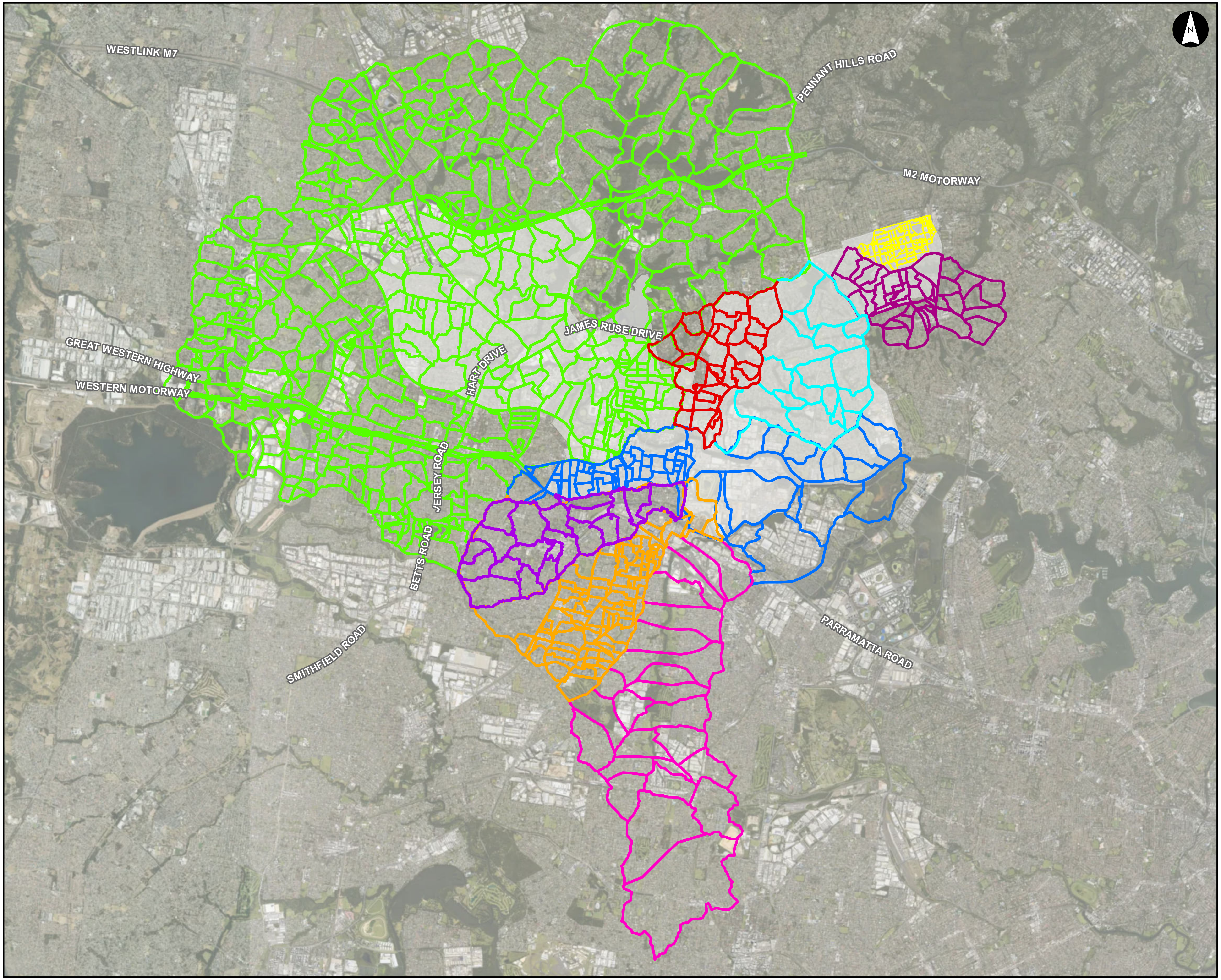
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 3 km

Scale at A3 1:65,000





Provided Hydrological Model Sub-Catchment Boundaries From Old Models

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-093-HydrologySubcatchments.mxd
Rev: 03
Date: 2023-05-18

Legend

- Study Area
- Upper Parramatta River Catchments
- Lower Parramatta River Catchments
- A'Becketts Creek Catchments
- Duck Creek Catchments
- Vineyard Creek Catchments
- Subiaco Creek Catchments
- Duck River Catchments
- Upper Devlins Catchments
- Terry's Creek Catchments

Figure 15.2

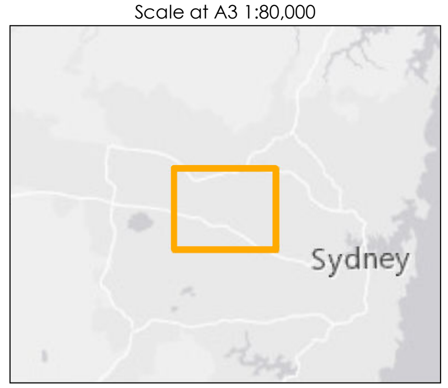
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

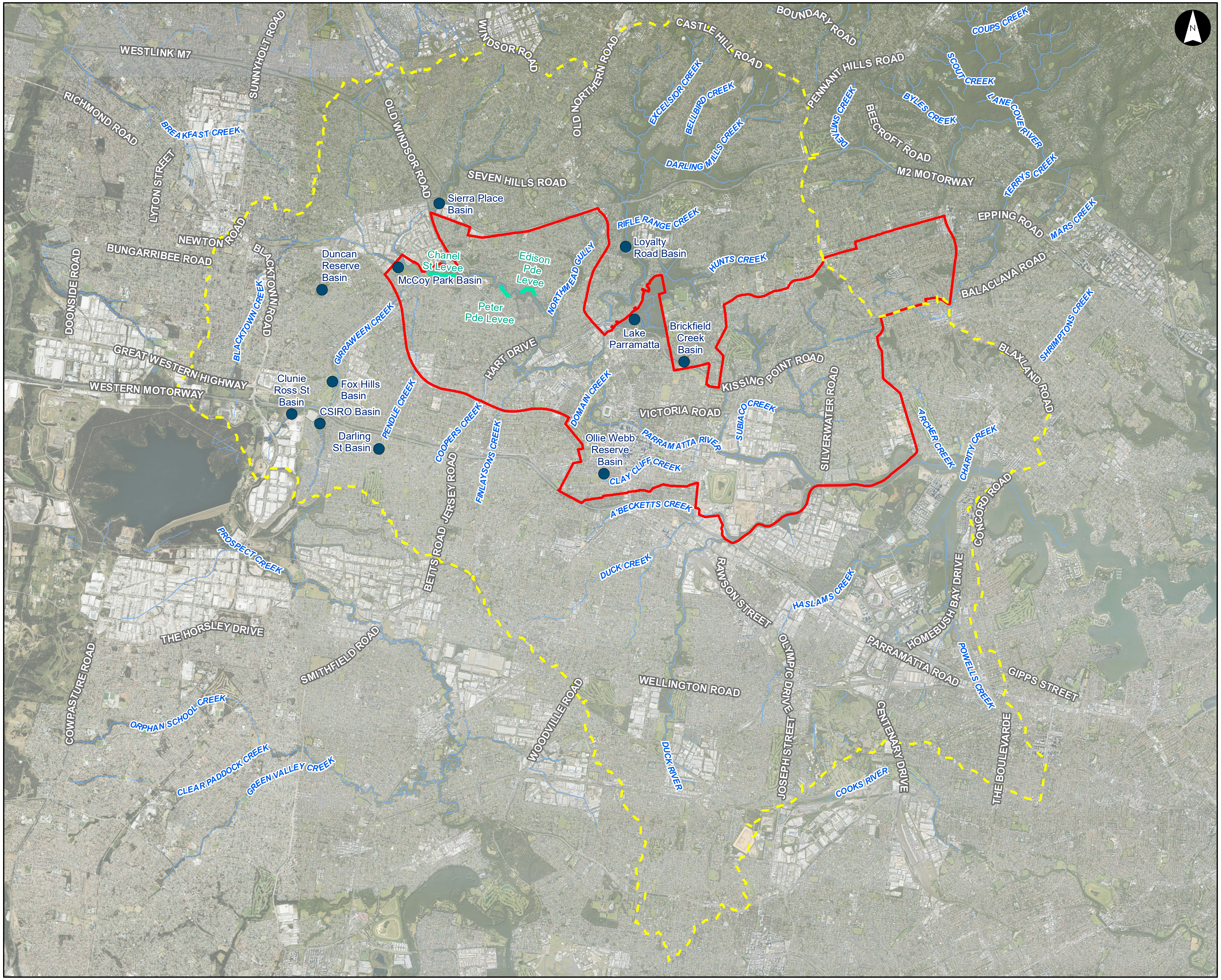
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 3 4 km

Scale at A3 1:80,000





Location of Significant Basins and Levees

Parramatta River Flood Study

Project Code: 59916074 / 304600102
Drawn By: ANK, Checked By: MM
Map: 59916074-GS-015-BasinsLevees.mxd
Rev: 05
Date: 2024-04-15

Legend

- Study Area
- Basin
- Levee
- Watercourse
- Flood Study Catchment Boundary for Parramatta River

Figure 15.3

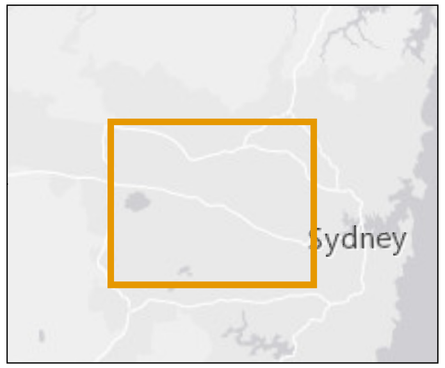
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

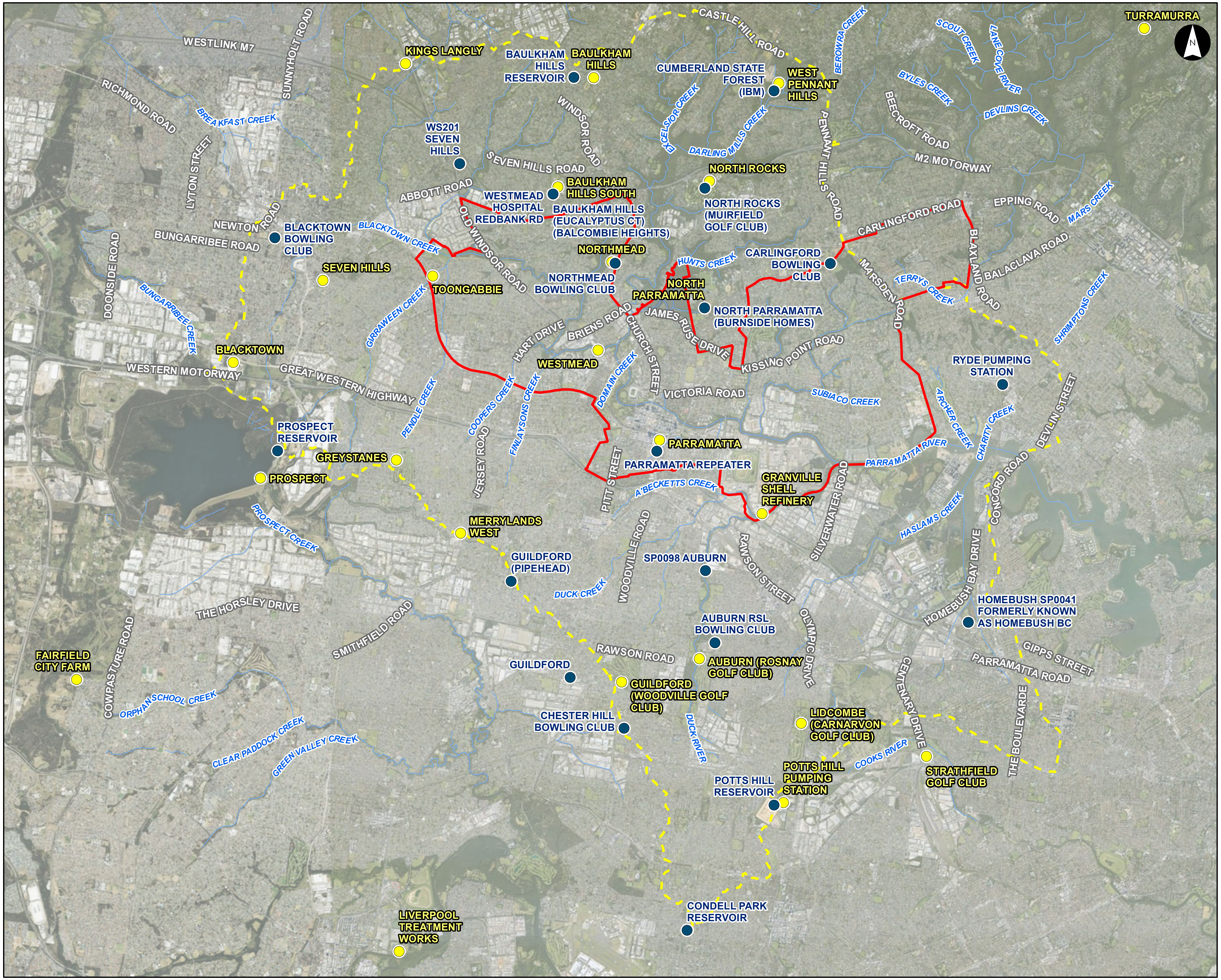
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 3 4 km

Scale at A3 1:80,000





Pluviometer and Rainfall Gauge Locations

Parramatta River Flood Study

Project Code: 59916074 / 304600102
Drawn By: ANK, Checked By: AS
Map: 59916074-GS-012-PluvRainGauge.mxd
Rev: 05
Date: 2024-04-11

Legend

- Study Area
- Pluviometer Gauge
- Rainfall Gauge
- Watercourse
- Flood Study Catchment Boundary for Parramatta River

Figure 15.4

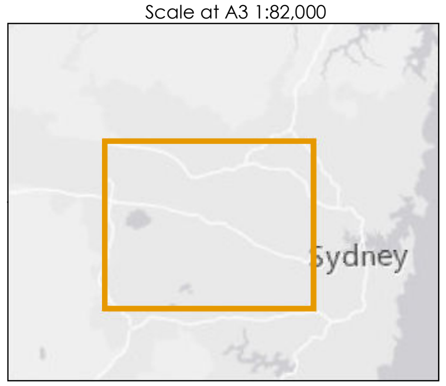
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

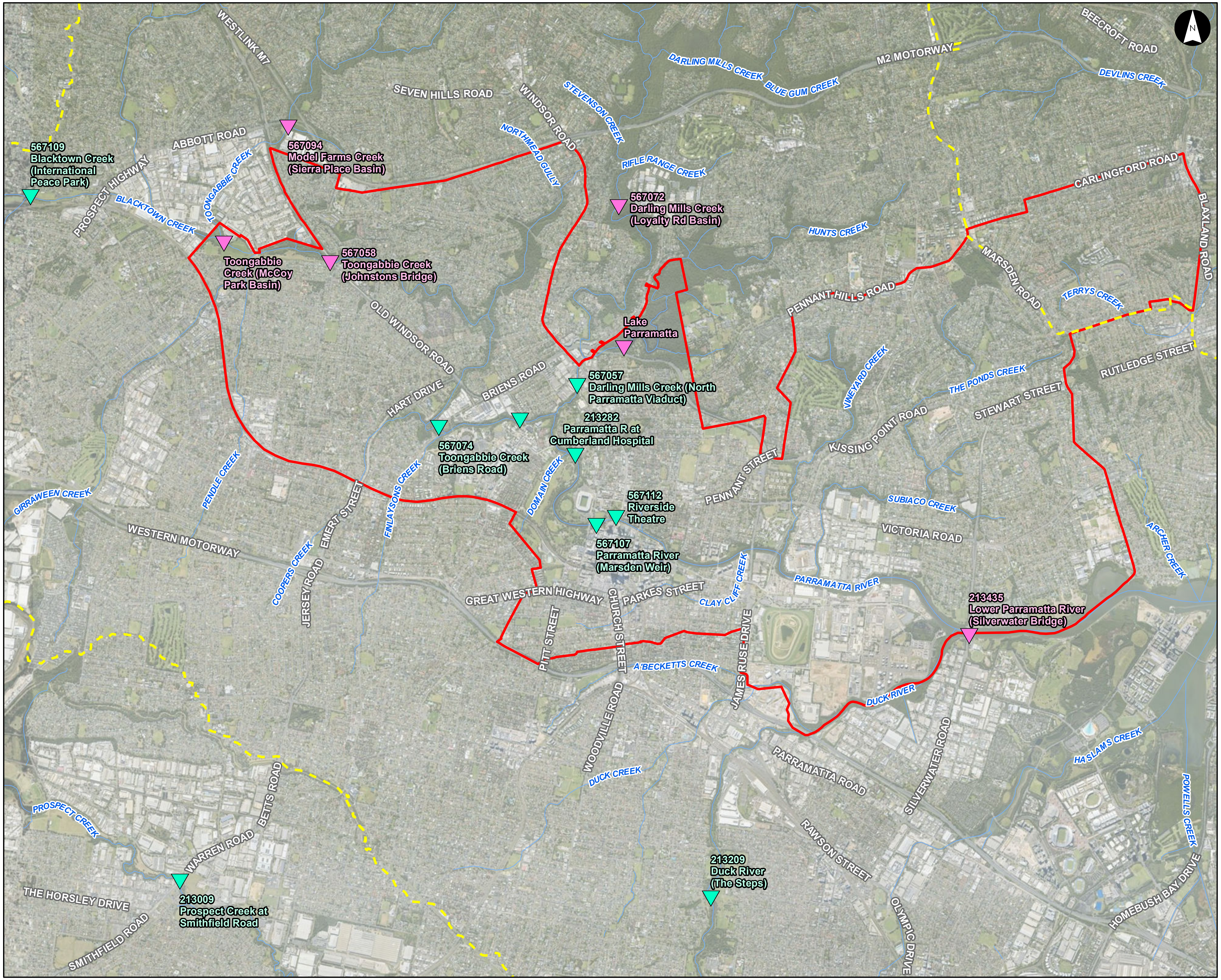
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 3 km

Scale at A3 1:82,000





Stream and Water Level Gauge Locations

Parramatta River Flood Study

Project Code: 59916074 / 304600102
Drawn By: ANK, Checked By: AS
Map: 59916074-GS-013-StreamWaterLevGauge.mxd
Rev: 04
Date: 2024-04-10

Legend

- Study Area
- Stream Flow Gauge (9)
- Water Level Gauge (6)
- Watercourse
- Flood Study Catchment Boundary for Parramatta River

Figure 15.5

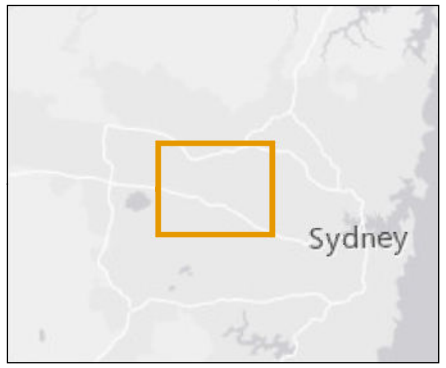
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

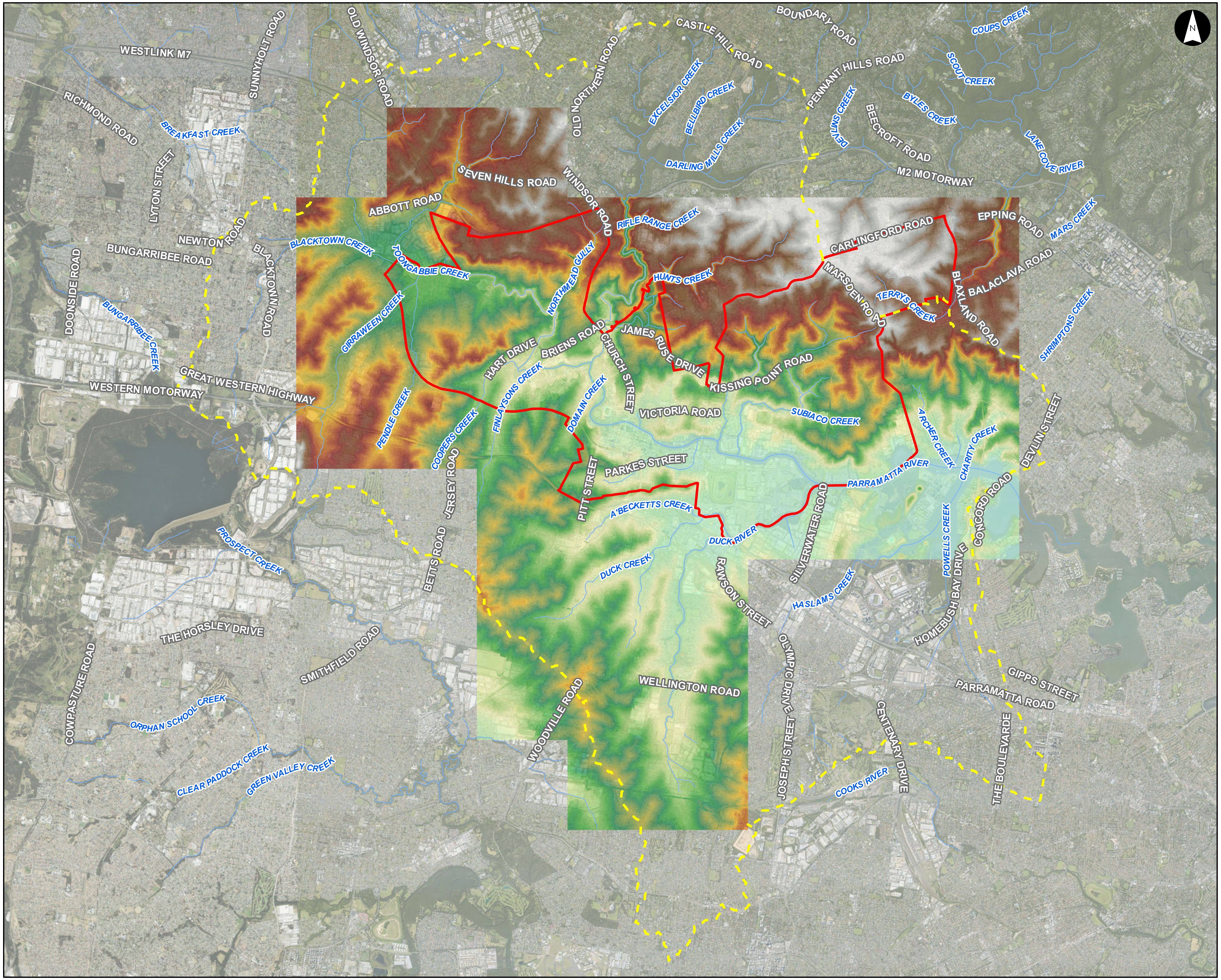
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 km

Scale at A3 1:45,000





Aerial Laser Survey

Parramatta River Flood Study

Project Code: 59916074 / 304600102
Drawn By: ANK, Checked By: AS
Map: 59916074-GS-014-AerialLaserSurvey.mxd
Rev: 05
Date: 2024-04-11

Legend

Study Area

Watercourse

Flood Study Catchment Boundary for Parramatta River

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.6

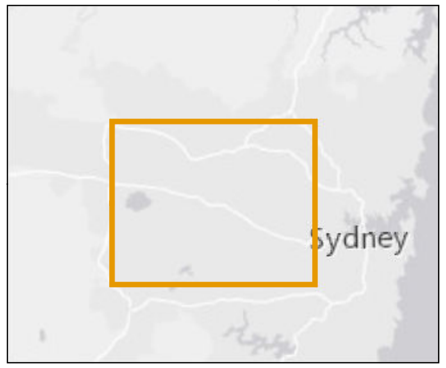
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

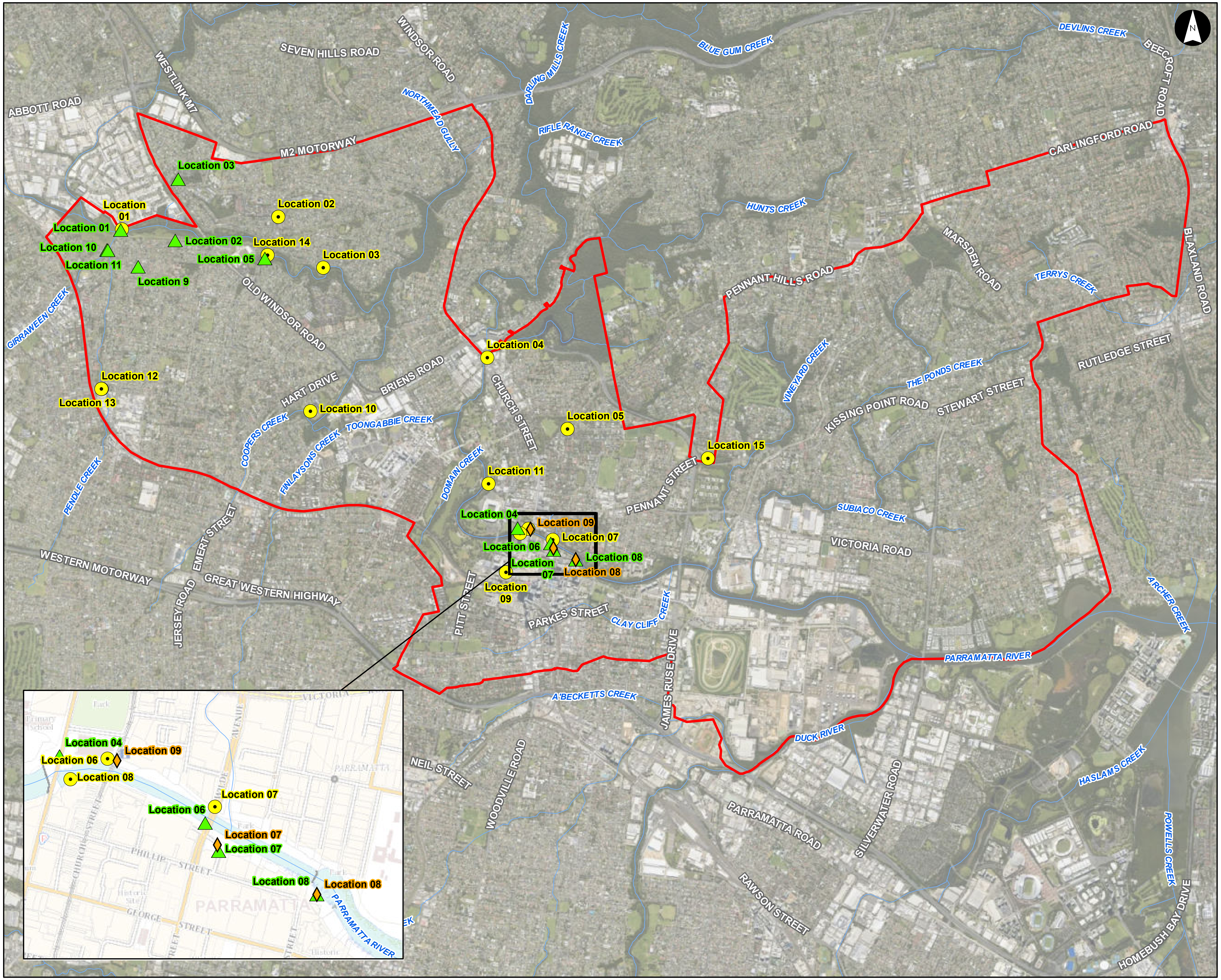
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 3 4 km

Scale at A3 1:80,000





Historic Flood Observation Photo Locations

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-033-HistoricObs.mxd
Rev: 05
Date: 2023-05-18

Legend

- Study Area
- 2016 Calibration Photos
- 2015 Calibration Photos
- 1988 Calibration Photos
- Watercourse

Figure 15.7

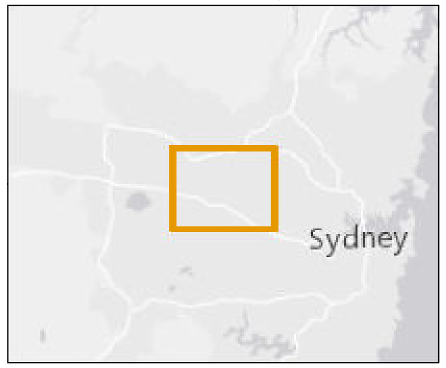
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

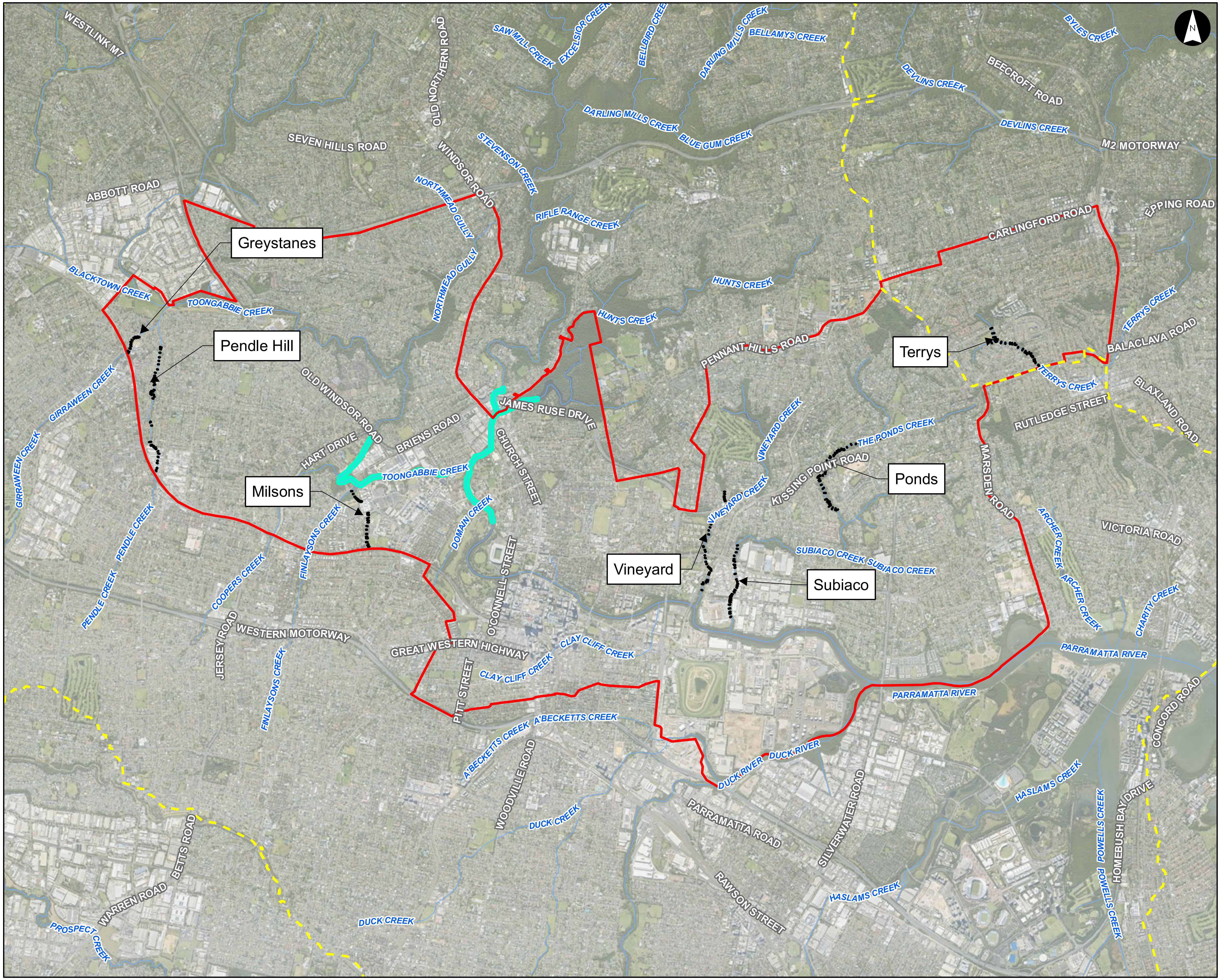
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 1.5 2 km

Scale at A3 1:40,000





Creek Cross Sections and Bathymetry Survey Scope

Parramatta River Flood Study

Project Code: 59916074 / 304600102
Drawn By: ANK, Checked By: AS
Map: 59916074-GS-035-CrossSectionBathy.mxd
Rev: 04
Date: 2024-04-10

Legend

- Study Area
- Watercourse
- Cross Section Locations
- Survey Bathymetry
- Flood Study Catchment Boundary for Parramatta River

Figure 15.8

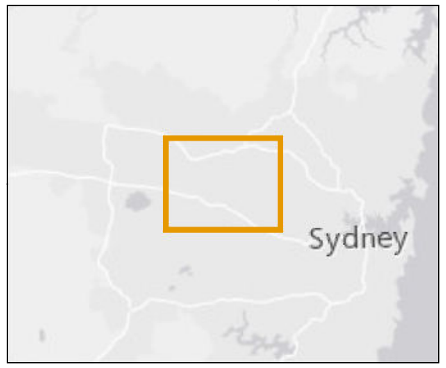
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 1.5 2 km

Scale at A3 1:45,000



Hydraulic Structure Survey Scope

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-034-BridgeSurveyScope.mxd
Rev: 04
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- Bridge (39)
- Culvert (27)
- Deck over river (1)
- Foot bridge (34)
- Pipe Bridge (6)
- Railway Bridge (4)
- Weir (6)

Figure 15.9

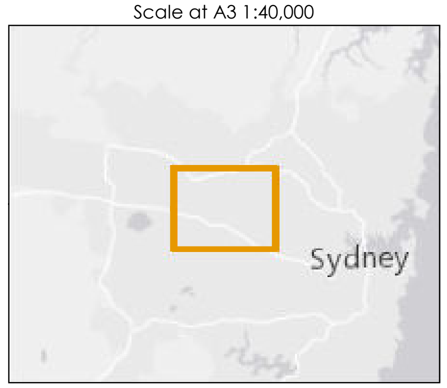
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

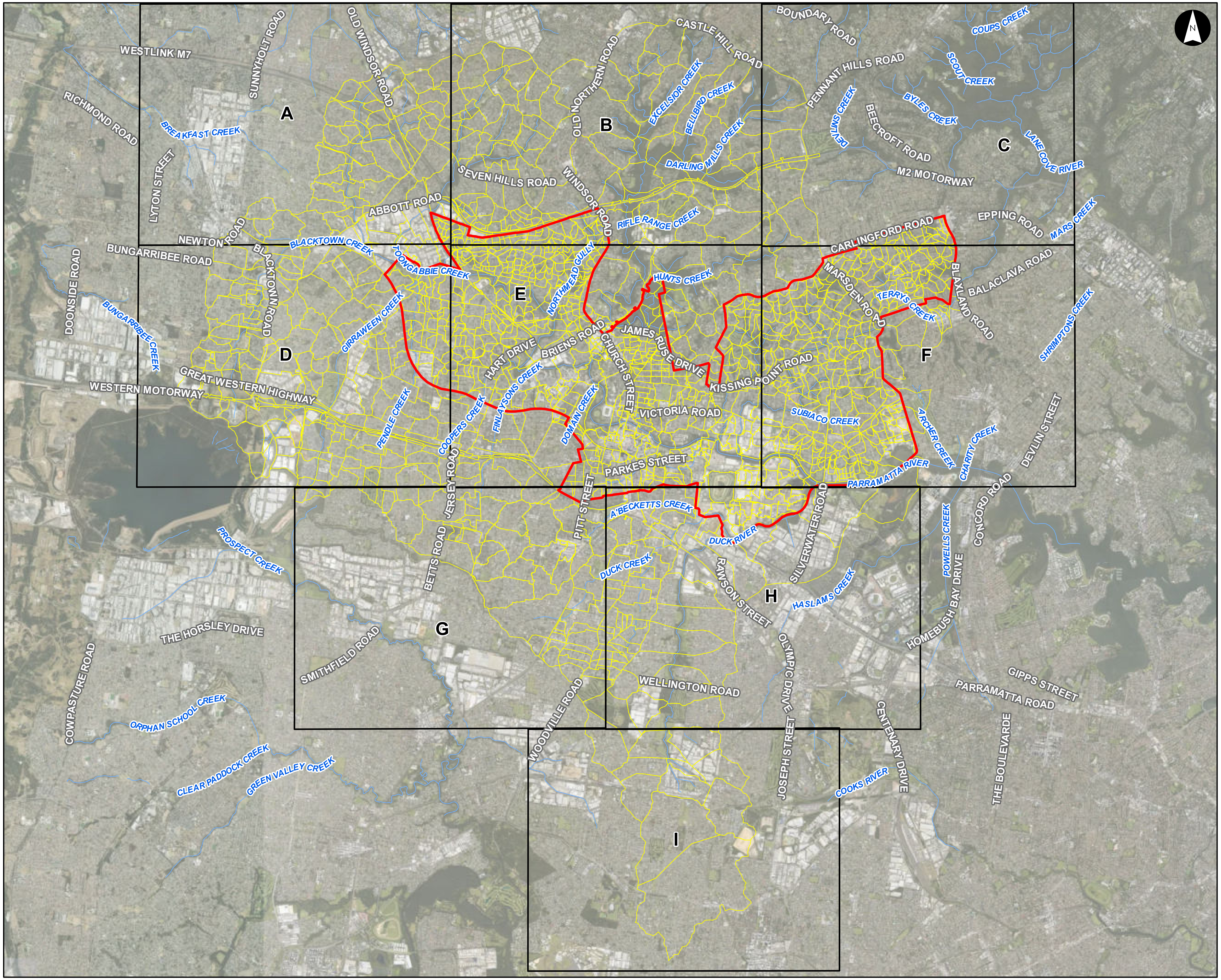
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 1.5 2 km

Scale at A3 1:40,000





Hydrologic Model Subcatchment Overview

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-026-OverviewHydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- Map Grid
- Subcatchment Boundary

Figure 15.10

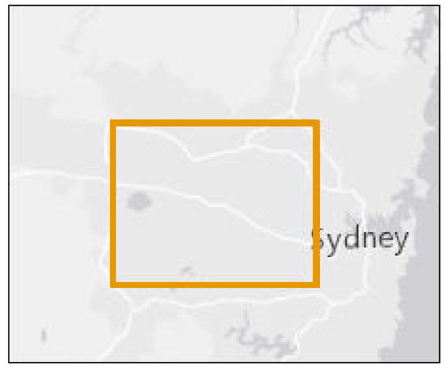
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

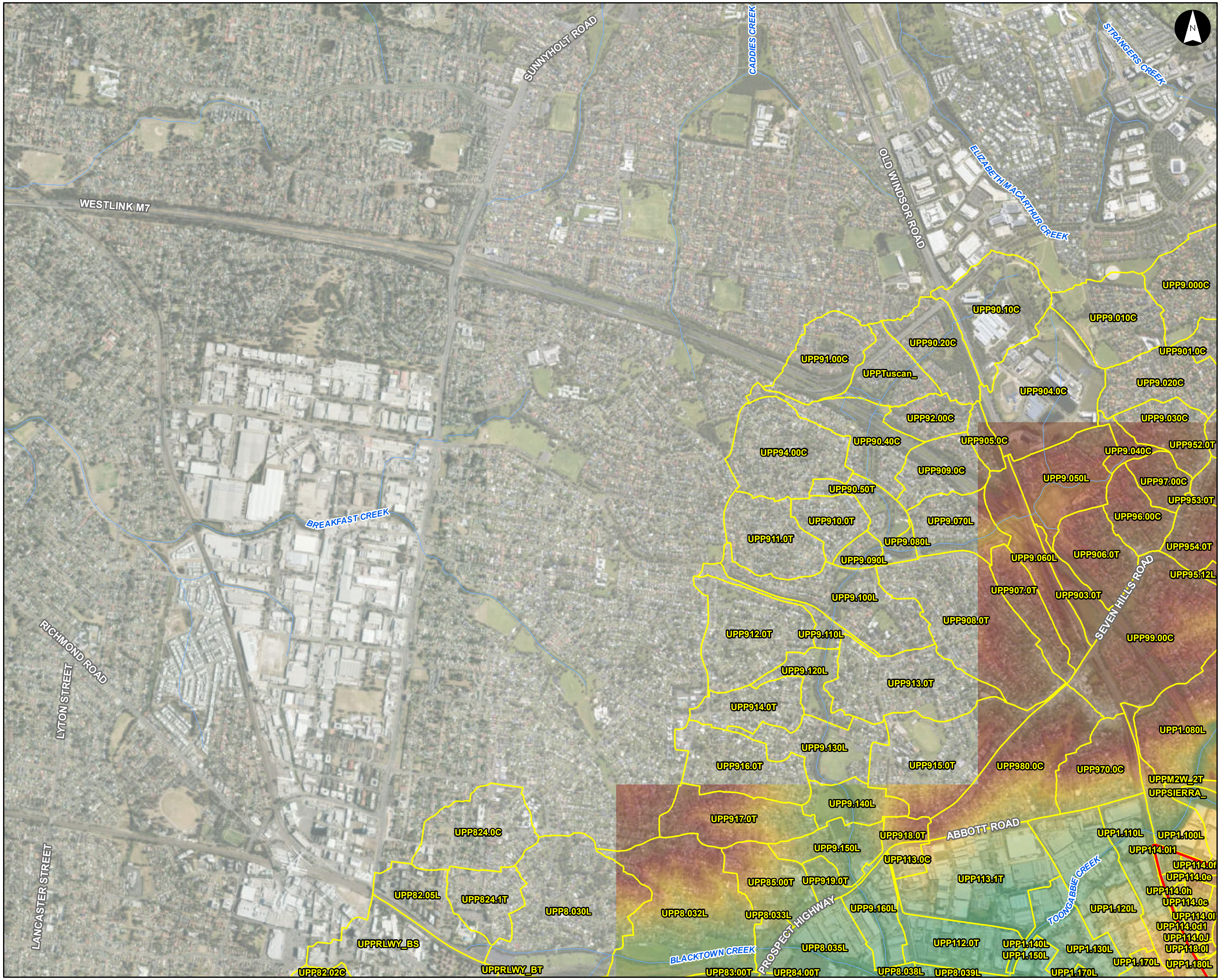
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 3 4 km

Scale at A3 1:80,000





Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

Study Area

Watercourse

Subcatchment Boundary

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.10A

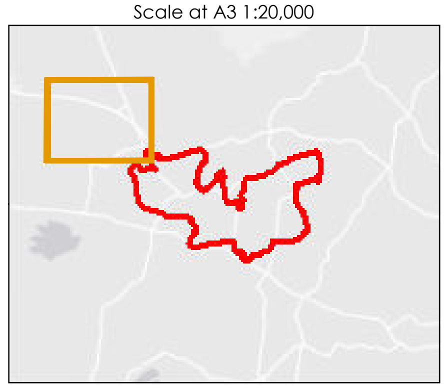
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 km

Scale at A3 1:20,000



Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- Subcatchment Boundary

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.10B

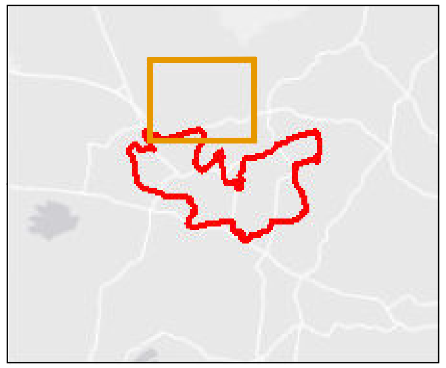
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

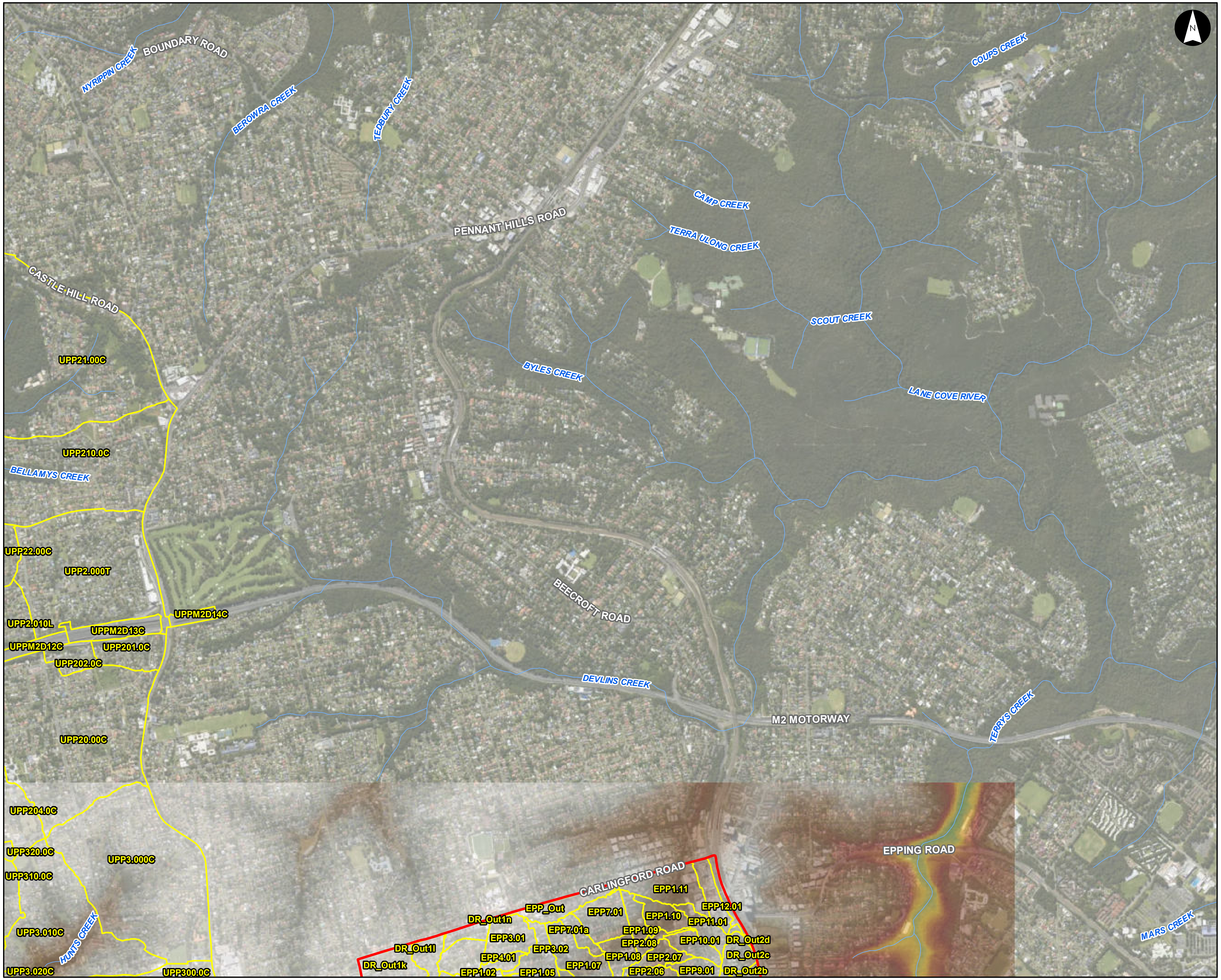
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 km

Scale at A3 1:20,000





Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- Subcatchment Boundary

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.10C

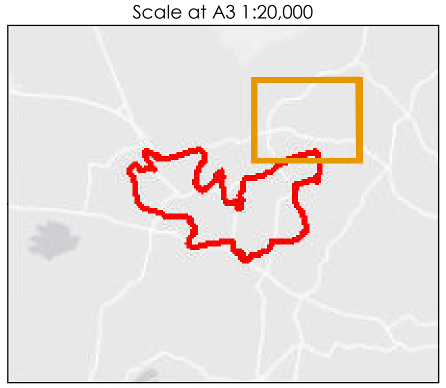
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

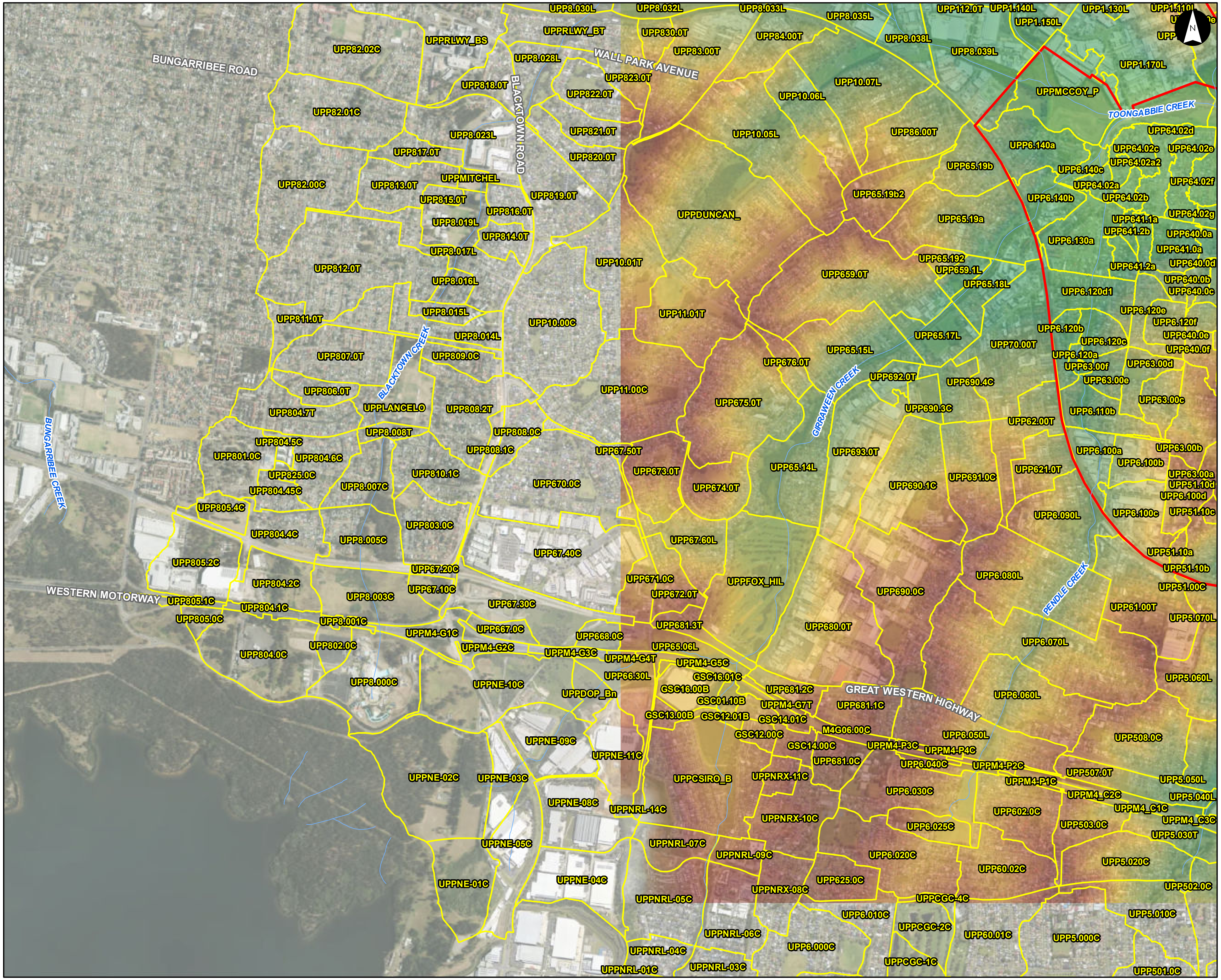
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 km

Scale at A3 1:20,000





Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

Study Area
Watercourse
Subcatchment Boundary

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.10D

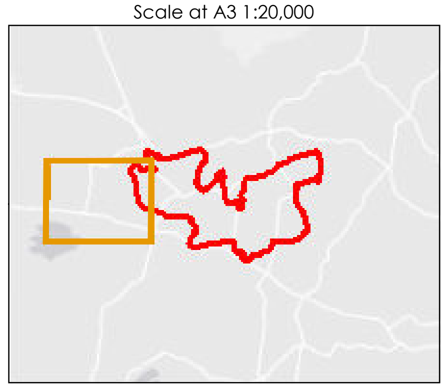
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

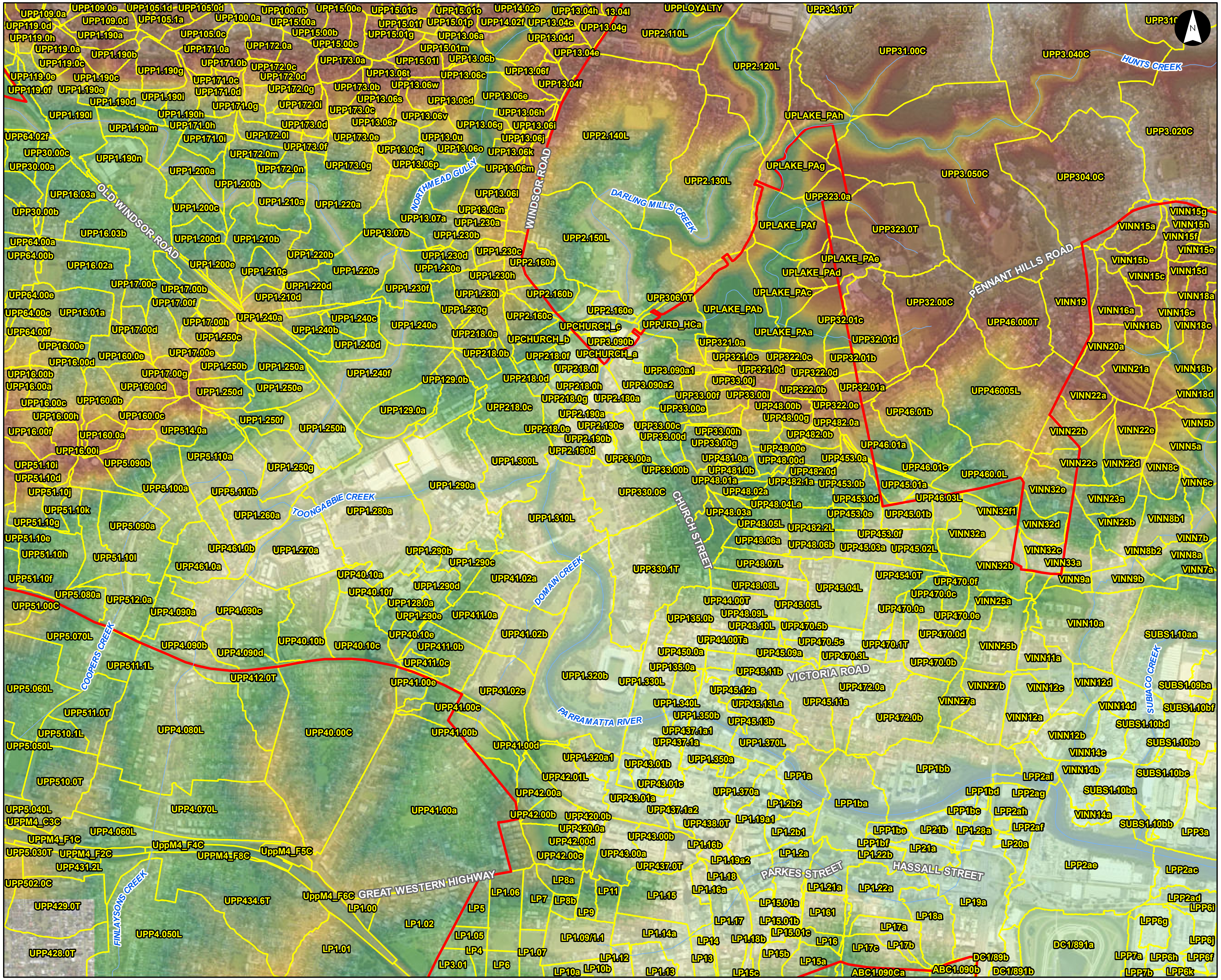
Stantec

0 0.5 1 km

Scale at A3 1:20,000



This document has been prepared based on information provided by others as cited in the data sources. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.



Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- Subcatchment Boundary

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.10E

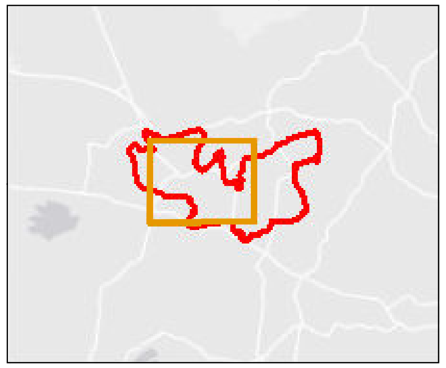
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

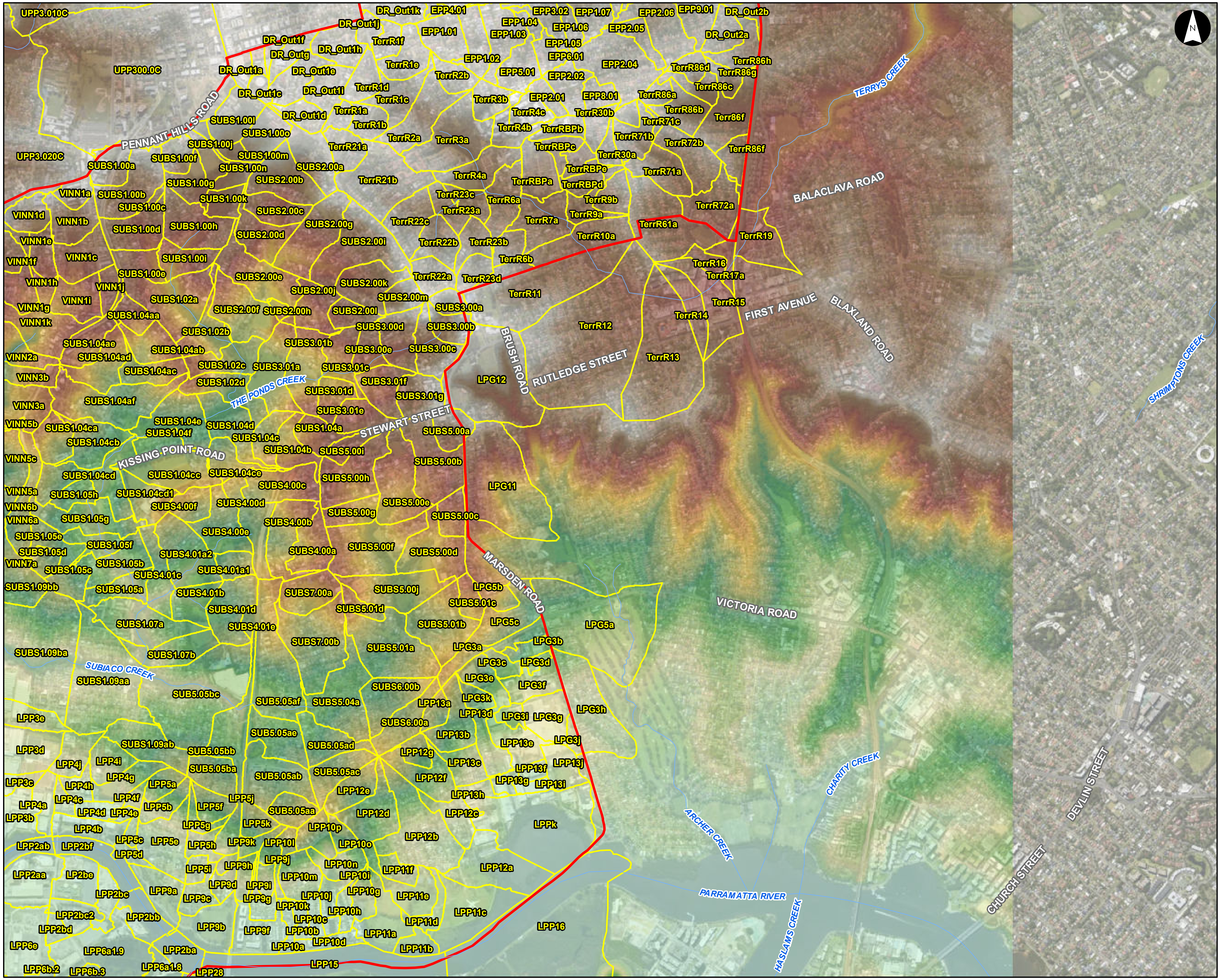
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 km

Scale at A3 1:20,000





Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

Study Area

Watercourse

Subcatchment Boundary

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.10F

Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 km

Scale at A3 1:20,000

Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

Study Area

Watercourse

Subcatchment Boundary

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.10G

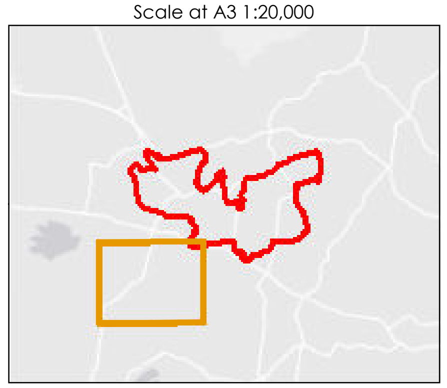
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 km

Scale at A3 1:20,000



Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- Subcatchment Boundary

Elevation (m)

High : 134.07

Low : -0.96

Figure 15.10H

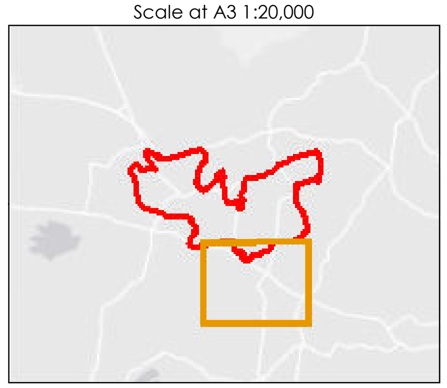
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 km

Scale at A3 1:20,000



Hydrologic Model Subcatchment Layout

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-016-HydrologicModel.mxd
Rev: 05
Date: 2023-05-18

Legend

Study Area
Watercourse
Subcatchment Boundary

Elevation (m)
High : 134.07
Low : -0.96

Figure 15.10I

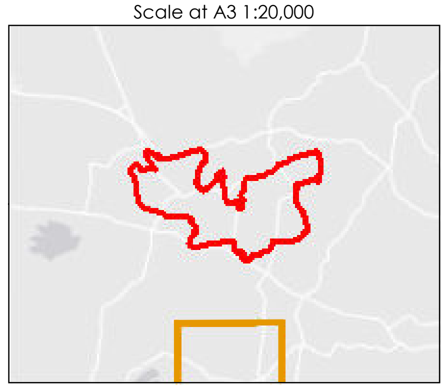
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

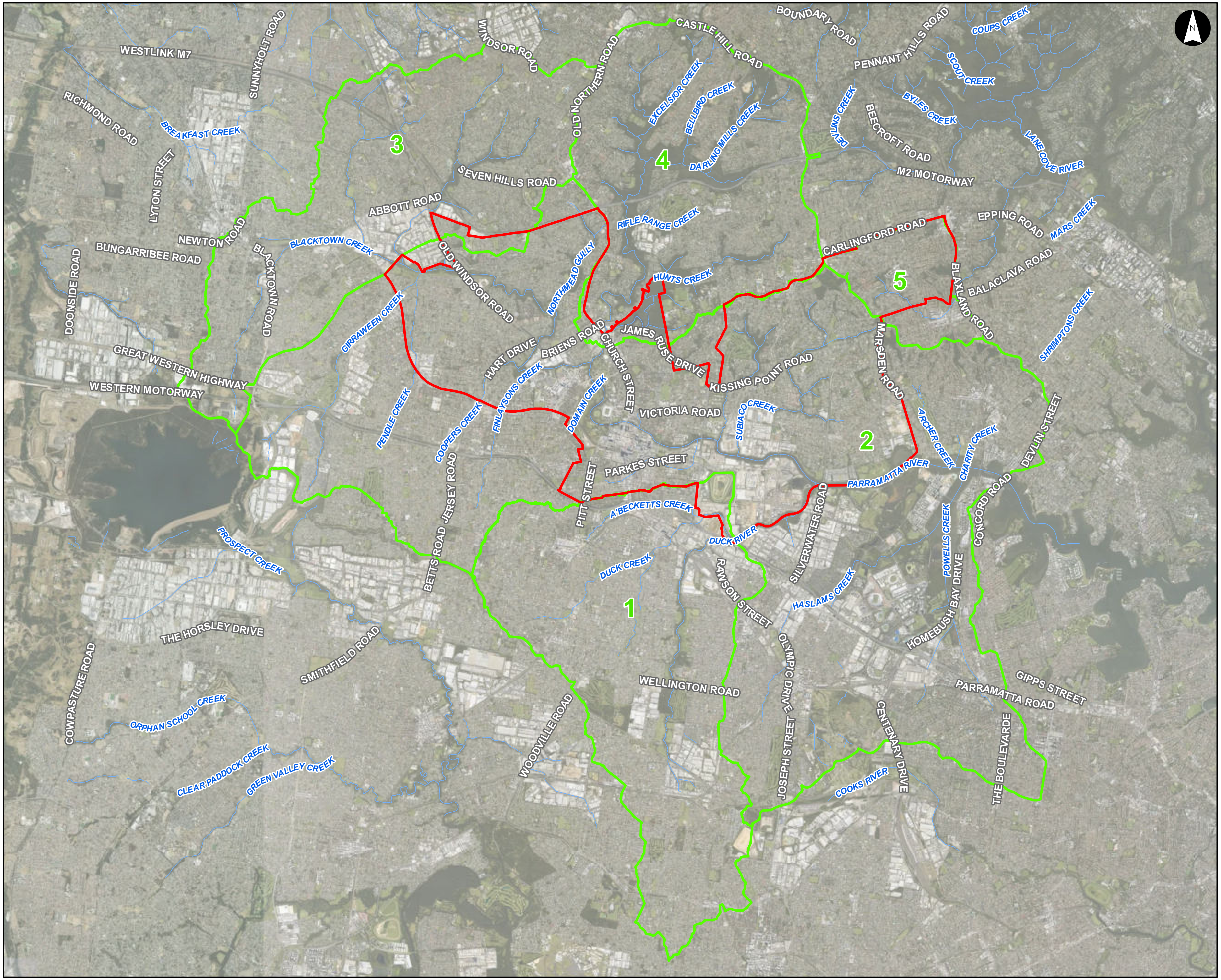
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 km

Scale at A3 1:20,000





Intensity-Frequency Duration Zones Adopted for Design Events

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-017-IntensityFrequency.mxd
Rev: 04
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- Intensity-Frequency-Duration Zones Adopted for Design Events

Figure 15.11

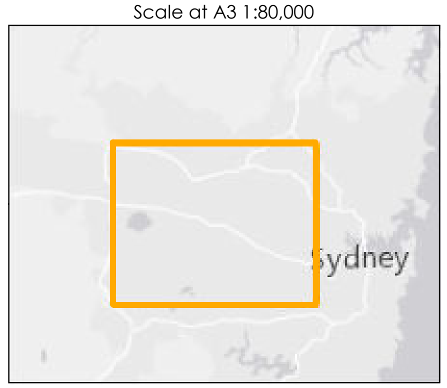
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 3 4 km

Scale at A3 1:80,000



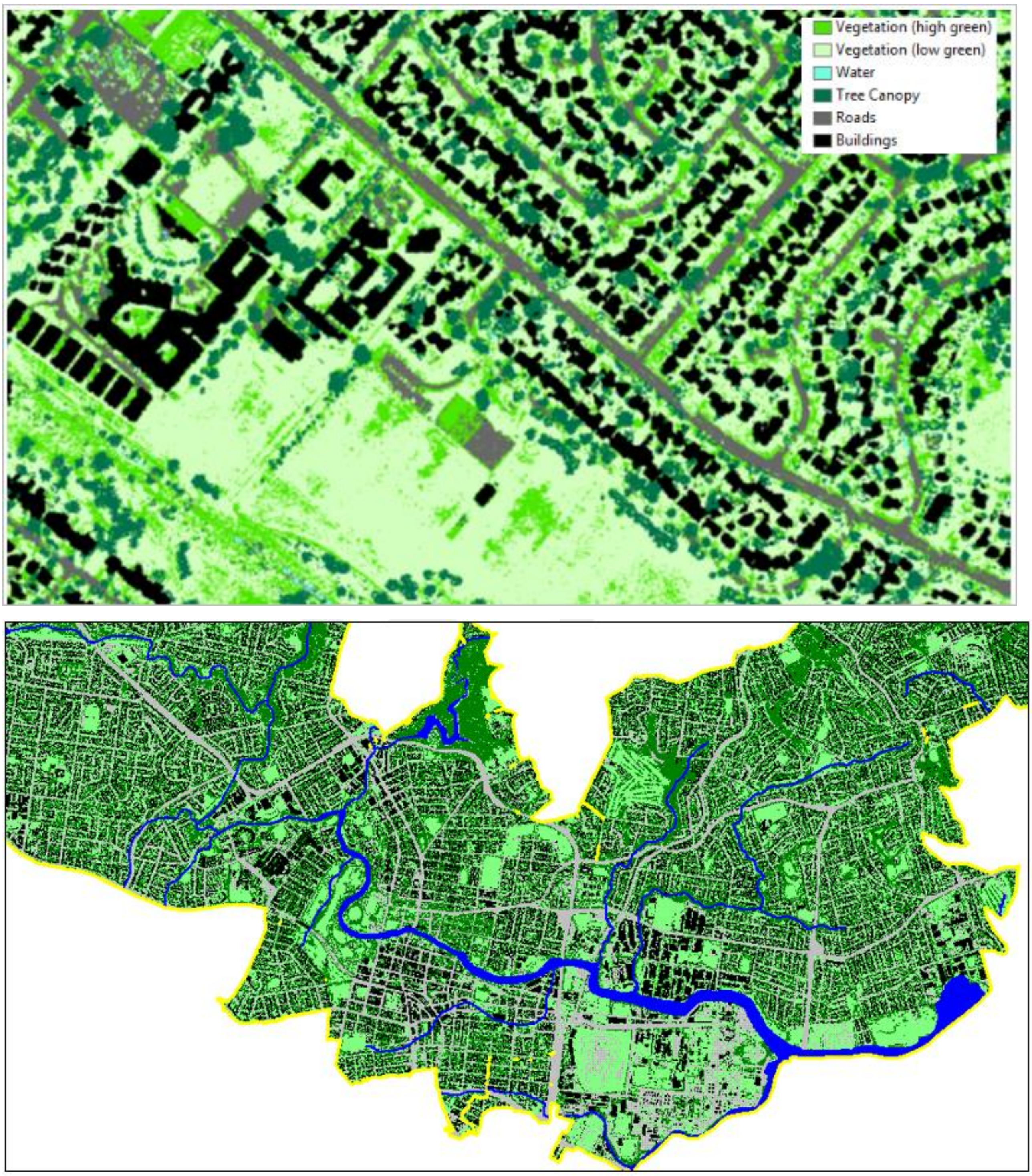


Figure 15-12 Land Use Raster Grid from Remote Sensing

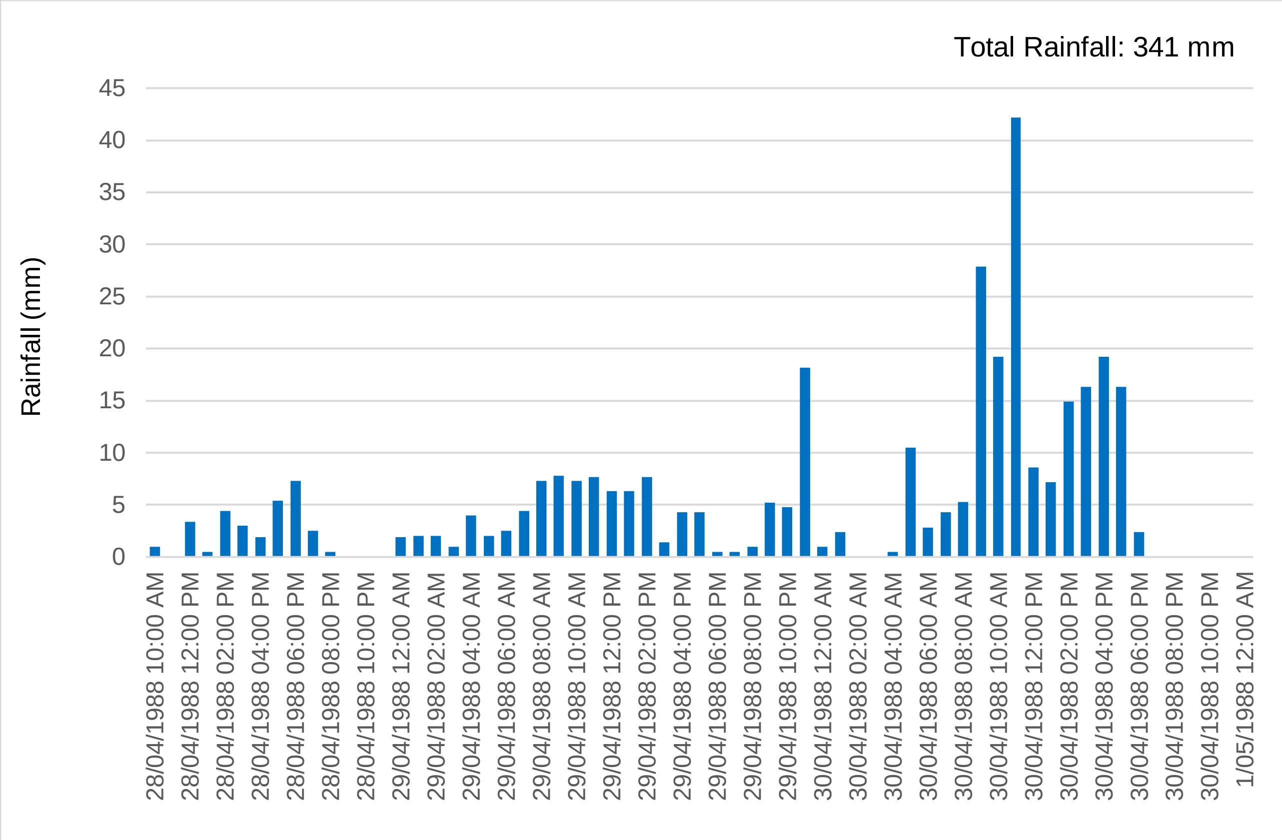


Figure 15-13 April 1988 Storm Event Rainfall at Marsden Street Weir (Station 7299)

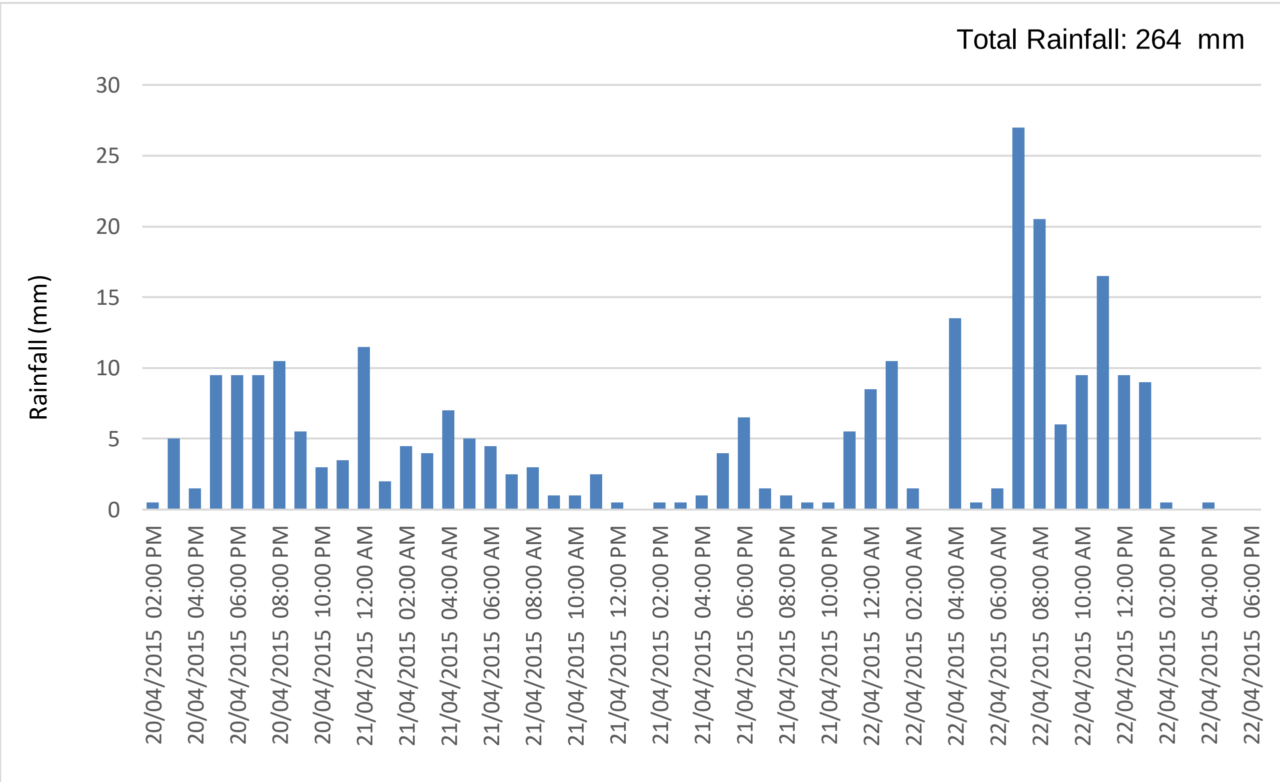


Figure 15-14 April 2015 Storm Event Rainfall at Northmead Bowling Club (Station 567104)

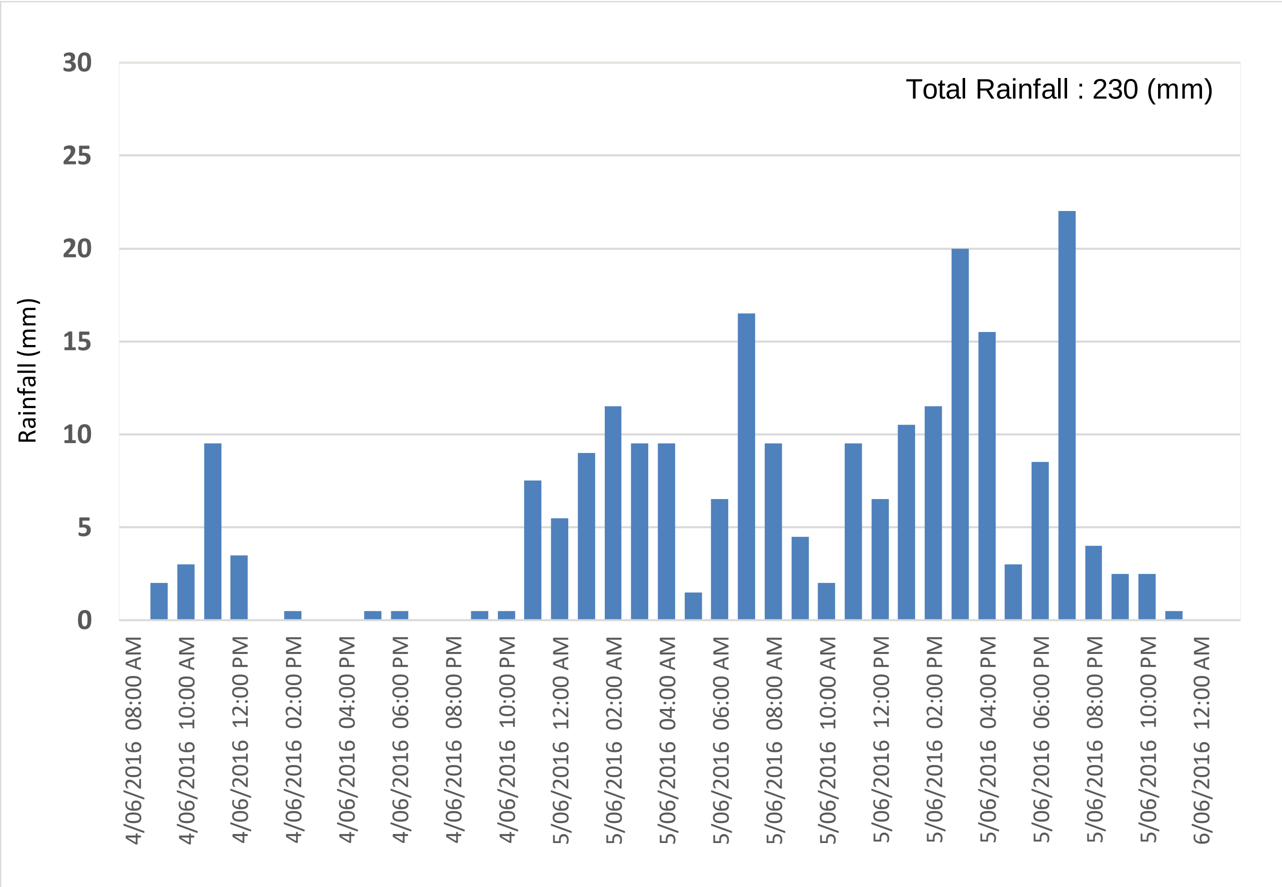
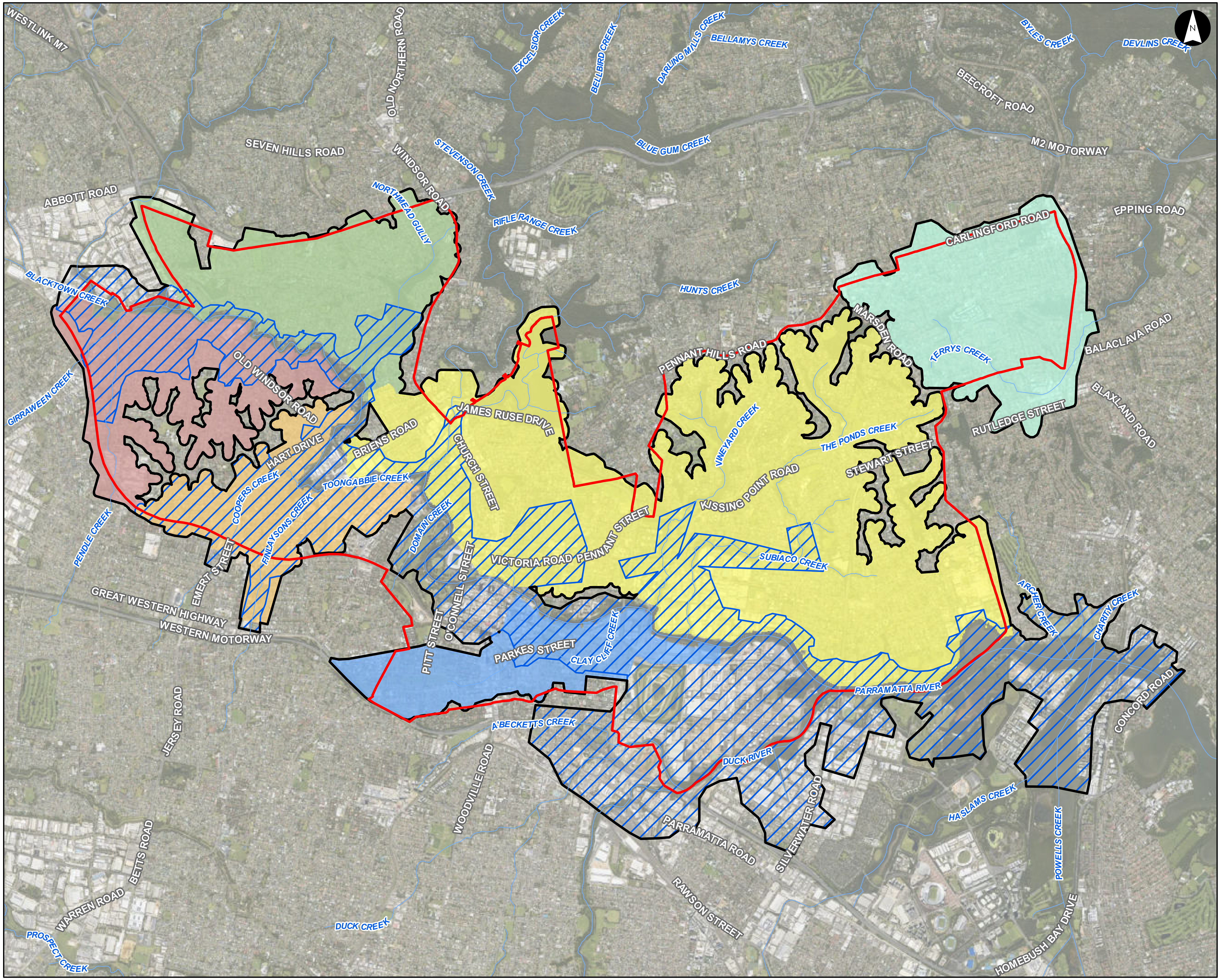


Figure 15-15 June 2016 Storm Event Rainfall at Northmead Bowling Club (Station 567104)



TUFLOW Model Extents

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-018-TUFLOWModelExtents.mxd
Rev: 05
Date: 2023-05-18

Legend

- Study Area
- Model Extent
- Watercourse
- Parramatta River
- Claycliff Creek
- Darling Mills, The Ponds, Subiaco, Vineyard and Brickfield Creeks
- Finlaysons and Coopers Creeks
- Pendle Hill Creek
- Terrys and Devlins Creek
- Quarry Creek

Figure 15.16

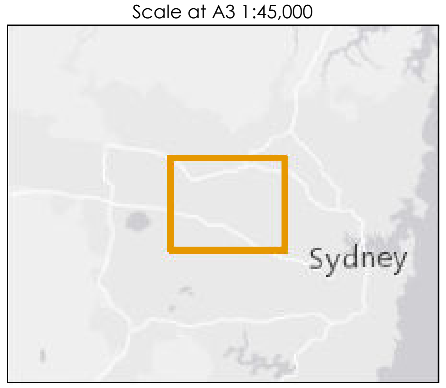
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 km

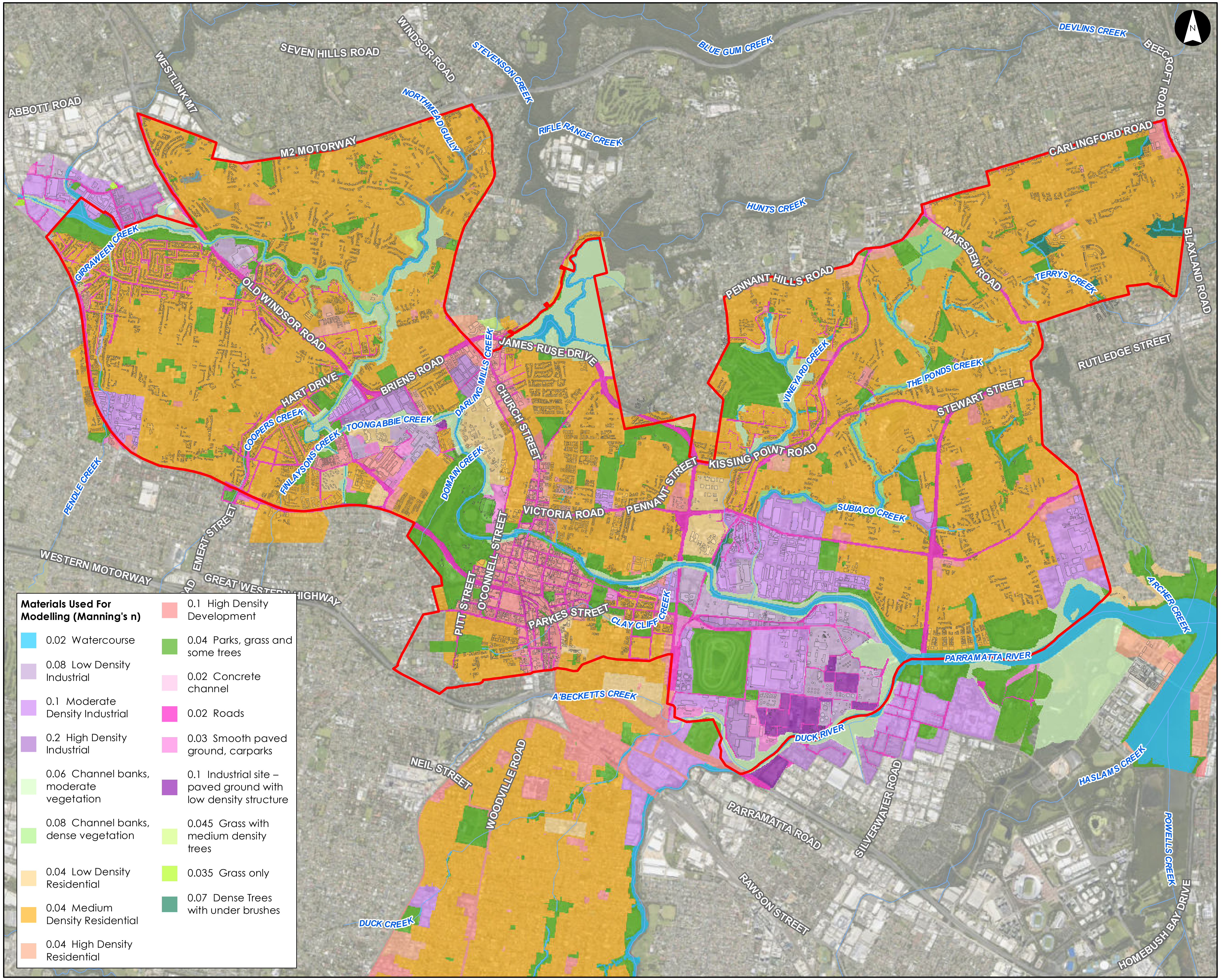
Scale at A3 1:45,000



TUFLOW Materials and Buildings

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-019-TUFLOWMaterialBuilding.mxd
Rev: 04
Date: 2023-05-18



Materials Used For Modelling (Manning's n)

- 0.02 Watercourse
- 0.08 Low Density Industrial
- 0.1 Moderate Density Industrial
- 0.2 High Density Industrial
- 0.06 Channel banks, moderate vegetation
- 0.08 Channel banks, dense vegetation
- 0.04 Low Density Residential
- 0.04 Medium Density Residential
- 0.04 High Density Residential
- 0.1 High Density Development
- 0.04 Parks, grass and some trees
- 0.02 Concrete channel
- 0.02 Roads
- 0.03 Smooth paved ground, carparks
- 0.1 Industrial site – paved ground with low density structure
- 0.045 Grass with medium density trees
- 0.035 Grass only
- 0.07 Dense Trees with under brushes

Legend

- Study Area
- Watercourse
- Buildings

Figure 15.17

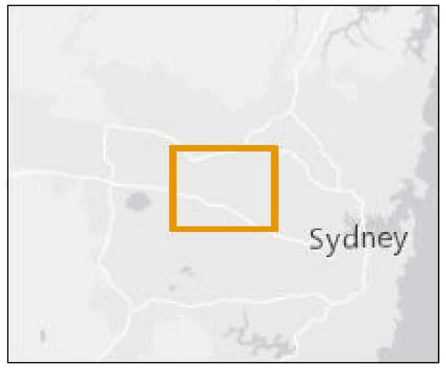
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

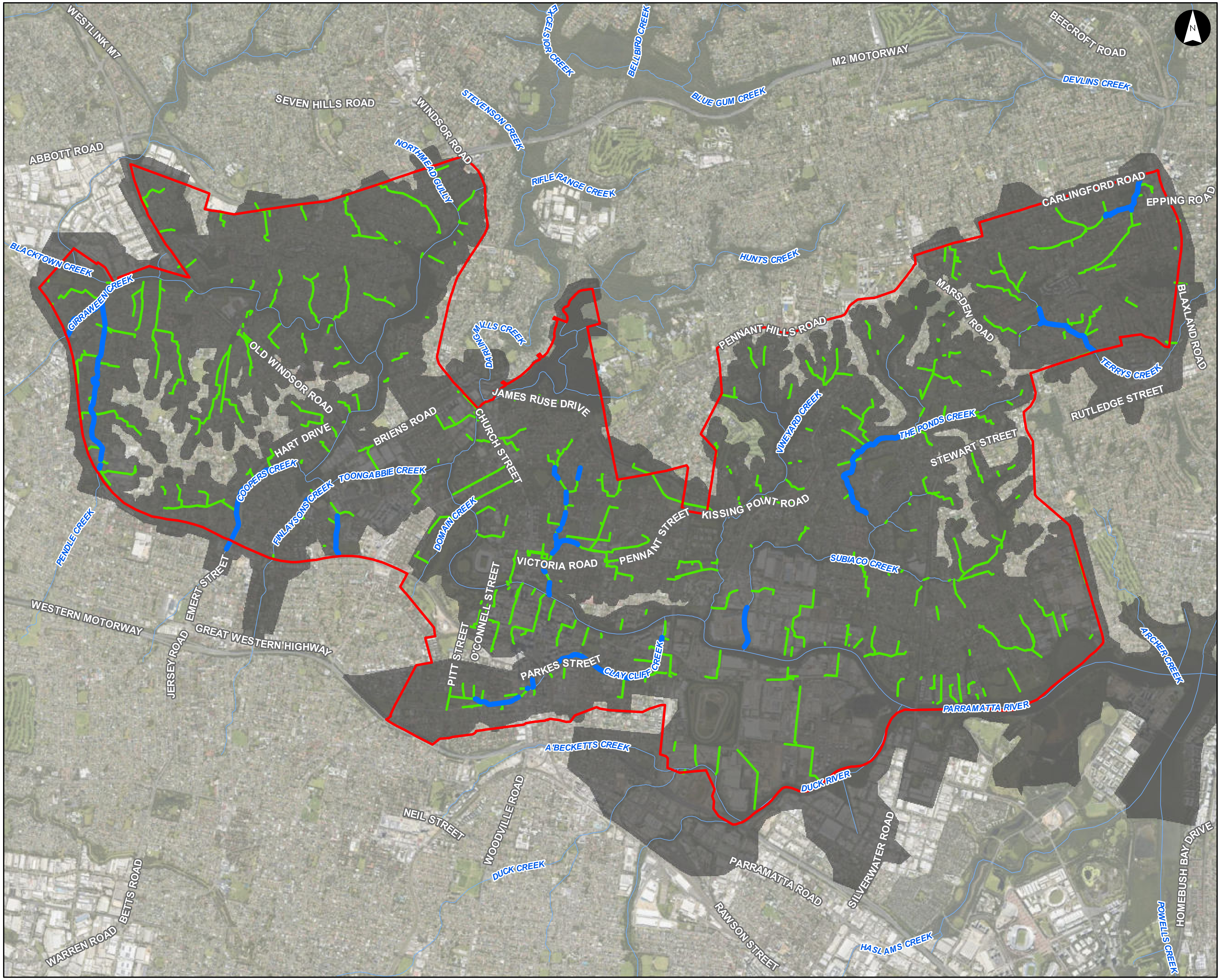
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 km

Scale at A3 1:40,000





TUFLOW Stormwater Pits and Pipes and 1D Channels

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-020-TUFLOWStormwaterPits.mxd
Rev: 05
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- 1D Channels
- Stormwater Pipes
- TUFLOW Model Extents

Figure 15.18

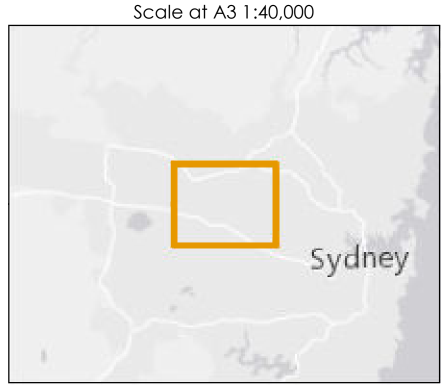
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

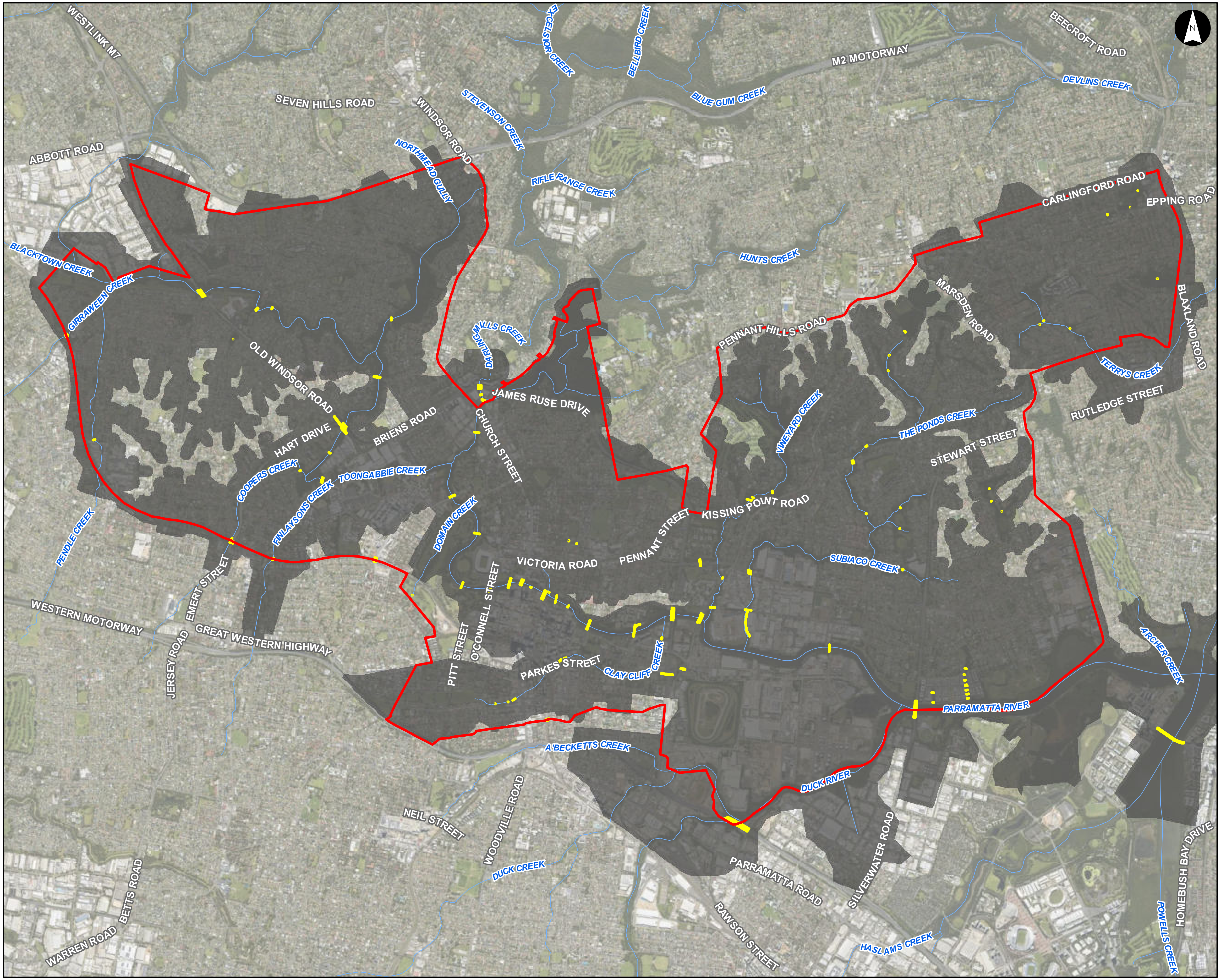
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 km

Scale at A3 1:40,000





TUFLOW Layered Flow Constrictions

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-021-TUFLOWFlowConstrictions.mxd
Rev: 04
Date: 2023-05-18

Legend

- Study Area
- Watercourse
- Bridges
- TUFLOW Model Extents

Figure 15.19

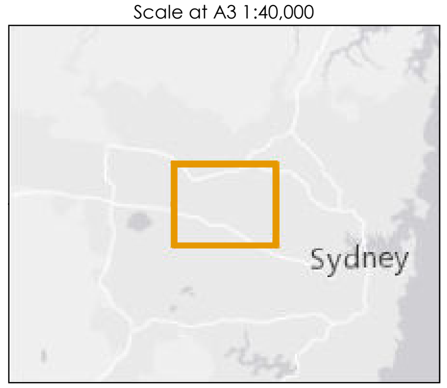
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 km

Scale at A3 1:40,000



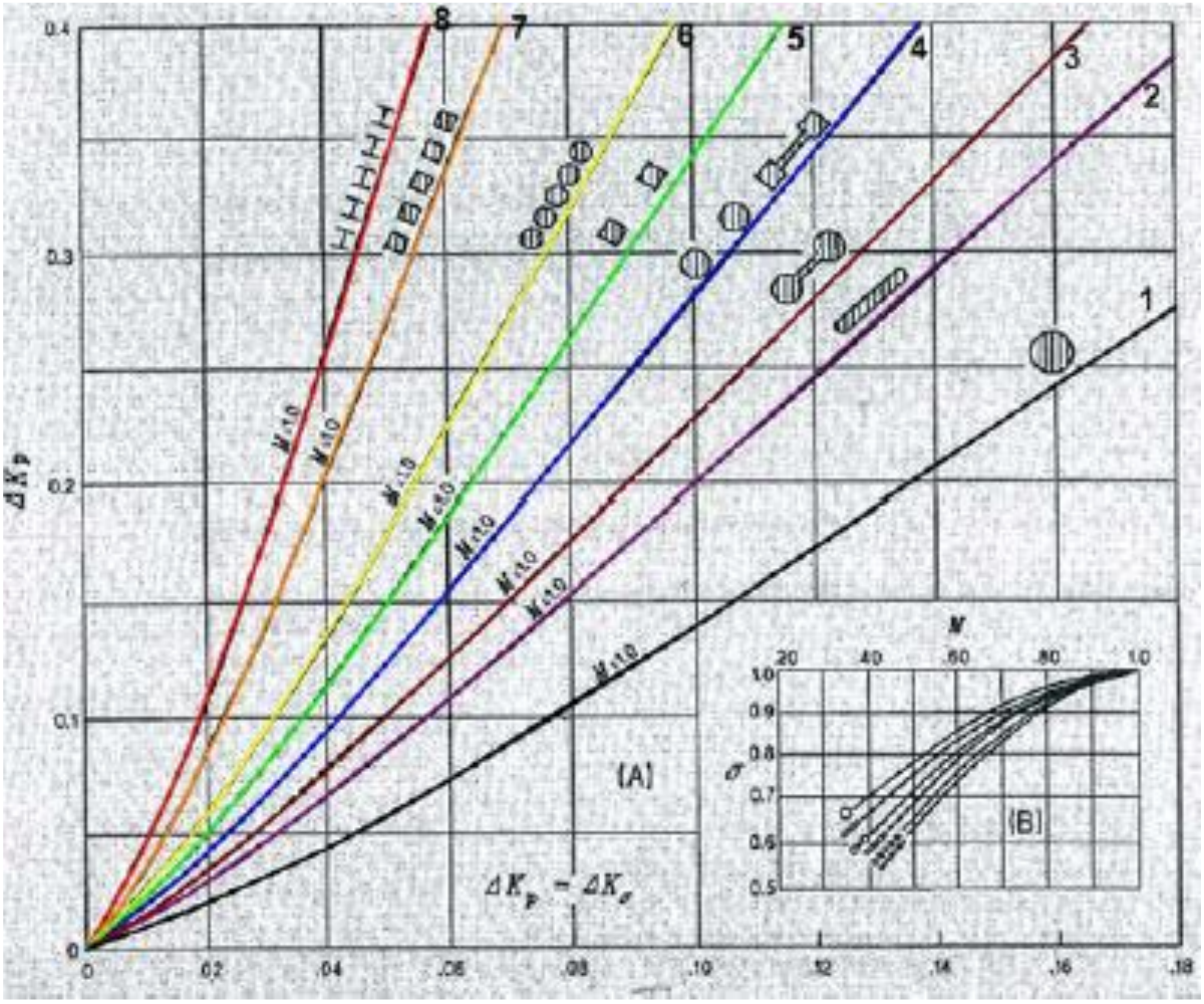
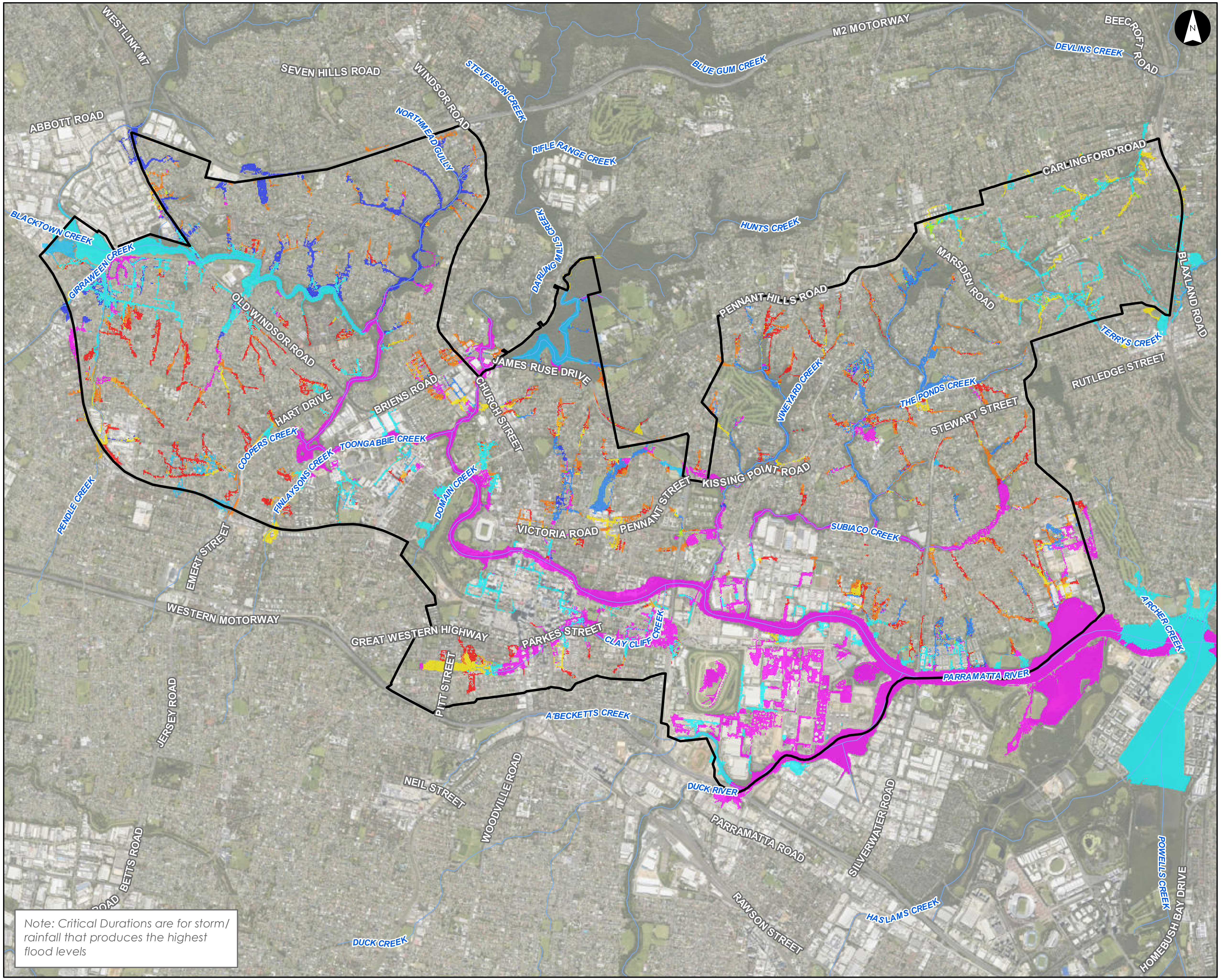


Figure 15-20 Bradleys Method Form Loss coefficient for piers (source AustRoads, 1994)



FFA 1% AEP Event Critical Durations

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS Checked By: TB
Map: 59916074-GS-031-100yCriticalDurations.mxd
Rev: 06
Date: 2023-05-18

Legend

- Study Area
- Watercourse

Critical Storm Durations

- 15 min
- 20 min
- 25 min
- 30 min
- 45 min
- 60 min
- 90 min
- 120 min
- 180 min
- 270 min
- 360 min
- 540 min
- 720 min

Figure 15.21

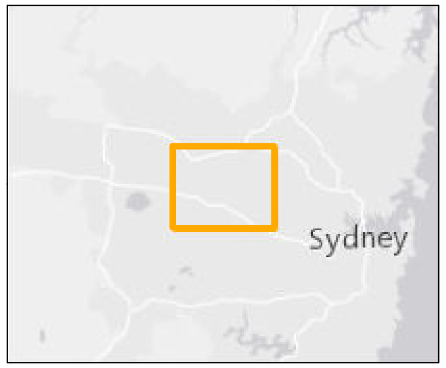
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

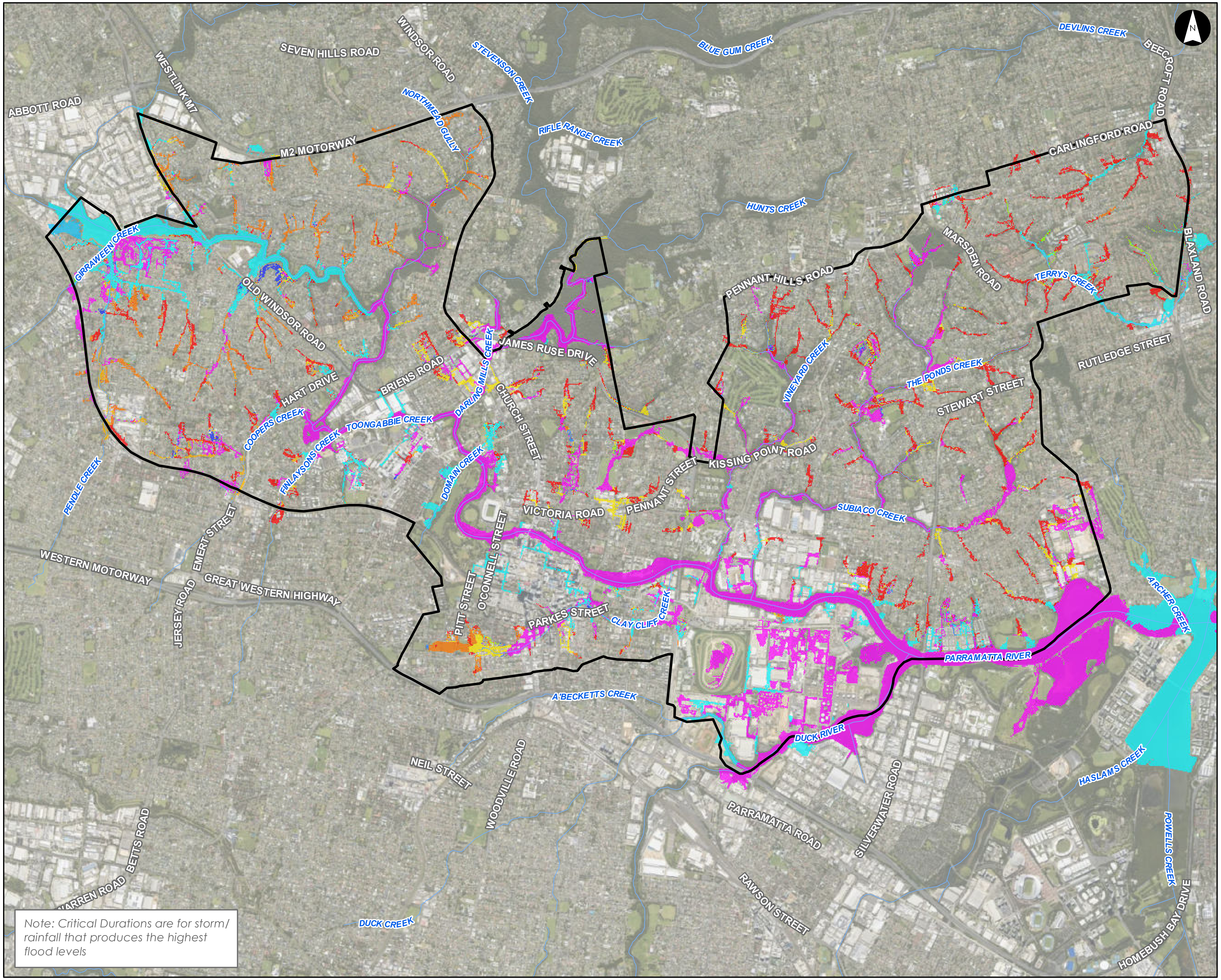
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 1.5 2 km

Scale at A3 1:40,000





2% AEP Event Critical Durations

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS Checked By: TB
Map: 59916074-GS-073-2p_CriticalDurations.mxd
Rev: 04
Date: 2023-05-18

Legend

Study Area

Watercourse

Critical Storm Durations

- 15 min
- 20 min
- 25 min
- 30 min
- 45 min
- 60 min
- 90 min
- 120 min
- 180 min
- 270 min
- 360 min
- 540 min
- 720 min

Figure 15.22

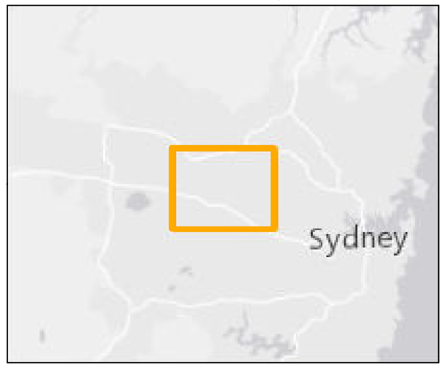
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

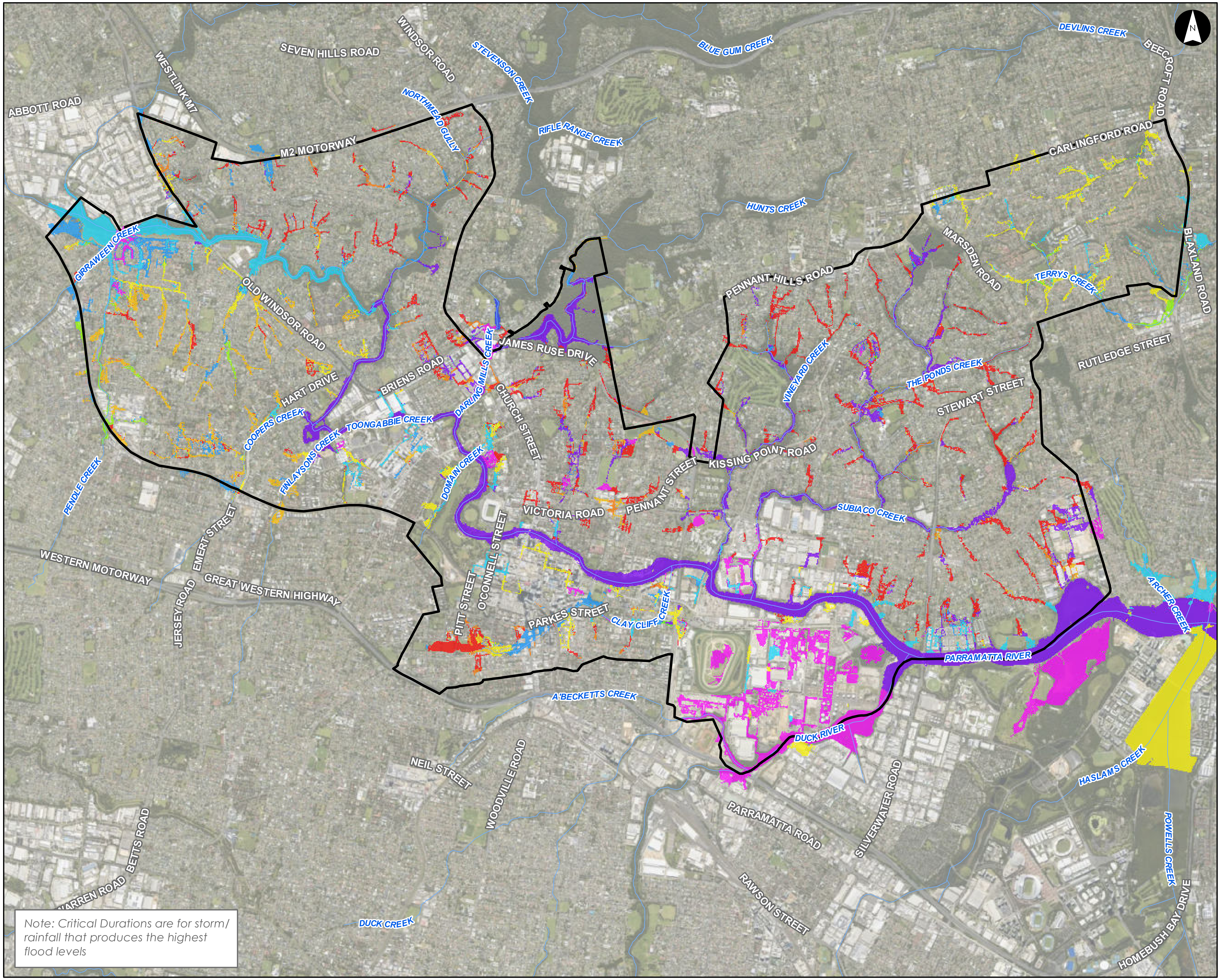
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 1.5 2 km

Scale at A3 1:40,000





N

5% AEP Event Critical Durations

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-074-5p_CriticalDurations.mxd
Rev: 04
Date: 2023-05-18

Legend

- Study Area
- Watercourse

Critical Storm Durations

- 15 min
- 20 min
- 25 min
- 30 min
- 45 min
- 60 min
- 90 min
- 120 min
- 180 min
- 270 min
- 360 min
- 720 min

Figure 15.23

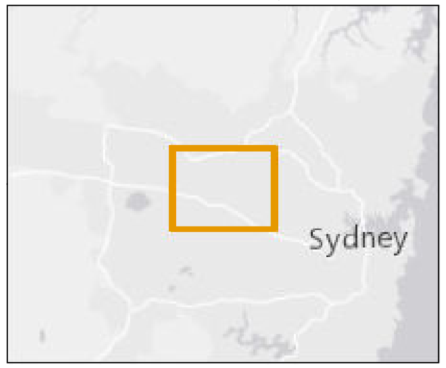
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

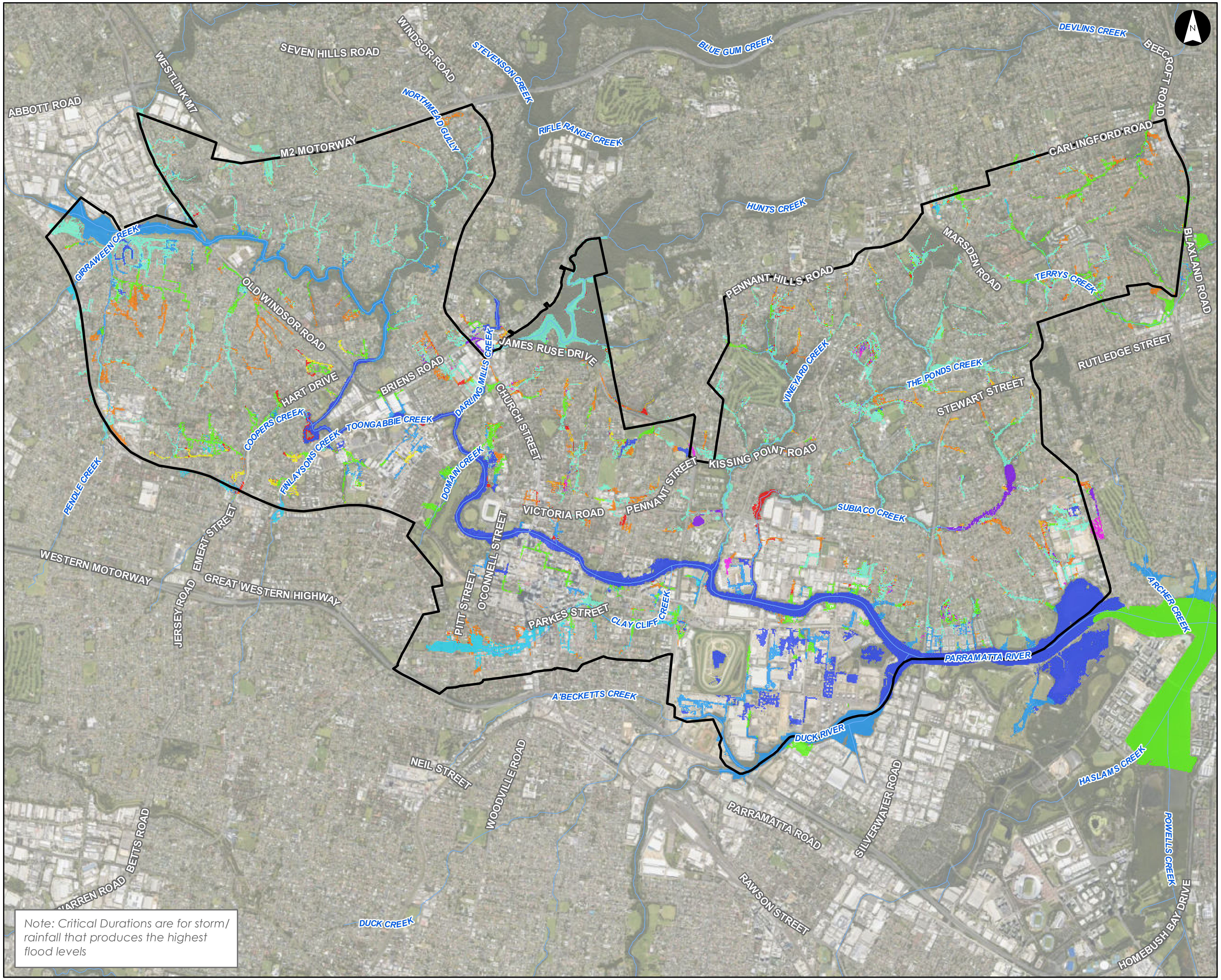
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 km

Scale at A3 1:40,000





20% AEP Event Critical Durations

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS Checked By: TB
Map: 59916074-GS-075-20p_CriticalDurations.mxd
Rev: 04
Date: 2023-05-18

Legend

Study Area
Watercourse

Critical Storm Durations

- 15 min
- 20 min
- 25 min
- 30 min
- 45 min
- 60 min
- 90 min
- 120 min
- 180 min
- 270 min
- 540 min
- 720 min

Figure 15.24

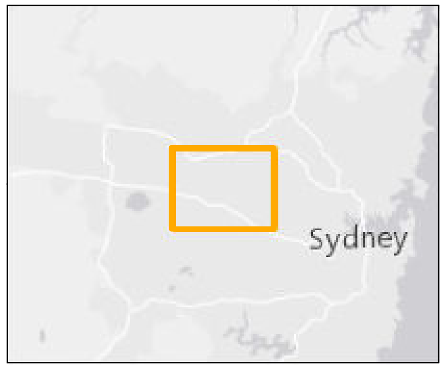
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

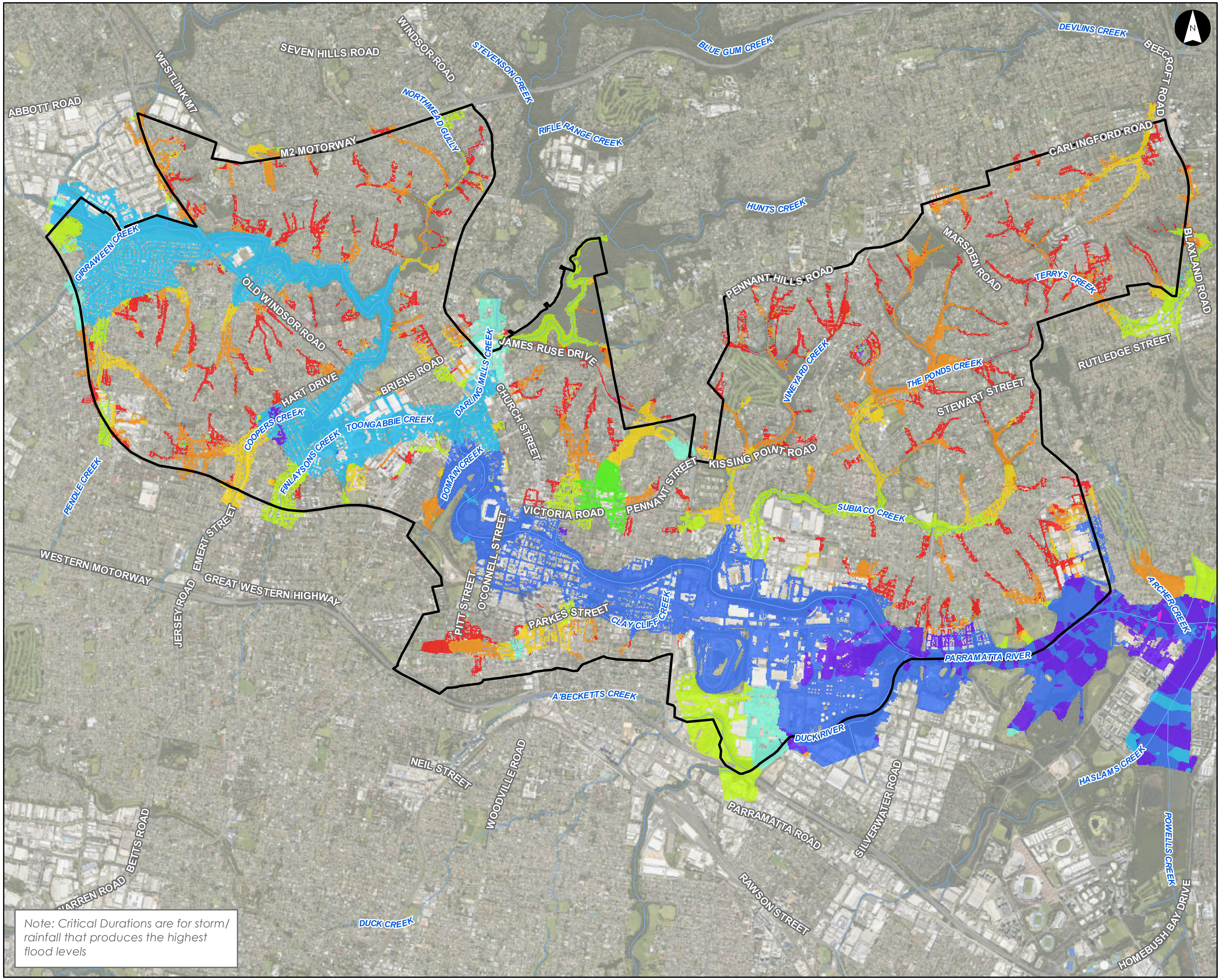
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 1.5 2 km

Scale at A3 1:40,000





PMF Event Critical Durations

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS Checked By: TB
Map: 59916074-GS-032-PMFCriticalDurations.mxd
Rev: 07
Date: 2023-05-18

Legend

Study Area

Watercourse

Critical Storm Durations

- 15 min
- 30 min
- 45 min
- 60 min
- 90 min
- 120 min
- 180 min
- 240 min
- 300 min
- 360 min

Figure 15.25

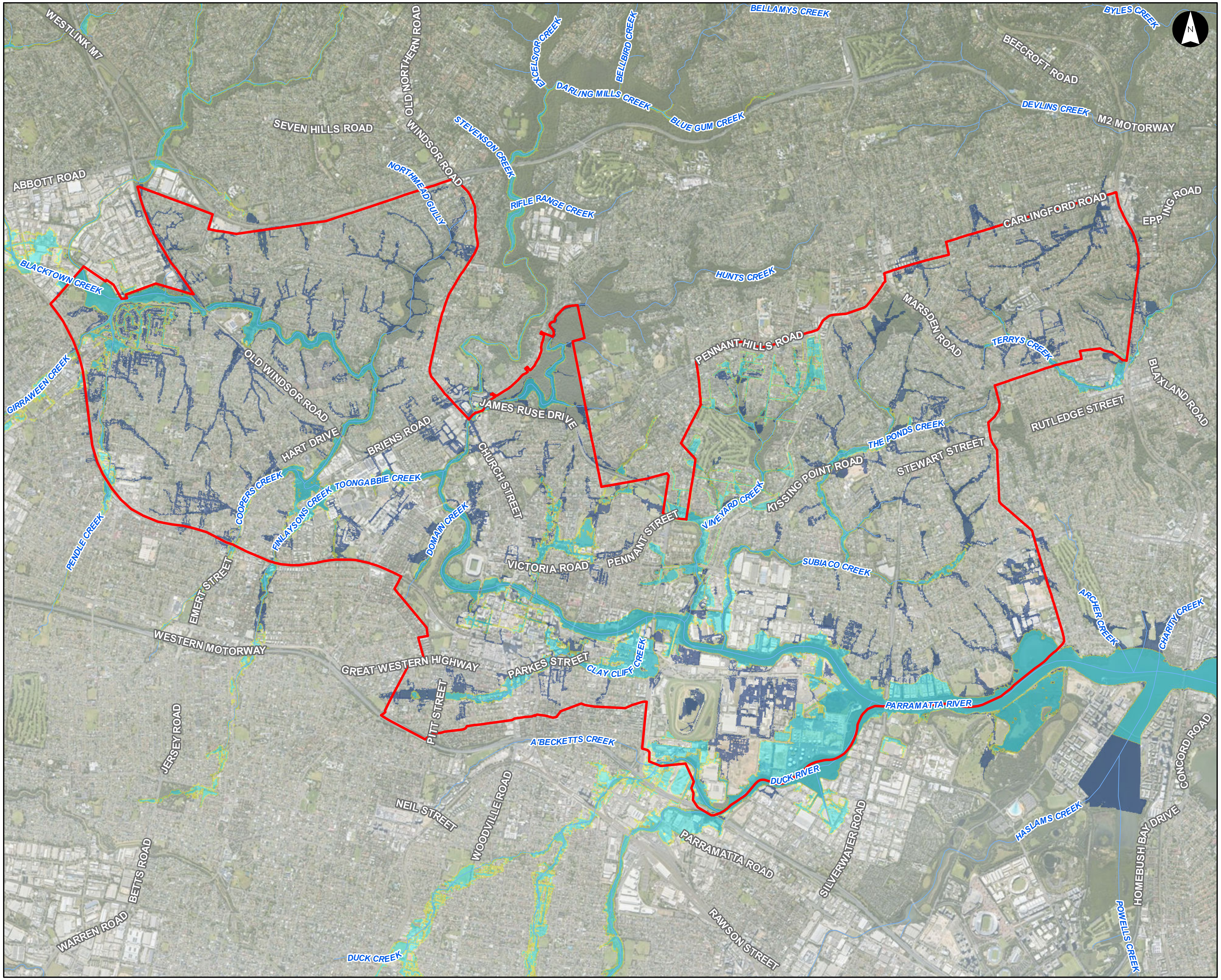
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 0.5 1 1.5 2 km

Scale at A3 1:40,000



FFA Calibrated 1% AEP Event Comparison with MIKE 11 Extents

Parramatta River Flood Study

Project Code: 59916074 / 304600102
Drawn By: ANK, Checked By: MM
Map: 59916074-GS-028-100yCompareMIKE11.mxd
Rev: 05
Date: 2024-04-15

Legend

- Study Area
- 1% AEP Mike 11 Extent
- FFA Calibrated 1% AEP Extent

Figure 15.26

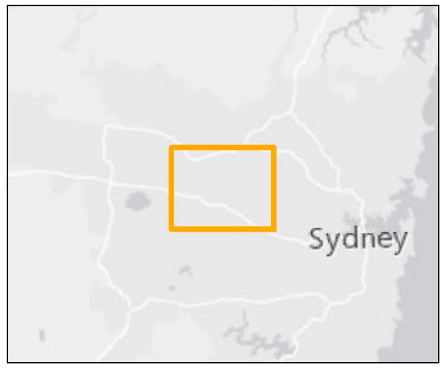
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

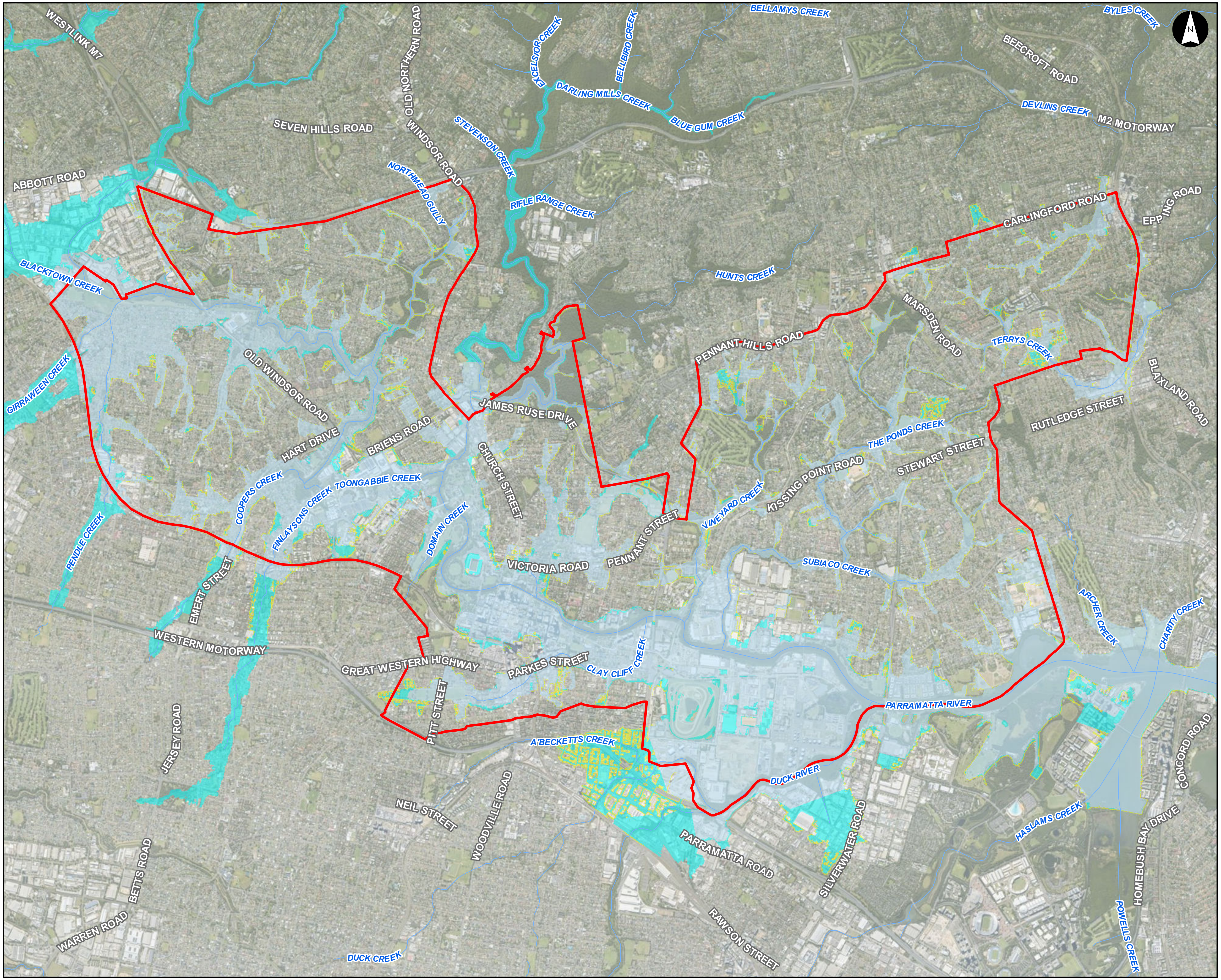
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 km

Scale at A3 1:42,000





PMF Event Comparison with MIKE 11 Extents

Parramatta River Flood Study

Project Code: 59916074 / 304600102
Drawn By: ANK, Checked By: AS
Map: 59916074-GS-029-PMFCompareMIKE11.mxd
Rev: 09
Date: 2024-04-11

Legend

- Study Area
- Watercourse
- PMF Extent
- PMF Mike 11 Extent

Figure 15.27

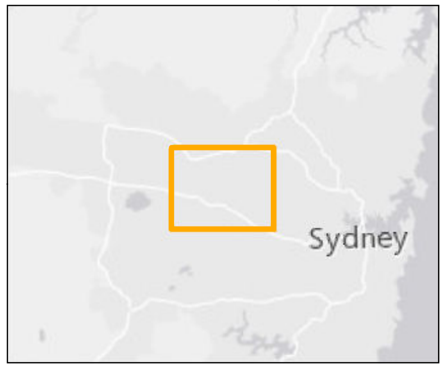
Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

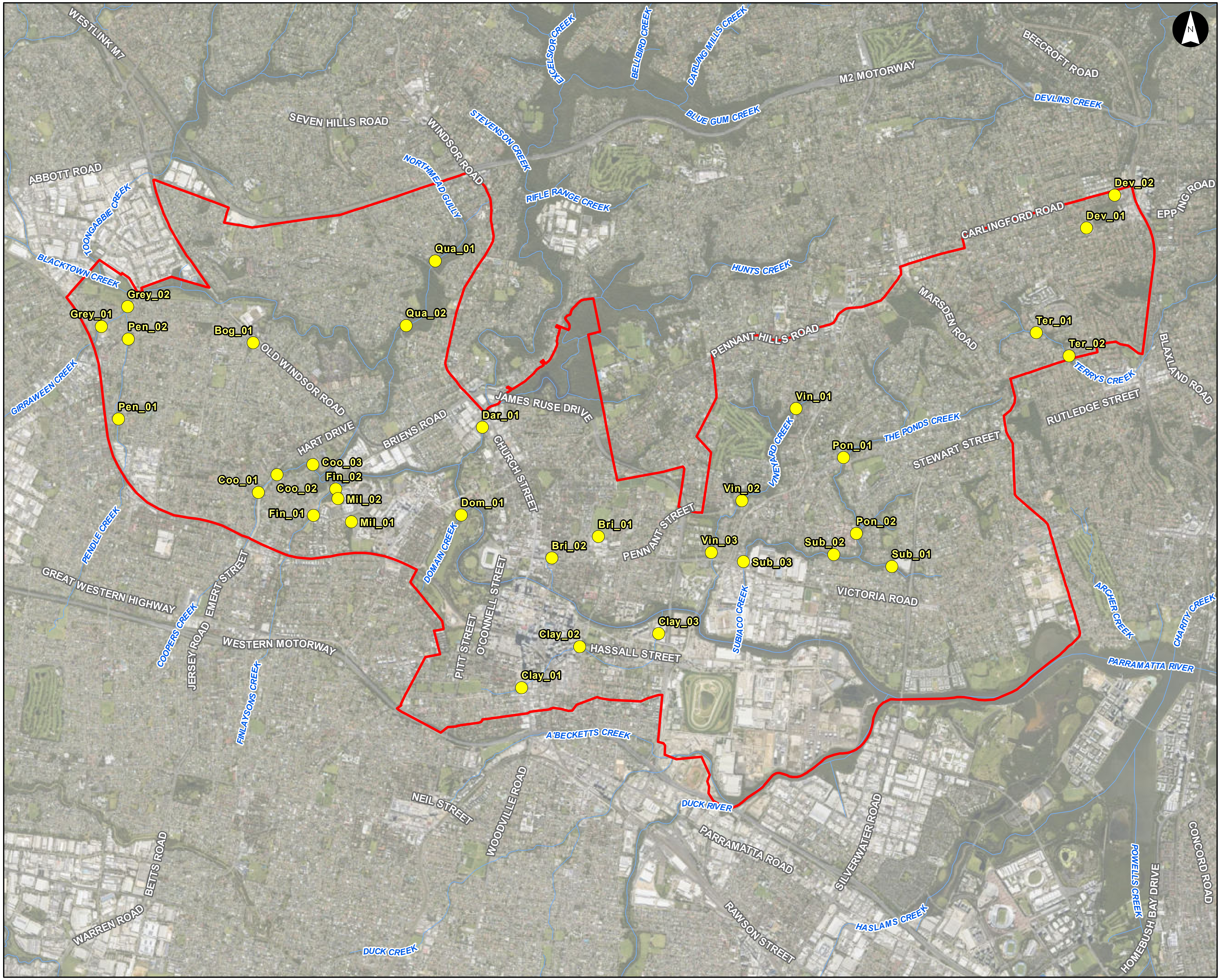
References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

Stantec

0 1 2 km

Scale at A3 1:42,000





Sensitivity and Climate Change Scenario Reference Locations

Parramatta River Flood Study

Project Code: 59916074
Drawn By: AS, Checked By: TB
Map: 59916074-GS-089-SensCC_RefLocations.mxd
Rev: 04
Date: 2023-05-18

Legend

- Study Area
- Sensitivity and Climate Change Scenario Reference Locations
- Watercourse

Figure 15.28

Notes:
1. Coordinate System: GDA 1994 MGA Zone 56

References:
1. Base data supplied by NSW SS and Esri
2. Aerial imagery supplied by MetroMap

0 1 2 km

Scale at A3 1:42,000