Cabravale Overland Flood Study

Final Report

Volume 1 of 2: Report and Appendices

Revision 4
January 2023

Catchment Simulation Solutions

Cabravale Overland Flood Study

Final Report

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REVISION / DISTRIBUTION

Rev	Description	Prepared by	Reviewed by	Distribution	Date
1	Draft Report	D. Tetley	C. Ryan	Fairfield City Council	08/06/2018
2	Draft Report incorporating updated to address OEH comments	D. Tetley	C. Ryan	Fairfield City Council	21/06/2018
3	Draft Report for Public Exhibition	D. Tetley	C. Ryan	Fairfield City Council	25/08/2022
4	Final Report	D. Tetley	C. Ryan	Fairfield City Council	24/01/2023

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File Reference: Cabravale Flood Study (Rev 4) - Vol 1 - Report.docx

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EXECUTIVE SUMMARY

The Cabravale Overland Flow Flood Study was prepared for Fairfield City Council to define overland flood behaviour across the 11.5 km^2 Cabravale study area. The flood study was overseen by Fairfield City Council's Floodplain Risk Management Committee and technical and financial support was provided by the State Government under the Floodplain Management Program. The study will serve to guide future development in a way that recognises the flood risk. The study will also serve as the basis for identifying options that may be implemented to reduce the existing flood risk as part of the subsequent floodplain risk management study and plan.

The study area includes the suburbs of Lansvale and Carramar as well as parts of Mt Pritchard, Cabramatta, Canley Vale, Fairfield and Villawood and is traversed or adjoined by a number of waterways including:

- Prout Creek;
- Long Creek;
- Cabramatta Creek;
- Prospect Creek; and,
- Georges River

Inundation of the study area can result from each of the above watercourses overtopping their banks (referred to as mainstream flooding) or as a result of floodwaters attempting to drain down into one of these watercourses (referred to as overland flooding). Overland flooding most commonly occurs when the capacity of the local stormwater system is exceeded and was the primary focus of the study.

A consultation program was implemented as part of the study to obtain information from the community regarding their past flooding experiences. The primary goals of the community consultation were to identify flooding "hot spots" and to collate historic flood information that could be used to assist in the calibration of the computer flood model that was developed as part of the study. This was achieved through the development of a flood study website and the distribution of a community information brochure and questionnaire to approximately 2,500 households and businesses.

The community responses to the questionnaire indicate that flooding has been experienced on a number of occasions across the study area. This includes floods in 1988 as well as more recent events in 2012, 2015 and 2016. Each of these floods resulted in traffic disruption, damage to private and public property (e.g., fences) as well as above floor inundation of several properties.

A computer flood model of the Cabravale study area was developed using the TUFLOW software as part of the study. The model was developed to include a representation of all features that will influence the movement of floodwaters across the study area. This included all stormwater pits and pipes, bridges, culverts, buildings and fences. The topography across the catchment was defined in the model based upon a digital elevation model derived from LiDAR. The LiDAR was supplemented with additional ground survey of creek cross-sections as well as hydraulic structures (e.g., bridges and culverts) that were collected by Council surveyors.

The computer model was calibrated against historic flood information that was extracted from the community questionnaire responses. This included seven flood marks for the 2016 flood, three flood marks for the 2015 flood and two flood marks for the 2012 flood. The outcomes of the calibration process showed that the developed computer model was providing a reliable representation of flood behaviour across the catchment (eleven of the reported flood marks were reproduced by the model to within ±0.1 metres).

The calibrated flood model was then used to simulate a range of design floods across the study area. This included the 20%, 5%, 1% and 0.2% annual exceedance probability (AEP) floods as well as the 1 in 10,000 year and Probable Maximum Flood (PMF).

The results of the design flood simulations are presented in a series of maps that are contained in Volume 2 of the flood study. These maps contain information on floodwater depths, levels, velocities, hazard, hydraulic categories, emergency response precinct classifications and flood risk precincts.

The results of the computer simulations confirmed that flooding across the study area can occur as a result of major watercourses (i.e., Long Creek and Prout Creek) overtopping their banks, overland flooding when the capacity of the stormwater system is exceeded as well as inundation from elevated water levels in Prospect Creek, Cabramatta Creek and the Georges River. Approximately 25% of properties located within the catchment will be at least partly inundated at the peak of the 1% AEP flood. This is predicted to increase to over 40% during the probable maximum flood (PMF), which is the largest flood that could occur. Accordingly, major flooding has the potential to impact a significant number of properties.

The worst-case flooding across most of the study area typically occurs as a result of rainfall bursts that are less than 2 hours in duration. However, longer storm durations will typically produce higher flood levels along Prospect Creek, Cabramatta Creek and the Georges River.

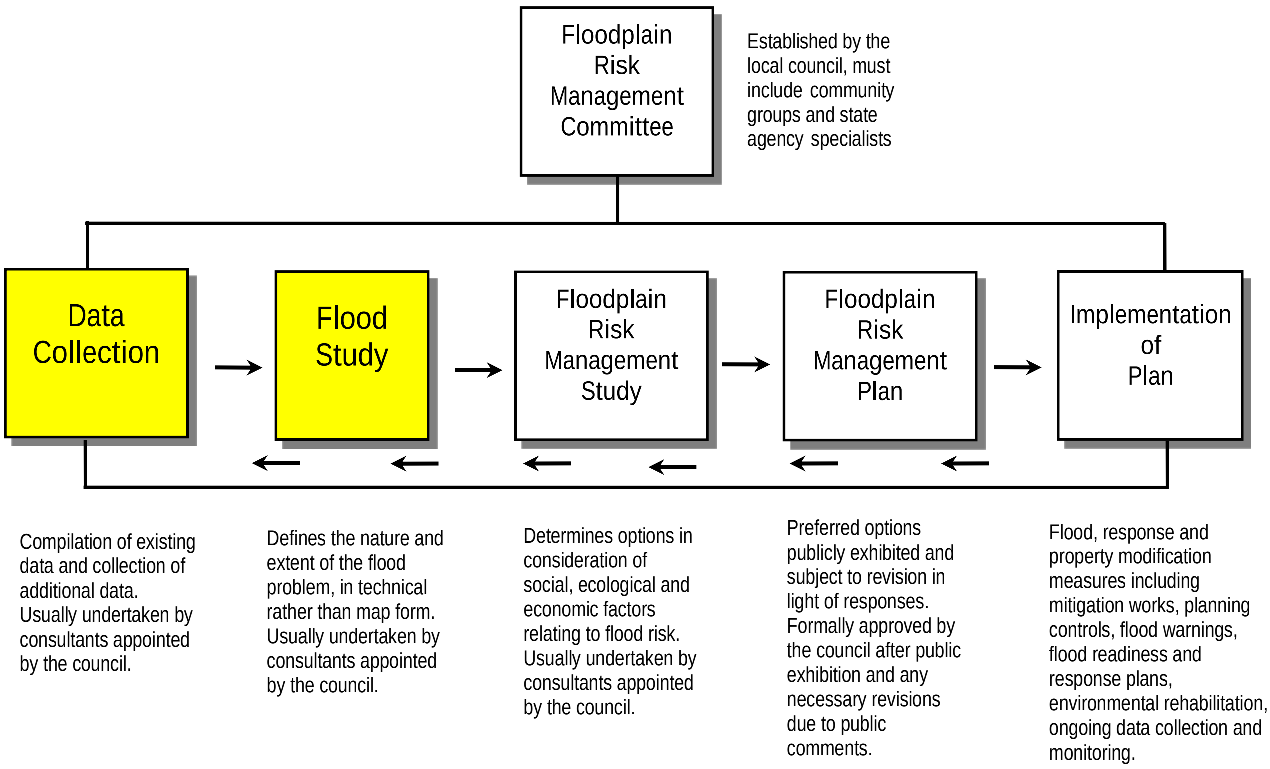
Many of the stormwater pipes in the area are predicted to have a capacity no greater than the 20% AEP flood. Therefore, during large storms, considerable flow can be concentrated along roadways, drainage depressions and overland flow paths. This is predicted to result in a number of roadways being overtopped during the 1% AEP flood. This would typically render the roadways impassable for at least 1 hour (but more commonly around 2 hours).

FOREWORD

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

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

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



The Cabravale Overland Flood Study represents the first of the four stages in the process outlined above. The aim of the Flood Study is to produce information on flood discharges, levels, depths and velocities, for a range of flood events under existing topographic and development conditions. This information can then be used as a basis for identifying those areas where the greatest flood damage is likely to occur, thereby allowing a targeted assessment of where flood mitigation measures would be best implemented as part of the subsequent Floodplain Risk Management Study and Plan.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF PLATES

1 INTRODUCTION

1.1 Catchment Description

The "Cabravale" catchment is located in the Fairfield City Council Local Government Area (LGA) and occupies a total area of approximately 11.5 km^2. The extent of the catchment is shown in **Figure 1**. As shown in **Figure 1**, the catchment incorporates the suburbs of Lansvale and Carramar as well as parts of Mt Pritchard, Cabramatta, Canley Vale, Fairfield and Villawood.

The southern sections of the catchment are typically drained by a stormwater system that conveys runoff into Cabramatta Creek. The northern and eastern sections of the catchment drain into Prospect Creek. Cabramatta Creek and Prospect Creek both drain into the Georges River (refer **Figure 1**).

1.2 Purpose of Study

During periods of heavy rainfall, there is potential for the capacity of the stormwater system across the study area to be exceeded. In such circumstances, the excess water travels overland, potentially leading to inundation of roadways and properties. There is also potential for water to overtop the banks of Prout and Long Creeks and inundate the adjoining floodplain.

Fairfield City Council commissioned an LGA wide overland flow study (SKM, 2004) to help gain a better understanding of the overland flood risk across the LGA. The overland flow study utilised simplified modelling tools to assist Council in defining the location of major overland flow paths and identifying properties at risk of overland flooding. This information was used to define the variation in flood hazard and potential for flood damage and ultimately rank each subcatchment within the LGA based on the severity of the flood risk. This ranking is being used to prioritise each subcatchment within the LGA for detailed overland flood studies.

The overland flow study identified the Cabravale overland catchment as the 8th ranked highest priority catchment for a detailed overland flow study. Accordingly, Council resolved to undertake a detailed overland flow flood study for the catchment to improve their understanding of the overland flow risk and provide a suitable foundation for the preparation of a floodplain risk management study for the catchment, which will look at options for better managing the existing flood risk.

This report forms the overland flow flood study for the Cabravale catchment. It documents flood behaviour across the catchment for a range of historic and design floods. This includes information on flood discharges, levels, depths and flow velocities. It also provides estimates of the variation in flood hazard and hydraulic categories across the catchment and provides an assessment of the potential impacts of climate change on existing flood behaviour.

The flood study comprises two volumes:

- Volume 1 (this document): contains the report text and appendices
- Volume 2: contains all figures and maps

It should be noted that the primary objective of the study is to define overland flood behaviour across the study area shown in **Figure 1**. Mainstream flooding along Prospect and Cabramatta Creeks was assessed as part of previous flood studies and is not analysed in detail as part of this current study.

2 METHODOLOGY

2.1 Objectives

Fairfield City Council outlined a range of objectives for the Cabravale Overland Flood Study. This included:

- to consult with the community to obtain information on historic floods and gain an understanding of flooding “trouble spots”;
- to review available flood-related information and historic flood data for the catchment;
- to develop a computer flood model to simulate the transformation of rainfall into runoff and determine how that runoff would be distributed across the catchment;
- to calibrate the computer model using data from historic floods;
- to use the calibrated computer model to define peak discharges, water levels, depths and velocities for the following design floods:
    - 20%, 5%, 1% and 0.2% AEP floods;
    - 1 in 10,000-year ARI flood; and,
    - Probable Maximum Flood (PMF);
- to produce maps showing flood hazard and hydraulic categories for the 1% AEP flood and PMF;
- to quantify the potential impact of climate change on existing design flood behaviour;
- to quantify the impact that modelling uncertainty may have on design flood behaviour; and,
- to prepare emergency response classifications.

2.2 Adopted Approach

The general approach and methodology employed to achieve the study objectives involved:

- compilation and review of available flood-related information and consultation with the community (Chapter 3);
- the development of a computer-based flood model to simulate the transformation of rainfall into runoff and simulate the movement of floodwaters across the catchment (Chapter 4);
- calibration of the computer flood model to reproduce historic flood information (Chapter 5);
- use of the computer models to determine peak discharges, water levels, depths, flow velocities and flood extents for a range of design events up to and including the PMF for existing topographic and development conditions (Chapter 6);
- use of the computer model results to generate flood hazard and hydraulic category mapping (Chapter 7);
- use of the computer model results to prepare flood emergency response classifications (Chapter 7);

- testing the sensitivity of the results generated by the computer model to variations in model input parameters (Chapter 8);
- testing the sensitivity of the results generated by the computer model to climate change (Chapter 9);

3 DATA COLLECTION AND REVIEW

3.1 Overview

A range of data were made available to assist with the preparation of the Cabravale Overland Flood Study. This included previous reports, hydrologic and hydraulic data, plans, survey information and GIS data.

A description of each dataset along with a synopsis of its relevance to the study is summarised below.

3.2 Previous Reports

3.2.1 Prospect Creek Floodplain Management Plan – Flood Study Review (2006)

The *'Prospect Creek Floodplain Management Plan - Flood Study Review'* was prepared by Bewsher Consulting for Fairfield City Council. The report was prepared as part of the *'Prospect Creek Floodplain Management Review 2010'* after a review of previous computer models of Prospect Creek showed some inconsistencies in modelling assumptions relative to other flood studies being completed across the Fairfield City Council LGA at the time.

The eastern portion of the Cabravale study area forms a subcatchment of the larger Prospect Creek catchment. As shown in **Figure 1**, Prospect Creek also flows through the Cabravale study area. As a result, elevated water levels in Prospect Creek can result in inundation of the Cabravale study area. In addition, if flooding along Prospect Creek occurs at the same time as flooding within the Cabravale subcatchment, it may prevent the local Cabravale drainage system from operating at full efficiency. Although mainstream flooding along Prospect Creek was not the focus of the current study, the impacts of coincidental flooding from Prospect Creek was considered to be an important component of this study.

Hydrology across the Prospect Creek catchment was defined as part of the study using an XP-RAFTS hydrologic model that was originally developed as part of the *"Review of Prospect Creek Flood Levels"* (Cardno Willing, 2004). However, the original model was updated to accommodate revised areal reduction factors, design rainfall information, rainfall losses and detention basin information. The updated model was verified against a January 2001 flood and was found to provide a reasonable reproduction of the historic peak discharges. The model was subsequently used to simulate a range of design floods and durations based upon the 1987 version of Australian Rainfall and Runoff. The results produced by the updated XP-RAFTS model are considered to provide the best broad-scale description of contemporary design flow hydrographs across the Prospect Creek catchment. However, the subcatchment delineation that forms the basis of the model is not considered to be detailed enough to reliably define the spatial variation in overland flows for those subcatchments falling within the Cabravale study area.

Flood hydraulics along Prospect Creek were defined using a TUFLOW model that was originally developed as part of the *"Review of Prospect Creek Flood Levels"* (Cardno Willing, 2004). However, the model was updated based on the outcomes of a review of the model completed by WBM Pty Ltd as part of the 2006 study. This included updates to culvert loss coefficients, channel cross-sections, 1d-2d connections as well as some topographic updates. The updated model was verified against historic flood mark information for the 2001 flood. The results of the verification showed that the TUFLOW model reproduced historic flood marks to within 0.05 metres (on average) and indicated that the model was providing a reasonable description of flood behaviour along Prospect Creek. Overall, this TUFLOW model is considered to provide the best contemporary description of flood hydraulics along Prospect Creek.

The updated XP-RAFTS and TUFLOW models that were developed as part of this previous study were provided by Council for use as part of the current study. These models were incorporated within the current study to define flood behaviour along that section of Prospect Creek extending through the Cabravale study area and determine the potential impact that coincidental flooding along Prospect Creek may have on flood behaviour across the Cabravale study area.

3.2.2 Cabramatta Creek Floodplain Management Study (1998)

The '*Cabramatta Creek Floodplain Management Study'* was prepared by the University of NSW Water Research Laboratory (WRL) in 1998. Although the full report was not provided by Council, several technical papers that were produced as part of this previous study were provided for the current study. The technical papers focussed on the flood modelling that was completed. The hydraulic model developed for the study used the RMA-2 software and utilised a "finite element" flexible mesh to define the hydraulic properties of the creek and floodplain. The model extended down Cabramatta Creek to the confluence with the Georges River. The model was calibrated and validated against the August 1986 and April 1988 events (estimated to be approximately 1% AEP floods). The 5% AEP, 2% AEP and 1% AEP design floods were also simulated using the RMA-2 model.

Cabramatta Creek forms the southern boundary for a significant proportion of the Cabravale study area. As discussed in the previous sections, coincidental flooding in the creeks could have an impact on flood behaviour across areas draining into the creek. Therefore, design flood information from the model could be used to assist in defining flood behaviour along the creek as part of the study. However, no model files from this study could be uncovered. Furthermore, it is considered that the models developed as part of this previous study have been superseded by the 'Cabramatta Creek Flood Study and Basin Strategy Review' (2011), which is discussed in more detail below. As a result, the information produced as part of this past study was of limited value for the current study.

3.2.3 Cabramatta Creek Flood Study and Basin Strategy Review (2011)

The *'Cabramatta Creek Flood Study and Basin Strategy Review'* was undertaken by Bewsher Consulting Pty Ltd for Liverpool City Council. The study area includes Cabramatta Creek down to its confluence with the Georges River and covers a significant proportion of the Cabravale study area, however, the focus was on mainstream flooding from Cabramatta Creek. That is, the study did not provide an assessment of local overland flood behaviour.

An XP-RAFTS hydrologic model and a TUFLOW hydraulic model were developed as part of the study. The models were calibrated against flood marks and flow hydrographs throughout the catchment for the August 1986 and April 1988 floods. The TUFLOW model was able to reproduce the recorded flood mark elevation to within 0.1 metres for the 1988 flood and 0.02 metre for the 1986 flood. The TUFLOW model was also compared to observed hydrographs at the "Orange Grove Road" gauging station, which is located within the Cabravale study area. For the 1988 design flood, the TUFLOW model under-represented flow at this gauge by about 10% but for the 1986 design flood it closely matched the peak flow.

The XP-RAFTS model was run for a variety of storm durations. It was found that the 2-hour storm was critical (i.e., produced the highest peak discharges) in the upper catchment and the 9 hour storm was critical in the lower catchment (this includes that section of Cabramatta Creek adjoining the Cabravale study area). An envelope of these two storm durations was used to present the results documented in the report.

The TUFLOW model utilised a 5 metre grid size that covers the entire floodplain of the creek. The representation of the drainage system is limited to drainage lines from detention basins, culverts under roads and selected trunk drainage lines (i.e., the local stormwater system is generally not represented in the model). The main creek system was represented as a 1-dimensional domain with the conveyance characteristics represented using surveyed channel cross-sections.

Flood levels in Cabramatta Creek can be affected by coincident flooding on the Georges River. Therefore, the study assumed that flooding along Cabramatta Creek will occur in conjunction with a similar magnitude flood on the Georges River. This assumption was based on observed flooding along both watercourses during the 1986 and 1988 floods. Therefore, tailwater conditions along the Georges River were applied as a constant water level.

Overall, the study estimates the absolute accuracy of the model to ±0.3 metres for flood levels. The model files for this study were provided and it is considered that these models provided the best available information for flooding along Cabramatta Creek. Therefore, they were extracted and used to define design flood behaviour along Cabramatta Creek in the more detailed flood model developed for the current study.

3.2.4 Georges River Floodplain Risk Management Study and Plan (2004)

The *'Georges River Floodplain Risk Management Study and Plan'* was undertaken by Bewsher Consulting Pty Ltd for Bankstown, Liverpool, Fairfield and Sutherland Shire Councils. The Georges River at Chipping Norton Lake forms part of the southern boundary of the Cabravale study area and flood conditions in the Georges River can impact on flood behaviour along the lower reaches of Cabramatta and Prospect Creeks.

Design flood levels were estimated as part of the study using a one-dimensional MIKE-11 hydraulic model of the Georges River. The model was calibrated against flood mark information for several historic floods (1956, 1978, 1986 and 1988). It was also verified against the results produced by a physical flood model that was previously developed for the mid-section of the river. The MIKE-11 model was found to produce results that were generally within 0.1 m of the physical flood model as well as the historic flood information.

The *'Georges River Floodplain Risk Management Study and Plan'* is over 13 years old, and the MIKE-11 model upon which it is based is considered to be dated relative to contemporary modelling technologies. Nevertheless, the results documented in this study are still considered to provide the best available design flood information for the Georges River.

3.2.5 Georges River and Prospect Creek Climate Change Sensitivity Assessment (2011)

The *'Georges River and Prospect Creek Climate Change Sensitivity Assessment'* was undertaken in 2011 by FloodMit for Fairfield City Council. The aim of the project was to determine the potential impacts that climate change may have on flood behaviour in the Fairfield City Council sections of Prospect Creek and the Georges River. The work was undertaken by using a "bath tub filling" approach on the tidal sections of the Georges River and Prospect Creek and running the existing Prospect Creek TUFLOW Model with changes to downstream tailwater conditions and increased rainfall intensity.

Apart from these boundary condition scenarios, no further modifications were completed to the existing XP-RAFTS and TUFLOW model that had been created for the *'Prospect Creek Floodplain Management Plan - Flood Study Review'* (Bewsher Consulting, 2006).

3.2.6 Fairfield City Overland Flood Study (2004)

The '*Fairfield City Overland Flood Study'* was undertaken by Sinclair Knight Merz (SKM) and Fairfield Consulting Services. The purpose of the study was to undertake a preliminary risk assessment to prioritise areas for further detailed overland flood studies. The study covers the entire Fairfield LGA, including the Cabravale study area.

The study made use of digital elevation data to identify potential overland flow paths (using flow direction and flow accumulation procedures within GIS) and then designated properties as flood affected by their proximity to the overland flow paths.

No hydrologic or hydraulic modelling was completed as part of the study. However, the XP-RAFTS model for Prospect Creek was used to establish a relationship between catchment area and flow. This relationship was used to estimate flows throughout the LGA and was combined with a Manning's calculation to estimate flood depths and velocities.

This methodology is considered appropriate to meet the objectives of the study. However, it is not sufficiently detailed to provide a reliable description of overland flow behaviour across the Cabravale study area. Nevertheless, the results generated as part of this previous study were used to verify the results generated by the flood models developed for the current study.

3.2.7 Overland Flood Studies

A range of overland flood studies have been prepared for priority subcatchments located across the Fairfield City Council LGA. This includes:

- Canley Corridor Overland Flood Study (SKM, 2009)
- Fairfield CBD Overland Flood Study (SKM, 2010)
- Old Guilford Overland Flood Study (SKM, 2010)
- Smithfield Overland Flood Study (SKM, 2011)
- Smithfield West Overland Flood Study (Catchment Simulation Solutions, 2014)

- Wetherill Park Overland Flood Study (Fairfield City Council, 2015)

It was considered important to maintain consistency with these previous studies wherever possible. Therefore, the above studies were reviewed and key features that were considered appropriate for application to the current study were identified. This included:

- The TUFLOW software was used to define overland flood behaviour. A 2 metre grid size was adopted to represent the spatial variation in hydraulic characteristics.
- The TUFLOW models were developed to include a representation of the stormwater system as a separate 1-dimensional domain inserted beneath the 2-dimensional domain. This approach allows for the representation of the conveyance of flows by the stormwater system below ground as well as simulation of overland flows in 2 dimensions once the capacity of the stormwater system is exceeded.
- For overland catchments draining into a receiving watercourse (e.g., Prospect Creek), it was assumed that floods of equivalent severity were occurring across the local overland catchment and receiving watercourse at the same time during all events up to and including the 1% AEP flood. A 1% AEP flood was retained in the receiving watercourse for all local catchment events greater than the 1% AEP event (e.g., PMF).
- A minimum depth threshold of 0.15 metres has typically been adopted to distinguish between areas of significant and negligible overland flooding. That is, areas subject to inundation depths of less than 0.15 metres were not mapped.

In general, the overland flood studies used the best available modelling approaches and technology that were available at the time each study was prepared. However, since these overland flood studies were prepared, computer modelling technology has evolved and improved approaches for representing urban overland flooding have been developed. In this regard, the following limitations were identified with the previous studies:

- Buildings were represented in the computer models as completely impervious flow obstructions whereby water is permitted to move around buildings, but not enter them. This approach does not account for the potential storage capacity provided within buildings. This is likely to result in conservative flood level estimates.
- The previous studies acknowledge that fences have the potential to obstruct overland flow. However, they were not explicitly represented in the modelling. The impediment to flow afforded by overland flow obstructions, such as fences, was indirectly represented by increasing the Manning's 'n' roughness value assigned to certain land uses. This approach is considered to provide a reasonable broad-scale description of overland flow behaviour but will likely fail to represent local variations in flood behaviour around specific urban flow obstructions.
- Separate hydrologic models were generally used to define rainfall-runoff processes with flow hydrographs applied to "critical" stormwater pits. This approach may underestimate the capacity of the stormwater system as runoff is not progressively "fed" into upstream stormwater pits and it may fail to represent the path of overland flow travelling to the critical pits. Advancements in the TUFLOW software allow application of rainfall directly to the TUFLOW grid avoiding the need for a separate hydrologic model and avoiding some of the limitations associated with application of flows at discreet locations.

It was considered important for the current study to use the best available approaches and technology to represent overland flood behaviour. Further information detailing how the TUFLOW model that was developed for this study overcame the limitations outlined above is provided in section 4.2.

3.3 Hydrologic Data

3.3.1 Rain Gauge Data

A number of daily and continuous rainfall gauges are located in the vicinity of the study area. The location of each gauge is shown in **Figure 2**. Key information for each gauge is summarised in **Table 1**.

As shown in **Figure 2**, there is one continuous Sydney Water rainfall gauge located within the study area (Gauge #567154 Cabramatta Bowling Club). Furthermore, the information provided in **Table 1** shows that there are 14 active rainfall stations within 10 km of the catchment centroid, of which, 9 are continuous gauges. However, the closest 5 gauges are no longer in operation. Nevertheless, there is still a good spatial and temporal distribution of rainfall gauges to describe historic rainfall events.

3.3.2 Stream Gauge Data

Several stream gauges are located in the immediate vicinity of the study area including gauges on Cabramatta, Prospect and Orphan School Creeks as well as the Georges River. The location of each gauge is shown in **Figure 2** and key information for each gage is summarised in **Table 2**.

Although there are two stream gauges located within the study area, they are located on Cabramatta Creek and Prospect Creek, which are not the focus of the current overland flood study. Nevertheless, they can be used to assist in identifying when significant mainstream floods have occurred along these major watercourse and for defining the time variation in water levels along both creek, which assisted in setting boundary conditions for the flood model as part of the calibration process.

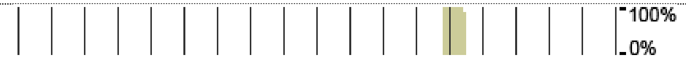
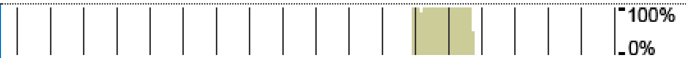
3.4 Topographic and Survey Information

3.4.1 Light Detection and Ranging (LiDAR) Survey

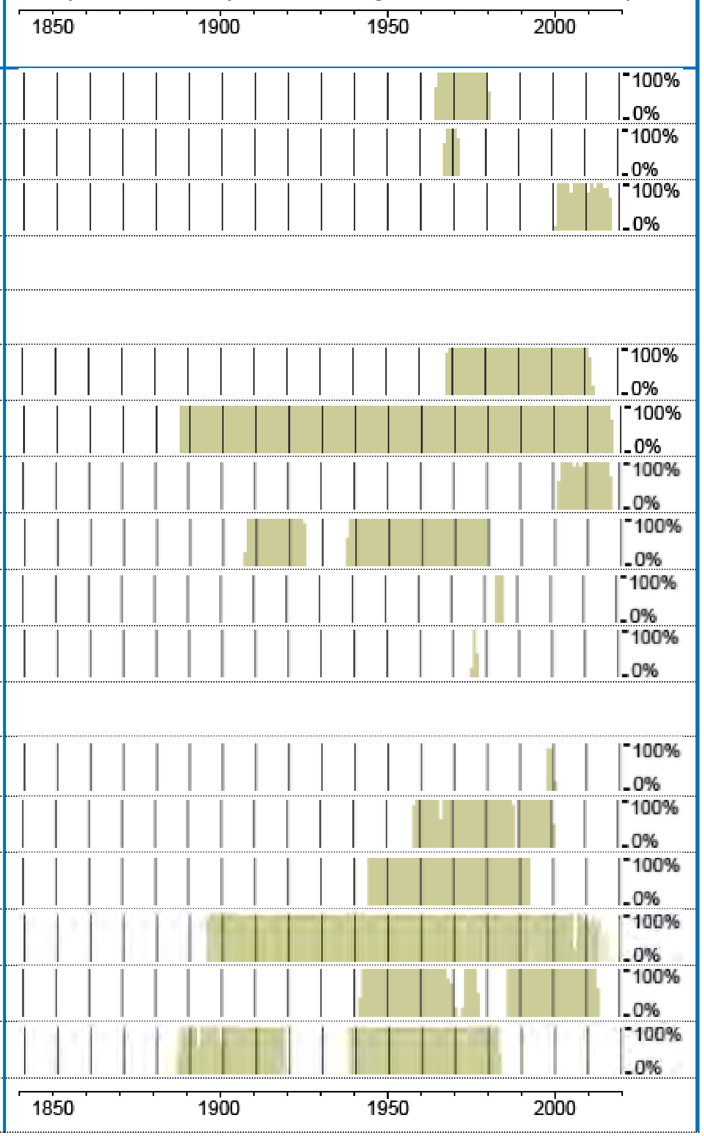
LiDAR data was collected across Sydney in June 2013 by the NSW Government's Land and Property Information Department. This included the full extent of the Cabravale study area. The LiDAR has a stated absolute horizontal accuracy of better than 0.8 metres and an absolute vertical accuracy of better than 0.3 metres and provides a stated minimum point density of one laser pulse per square metre.

A review of recent (i.e., 2015) and 2013 aerial imagery indicates negligible large-scale developments have occurred across the catchment since the LiDAR was collected. Therefore, the LiDAR data is considered to provide a reliable representation of the variation in ground surface elevations across the catchment.

Table 1 Available rain gauges in the vicinity of Cabravale

Gauge Number	Gauge Name	Gauge Type	Source*	Start of Records	End of Records	Distance from Catchment (km)	Temporal Availability and Percentage of Annual Record Complete 1850 1900 1950 2000
567154	Cabramatta Bowling Club	Continuous	Sydney Water	Jan 1992	Sep 2017	0.41	
67006	Fairfield MWSDB	Continuous	BOM	Jan 1961	Dec 1973	0.64	
567077	Fairfield STP	Continuous	Sydney Water	Jan 1990	Sep 2017	2.02	
67072	Fairfield Heights Post Office	Daily	BOM	Jan 1968	Jan 1975	2.22	
67091	Cabramatta	Daily	BOM	Mar 1945	Aug 1967	2.59	
66025	Liverpool Treatment Works	Daily	BOM	Jan 1947	Oct 1990	3.65	
566054	Liverpool Weir U/S Georges River	Operational	BOM	Sep 1994	Aug 2000	4.78	
67008	Guildford	Daily	BOM	Jan 1958	Jan 1977	4.90	
67035	Liverpool (Whitlam Centre)	Synop	BOM	Jun 1962	Sep 2001	4.99	
567064	Merrylands West (Finlayson Ck)	Operational	BOM	Aug 1999		5.64	
566060	Guildford (Woodville Golf Club)	Operational	BOM	Aug 1999		5.76	
66137	Bankstown Airport AWS	Continuous	BOM	Apr 1968	Jun 1992	5.83	
66121	Chester Hill	Daily	BOM	Apr 1964	Dec 1976	5.93	
67020	Liverpool (Michael Wenden Centre)	Daily	BOM	Sep 2001		6.02	
66168	Milperra Br (Georges River)	Operational	BOM	May 1999		6.40	
568129	Waterfall (Garrawarra Hospital)	Daily	SW	Aug 1907		6.86	
66154	Holsworthy Air Cavalry	Daily	BOM	Jan 1970	Dec 1974	7.15	
							1850 1900 1950 2000

Gauge Number	Gauge Name	Gauge Type	Source*	Start of Records	End of Records	Distance from Catchment (km)	Temporal Availability and Percentage of Annual Record Complete
66171	Moorebark N.B.Golf Club	Daily	BOM	Apr 1964	Dec 1980	7.15	
67069	Miller	Daily	BOM	Apr 1967	Dec 1971	7.23	
67114	Fairfield City Farm	Operational	BOM	Jan 1999		7.27	
567083	Prospect Reservoir	Continuous	SCA			7.46	
566059	Auburn (Rosnay Golf Club)	Operational	BOM	Aug 1999		7.60	
67070	Merrylands (Welsford Street)	Daily	BOM	Feb 1968		7.62	
67019	Prospect Dam	Synop	BOM			7.77	
67017	Greystanes (Bathurst Street)	Daily	BOM	May 2001		8.1	
66003	Bankstown (Condell Park)	Daily	BOM	Jan 1906	Jan 1979	8.18	
67097	Prestons Bernera Rd	Daily	BOM	Jan 1983	Jan 1985	8.24	
66169	Villawood Archives	Daily	BOM	Oct 1975	Dec 1977	8.37	
566093	Engadine Bowling Club	Continuous	SW	Nov 1991	Feb 2001	8.72	
67120	Ranieri Place	Daily	BOM	Feb 1998	Nov 2001	9.00	
66085	Granville Rsl Bowling Club	Daily	BOM	Feb 1958	Sep 2000	9.05	
67032	Westmead Austral Avenue	Daily	BOM	Jan 1944	Jan 1992	9.13	
66050	Potts Hill Reservoir	Daily	BOM		Jan 2006	9.15	
66054	Revesby (Paten Street)	Daily	BOM	Aug 1941		9.38	
67009	Macquarie	Daily	BOM		Dec 1983	9.49	



Gauge Number	Gauge Name	Gauge Type	Source*	Start of Records	End of Records	Distance from Catchment (km)	Temporal Availability and Percentage of Annual Record Complete 1850 1900 1950 2000
566064	Lidcombe (Carnarvon Golf Club)	Operational	BOM	Aug 1999		9.53	
568189	Helensburgh Post Office and Bowling Club Composite	Continuous	SW	Dec 1992		9.64	
566094	Lucas Heights Reservoir	Continuous	SW	Nov 1991		9.74	
							1850 1900 1950 2000

NOTE: * BOM = Bureau of Meteorology, SW = Sydney Water, SCA = Sydney Catchment Authority

Table 2 Available stream gauges in the vicinity of Cabravale

Gauge Number	Gauge Name	Stream Name	Start of Records	End of Records	Located with study area?
213014	Sackville Road	Orphan School Creek	Jan 1987		Upstream of the study area
213401	Lansvale – Cutler Road	Georges River	May 1997		On the study area boundary
213011	Orange Grove Road	Cabramatta Creek	Jan 1986		Within the study area
213009	Smithfield Rd	Prospect Creek	Jan 1986		Upstream of the study area
213402	Lansdowne Bridge	Prospect Creek	N/A	N/A	Within the study area

The LiDAR information was used as a basis for developing a Digital Elevation Model (DEM) of the study area. The DEM that was developed is provided in **Figure 3** and shows the variation in ground elevations. It shows that ground surface elevations across the study area varies between 0 mAHD in the vicinity of the Georges River, Prospect Creek and Cabramatta Creek to well over 50 mAHD around Mount Pritchard. The area adjoining the lower sections of Prospect Creek and the Georges River are particularly low-lying.

The LiDAR generally provides a good representation of the variation in ground surface elevations across the study area. However, these aerial survey techniques can provide a less reliable representation of the terrain in areas of high vegetation density. This is associated with the laser ground strikes often being restricted by the vegetation canopy. Errors can also arise if non-ground elevation points (e.g., vegetation canopy, buildings) are not correctly removed from the raw dataset. Therefore, a review of the raw LiDAR data points was completed.

Plate 1 provides an example of the LiDAR points along a section of Long Creek. It shows that there are negligible points overlaying buildings indicating that building roof elevations have been removed from the raw data. It also shows a significant point density across areas of open space (e.g., grass and roads), but reduced point density in areas of more significant vegetation density. This is likely associated with some LiDAR laser strikes hitting the vegetation canopy and subsequently being removed from the ground data points.

Overall, it appears that non-ground data points have been successfully removed from the LiDAR datasets. However, this does mean that less topographic information is available in areas of significant vegetation density. This includes major conveyance areas such as Long and Prout Creeks. Therefore, it was considered necessary to gather additional survey along these creeks to ensure the conveyance characteristics could be reliably defined. Further details on the cross-section survey is provided in Section 3.8.1.

It was also recognised that the LiDAR data will not pick up the details of drainage features that are obscured from aerial survey techniques, such as bridge and culvert dimensions. Therefore, it was also necessary to undertake additional survey of hydraulic structures. Further details on the hydraulic structure survey is provided in Section 3.8.1.

3.4.2 Stormwater Survey

Bankstown City Council completed a survey of major (i.e., generally 900mm diameter and above) stormwater pipes across large sections of the Fairfield City Council LGA in 2010. This includes part of the Cabravale study area. The extent of the surveyed stormwater pits and pipes is shown in **Figure 4**.

Plate 1 Example of LiDAR data point density in the vicinity of Long Creek

The survey provides the alignment and size of major pipes along with the location and details of selected stormwater pits (e.g., pit type, lintel length and pit invert depth). This provided detailed information on 528 stormwater pits and 492 stormwater pipes which was sufficient for describing the capacity of these parts of the stormwater system in the flood model. However, it is noted that this dataset does not pick up the details of all stormwater pits and pipes in the study area. Therefore, it was necessary to supplement the survey data with GIS information, which is discussed in more detail below.

3.5 Geographic Information System (GIS) Data

A number of Geographic Information System (GIS) layers were also provided by Fairfield City Council to assist with the study. This included:

- Aerial Photography – provides ortho-rectified aerial imagery collected in 2015.
- Cadastre – provides property boundary polygons
- Roads – provides road centreline alignments and road name;
- Rivers – provide the alignment and names of major streams;
- Local Environmental Plan (LEP) – provides zoning / land use information;
- Pipes – provides the alignment and size of stormwater pipes;
- Pits – provides locations of stormwater pits/inlets;

The majority of the above layers served as a basis for preparing the various figures displaying the study results (most notably the aerial photography and cadastre). In this regard, the layers are considered fit for purpose.

As discussed in the previous section, detailed survey information was not available for all stormwater pits and pipes in the study area. Therefore, a detailed review of the stormwater GIS layers was completed to confirm if they could be used to supplement the survey information.

The extent of the stormwater GIS layers are shown in **Figure 4**. The review of these GIS layers determined that there are 1,702 pipes and 1,439 pits located within the study area. As discussed in Section 3.4.2, detailed survey information is available for 528 stormwater pits and 492 stormwater pipes. Therefore, there are 1,210 pipes and 911 pits where no survey information is available and a reliance on the GIS layers was required (it was considered prohibitively expensive and time consuming to survey all of the pits and pipes).

In general, the stormwater GIS layers provide sufficient information for describing the conveyance of the pipe system. This, most importantly, includes stormwater pipe size information. Pit depths were also available, allowing the pit invert elevations to be estimated from the LiDAR. However, there was no information describing the pit inlet capacity (i.e., no information on grate sizes and/or lintel lengths).

The review also determined that the GIS information did not always provide a reliable description of the pit locations. For example, **Plate 2** shows the stormwater GIS layers (red) superimposed on the 2015 aerial imagery. It shows that the stormwater pits in this area are located a significant distance from the “correct” location and are generally not located along gutters (more often they are located on the more elevated “nature strips”). Therefore, manual relocation of stormwater pits was completed by hand to better align with the aerial imagery.

The surveyed stormwater and GIS stormwater layers were subsequently combined to form a complete representation of the stormwater system across Cabravale. A review of the combined layer was completed to determine if all stormwater pits and pipes within the study area were identified in this combined dataset. This review determined that the majority of the stormwater system was included in the combined dataset. However, there were five areas where stormwater pits and/or pipes appeared to be missing from the dataset. The location of each of these areas is shown in **Figure 4** and an example of the missing data is provided in **Plate 3**.

Accordingly, it was evident that not all sections of the stormwater system were included in the available stormwater datasets. Therefore, it was considered necessary to collect additional information describing the stormwater system across the “missing” areas. Further information on the additional stormwater information that was collected as part of the study is provided in Section 3.8.2.

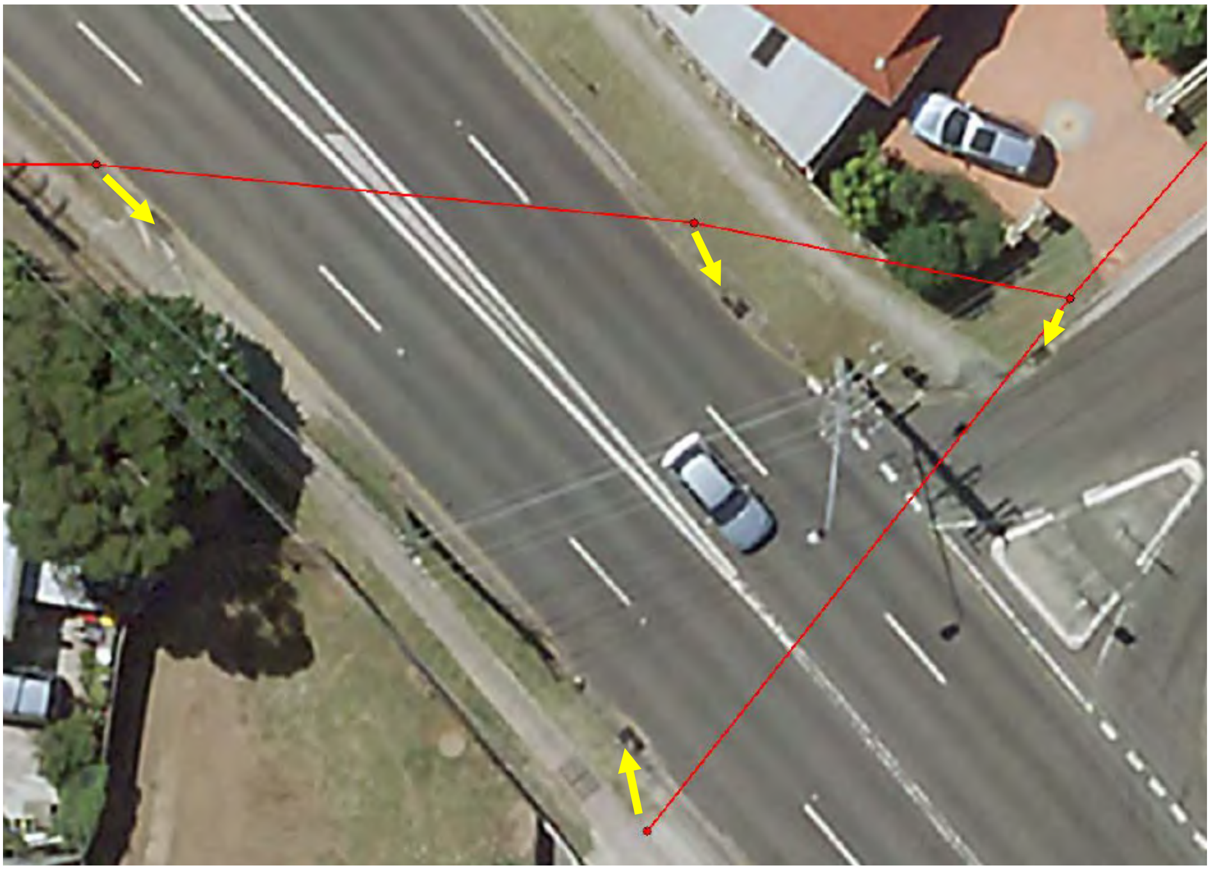


Plate 2 Example of Drainage Network Spatial Error

Plate 3 Example of stormwater pits (and pipes) that are missing from GIS and survey stormwater layers

3.6 Remote Sensing

In addition to providing ground point elevations, the 2013 LiDAR also provides basic point type classifications (e.g., ground, building, vegetation) as well as other information including point intensity and multiple return information. This information can be used with aerial photography to identify different land uses across the catchment. This, in turn, can be used to assist in defining the spatial variation in different land uses across the catchment which can inform Manning's 'n' roughness coefficients and rainfall losses in the computer flood model.

This technique of land use classification was based on research documented in a paper prepared by Ryan titled *'Using LiDAR Survey for Land Use Classification'* (2013) and was applied based upon the 2013 LiDAR and 2015 aerial imagery. The classification algorithm divided the study area into the following land use classifications:

- Buildings
- Water
- Trees
- Grass
- Concrete
- Roads

It should be noted that perfect accuracy cannot be expected from any automated classification, particularly when the LiDAR and aerial imagery date from different periods (i.e., 2013 & 2015). Errors can also arise due to shadowing effects. As a result, manual updates to the remote sensing outputs were completed to ensure a reliable representation of the spatial variation in land use was provided across the study area.

The final remote sensing output is shown in **Figure 5**.

3.7 Engineering Plans

Engineering plans were also provided by Council for drainage amplification works around Mitchell St and The Horsely Drive. The plans provided design details for upgraded stormwater pits and pipes that were installed as part of road upgrade works in the area.

The stormwater drainage information (i.e., stormwater pits and pipes) contained in the plans was extracted and incorporated in the stormwater GIS database for the catchment.

3.8 Survey

3.8.1 Cross-Sections and Structures

To enable development of a hydraulic model capable of providing reliable estimates of flood behaviour within the study area it was necessary to collect additional survey information across the Cabravale area. Fairfield City Council surveyors collected the survey information.

The additional data collection comprised the survey of 36 creek cross-sections and 8 hydraulic structures (i.e., culverts and bridges). The location of cross-sections and structures that were surveyed is shown in **Figure 6**.

3.8.2 Stormwater

As discussed in Section 3.5, a review of the available stormwater datasets determined that not all stormwater pits and pipes were represented. Therefore, Fairfield City Council staff collected additional information for a selection of missing pits and pipes that would allow a fully "connected" representation of the stormwater system to be provided.

The location of the stormwater pits where the additional data collection was completed is shown in **Figure 6**. The following information was collected at each location:

- Pipe diameters
- Pit invert depths (when combined with LiDAR information, this could be used to establish the pit invert elevation)
- Pit inlet characteristics (i.e., grate sizes and lintel lengths).

When this information was combined with the stormwater GIS and previously surveyed stormwater layers, it provided a more complete and connected representation of the stormwater system.

It was noted that not all stormwater pits could be accessed by Council staff. This was primarily associated with stormwater pits being blocked by debris and, therefore, being inaccessible to Council staff. This was primarily concentrated around the Tomki St and Barkley St areas of Carramar. Therefore, a reduced level of accuracy is available for the stormwater system in this area.

3.9 Community Consultation

3.9.1 General

A key component of the flood study involved development of a computer flood model. The computer model is typically calibrated to ensure it is providing a reliable representation of flood behaviour. This is completed by using the model to replicate floods that have occurred in the past (i.e., historic floods).

Although some historic flood information could be sourced from the previous flood investigations, additional information on past flooding was sought from the community to assist with the model calibration. Therefore, several community consultation devices were developed to inform the community about the study and to obtain information from the community about their past flooding experiences. Further information on each of these consultation devices is provided below.

3.9.2 Flood Study Website

A flood study website was established for the duration of the study. The website address is: https://cabravale.floodstudy.com.au/.

The website was developed to provide the community with detailed information about the study and also provide a chance for the community to ask questions and complete an online questionnaire (this online questionnaire was identical to the questionnaire distributed to residents and business owners, as discussed below).

During the course of the study, the website was visited 68 times by 25 unique users.

3.9.3 Community Information Brochure and Questionnaire

A community information brochure and questionnaire were prepared and distributed to all potentially flood affected residential and business properties in the catchment. This was based upon identifying all properties located with a preliminary 1% AEP flood extent and resulted in brochures and questionnaires being distributed to 2,527addresses. A copy of the brochure and questionnaire is included in **Appendix A**.

The questionnaire sought information from the community regarding whether they had experienced flooding, the nature of flood behaviour, if roads and houses were inundated and whether residents could identify any historic flood marks. A total of 86 questionnaire responses were received. A summary of all questionnaire responses is provided in **Appendix A**. The spatial distribution of questionnaire respondents is shown in **Figure A1**, which is also enclosed in **Appendix A**.

The responses to the questionnaire indicate that:

- The majority of respondents have lived in or around the catchment for about 30 years.
- 39% of respondents have experienced inundation or disruption as a result of flooding in the study area. This includes (also refer **Plate 4** and **Plate 5**):
    - 9 respondents have experienced traffic disruptions
    - 12 respondents have had their front or back yard inundated
    - 7 respondents have had their garage inundated, and
    - 2 respondents have had their house or business inundated above floor level.

  The spatial distribution of respondents that have reported past flooding problems is shown in **Figure A1** in **Appendix A** (refer red dots).
- Flooding problems were reported in the following streets:
    - Albert St, Cabramatta
    - Booyong St, Cabramatta (reported in multiple questionnaire responses)
    - Broomfield St, Cabramatta
    - Chadderton St, Cabramatta
    - Kauri St, Cabramatta
    - Longfield St, Cabramatta (reported in multiple questionnaire responses)
    - Roebuck St, Cabramatta
    - Premier St, Cabramatta
    - Stonehaven Pde, Cabramatta
    - Waterside Cres, Cabramatta
    - Chancery St, Canley Vale
    - Vale St, Canley Vale (reported in multiple questionnaire responses)
    - Cummings Cres, Lansvale
    - Georges River Rd, Lansvale
    - Reservoir Rd, Mount Pritchard

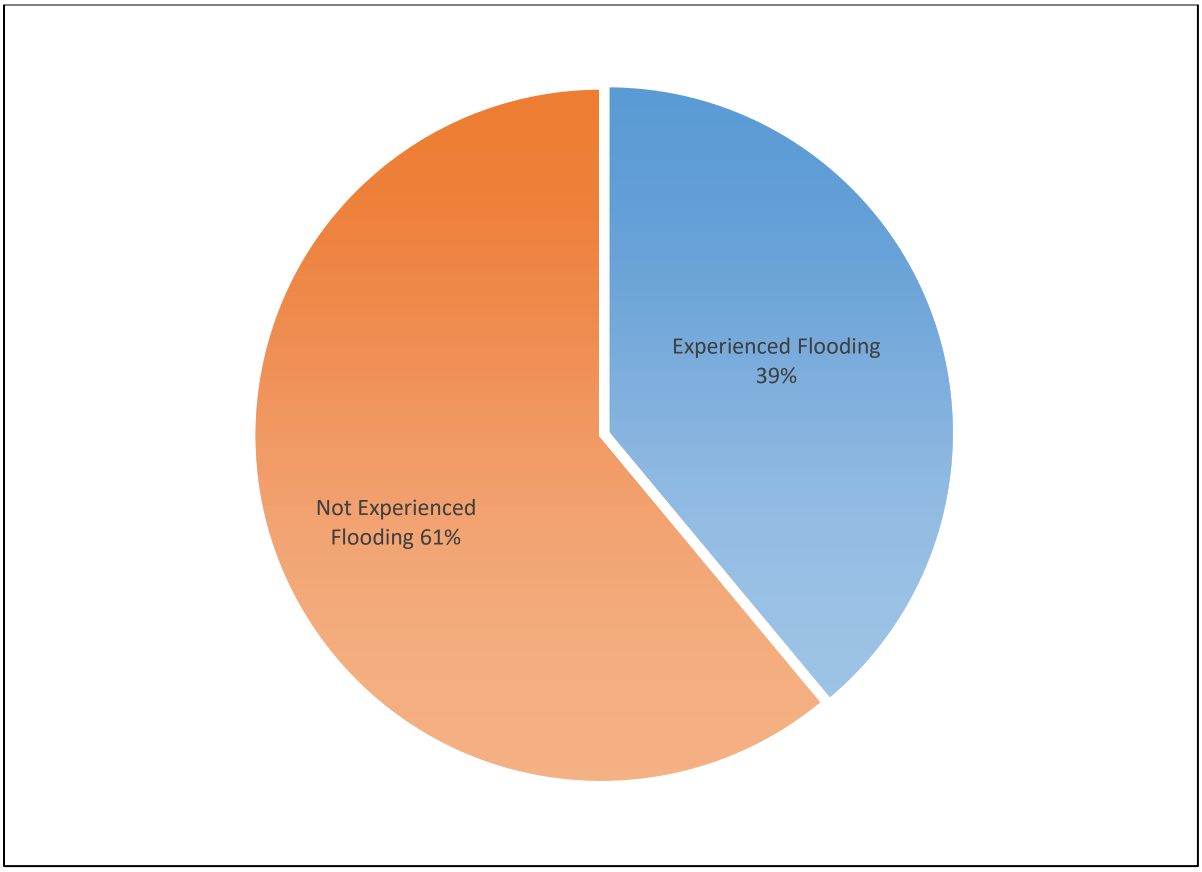


Plate 4 Number of Questionnaire Respondents Impacted by Past Floods

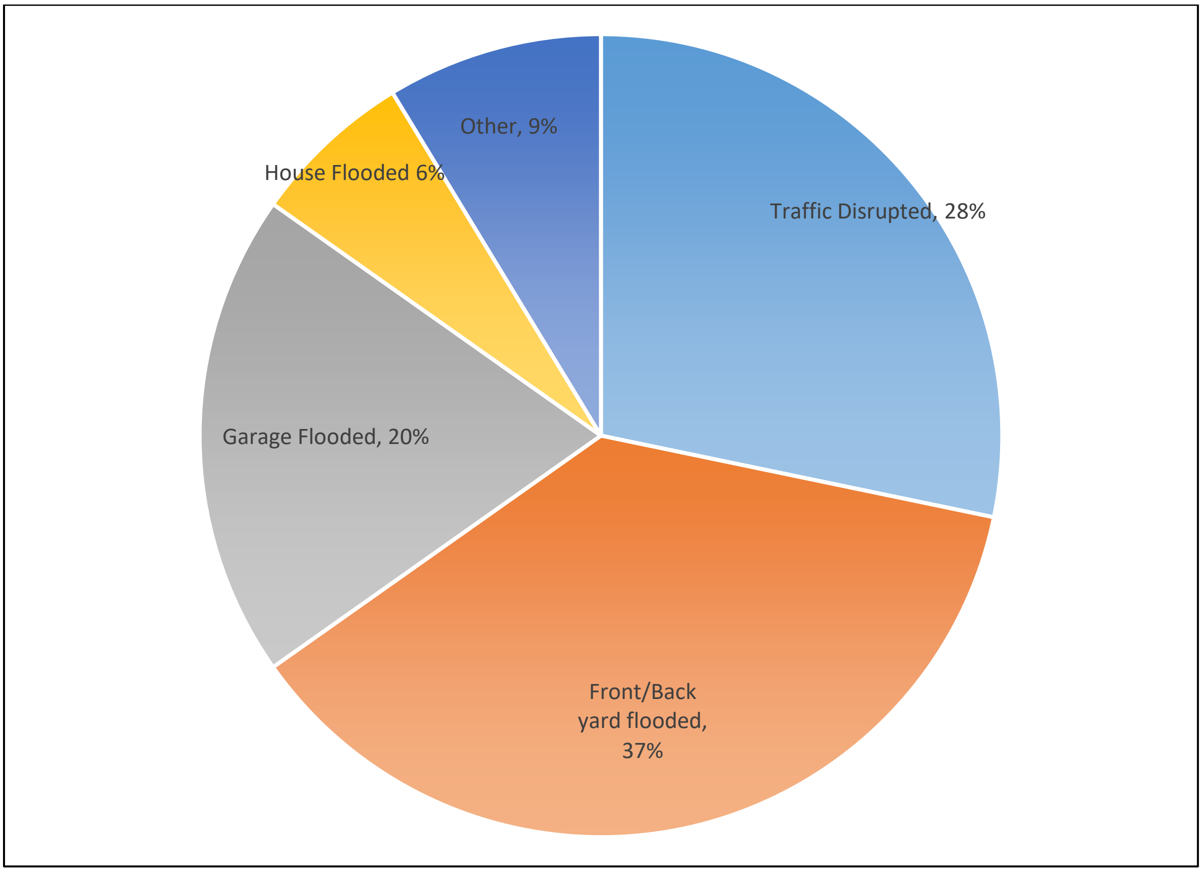


Plate 5 Type of Flood Impact Reported by Questionnaire Respondents

  - Matheson Ave, Mount Pritchard
  - O'Shannesy St, Mount Pritchard
  - Matheson Ave, Mount Pritchard
  - Curring Rd, Villawood
  - Koonoona Ave, Villawood (reported in multiple questionnaire responses)
- A number of respondents believe inundation in the catchment is exacerbated by:
  - Limited capacity of the exiting stormwater system
  - Blockage of the creek, stormwater inlets and/or drains (e.g., illegal dumping)
  - Overland flow obstructions (e.g., fences, buildings)
  - Elevated water levels in the creek system preventing water from draining through stormwater system
- One respondent noted that flooding can often be coupled with sewer overflows, posing a health risk during and after the flood.

Several residents also provided photos of past floods in the study area. These photographs are provided in **Plate 6** to **8**. The photos generally show shallow depths of water across front and back yards. However, there are instances where floodwater depths appear to exceed ~0.2metres.

Plate 6 Inundation across property at 16 Vale Street, Canley Vale in 1988

Plate 7 Inundation across front yard of property at 30 Booyong Street, Cabramatta on unknown date

Plate 8 Shallow inundation across front yard of 20 Premier Street, Canley Vale on unknown date

Plate 9 Shallow inundation across front yard of 20 Premier Street, Canley Vale on unknown date

3.9.4 Public Exhibition

The draft 'Cabravale Overland Flood Study' was placed on Public Exhibition from the 20 October 2021 until 18 November 2022. A copy of the draft report was made available for review on Council's website and all residents within the 'Low Risk Precinct' area were notified in writing advertising the public exhibition.

A total of forty (40) submissions were received during the public exhibition period. A summary of all submissions that were received is provided in **Appendix J**.

Each submission was reviewed to determine if modifications to the draft report and/or figures were required to address each submission. **Appendix J** summarises the responses/actions that were taken to address each submission.

Overall, no modifications to the draft report were required to address the submissions received. However, some updates to the flood risk precinct mapping (**Figure 33**) were completed and this is reflected in Volume 2.

4 COMPUTER FLOOD MODEL

4.1 General

Computer models are the most common method of simulating flood behaviour through a particular area of interest. They can be used to represent the conversion of rainfall into runoff and simulate the movement of that runoff throughout the catchment.

Historically, separate computer models were developed to represent the rainfall-runoff processes (referred to as a hydrologic model) and the movement of floodwaters across the catchment (referred to as a hydraulic model). However, recent advancements in modelling software as well as computer processing power have allowed for the hydrologic and hydraulic processes to be represented in a single model (referred to as a “direct rainfall” computer model).

The TUFLOW software was used to develop a “direct rainfall” computer model of the Cabravale catchment. TUFLOW is a fully dynamic, 1D/2D finite difference model developed by BMT WBM (2016). It is used extensively across Australia to assist in defining flood behaviour.

The following sections describe the model development process. The outcomes of the calibration of the model are described in Chapter 5.

4.2 Model Development

4.2.1 Model Extent

A 2-dimensional computer model of the Cabravale catchment was developed using the TUFLOW software (version 2016-04-AD). The extent of the model area is shown in **Figure 7**. As discussed, the southern sections of the catchment drain into Cabramatta Creek, and the northern and eastern sections of the catchment drain into Prospect Creek. Therefore, the TUFLOW model incorporates both Cabramatta Creek and Prospect Creek and their adjoining floodplain to ensure the interaction between local catchment flows and flows along Cabramatta and Prospect Creeks were represented.

Cabramatta Creek and Prospect Creek drain into the Georges River, which forms the very downstream boundary of the study area. The Georges River was not included in the model domain. However, flooding from the Georges River can be represented in the model by defining a suitable downstream stage (i.e., water level) hydrograph.

4.2.2 Grid Size

The TUFLOW software uses a grid to define the spatial variation in topography and hydrologic/hydraulic properties (e.g., Manning’s ‘n’ roughness, rainfall losses) across the study area. Accordingly, the choice of grid size can have a significant impact on the performance of the model. In general, a smaller grid size will provide a more detailed and reliable representation of flood behaviour relative to a larger grid size. However, a smaller grid size will take longer to perform all of the necessary hydraulic calculations. Therefore, it is typically necessary to select a grid size that makes an appropriate compromise between the level of detail provided by the model and the associated computational time required. A grid size of 2 metres was adopted and is considered to provide a reasonable compromise between detail and simulation time.

Elevations were assigned to grid cells within the TUFLOW model based on the Digital Elevation Model derived from LiDAR data and ground survey for areas not accurately defined by LIDAR.

4.2.3 1D Domain

Creeks

A dynamically linked 1-dimensional (1D) network was embedded within the 2D domain to represent major conveyance areas that would not be well represented using the 2-metre grid size. This included the Long Creek and Prout Creek channels. The culverts and bridge crossings along these waterways were also represented as part of the 1D network. The flow carrying capacity of Long Creek and the Prout Creek channels were defined using the surveyed cross-sections gathered by Council (refer Section 3.8.1).

Prospect Creek as well as Orphan School Creek and Burns Creek were included in the TUFLOW model domain. The conveyance characteristics for each of these watercourses was defined using cross-section information extracted from the TUFLOW model prepared for the *'*Prospect Creek Floodplain Management Plan - Flood Study Review*'* (Bewsher Consulting, 2006).

Similarly, Cabramatta Creek was also included as an additional 1D domain embedded within the 2D domain. The creek conveyance characteristics were defined using cross-section information extracted from the TUFLOW model prepared for the *'Cabramatta Creek Flood Study and Basin Strategy Review'* (Bewsher Consulting, 2011).

The extent of the 1D domains are shown in **Figure 7**.

Stormwater System

The stormwater system has the potential to convey a significant proportion of runoff across the study area during relatively frequent rainfall events. Therefore, it was considered important to incorporate the conveyance provided by the stormwater system in the TUFLOW model to ensure the interaction between piped stormwater and overland flows was represented.

The stormwater system was included within the TUFLOW models as a dynamically linked 1-Dimensional (1D) network. This allowed representation of the conveyance of flows by the stormwater system below ground as well as simulation of overland flows in two dimensions once the capacity of the stormwater system is exceeded.

Data from the Bankstown City Council stormwater survey was used to define the characteristics of the major trunk stormwater system. This was supplemented with additional pit survey collected by Council specifically for the study. Further information on both stormwater datasets is provided in Section 3.4.2 and 3.8.2.

The remaining stormwater pits and pipes were defined based upon information contained in Council's stormwater asset GIS layers.

Any missing pit and pipe GIS information was estimated to ensure all required information describing the stormwater system was represented. The missing pipe information was estimated using the following approach:

- Where pipe diameter information was not available, the diameter was interpolated based upon inspection of the upstream and downstream pipe diameters
- Where pit/pipe locations did not agree / connect with surveyed data, the pits and pipes were manually adjusted.

Stormwater inlet capacity curves were also prepared to define the pit inflow capacity with respect to water depth at each pit location. The 'Drains Generic Pit Spreadsheet' (Watercom Pty Ltd, July 2005), was used to develop the inlet capacity curves. The inlet capacity curves were developed to take account of:

- The different pit inlet types (e.g., sag inlets, grated inlets, kerb inlets, combination inlets); and,
- The different pit dimensions and lintel sizes.

A copy of the inlet capacity curves are provided in **Appendix C**. The extent of the stormwater system included within the TUFLOW model is shown in **Figure 7**.

4.2.4 Material Types

The TUFLOW software employs material polygons to define the variation in hydrologic (i.e., rainfall losses) and hydraulic (i.e., Manning's 'n') properties across the study area. The material polygons for this study were defined based upon the remote sensing outputs previously described in Section 3.6 and shown in **Figure 5**.

As shown in **Figure 5**, the study area was subdivided into six different material types:

- Buildings
- Water
- Trees
- Grass
- Roads
- Concrete.

4.2.5 Manning's "n" Roughness Coefficients

Manning's "n" is an empirically derived coefficient that is used to define the resistance to flow (i.e., roughness) afforded by different material types / land uses. It is one of the key input parameters used in the development of any computer flood model.

Manning's "n" values are dependent on a number of factors including vegetation type/density, topographic irregularities and flow obstructions. All of these factors are typically aggregated into a single Manning's 'n' value for each material type and representative Manning's "n" values for different materials can be obtained from literature (e.g., Chow, 1959). However, the Manning's "n" values found in literature are only valid when the flow depth is large relative to the material/vegetation height and the material is rigid.

When using a "direct rainfall" computer model, the depth of flow across much of the study area will be shallow (often referred to as "sheet" flow). In such instances, the depth of flow can be equal to or less than the height of the vegetation and the vegetation is not necessarily rigid (e.g., grass can bend under the force of flowing water). Accordingly, Manning's "n" values obtained from literature are generally no longer valid for shallow flow depths.

Research completed by McCarten (2011) and others (e.g., Engineers Australia, 2012) indicates that Manning's "n" values will not be "static" but will vary with flow regime/depth. Specifically, the research indicates that Manning's' "n" values will typically decrease with increasing flow depths. This is associated with the resistance to flow at higher depths being driven by bed resistance only, while at shallow depths, the resistance is driven by vegetation/stem drag as well as bed resistance (i.e., the "effective" roughness is higher at shallow depths).

In an effort to represent the depth dependence of Manning's "n" values in the TUFLOW model, flow depth versus Manning's "n" relationships were developed for each material type. The relationships were developed using the modified Cowan method, which is documented in the USGS water supply paper 2339 titled 'Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The modified Cowan method was selected as it allows the Manning's "n" values to be calculated based on the depth of the flow relative to the vegetation/obstruction height. The Manning's "n" calculations are included in **Appendix B** and the final Manning's "n" values for each material type at each depth are summarised in **Table 4**.

Table 3 Manning's 'n' Roughness Values

Material Description	Depth Varying Manning's 'n' Values							
	$Depth_1$ *(metres)*	**n_1**	**$Depth_2$** *(metres)*	**n_2**	**$Depth_3$** *(metres)*	**n_3**	**$Depth_4$** *(metres)*	**n_4**
Grass	<0.03	0.110	0.05	0.075	0.07	0.055	>0.10	0.030
Trees	<0.30	0.160	1.50	0.110	>2.00	0.080		
Roads	<0.04	0.017	0.10	0.021	>0.15	0.020		
Concrete	<0.005	0.034	>0.005	0.015				
Buildings	<0.03	0.030	>1.0	1.000				

4.2.6 Building Representation

The Cabravale catchment is highly urbanised. The high level of urbanisation across the study area creates many overland flow obstructions. One of the most significant impediments to overland flow in urban environments is buildings. Available research indicates that buildings have a considerable influence on flow behaviour in urban environments by significantly deflecting flows (Smith et al, 2012). Accordingly, it was considered necessary to include a representation of the buildings in the computer model.

The lower part (i.e., the area between the ground surface and the floor level) of each building located within major overland flow paths was represented as a complete flow obstruction. This is shown conceptually in **Plate 10**. This was implemented by elevating all TUFLOW elevations contained within the building footprint to the floor level of the building. For this study, it was assumed that the floor level of each building was 300 mm above ground level.

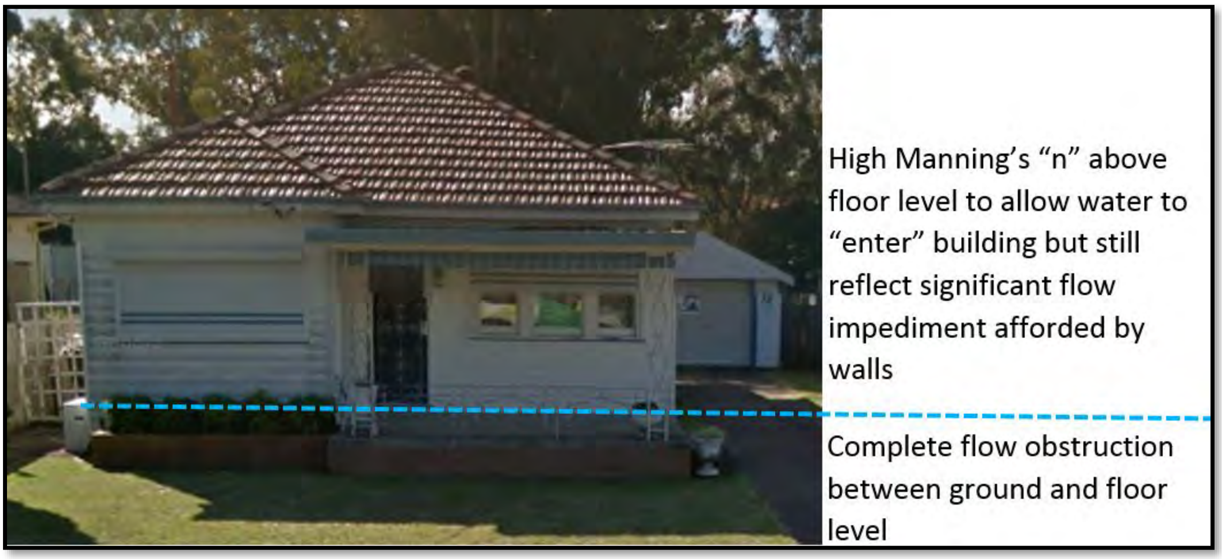


Plate 10 Conceptual representation of buildings in TUFLOW model

Once the water level exceeded the floor level of each building, it was allowed to "enter" the building. However, a high Manning's "n" value of 1.0 was adopted to reflect the significant impediment to flow afforded by the many flow obstructions contained with a typical house (e.g., walls, furniture etc). This is also shown conceptually in **Plate 10**.

4.2.7 Fences

Fences can also provide a significant impediment to flow in urbanised catchments. Therefore, it was also considered important to include a representation of fences within the TUFLOW model. Unfortunately, there is considerable uncertainty associated with fences and the degree of blockage that they may afford during floods. Areas of uncertainty include:

- The large array of fence types and debris types and availability means that there is likely to be considerable variability in the overall blockage provided by different fence types.
- When fences are exposed to significant floodwater depths and velocities, they may be subject to failure/collapse.

Given the large number of fences across the study area and the uncertainty associated with potential fence failure, completing a detailed survey of every fence was not considered worthwhile. Therefore, an automated approach was employed to extract approximate fence alignments across the study area based on information contained in cadastre, roadway and LEP GIS layers. The extent of the fence alignments extracted using this approach is shown in **Plate 11**.

Plate 11 Fence alignments included in the TUFLOW model

Unfortunately, there is little information available describing the blockage afforded by fences. The Australian Rainfall & Runoff 'Project 11: Blockage of Hydraulic Structures' (Engineers Australia, 2013) suggests that blockage factors of between 50% and 100% would typically be appropriate for fences located in overland flow paths. Therefore, a 50% blockage factor was adopted for all fences. It was also assumed that fences provided 50% blockage for the first 0.5 metres depth of flow only. Although it was acknowledged that fences can often exceed 0.5 metre in height, most fence types will fail once the water depth exceeds 0.5 metre. As a result, the 0.5 metre fence height was considered to provide a reasonable "upper limit" of the degree of blockage that can be provided by an average fence without failing. Flow depths above 0.5 metres were not subject to any blockage.

The fences were included in the TUFLOW model as a "flow constriction" line. This representation allows a blockage factor to be applied to each cell located beneath a fence line to reflect the impediment to flow / reduced conveyance capacity through fences.

5 COMPUTER MODEL CALIBRATION

5.1 Overview

Computer flood models are approximations of a very complex process and are generally developed using parameters that are not known with a high degree of certainty and/or are subject to natural variability. This includes catchment roughness/vegetation density as well as blockage of culverts, stormwater pits and fences. Accordingly, the model should be calibrated using flow and flood mark information from historic floods to ensure the adopted model parameters are producing reliable estimates of flood behaviour.

Calibration is typically completed by routing recorded rainfall from historic floods through a computer model. Simulated flows and flood levels/depths are extracted from the model results at locations where recorded data are available. Calibration is completed by iteratively adjusting the model parameters within reasonable bounds to achieve the best possible match between simulated and recorded flood flows and flood marks.

Unfortunately, there are no stream gauges located within the overland sections of the study area. Therefore, it is not possible to complete a full calibration of the computer model developed for this study.

However, historic flood information was extracted from the responses to the community questionnaire for events that occurred in 2012, 2015 and 2016. Therefore, it is possible to complete a 'pseudo-calibration' by routing historic rainfall through the model and comparing simulated water depths/extents against the descriptions of each historic flood provided by the community.

Further details on the TUFLOW model calibration are provided in the following sections.

5.2 June 2016 Flood

5.2.1 Local Catchment Rainfall

The June 2016 flood occurred as a result of rainfall over a 24-hour period starting around 8:30pm on the 3rd June 2016. Accumulated daily rainfall totals for each rainfall gauge that was operational during the 2016 event were used to develop a rainfall isohyet (i.e., rainfall depth contour) map for the event, which is shown in **Figure 8**.

The isohyet map indicates that there was only a slight spatial variation in rainfall across the catchment during the 2016 event. It indicates that around 250 mm of rain fell across the catchment during the event. Accordingly, this rainfall depth was applied to the TUFLOW model.

The temporal (i.e, time-varying) distribution of rainfall was applied based on the closest continuous rainfall gauge. The closest continuous gauge with data for the 2016 event was determined to be the Fairfield STP gauge (Gauge #567077), which is located immediately north of the catchment (refer **Figure 8**). This gauge recorded nearly 250 mm depth of rain within the 24 hour period indicating it provides a reasonable description of the rainfall that was experienced across the study area during this event.

The continuous rainfall information was also analysed relative to design rainfall-intensity-duration information. This information is presented in **Appendix D** and indicates that over a 24-hour storm duration, the 2016 event approached a 2% AEP design rainfall intensity. However, it should be noted that the critical duration for the local catchment is likely much shorter. Therefore, the actual severity of flooding experience was likely to be much less severe than a 2% AEP flood.

5.2.2 Prospect Creek and Cabramatta Creek Inflows

As discussed, Prospect Creek and Cabramatta Creek form part of the study area for the Cabravale catchment. Two tributaries of Prospect Creek (Burns Creek and Orphan School Creek) also drain into the study area.

Due to the large size of the upstream catchments for these watercourses, it was not possible to represent them using the direct rainfall modelling approach that was adopted across the balance of the Cabravale study area. Therefore, inflow boundary conditions for each of these watercourses were defined using flow hydrographs extracted from XP-RAFTS hydrologic models that were developed as part of the *'Prospect Creek Floodplain Management Plan - Flood Study Review'* (Bewsher Consulting, 2006) and the *'Cabramatta Creek Flood Study and Basin Strategy Review'* (Bewsher Consulting, 2011). The same historic rainfall that was applied to the TUFLOW model (as described in the previous section) was also applied to the XP-RAFTS models.

5.2.3 Georges River Water Level

No historic water level information is available for the Georges River in the vicinity of the study area for any of the historic floods. Therefore, the Georges River water level at the time of the 2016 flood is not known.

No historic flooding information was provided as part of the community questionnaire responses. Therefore, it is unlikely that water levels were significantly elevated in the Georges River. Therefore, a static water level of 3 mAHD was adopted for the Georges River which approximately corresponds to a "bank full" capacity for the Georges River. As each of the historic flood marks is located a significant distance from the Georges River, any uncertainties associated with the adopted river level should not impact on results in the vicinity of each flood mark.

5.2.4 Results

Calibration of the TUFLOW model was attempted based upon floodwater depths that were reported by the community for the 2016 flood at seven different locations across the Cabravale study area. The calibration was undertaken by routing the historic rainfall through the TUFLOW model and adjusting model parameter values until a reasonable agreement between simulated flood levels and recorded floodwater depths was achieved.

Peak floodwater depths were extracted from the results of the 2016 simulation and are included on **Figure 9**. It should be noted that only water depths greater than 0.15 metres are shown in **Figure 9**.

A comparison between the peak floodwater depths generated by the TUFLOW model and the reported floodwater depths for the 2012 flood is also provided in **Figure 9**. Reported floodwater depths and simulated floodwater depths have also been tabulated in **Table 4**.

Table 4 Comparison between simulated flood levels and recorded flood depth for the 2016 flood

Location	Reported Floodwater Depth (m)	Simulated Floodwater Depth (m)	Difference (m)
21 Albert St, Cabramatta	0.20	0.22	0.02
64 Koonoona Ave, Villawood	0.10	0.09	-0.01
87 Koonoona Ave, Villawood	0.45	0.45	0.00
33 Eurabbie St, Cabramatta	0.20	0.06	-0.14
18 Vale Street, Cabramatta	0.30	0.31	0.01
18 Canva Street, Cabramatta	0.30	0.28	-0.02
7 Canva Street, Cabramatta	0.30	0.30	0.00
		Average	-0.02

The floodwater depth comparison provided in **Table 4** indicate that the TUFLOW model provides a reasonable reproduction of reported floodwater depths. In general, the TUFLOW model is able to reproduce the reported floodwater depths to within 0.02 metres with the average difference being -0.02 metres.

One flood mark could not be closely reproduced by the model, with the TUFLOW model underpredicting the reported floodwater depth by 0.14 metres. A specific reason for this difference could not be identified. However, as the TUFLOW model is predicting lower floodwater depths, local blockage of the stormwater drainage system may have generated localised increases in flood level at this location (no blockage of the drainage system was assumed as part of the 2016 simulation).

5.3 April 2015 Flood

5.3.1 Local Catchment Rainfall

The April 2015 flood occurred as a result of an extended period of rainfall commencing on the 19th April 2015. Accumulated daily rainfall totals for each rainfall gauge that was operational during the 2015 event were used to develop a rainfall isohyet map for the event, which is shown in **Figure 10**. The isohyet map indicates that there was significant spatial variation in rainfall across the study area during the 2015 event. It indicates that between 175 and 230 mm of rain fell across the Cabravale catchment. In recognition of the significant variation in rainfall across Cabravale during this event, the isohyets shown in **Figure 10** were using as the basis for defining spatially varying rainfall across the catchment as part of the 2015 flood simulation.

The temporal (i.e, time-varying) distribution of rainfall within the TUFLOW model was applied based on the closest continuous rainfall gauge. The closest continuous gauge was determined to be the Cabramatta Bowling Club gauge (Gauge #567154), which is located within the catchment (refer **Figure 10**). This gauge recorded 193 mm of rain falling within the 72 hour period. However, a review of the continuous rainfall information indicates that the most intense rainfall during this event occurred between 7am and 12:30pm on 22nd April 2015, with 67mm of rain falling within this 5.5 hour period.

The continuous rainfall information was also analysed relative to design rainfall-intensity-duration information. This information is presented in **Appendix D** and indicates that the 2015 rainfall approached the design 20% AEP rainfall.

5.3.2 Georges River Water Level

As with the 2016 simulation, no historic water level information is available for the Georges River for the 2015 event. Therefore, a static water level of 3 mAHD was adopted for the Georges River for the 2015 simulation. As each of the historic flood marks is located a significant distance from the Georges River, any uncertainties associated with the adopted river level should not impact on results in the vicinity of each flood mark.

5.3.3 Results

Calibration of the TUFLOW hydraulic model was attempted based upon reported floodwater depths at three difference locations across the Cabravale catchment for the 2015 flood. The calibration was undertaken by routing the historic rainfall through the TUFLOW model and comparing simulated floodwater depths against reported floodwater depths.

Peak floodwater depths were extracted from the results of the 2015 simulation and are included on **Figure 11**. It should be noted that only water depths greater than 0.15 metres are shown in **Figure 11**.

A comparison between the peak floodwater depths generated by the TUFLOW model and the reported floodwater depths for the 2012 flood is also provided in **Figure 11**. A comparison between reported and simulated floodwater depths is also presented in **Table 5.**

Table 5 Comparison between simulated flood levels and recorded flood depths for the 2015 flood

Location	Reported Floodwater Depth (m)	Simulated Floodwater Depth (m)	Difference (m)
21 Albert St Cabramatta	0.20	0.13	-0.07
64 Koonoona Ave, Villawood	0.10	0.05	0.05
87 Koonoona Ave, Villawood	0.45	0.51	0.06
		Average	0.01

The flood level comparisons provided in **Table 5** indicates that the TUFLOW model provides a reasonable reproduction of recorded flood mark elevations. The TUFLOW model reproduces all reported floodwater depths to within 0.07 metres. **Table 5** also shows that the average difference between simulated and recorded flood levels is 0.01 metres.

Accordingly, it is considered that the TUFLOW model is providing a good reproduction of the reported flood behaviour across the catchment

5.4 April 2012

5.4.1 Local Catchment Rainfall

The April 2012 flood occurred over a 48 hour period starting on 17 April 2012. Accumulated daily rainfall totals for each rainfall gauge that was operational during this event were used to develop a rainfall isohyet map, which is shown in **Figure 12**. The isohyet map shows that around 120 mm of rain fell across the catchment within a 48 hour period. As there was minimal spatial variation in rainfall across the catchment during the 2012 event, a uniform rainfall depth of 120 mm was applied to the TUFLOW model. This same rainfall depth was also applied to the Prospect Creek and Cabramatta Creek TUFLOW models to define upstream inflows to the study area.

The temporal (i.e., time-varying) distribution of rainfall was applied to the TUFLOW model based on the Cabramatta Bowling Club gauge (Gauge #567154), which is located within the catchment (refer **Figure 12**). This gauge recorded 112 mm depth of rain within the 48 hour period. However, a review of the continuous rainfall information indicates that 85mm of this rainfall fell over a 17 hour period.

The continuous rainfall information was also analysed relative to design rainfall-intensity-duration information. This information is presented in **Appendix D** and indicates that the 2012 rainfall was approximately equal to a 50% AEP event over a 48 hour period.

5.4.2 Georges River Water Level

As with the 2015 and 2016 simulations, a static water level of 3 mAHD was adopted as the downstream boundary condition for the Georges River.

5.4.3 Results

Calibration of the TUFLOW hydraulic model was attempted based upon two reports of floodwater depths during the 2012 event. Peak floodwater depths were extracted from the results of the simulation and are included on **Figure 13**.

A comparison between the peak flood depths generated by the TUFLOW model and the reported flood depths for the 2012 flood is also provided in **Figure 13**. A comparison between reported floodwater depths and simulated flood depths is also presented in **Table 6**.

The floodwater depth comparison provided in **Table 6** shows that the TUFLOW model provides a close reproduction of reported floodwater depths during the 2012 event. In both cases the TUFLOW model reproduces the reported floodwater depth to at least 0.02 metres. Although there is only limited reported flooding information available for this event, the TUFLOW model provides a good reproduction of this information.

Table 6 Comparison between simulated flood levels and recorded flood depths for the 2012 flood

Location	Reported Floodwater Depth (m)	Simulated Floodwater Depth (m)	Difference (m)
21 Albert St, Cabrammatta	0.45	0.43	-0.02
87 Koonoona Ave, Villawood	0.20	0.20	0.00
		Average	-0.01

Overall, it was considered that the TUFLOW model provides a good reproduction of reported floodwater depths for the 2012, 2015 and 2016 floods, with 11 of the 12 reported depths being reproduced to better than 0.1 metres. As a result of the good reproduction of historic flood depths, it was considered that the TUFLOW model was providing a reliable representation of overland flood behaviour. Moreover, as there have been negligible changes across the catchment since these historic floods, it was considered that the TUFLOW model used to simulate these floods could also be used to simulate design flood behaviour across the Cabravale catchment for current (i.e., 2022) conditions.

5.5 Quality Review of TUFLOW Model

As discussed above, the TUFLOW computer model provided a good reproduction of historic flood information. However, to further ensure that the model was appropriately setup and parameterised, an independent review of the model was completed by BMT WBM (developers of the TUFLOW software).

The review focused on the following components of the TUFLOW model:

- Overall model health (e.g., mass balance, instabilities).
- Model schematisation (e.g., 1D/2D links, stormwater system representation).
- Representation of fences.
- Appropriate choice of model parameters (e.g., Manning's 'n', stormwater/culvert loss coefficients).
- Suitability of boundary conditions.

The outcomes of the review are summarised in **Appendix H**.

The review recommended several updates to the TUFLOW model. It was noted that several of the comments related to Prospect Creek and Cabramatta Creek, which were carried across from past studies/TUFLOW models into the current model. Although the current study did not intend to update the description of design flood behaviour along Prospect Creek and Cabramatta Creeks, updates to these sections of the models were nevertheless addressed before proceeding with the design flood simulations.

A summary of the key recommendations arising from the review are provided in **Table 7**. **Table 7** also provides a summary of the updates that were completed to the model to address each comment.

Table 7 Summary of Quality Review Comments and Actions

#	Comment	Response / Action
1	Change the following commands in the control files: • GIS Projection Check == ERROR (not Warning) • Bed Resistance Cell Sides == INTEROGATE (not AVERAGE n) • Remove Interpolate ZUVH ALL Command	Control files were updated to include the recommended changes
2	Review Manning's 'n' values for Material 3 (trees) and address inconsistency between report and model	Manning's "n" values were updated in TUFLOW model to ensure consistency with report
3	Review and action (as required) the warning messages identified in the model initialisation	The warning messages were reviewed and the following updates were made to the TUFLOW model: • Pits located within the 1d domain (and hence not active) relocated to 2d domain if within reasonable bounds (ie: ~5m of original location) • Structure/Channel inverts and/or cross-section application modified to allow coincidence of inverts at junctions (unless obviously different) • modified locations of cross-section application where it was being inadvertently ignored or applied incorrectly
4	Review the application of the hx lines in the 1d-2d linking – in particular the use of the 's' and 'z' flags and consider the use of a thick z lines along the alignment of a hx line	Thick z lines included along 1d-2d boundaries and "s" and "z" flags removed
5	Review and action the representation of the bridges with regard to the applied loss coefficients and the lack of storage applied	The lengths of hydraulic structures were updated in line with recommendations.
6	Review and action (as appropriate) the 1D negative depths.	Modifications were made to node Pr1.20.2 to address negative depths

6 Design Flood Estimation

6.1 General

Design floods are hypothetical floods that are commonly used for planning and floodplain management investigations. Design floods are based on statistical analysis of rainfall and flood records and are typically defined by their probability of exceedance. This is most often expressed as an Annual Exceedance Probability (AEP).

The AEP of a flood flow or level or depth at a particular location is the probability that the flood flow or level or depth will be equalled or exceeded in any one year. For example, a 1% AEP flood is the best estimate of a flood that has a 1% chance of being equalled or exceeded in any one year.

Design floods can also be expressed by their Average Recurrence Interval (ARI). For example, the 1% AEP flood can also be expressed as a 1 in 100 year ARI flood. That is, the 1% AEP flood will be equalled or exceeded, on average, once in a 100 years.

It should be noted that there is no guarantee that a 1% AEP flood will occur once in a 100-year period. It may occur more than once, or at no time at all in the 100-year period. This is because design floods are based upon a long-term statistical average. Therefore, it is prudent to understand that the occurrence of recent large floods does not preclude the potential for another large flood to occur in the immediate future.

Design floods are typically estimated by applying design rainfall to the computer model and using the model to route the rainfall excess across the catchment to determine design flood level, depth and velocity estimates. The procedures employed in deriving design flood estimates for the Cabravale study area are outlined in the following sections.

6.2 Australian Rainfall and Runoff

Recent flood studies across the Fairfield City Council LGA have been prepared in accordance with *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987) (referred to herein as ARR1987). In 2016, a revised version of Australian Rainfall and Runoff was released (Geoscience Australia, 2016) (referred to herein as ARR2016). The engineering professional is gradually transitioning from ARR1987 to ARR2016. However, as application of ARR2016 is still in its infancy, it was considered important to gain an understanding of the impacts that ARR2016 may have on design flood estimates relative to ARR1987 to confirm its suitability for application to the Cabravale study area. Therefore, a hydrologic assessment was completed to determine the most appropriate hydrologic approach to apply as part of the current flood study.

The analysis was completed using an XP-RAFTS hydrologic model that was developed specifically for the study. The outcomes of the assessment are summarised in **Appendix E.**

The assessment determined that the revised hydrologic procedures summarised in ARR2016 would produce lower peak design discharges relative to ARR1987. As application of ARR2016 is yet to be fully tested/verified, particularly across the Fairfield LGA, the more conservative ARR1987 procedures were retained for application as part of the Cabravale flood study. Further detailed information on the application of ARR1987 is provided below.

6.3 Computer Model Setup

6.3.1 Boundary Conditions

Design Rainfall

Design rainfall for the 20%, 5% and 1% AEP events were extracted using standard procedures outlined in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987). This involved extracting base design intensity-frequency-duration values at the centroid of the Cabravale study area from Volume 2 of *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987).

This base design rainfall information was used to interpolate design rainfall for other design rainfall frequencies and durations. Adopted rainfall intensities for each design storm and duration are summarised in **Table 8**. The resulting intensity-frequency-duration (IFD) curves are also provided in **Appendix D**. The resulting design rainfall information was also verified against design rainfall extracted using the Bureau of Meteorology's Computerised Design IFD Rainfall System and was found to be consistent.

Table 8 Design Rainfall Intensities

DURATION	Design Rainfall Intensities (mm/hour)					
	20% AEP	5%AEP	1%AEP	0.2%AEP	1 in 10,000 Year	PMP
5 mins	135	172	220	-	-	-
10 mins	103	132	169	-	-	-
15 mins	86.0	110	141	163	232	600
30 mins	61.1	77.9	99.7	116	167	440
1 hour	41.4	52.9	67.8	80.0	118	320
1.5 hour	32.5	41.6	53.4	64.0	96.8	273
2 hours	27.2	34.9	44.9	54.5	84.4	245
3 hours	21.0	27.1	35.0	42.6	66.2	193
6 hours	13.5	17.6	22.9	28.0	44.0	130
9 hours	10.5	13.7	17.9	-	-	-
12 hours	8.75	11.5	15.1	-	-	-

NOTE: - indicates a design rainfall is not available for the nominated storm duration

Design rainfall was also calculated for the 0.2% AEP event and 1 in 10,000 year event. The approach that was employed to derive design rainfall for these events is summarised in **Appendix F** and the resulting rainfall intensities are provided in **Table 8**.

For all design storms up to and including the 1 in 10,000 Year event, the design rainfall was uniformly distributed across the entire study area. That is, there was no spatial variation in design rainfall across the study area.

The design rainfall estimates were used in conjunction with standard design temporal patterns documented in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987) to describe how the design rainfall varies with respect to time throughout each design storm.

As part of the flood study it was also necessary to define flood characteristics for the Probable Maximum Flood (PMF). The PMF is considered to be the largest flood that could conceivably occur across a particular area.

The PMF is estimated by routing the Probable Maximum Precipitation (PMP) through the computer model. The PMP is defined as the greatest depth of rainfall that is meteorologically possible at a specific location.

PMP depths were derived for a range of storm durations up to and including the 6-hour event based on procedures set out in the Bureau of Meteorology's *'Generalised Short Duration Method'* (GSDM) (Bureau of Meteorology, 2003). The PMP estimates were varied spatially and temporally based on the GSDM approach before application to the XP-RAFTS and TUFLOW models. The GSDM PMP calculations are included in **Appendix F**. The PMP rainfall intensities are also summarised in **Table 8**.

Cabramatta Creek and Prospect Creek

As discussed, the southern boundary of the Cabravale study area is adjoined by Cabramatta Creek. Prospect Creek also drains through the study areas and forms a study area boundary along a part of its length. Accordingly, the prevailing water levels within Prospect and Cabramatta Creeks can have an impact on flood behaviour across the lower lying sections of the study area that adjoin each of these waterbodies. Although the focus of the current study was not to define design flood behaviour along Prospect and Cabramatta Creeks (this was completed as part of previous flood and floodplain risk management studies), it was considered important to represent the potential interaction between runoff from the local Cabravale study area and these receiving creeks.

As discussed in Section 4.2.3, a full representation of Cabramatta and Prospect Creeks was included in the TUFLOW model developed for the study. Therefore, to represent flood behaviour along each watercourse, it was necessary to define inflows at the upstream boundary of each watercourse. Inflow boundary conditions for each of these watercourses were defined using design flow hydrographs extracted from XP-RAFTS hydrologic models that were developed as part of the *'Prospect Creek Floodplain Management Plan - Flood Study Review'* (Bewsher Consulting, 2006) and the *'Cabramatta Creek Flood Study and Basin Strategy Review'* (Bewsher Consulting, 2011).

In all cases, it was assumed that the same rainfall event was occurring across the Cabramatta Creek and Prospect Creek catchments as well as the local Cabravale study area as part of the design flood simulations. That is, the exact same rainfall distribution was applied to the XP-RAFTS models and the TUFLOW model and the rainfall was assumed to start at the same time. This should provide a reasonable representation of the variation in timing and interaction between local catchment and Prospect Creek/Cabramatta Creek flows.

To ensure consistency with other flood studies that have been completed across the Fairfield City Council LGA, it was assumed that floods of equivalent severity were occurring across the Cabravale catchment at the same time as across the broader Prospect Creek and Cabramatta Creek catchments during all events up to and including the 1% AEP event. The 1% AEP flood was adopted for Prospect Creek and Cabramatta Creek during all Cabravale events greater than the 1% AEP flood (i.e., 0.2% AEP, 1 in 10,000 year ARI and PMF). A summary of the adopted local catchment and Prospect/Cabramatta Creek design flood combinations that were considered as part of the design flood simulations are provided in **Table 9**.

Table 9 Adopted Prospect Creek Downstream Boundary Conditions for Design Simulations

Cabravale Design Flood	Cabramatta and Prospect Creek Design Flood		
	20% AEP	5% AEP	1% AEP
20% AEP	×		
5% AEP		×	
1% AEP			×
0.2% AEP			×
1 in 10,000 Year			×
PMF			×

6.3.2 Hydraulic Structure Blockage

Culvert and Bridge Blockage

During a typical flood, sediment, vegetation and urban debris (e.g., litter, shopping trolleys, wheely bins) from the catchment can become mobilised leading to blockage of downstream culverts and bridges. Consequently, bridges and culverts will typically not operate at full efficiency during most floods. This can increase the severity of flooding across areas located adjacent to these structures.

In recognition of this, blockage factors varying between 0% and 100% were applied to all bridges and culverts. The blockage factors were calculated based on blockage guidelines contained in the Australian Rainfall & Runoff document titled 'Blockage of Hydraulic Structures' (Engineers Australia, 2015). This document also recommends adjusting the 'base' blockage factors up or down depending on the severity of the event (i.e., higher blockage factors during larger floods and lower blockage factors during smaller floods). A summary of the blockage scenarios that were adopted for each design flood is provided in **Appendix G** and are also summarised below:

- Low Blockage Scenario –20% AEP event
- Medium Blockage Scenario – 5% and 1% AEP events

- High Blockage Scenario – 0.2% AEP, 1 in 10000 Year and PMF events

No blockage as well as complete blockage scenarios were also assessed as part of the sensitivity analysis to further quantify the impact that blockage of culverts and bridges has on flood behaviour across the study area (refer Section 8.2.4).

Stormwater

Blockage factors were also assigned to stormwater pits/inlets for each design flood simulation. The adopted blockage factors are summarised in **Table 10**. The blockage factors listed in **Table 10** have been applied in other similar studies across the Fairfield City Council LGA.

Table 10 Adopted Blockage for Design Flood Simulations

Smithfield West Design Flood	Adopted Stormwater Pit Blockage			
	0% Blockage	30% Blockage	50% Blockage	100% Blockage
50% AEP		×		
20% AEP		×		
5% AEP		×		
1% AEP	Sensitivity Analysis		×	Sensitivity Analysis
0.2% AEP			×	
1 in 10,000 Year ARI			×	
PMF			×	

As outlined in **Table 10**, 30% blockage was applied to all stormwater pits for all design floods up to and including the 5% AEP event. 50% blockage was applied for all events in excess of the 5% AEP event. The impact of no blockage as well as complete blockage of pits was also assessed as part of the sensitivity analysis (refer Section 8.2.4).

6.4 Results

6.4.1 Critical Duration

It was recognised that a single storm duration will not necessarily produce the “worst case” flooding across all sections of the study area. An important outcome of this study was to ensure that the most critical flooding conditions were defined across the full catchment. Therefore, the TUFLOW model was used to simulate flood behaviour across the study area for a range of different durations for each design storm (i.e., 15 minutes up to 3 hours). The results from the 1% AEP design flood simulations were subsequently interrogated to determine the “critical” storm duration or durations across the study. The outcomes from this assessment are shown graphically in **Plate 12**.

The information contained in **Plate 12** shows that the 120-minute storm duration typically generated the highest 1% AEP flood levels across most areas with a significant overland flow path. However, the 15-minute storm also featured in the upstream sections of the study area where overland flow depths were typically shallow. The 60-minute and 90-minute storms were also critical at a select number of locations.

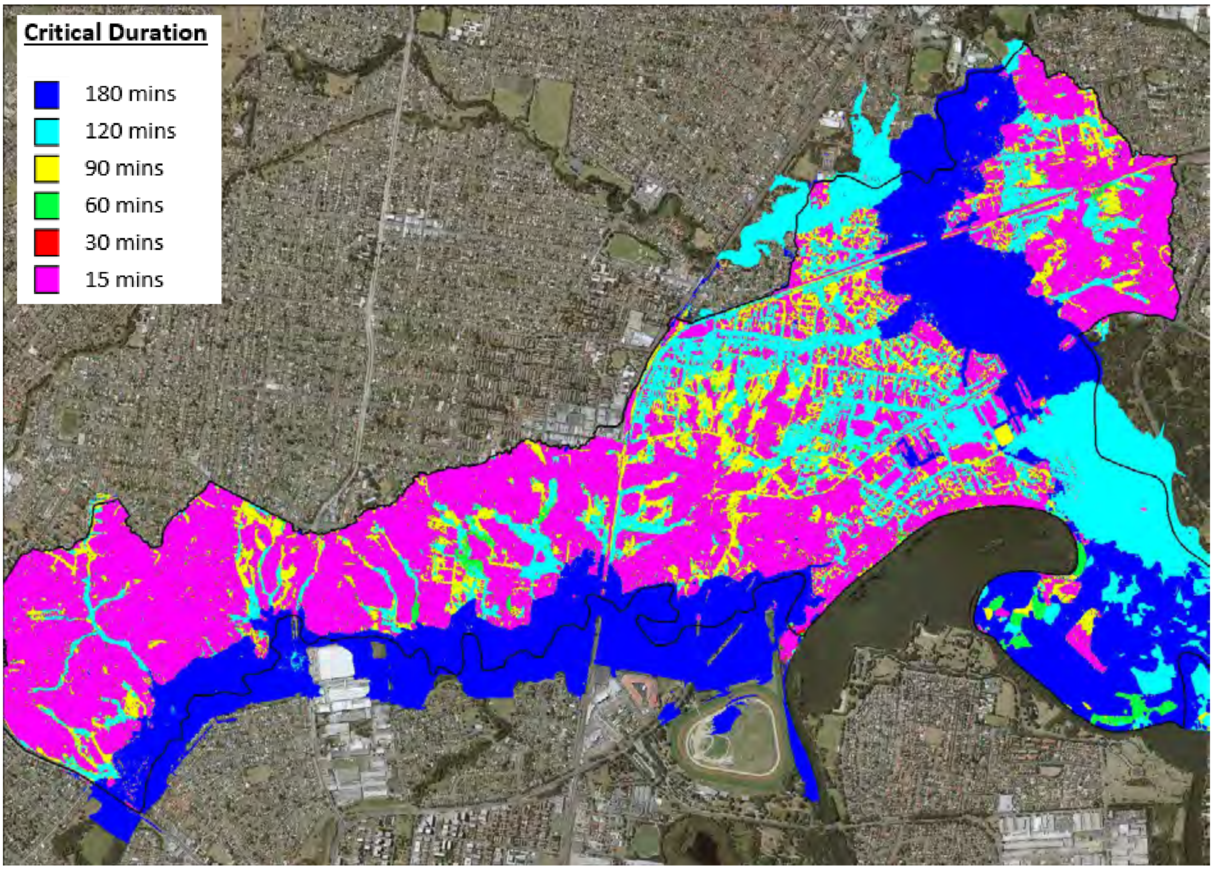


Plate 12 Spatial Variation in Critical Duration for the 1% AEP Storm

It was noted that the 180-minute storm was critical along Cabramatta Creek and Prospect Creek. However, as this study was not aiming to define flood behaviour along each of these watercourses, the 180-minute storm was omitted from the design flood simulations.

6.4.2 Design Flood Envelope

As discussed, a range of storm durations were simulated to ensure the worst-case flood conditions were represented across all sections of the study area for each design flood. Therefore, the results from each of the different storm durations for each design flood were interrogated and combined to form a single "design flood envelope" for each design flood representing the most critical flood levels, depths and velocities at each location in the study area.

In addition, it was considered important to ensure consistency with existing design flood results for Cabramatta Creek, Prospect Creek and the Georges River, which extend across part sections of the Cabravale study area. Accordingly, peak design flood level surfaces from each of these studies were included in the design flood envelope based on the combination of local catchment and receiving waterbody events presented in **Table 9**.

For example, the peak 1% AEP flood level surface from the Cabravale TUFLOW model simulations was combined with the peak 1% AEP flood level surfaces for Cabramatta Creek, Prospect Creek and the Georges River to form the final design flood surface for the 1% AEP event covering the full Cabravale study area. The available terrain information was also subtracted from this combined water level surface to develop final floodwater depth envelopes.

No flood level results were available for the Georges River for events more frequent than the 5% AEP event. For these events, a nominal Georges River water level of 3 mAHD was adopted in the design flood envelope. This is intended to reflect a small Georges River flood (however, a precise frequency for this water surface elevation cannot be defined).

It should also be noted that the 1% AEP depth and water level results surface for Cabramatta Creek, Prospect Creek and Georges River were also incorporated into the design flood envelope for each Cabravale local catchment event greater than the 1% AEP event in accordance with **Table 9**. For example, the local catchment PMF flood was combined with the 1% AEP results surface for Cabramatta Creek, Prospect Creek and Georges River to form the final depth and water level design flood envelope.

It was noted that velocity output surfaces were generally not available for Cabramatta Creek, Prospect Creek and the Georges River. Accordingly, it was not possible to incorporate peak velocity information for these receiving watercourses into the velocity mapping presented as part of the study. Therefore, the velocity mapping only reflects the Cabravale TUFLOW model outputs.

6.4.3 Presentation of Results

The adopted modelling approach for the study involves applying rainfall directly to each cell in the computer model and routing the rainfall excess based on the physical characteristics of the catchment (e.g., variation in terrain, stormwater system). Once the rain falling on each grid cell exceeds the rainfall losses, each cell will be "wet". However, water depths across most of the catchment will be very shallow and would not present a significant flooding problem. Therefore, it was necessary for the results of the computer simulations to be "filtered" to distinguish between areas of significant inundation depth / flood hazard and those areas subject to negligible inundation.

A minimum depth threshold of 0.15 metres has been adopted in other overland flood studies completed across the Fairfield LGA for the following reasons:

- Council's standard kerb height is generally 0.15 metres. Therefore, water depths less than 0.15 metre will typically be contained to roadways and will not spill over kerbs and travel overland through properties
- The National Construction Code 2022 requires the floor level of buildings in poorly drained areas to be elevated 0.15 metres above the finished ground level. Accordingly, there is limited chance of over floor flooding when water depths are less than 0.15 metres
- Removing areas inundated by more than 0.15 metres typically resulted in many isolated "puddles" and was considered to underestimate the flood risk.

The adoption of a minimum depth threshold of 0.15 metres was also considered appropriate for the current study. That is, flood model results were only presented in the maps/figures where the depth of inundation was predicted to exceed 0.15 metres.

It was noted that application of a depth filter in isolation did still result in a number of isolated "puddles". Where these "puddles" did not form part of a relatively continuous overland flow path, they were removed from the mapping. That is, any small, isolated puddles were typically removed from the mapping.

The TUFLOW model results were also "clipped" to the Fairfield City Council Local Government Area. That is, results are not displayed in areas outside of the Fairfield City Council LGA.

6.4.4 Field Verification of Preliminary Results

Preliminary floodwater depth maps were prepared for the 1% AEP flood based upon the depth and area filter criteria outlined above. The preliminary maps were subject to an initial desktop review to determine if the mapped inundation depths and extents appeared realistic.

In areas where the desktop analysis proved inconclusive, "ground truthing" was completed to confirm the veracity of the modelling results. The ground truthing involved undertaking a field review of locations where there was some uncertainty associated with the preliminary mapping results. This aimed to confirm whether the modelling results were realistic in the first instance and whether the results should be retained or removed across these areas. In a number of cases the modelling results were considered to overestimate floodwater depths, particularly in areas where there were relatively narrow flow paths between buildings that could not be well represented in the model. Consequently, the ground truthing resulted in the preliminary modelling results being removed from the final flood mapping across a number of locations and/or the model being modified to better reflect field conditions.

The outcomes of the field verification are summarised in **Appendix I**.

6.4.5 Peak Depths and Velocities

The final floodwater depth mapping for the 20% AEP, 5% AEP, 1% AEP, 0.2% AEP, 1 in 10,000 year flood and PMF events are presented in **Figures 14** to **19** respectively. As noted above, the depth mapping was developed to include a representation of both overland flooding (as defined by the TUFLOW model developed for this study) as well as mainstream flooding (based upon existing flood level results for Prospect Creek, Cabramatta Creek and the Georges River).

Peak flow velocities were also extracted from the results of the design modelling for each design flood and are presented in **Figures 20** to **25**. As noted above, the velocity mapping only reflects results extracted from the TUFLOW model developed for the current study (velocity results surfaces were not available for Prospect Creek, Cabramatta Creek and the Georges River).

6.4.6 Inundated Properties

The number of properties inundated during each design flood was also determined. This information is summarised in **Table 11** (there are 7,966 properties contained within the Cabravale study area). The information presented in **Table 11** indicates that approximately 25% of properties located within the study area will be at least partly inundated at the peak of the 1% AEP flood. This is predicted to increase to well over 40% during the PMF. Accordingly, major flooding has the potential to impact a significant number of properties within the study area.

Table 11 Number of Inundated Properties

Event	Residential	Commercial	Industrial	Total
20% AEP	1,042	72	22	1,136
5% AEP	1,558	93	59	1,710
1% AEP	2,000	108	60	2,168
0.2% AEP	2,102	119	61	2,282
1 in 10,000 Year	2,314	127	65	2,506
PMF	3,433	154	78	3,665

6.5 Stormwater System Capacity

The TUFLOW model also produces information describing the amount of water flowing into each stormwater pit and through each stormwater pipe. This includes information describing which pipes are flowing completely full during each design flood. This information can be used to provide an assessment of the capacity of each pit and pipe in the stormwater system. In doing so, it identifies where stormwater capacity constraints may exist across the catchment.

The pipe flow results of all design flood simulations were interrogated to determine the capacity of each stormwater pipe in terms of a nominal return period (i.e., AEP). The capacity of the pipe was defined as the largest design event whereby the pipe was not flowing completely full. For example, if a particular stormwater pipe was flowing 95% full during the 10% AEP event and 100% full during the 5% AEP event, the pipe capacity would be defined as "10% AEP".

A nominal return period was also calculated for each pit based on one of the following "failure" criteria:

- AEP at which the pit begins to surcharge
- AEP at which the water depth at the pit exceeds 0.2 metres (while the downstream pipe still has excess capacity).

The resulting stormwater capacity maps are presented in **Figure 26**. As shown in **Figure 26**, the pit and pipe capacities are colour coded based on the nominal capacity that was calculated. Furthermore, different symbols have been applied to each pit to define whether the pit first "fails" via ponding depth or surcharge.

The information presented in **Figure 26** shows that the capacity of the system varies considerably across the study area. Some sections of the stormwater system have a capacity of less than the 20% AEP while other sections of the stormwater system are able to convey flows in excess of the 1% AEP event. In general, the major trunk drainage lines where flows are concentrated appear to have a lower capacity than the minor drainage lines. **Figure 26** also indicates that the pipe capacity rather than pit capacity appears to be the limiting factor in the performance of the stormwater system.

6.6 Results Verification

The TUFLOW model developed as part of this study was calibrated against observed flood information for three historic floods. In general, the model was found to provide a good reproduction of historic flood observations. However, the outcomes of the calibration only provide evidence that the model is providing a reliable representation of flood behaviour at isolated locations (i.e., at recorded flood mark locations).

With the exception of the mainstream flood studies for Prospect Creek, Cabramatta Creek and the Georges River, no flood studies have previously been prepared for the Cabravale study area. Furthermore, since the results from these previous flood studies were merged into the current study results, there did not appear to be any benefit in verifying the current study results against these previous studies.

Therefore, validation of the TUFLOW model was restricted to comparing the TUFLOW model results against alternate modelling approaches and calculations. Further details on the outcomes of the TUFLOW model verification is presented below.

6.6.1 XP-RAFTS Hydrologic Model

The ability of the TUFLOW model to represent rainfall-runoff processes was verified against a hydrologic model of the Cabravale study area that was established specifically for the study using the XP-RAFTS software. The verification was completed by comparing peak 1% AEP discharges extracted from the TUFLOW model and the XP-RAFTS model against peak 1% AEP discharges along the two major watercourses within the study area (i.e., Long Creek and Prout Creek). The outcomes of the verification are summarised in **Table 12**.

Table 12 Comparison between TUFLOW, XP-RAFTS, RFFE and PRM Discharges

Location	1% AEP Discharge (m^3/s)		
	TUFLOW	XP-RAFTS	PRM
Long Creek at Vale St	12.0	16.7	15.8
Long Creek at Beckenham St	20.6	26.9	23.6
Prout Creek east of Verona Avenue	16.9	18.4	13.3
Prout Creek at Townview Road	18.9	21.8	15.7

In general, the peak discharge comparison provided in **Table 12** shows that the XP-RAFTS model is producing comparable but higher discharges relative to the TUFLOW model. This is most likely associated with the XP-RAFTS model not including a representation of any flood storage areas. Although there are no formal flood detention basins in the study area, informal storages would form behind roadway embankments and within other topographic depressions. All of these storages would be better represented in the TUFLOW model and would serve to attenuate peak downstream discharges.

6.6.2 Probabilistic Rational Method (PRM)

Additional verification of the peak design discharges generated by the TUFLOW model was completed by comparing them against peak discharges calculated using the Probabilistic Rational Method (PRM). The outcome of the comparison is also provided in **Table 12**.

In general, the TUFLOW and PRM discharges show a reasonable correlation with the TUFLOW model generally producing higher peak discharges in the Prout Creek catchment and lower peak discharges in the Long Creek catchment.

Overall, the TUFLOW model produces 1% AEP peak discharges that are higher than the PRM but lower than the XP-RAFTS model. This indicates that the TUFLOW model is producing realistic 1% AEP discharge estimates.

7 FLOOD HAZARD AND HYDRAULIC CATEGORIES

7.1 Flood Hazard

7.1.1 Overview

Flood hazard defines the potential impact that flooding will have on development and people across different sections of the floodplain.

The determination of flood hazard at a particular location requires consideration of a number of factors, including (NSW Government, 2005):

- depth and velocity of floodwaters;
- size of the flood;
- effective warning time;
- flood awareness;
- rate of rise of floodwaters;
- duration of flooding; and
- potential for evacuation.

Consideration of the depth and velocity of floodwater in isolation is referred to as the *hydraulic* or *provisional* flood hazard. The provisional flood hazard at a particular area of a floodplain can be established from Figure L2 of the *'Floodplain Development Manual'* (NSW Government, 2005). This figure is reproduced on the right.

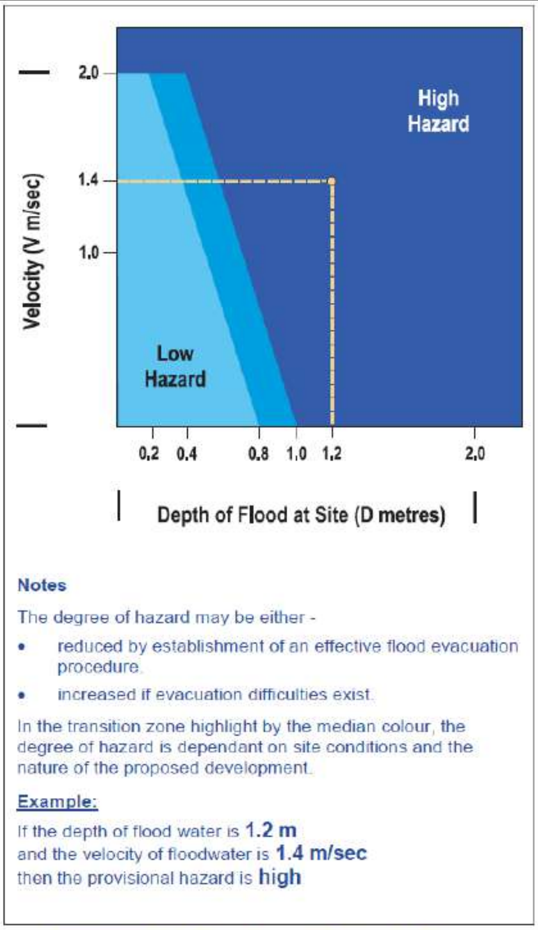


FIGURE L2 - Provisional Hydraulic Hazard Categories

As shown in Figure L2, the *"Floodplain Development Manual"* (NSW Government, 2005) divides provisional hazard into two categories, namely high and low. It also includes a *transition zone* between the low and high hazard categories. Sections of the floodplain located in the "transition zone" may be classified as either high or low depending on site conditions or the nature of any proposed development.

7.1.2 Provisional Flood Hazard

The TUFLOW software was used to automatically calculate the variation in provisional flood hazard across the study area based on the criteria shown in Figure L2 for the 1% AEP flood as well as the PMF. These hazard category maps are shown in **Figures 27** and **28**.

It needs to be reinforced that the hazard represented in this mapping is provisional only. This is because it is based only on an interpretation of the flood hydraulics and does not reflect the other factors that influence flood hazard. Refinement of the provisional hazard categories to include consideration of these other factors will be completed as part of the future floodplain risk management study.

7.1.3 Flood Emergency Response Classifications

The provisional hazard mapping presented in **Figures 27** and **28** can provide an indication of the risk to life and property across different sections of the catchment based on the depth and the velocity of floodwaters. Those areas subject to a low flood hazard can, if necessary, be evacuated by trucks and able-bodied adults would have little difficulty wading to safety (NOTE: evacuation by car may <u>not</u> be possible). Those areas of the floodplain exposed to a high flood hazard would have difficulty evacuating by trucks, there is potential for structural damage to buildings and there is possible danger to personal safety (i.e., evacuation by wading may not be possible).

Accordingly, the provisional hazard categories provide an initial appraisal of the variation in flood hazard across the catchment based on the depth and velocity of floodwaters. However, a number of other factors need to be considered to determine the potential vulnerability of the community during specific floods.

In an effort to quantify the other factors that impact on the vulnerability of the community during floods, flood emergency response precinct (ERP) classifications were prepared in accordance with information presented in "*Australian Disaster Resilience Guideline 7-2: Flood Emergency Response Classification of the Floodplain*" (AIDR, 2017). This guideline includes the flow chart shown in **Plate 13**, which can be used to assign emergency response classifications for different sections of the floodplain (AIDR, 2017).

The ERP classifications can be used to provide an indication of areas which may be inundated or may be isolated during floods. This information, in turn, can be used to quantify the type of emergency response that may be required across different sections of the floodplain during future floods. This information can be useful in emergency response planning.

Each allotment within the Cabravale study area was classified based upon the ERP flow chart for the 1% AEP flood as well as the PMF. This was completed using the TUFLOW model results, digital elevation model and a road network GIS layer in conjunction with proprietary software that considered the following factors:

- whether evacuation routes/roadways get "cut off" and the depth of inundation (a 0.2m depth threshold was used to define a "cut" road)
- whether evacuation routes continuously rise out of the floodplain
- if evacuation by car was not possible, whether evacuation by walking was possible (a 0.5 metre depth threshold was used to define when a route could not be traversed by walking).

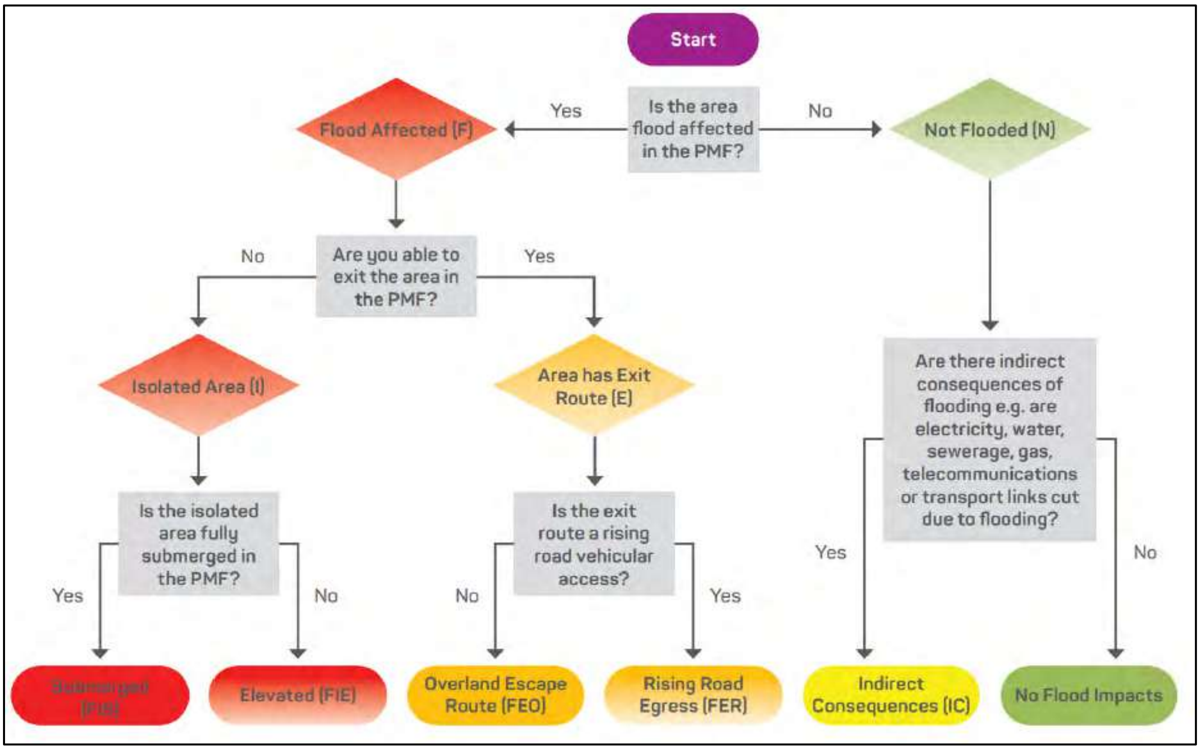


Plate 13 Flow Chart for Determining Flood Emergency Response Classifications (AIDR, 2017).

The resulting ERP classifications for the 1% AEP flood as well as the PMF are provided in **Figures 29** and **30**. A range of other datasets were also generated as part of the classification process to assist Council and the SES. This includes roadway overtopping locations, which are also included on **Figures 29** and **30**.

Figure 29 shows that during the 1% AEP flood, the most common ERP classification is "Rising Road Egress", which indicates that evacuation routes grade up and out of the floodwaters. However, there are some "flooded isolated submerged" areas (i.e., low flood islands), which indicates that evacuation routes are likely to be cut early in the flood.

Figure 30 shows that during the PMF, the number of "flooded isolated submerged" areas increase significantly, particularly for areas adjoining Prospect and Cabramatta Creeks. Accordingly, if a large flood was to occur, there is potential for a very large number of lots to become isolated. The sheer number of these "flooded isolated submerged" lots during the PMF and the limited warning times means that it is unlikely emergency services will be able to offer assistance.

The road inundation information contained in **Figures 29** and **30** shows that little warning time would be available before many roadways cut by floodwaters. In general, roadways would be inundated within 20-30 minutes during the 1% AEP flood and, during the PMF, roadways would be cut in as little as 15 minutes. Floodwaters would begin to subside, and the roadways would become trafficable again across most areas within 1 hour. Therefore, little warning time would be available during large floods, but the roadways would not be inundated/cut for an extended amount of time.

7.2 Hydraulic Categories

7.2.1 Overview

The NSW Government's *'Floodplain Development Manual'* (NSW Government, 2005) also characterises flood prone areas according to the hydraulic categories presented in **Table 13**. The hydraulic categories provide an indication of the potential for development across different sections of the floodplain to impact on existing flood behaviour and highlights areas that should be retained for the conveyance of floodwaters.

Table 13 Qualitative and Quantitative Criteria for Hydraulic Categories

Hydraulic Category	Floodplain Development Manual Definition	Adopted Criteria
Floodway	• those areas where a significant volume of water flows during floods • often aligned with obvious natural channels and drainage depressions • they are areas that, even if only partially blocked, would have a significant impact on upstream water levels and/or would divert water from existing flowpaths resulting in the development of new flowpaths. • they are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.	o Overland Flood Areas - VxD >= 0.25 m^2/s or - V >= 0.5 m/s o Mainstream Flood Areas - Minimum top of bank to top of bank plus - VxD >= 0.4 m^2/s or - V >= 0.5 m/s
Flood Storage	• those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood • if the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. • substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.	o If not Floodway and D >= 0.15 m
Flood Fringe	• the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. • development (e.g., filling) in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.	o All areas not mapped as floodway or flood storage

7.2.2 Adopted Hydraulic Categories

Unlike provisional hazard categories, the *"Floodplain Development Manual"* (NSW Government, 2005) does not provide explicit quantitative criteria for defining hydraulic categories. This is because the extent of floodway, flood storage and flood fringe areas are typically specific to a particular catchment.

The results of the design flood simulations were interrogated to assess the potential extent of floodway, flood storage and flood fringe areas based on the qualitative guidelines listed in **Table 13**. This involved delineating preliminary hydraulic category boundaries by hand across different areas of the study area. The extent of each preliminary hydraulic category boundary was superimposed on peak depth, flow velocity and velocity-depth product values to determine if the hydraulic category boundaries could be defined numerically. This assessment determined that it was not possible to define a single set of numerical values to define hydraulic categories for all parts of the study area. This is associated with the significantly different flooding characteristics along the main creeks where floodwater depths are significant versus the overland flow areas where inundation depths are comparatively shallow. Therefore, different criteria were adopted for defining floodways areas in the mainstream versus the overland flood areas, which are summarised in **Table 13**.

Flood storage areas were subsequently defined as areas that were not classified as floodways but where the depth of inundation was greater than 0.15 metres.

As discussed in Section 6.4.3, "filtering" of the raw modelling results was completed to remove areas of insignificant inundation from the flood mapping (i.e., areas where the depth of inundation was less than 0.15 metres). It was considered that the areas that were removed from the flood mapping as part of the filtering process would fall under the "flood fringe" hydraulic category. Accordingly, those areas where no depth or hydraulic category mapping is presented would be considered flood fringe.

The resulting hydraulic category maps for the 1% AEP flood as well as the PMF are shown in **Figures 31** and **32**.

7.3 Flood Risk Precincts

Fairfield City Council subdivides each floodplain within their LGA into Flood Risk Precincts. The Flood Risk Precincts are used as the basis for defining the variation in flood risk across the Fairfield City Council LGA and are used as the basis for determining what development controls apply to land within the floodplain. This is one measure that Council currently employs to ensure the flood risk is suitably managed.

Chapter 11 of the *'Fairfield City Wide Development Control Plan'* (Fairfield City Council, 2013) provides definitions for three Flood Risk Precincts (i.e., Low, Medium and High). The definition for each precinct is reproduced in **Table 14.**

Table 14 Flood Risk Precinct Definitions

Flood Risk Precinct	Definition
High	Land below the 1% AEP flood that is either subject to a high hydraulic hazard or where there are significant evacuation difficulties
Medium	Land below the 1% AEP flood that is not subject to a high hydraulic hazard and where there are no significant evacuation difficulties
Low	This has been defined as all other land within the floodplain (i.e. within the extent of the probable maximum flood) but not identified within either the High Flood Risk or the Medium Flood Risk Precinct.

As shown in **Table 14**, land where there are significant evacuation difficulties fall under the "High" Flood Risk Precinct classification. For the purposes of this study, any property that was categorised as a "flooded, isolated, submerged" during the 1% AEP flood as part of the Flood Emergency Response Precinct classifications (**Figure 29**) was classified as having significant evacuation difficulties.

The Flood Risk Precinct Map that was developed for Cabravale is shown in **Figure 33**.

8 Sensitivity Analysis

8.1 General

Computer flood models require the adoption of several parameters that are not necessarily known with a high degree of certainty or are subject to variability. Each of these parameters can impact on the results generated by the model.

As outlined in Section 5, computer models are typically calibrated using recorded rainfall, stream flow and/or flood mark information. Calibration is achieved by adjusting the parameters that are not known with a high degree of certainty until the computer model is able to reproduce the recorded flood information.

As discussed in Section 5 and Section 6.6, the TUFLOW model was calibrated against recorded and observed flood information for three historic events and was further verified against alternate calculation approaches and results documented in past studies. In general, this information confirmed that the model was providing realistic descriptions of flood behaviour across the catchment.

Nevertheless, it is important to understand how any uncertainties and variability in model input parameters may impact on the results produced by the model. Therefore, a sensitivity analysis was undertaken to establish the sensitivity of the results generated by the computer model to changes in model input parameter values. The outcomes of the sensitivity analysis are presented below.

8.2 Model Parameter Sensitivity

8.2.1 Initial Loss / Antecedent Conditions

An analysis was undertaken for the 1% AEP storm to assess the sensitivity of the results generated by the TUFLOW model to variations in antecedent wetness conditions (i.e., the dryness or wetness of the catchment prior to the rainfall). A catchment that has been saturated prior to a major storm will have less capacity to absorb rainfall. Therefore, under wet antecedent conditions, there will be less "initial loss" of rainfall and consequently more runoff.

The variation in antecedent wetness conditions was represented by increasing and decreasing the initial rainfall losses in the TUFLOW model. Specifically, initial losses were changed from the "design" values of 10mm/1mm (for pervious/impervious areas respectively) to:

- "Wet" catchment: 0mm for pervious and impervious areas; and,
- "Dry" catchment: 20mm for pervious areas and 2mm for impervious areas

The TUFLOW model was used to re-simulate the 1% AEP event with the modified initial losses. Peak water levels were extracted from the results of the modelling and were compared against peak water flood levels for "base" design conditions. This allowed water level difference mapping to be prepared showing the magnitude of any change in water levels associated with the change in initial loss values. The difference mapping is presented in **Plate 14** and **Plate 15** for the "dry" and "wet" catchment scenarios respectively. Decreases in 1% AEP "design" flood levels associated with the changes in initial losses are shown in shades of green and blue and increases in 1% AEP flood levels are shown in shades of yellow and red.

The difference mapping was statistically analysed to determine the magnitude of changes in peak 1% AEP water levels across areas of significant inundation depth (i.e., greater than 0.15 metres). The outcomes of this statistical assessment are shown in **Table 15**. As shown in **Table 15**, the flood level differences are reported as a series of percentiles. For example, the complete blockage of hydraulic structures 95th percentile value of 0.13 metres indicates that 95% of the inundated areas are predicted to be exposed to changes in existing 1% AEP flood level of less than or equal to 0.13 metres.

Table 15 Percentile Change in 1% AEP Flood Levels Associated with Changes to TUFLOW Model Input Parameters

Sensitivity Analysis	**Percentile Changes in Levels** (metres)								
	1st	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**	**99th**
Lower Initial Rainfall Losses (Wet Catchment)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
Higher Initial Rainfall Losses (Dry Catchment)	-0.03	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lower Continuing Loss Rates	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Higher Continuing Loss Rates	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manning's "n" reduced by 20%	-0.09	-0.06	-0.04	-0.03	-0.01	0.00	0.02	0.04	0.07
Manning's "n" increased by 20%	-0.03	-0.01	0.00	0.00	0.01	0.03	0.04	0.06	0.09
No Blockage of Hydraulic Structures	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Complete Blockage of Hydraulic Structures	-0.03	-0.03	-0.01	0.00	0.00	0.00	0.06	0.13	0.42
Fence Blockage 0%	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Fence Blockage 90%	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08
Lower Downstream Water Levels	-0.50	-0.50	-0.50	-0.50	-0.39	-0.20	0.00	0.00	0.00
Higher Downstream Water Levels	0.00	0.00	0.04	0.28	0.42	0.49	0.50	0.50	0.50

Peak 1% AEP flood levels were also extracted from the results of the sensitivity simulations at various locations across the catchment and are presented in **Table 16**.

The difference mapping shows that a lower initial loss value will produce increases in 1% AEP flood levels at isolated locations across the study area. Conversely, the higher initial loss is predicted to generate scattered reductions in 1% AEP water levels. However, the difference mapping and information presented in **Table 15** shows that the magnitude of the changes is generally predicted to be less than 0.03 metres.

Overall, the model is relatively insensitive to changes in the adopted initial losses across most of the study area. Therefore, it can be concluded that any uncertainties associated with the adopted initial loss rates are not predicted to have a significant impact on the results generated by the TUFLOW model.

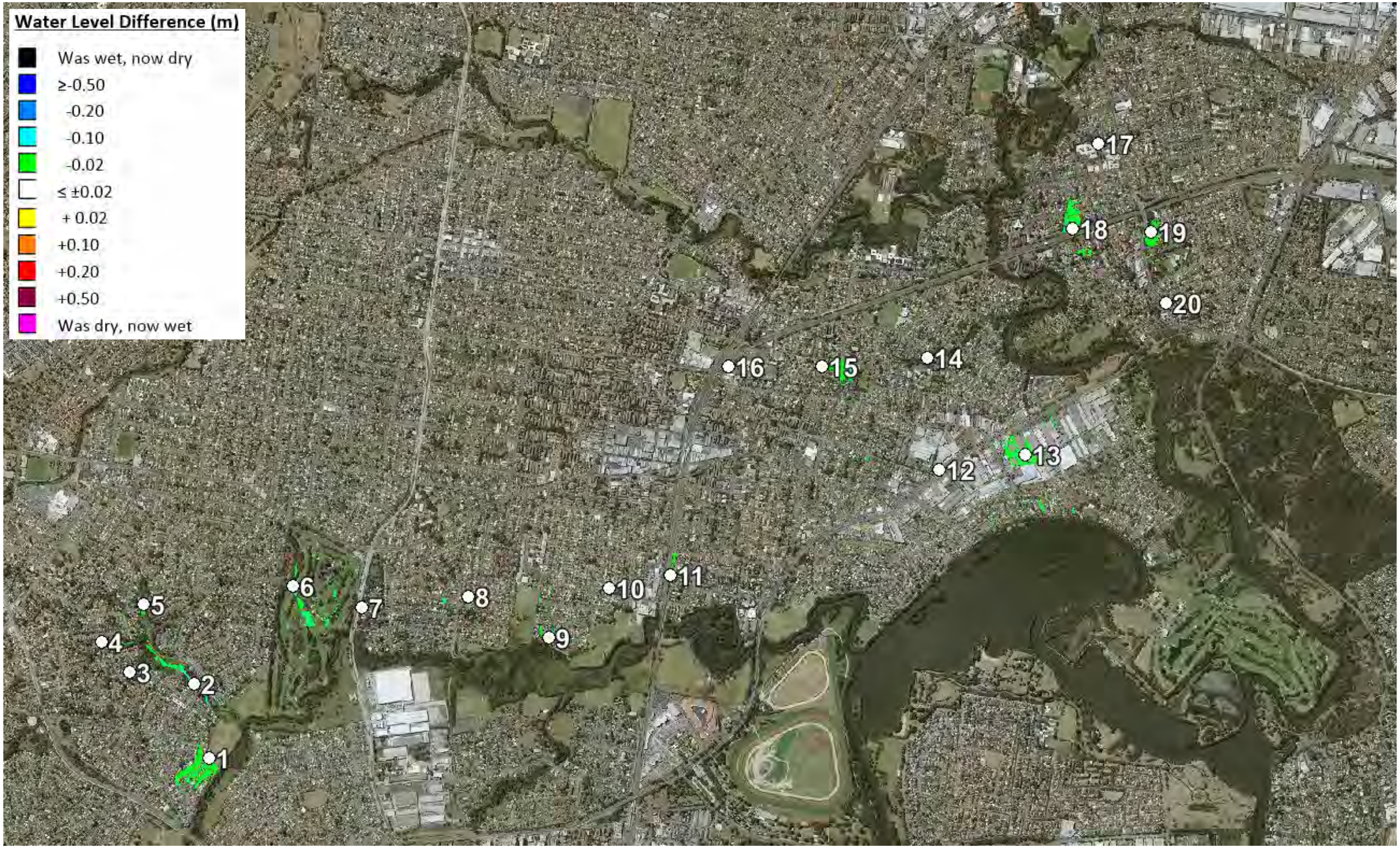


Plate 14 Flood level difference map with higher initial rainfall losses (i.e., dry catchment)

Plate 15 Flood level difference map with lower initial rainfall losses (i.e., wet catchment)

Table 16 Peak 1% AEP Sensitivity Simulation Flood Levels at Various Locations across the Catchment

Location ID	Peak 1% AEP Flood Levels (mAHD)												
	"Base" Case	Lower Initial Loses	Higher Initial Loses	Lower Continuing Loses	Higher Continuing Loses	Lower Manning's "n"	Higher Manning's "n"	No Blockage	Complete Blockage	Fence Blockage 0%	Fence Blockage 90%	Lower Creek Level	Higher Creek Level
1	11.86	11.88	11.83	11.87	11.85	11.83	11.89	11.85	12.15	11.86	11.89	11.82	11.92
2	15.49	15.51	15.37	15.49	15.47	15.51	15.45	15.51	15.87	15.50	15.32	15.49	15.48
3	25.59	25.59	25.57	25.59	25.59	25.59	25.59	25.59	25.69	25.48	25.48	25.59	25.59
4	31.92	31.92	31.90	31.92	31.92	31.90	31.94	31.92	31.98	31.90	32.19	31.92	31.92
5	28.72	28.73	28.70	28.72	28.72	28.72	28.72	28.73	28.72	28.73	28.69	28.72	28.72
6	18.74	18.75	18.71	18.74	18.74	18.72	18.76	18.74	18.74	18.74	18.74	18.74	18.74
7	18.48	18.48	18.46	18.48	18.48	18.48	18.48	18.44	18.57	18.48	18.48	18.48	18.48
8	19.76	19.76	19.74	19.76	19.76	19.73	19.78	19.76	19.91	19.77	19.65	19.76	19.76
9	7.81	7.81	7.78	7.81	7.80	7.82	7.79	7.75	7.98	7.81	7.79	7.79	7.82
10	7.75	7.76	7.73	7.75	7.74	7.74	7.75	7.74	7.83	7.75	7.73	7.74	7.76
11	7.65	7.66	7.63	7.65	7.65	7.64	7.66	7.64	7.71	7.65	7.63	7.65	7.65
12	8.99	9.00	8.97	8.99	8.98	8.99	8.98	8.98	9.05	8.99	8.98	8.99	8.99
13	6.95	7.00	6.94	6.96	6.94	6.95	6.95	6.94	7.16	6.95	6.94	6.94	7.03
14	6.59	6.59	6.59	6.59	6.59	6.55	6.61	6.59	6.59	6.59	6.58	6.34	6.97
15	8.19	8.21	8.18	8.20	8.19	8.19	8.20	8.19	8.28	8.19	8.21	8.19	8.20
16	10.41	10.42	10.40	10.41	10.41	10.41	10.41	10.40	10.52	10.41	10.39	10.41	10.41
17	9.27	9.27	9.26	9.27	9.27	9.26	9.27	9.24	9.33	9.25	9.35	9.27	9.27
18	7.65	7.68	7.62	7.65	7.64	7.65	7.65	7.64	7.87	7.65	7.64	7.63	7.68
19	13.29	13.31	13.27	13.29	13.29	13.29	13.29	13.22	13.47	13.29	13.31	13.29	13.29
20	14.04	14.05	14.03	14.04	14.04	14.04	14.04	14.04	14.10	14.04	14.08	14.04	14.04

8.2.2 Continuing Loss Rate

An analysis was also undertaken to assess the sensitivity of the results generated by the TUFLOW model to variations in the adopted continuing loss rates. Accordingly, the continuing loss rates within the TUFLOW model were changed from the "design" values of 2.5 mm/hr (pervious areas) and 0 mm/hr (impervious areas) to:

- <u>Increased Continuing Loss Rates</u>: 3.5mm/hr for pervious areas and 1mm/hr for impervious areas.
- <u>Decreased Continuing Loss Rates</u>: 1.5mm/hr for pervious areas and 0mm/hr for impervious areas.

The TUFLOW model was used to re-simulate the 1% AEP flood with the modified continuing loss rates. Flood level difference mapping was prepared based upon the results of modelling. However, this determined that the changes in rainfall losses had negligible impact on peak 1% AEP flood levels (changes in levels in almost all instances were ≤0.02 m). This outcome is also reflected in **Table 15** as well as **Table 16**., which shows percentile changes in existing flood levels of only 0.01 metres.

Overall, the results of the sensitivity analysis show that the TUFLOW model is insensitive to changes in continuing loss rates. Therefore, it can be concluded that any uncertainties associated with the adopted continuing loss rates are not predicted to have a significant impact on the results generated by the TUFLOW model.

8.2.3 Manning's "n"

Manning's' "n" roughness coefficients are used to describe the resistance to flow afforded by different land uses and surfaces across the catchment. However, they can be subject to variability (e.g., vegetation density in the summer would typically be higher than the winter leading to higher Manning's "n" values). Therefore, additional analyses were completed to quantify the impact that any uncertainties associated with Manning's "n" roughness values may have on predicted design flood behaviour.

The TUFLOW model was updated to reflect a 20% increase and a 20% decrease in the adopted design Manning's "n" values and additional 1% AEP simulations were completed with the modified "n" values. Flood level difference mapping was prepared based on the results of the revised simulations and are presented in **Plate 16** and **Plate 17**.

The difference maps were also statistically analysed, and the outcomes of the analysis are presented in **Table 15**. Peak 1% AEP flood levels were also extracted from the results of the sensitivity simulations at various locations across the study area and are presented in **Table 16**.

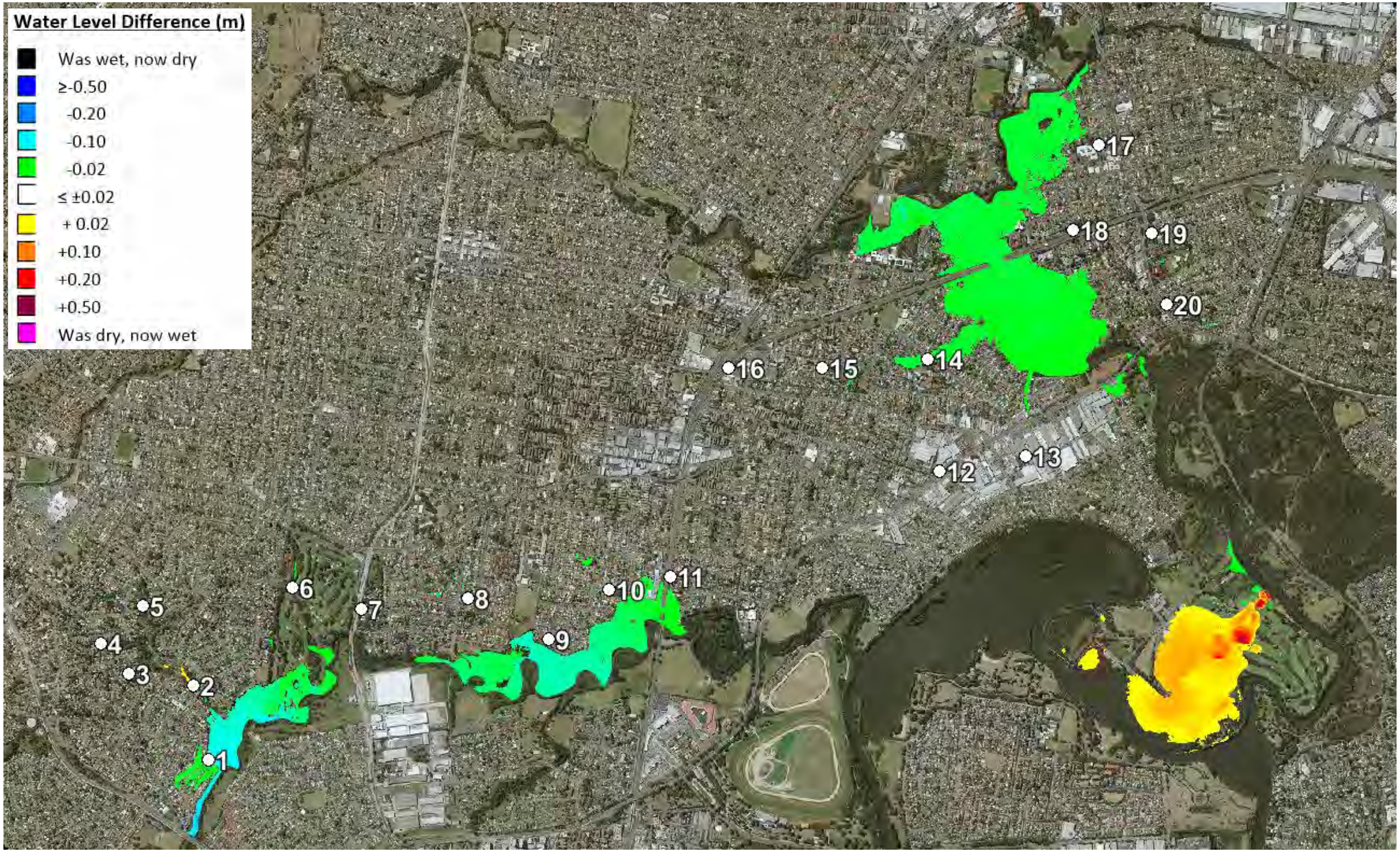


Plate 16 Flood level difference map with decreased Manning's "n" roughness values

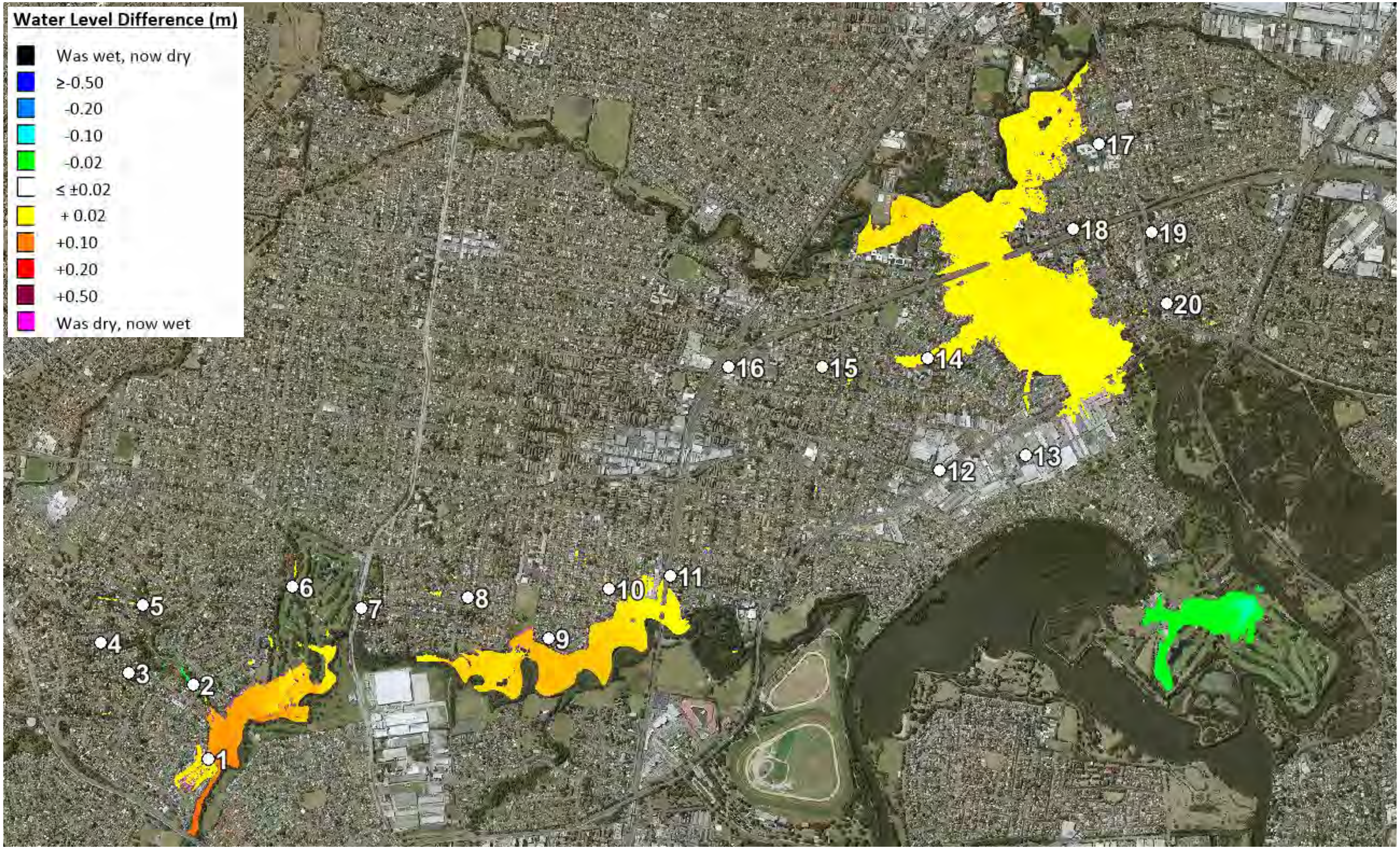


Plate 17 Flood level difference map with increased Manning's "n" roughness values

The results show that altering the Manning 's "n" values have the potential to both increase and decrease "design" 1% AEP flood levels. **Plate 16** shows that decreasing the "n" values will typically lower flood levels along major flow paths and waterways as water is able to "escape" more readily from these areas. However, this can result in localised increases in water level across volume sensitive sections of the catchment where flow is concentrated (e.g., behind roadway embankments).

In general, the changes in 1% AEP flood levels are predicted to be less than 0.1 metres. As a result, it is considered that the model is relatively insensitive to changes in Manning's 'n' values.

8.2.4 Hydraulic Structure Blockage

As discussed in Section 6.3.2, blockage factors ranging between 0% and 100% were applied to all bridges, culverts and stormwater inlets as part of the design flood simulations. However, as it is not known which structures will be subject to what percentage of blockage during any particular flood, additional TUFLOW simulations were completed to determine the impact that alternate blockage scenarios would have on flood behaviour. Specifically, additional simulations were undertaken with no blockage as well as complete blockage of all stormwater inlets, bridges and culverts.

Flood level difference mapping was prepared based on the results of the blockage sensitivity simulations and is presented in **Plate 18** and **Plate 19**. The difference maps were also statistically analysed, and the outcomes of the analysis are presented in **Table 15**.

Peak 1% AEP flood levels were also extracted from the results of the sensitivity simulations at various locations across the catchment and are presented in **Plate 18**. This information shows that no blockage will generally produce localised decreases in 1% AEP water levels upstream of major hydraulic structures and will increase water levels downstream of major hydraulic structures as well as along major watercourses. However, the magnitude of the flood level difference is generally less than 0.1 metres.

Plate 19 shows that complete blockage will cause some more significant changes to 1% AEP flood levels. 1% AEP flood levels are predicted to increase by well over 1 metre at some locations and are driven by the significantly elevated road and rail embankments in some areas. There are predicted to be some commensurate decreases in water level downstream of these structures, which are associated with the "damming" effect provided by the embankment. However, complete blockage is predicted to increase water levels across most of the catchment.

Plate 19 also shows that complete blockage of the stormwater inlets is predicted to increase flood levels along most overland flow paths. Accordingly, even though the stormwater system has a relatively limited capacity, it still plays an important role in reducing the severity of flooding during most floods.

Plate 18 Flood level difference map with no blockage of hydraulic structures

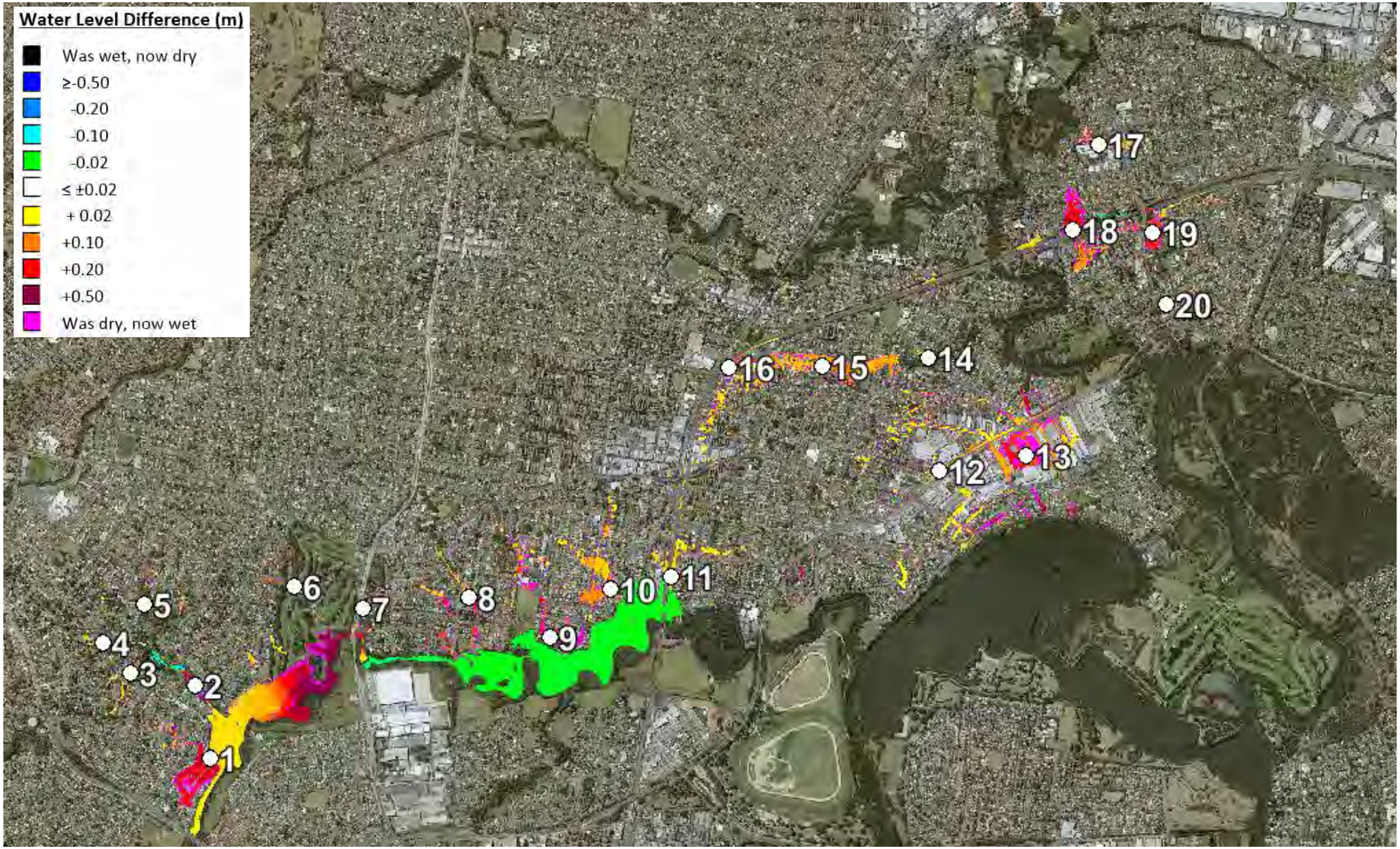


Plate 19 Flood level difference map with complete blockage of hydraulic structures

The results of the blockage sensitivity analysis do show that the model results are sensitive to variations in blockage in the immediate vicinity of major hydraulic structures, particularly if complete blockage of structures/stormwater inlets occurs. Areas located upstream of elevated roadway embankments are predicted to be the most significantly impacted. This outcome emphasises the need to ensure key drainage infrastructure, bridges and culverts are well maintained (i.e., debris is removed on a regular basis).

8.2.5 Fence Blockage

As discussed in Section 4.2.7, a representation of fences was included in the TUFLOW due to their potential to have an impact on the distribution of overland flows. It is acknowledged that there is considerable uncertainty associated with fences and the degree of blockage that they may afford during floods due to the wide range of fence types located across the study area. As part of the "design" simulations, it was assumed that each fence would afford a 50% blockage.

To assess the impact that alternate fence blockage factors may have on peak flood level estimates, additional 1% AEP simulations were completed assuming no blockage of fences as well as 90% blockage.

Flood level difference mapping was prepared for the zero blockage and 90% blockage cases and is presented in **Plate 20** and **Plate 21** respectively. A statistical analysis of the differences is presented in **Table 15**. Flood level values extracted at key locations are presented in **Table 16**.

Plate 20 shows that removing fence blockage produces small, localised changes in peak flood levels in the immediately vicinity of the fence. However, the changes are very localised and typically do not exceed ±0.03 metres.

Plate 21 shows that increasing the blockage from 50% to 90% is predicted to generate some more extensive changes in flood levels. In general, flood levels upstream of the fences are predicted to increase by between 0.05 and 0.10 metres (on average), although increases of around 0.2 metres are predicted across some areas. Decreases in flood levels are predicted along Prout Creek and are likely associated with the fence blockage serving to attenuate flows.

Overall, fence blockage is predicted to have some impact of flood levels across the study area. In general, the model is more sensitive to increases in blockage factors rather than decreases.

Plate 20 Flood level difference map with zero fence blockage

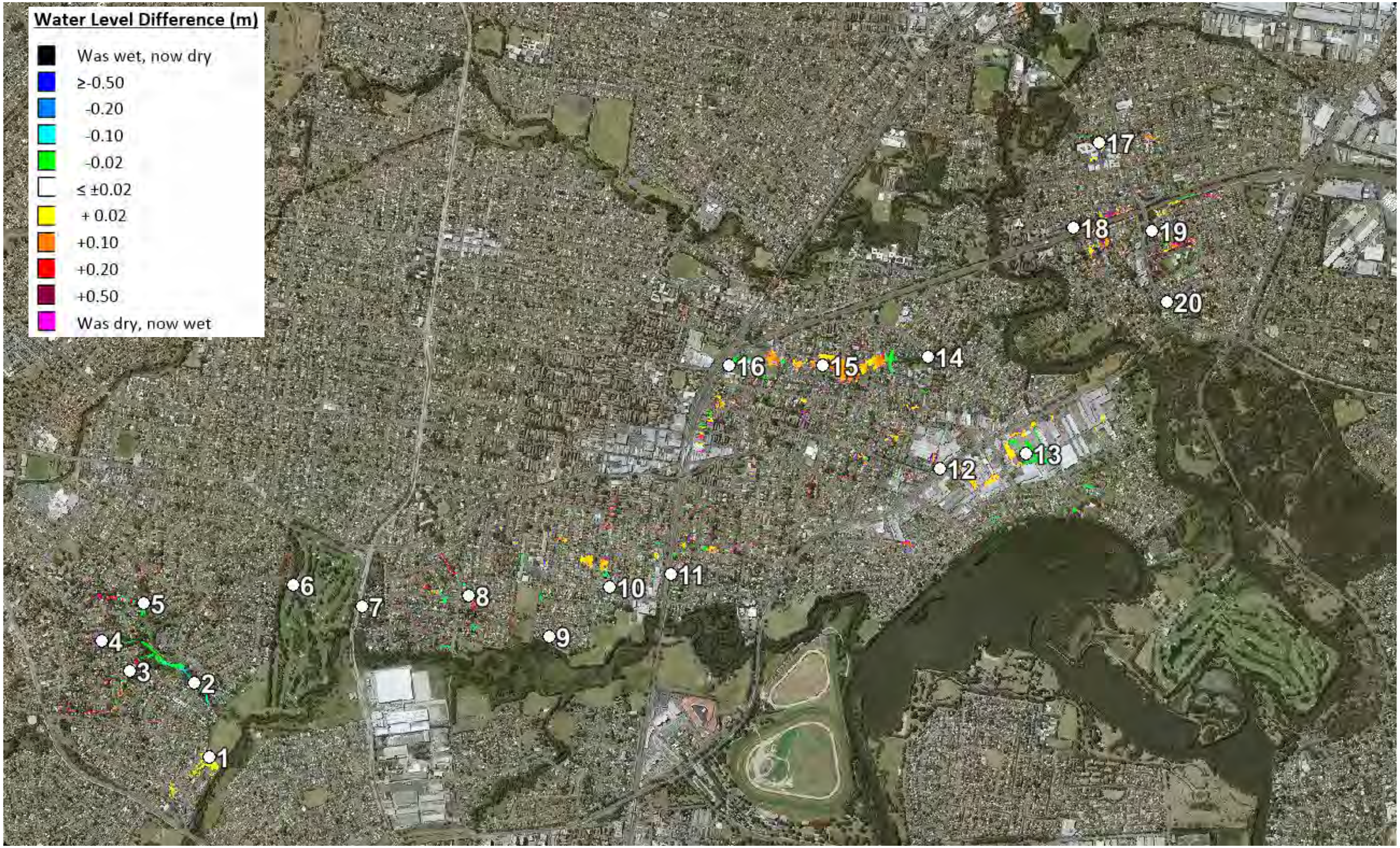


Plate 21 Flood level difference map with increased fence blockage

8.2.6 Downstream Boundary Conditions

The downstream boundary of the study area is formed by Prospect Creek, Cabramatta Creek and the Georges River. The "base" simulations assumed coincidental flooding was occurring in these receiving waterways at the same time as the local catchment. However, given the differing characteristic of these catchments relative to the much smaller local catchment, there is potential of floods of differing severities occurring in each receiving waterway relative to the local catchment. Therefore, additional sensitivity simulations were completed to quantify the impact that higher and lower receiving water levels would have across the study area.

The additional 1% AEP sensitivity simulations included:

- A 10% increase in Prospect and Cabramatta Creek inflows in addition to the Georges River level being 0.5 metres higher; and,
- A 10% decrease in Prospect and Cabramatta Creek inflows in addition to the Georges River level being 0.5 metres lower.

The TUFLOW model was used to re-simulate the 1% AEP flood with the different downstream boundary conditions. Flood level difference mapping was prepared based on the results of the revised simulations and is presented in **Plate 22** and **Plate 23.**

The difference maps were also statistically analysed, and the outcomes of the analysis are presented in **Table 15**. Peak 1% AEP flood levels were also extracted from the results of the sensitivity simulations at various locations across the catchment and are presented in **Table 16**.

Plate 22 shows that reducing the downstream flows / water levels is predicted to reduce water levels along each receiving waterway. The reductions are typically contained between 0.1 and 0.5 metres (with 0.4 metre reductions being most typical). Accordingly, the reductions do have the potential to produce some significant reductions in flood levels. However, the reductions are generally contained in close proximity to each of the receiving waterways. More specifically, the flood level reductions are generally contained within 150 metres of Cabramatta Creek and 250 meters of Prospect Creek (although more extensive areas are impacted towards the confluence of Prospect Creek and the Georges River). Flood levels across those sections of the study area that are elevated well above the floodplain of the receiving waterways are not predicted to be impacted by variations in downstream water levels/flows.

Plate 23 shows that increasing the downstream flows / water levels is predicted to increase flood levels along each receiving waterway. The magnitude of the flood level increases along the watercourses are generally predicted to vary between 0.1 and 0.5 metres, with the median increase being 0.42 metres. Like the reduced downstream boundary condition scenario, the flood level differences are contained to areas adjoining each of the receiving waterways, with elevated sections of the study area not being impacted.

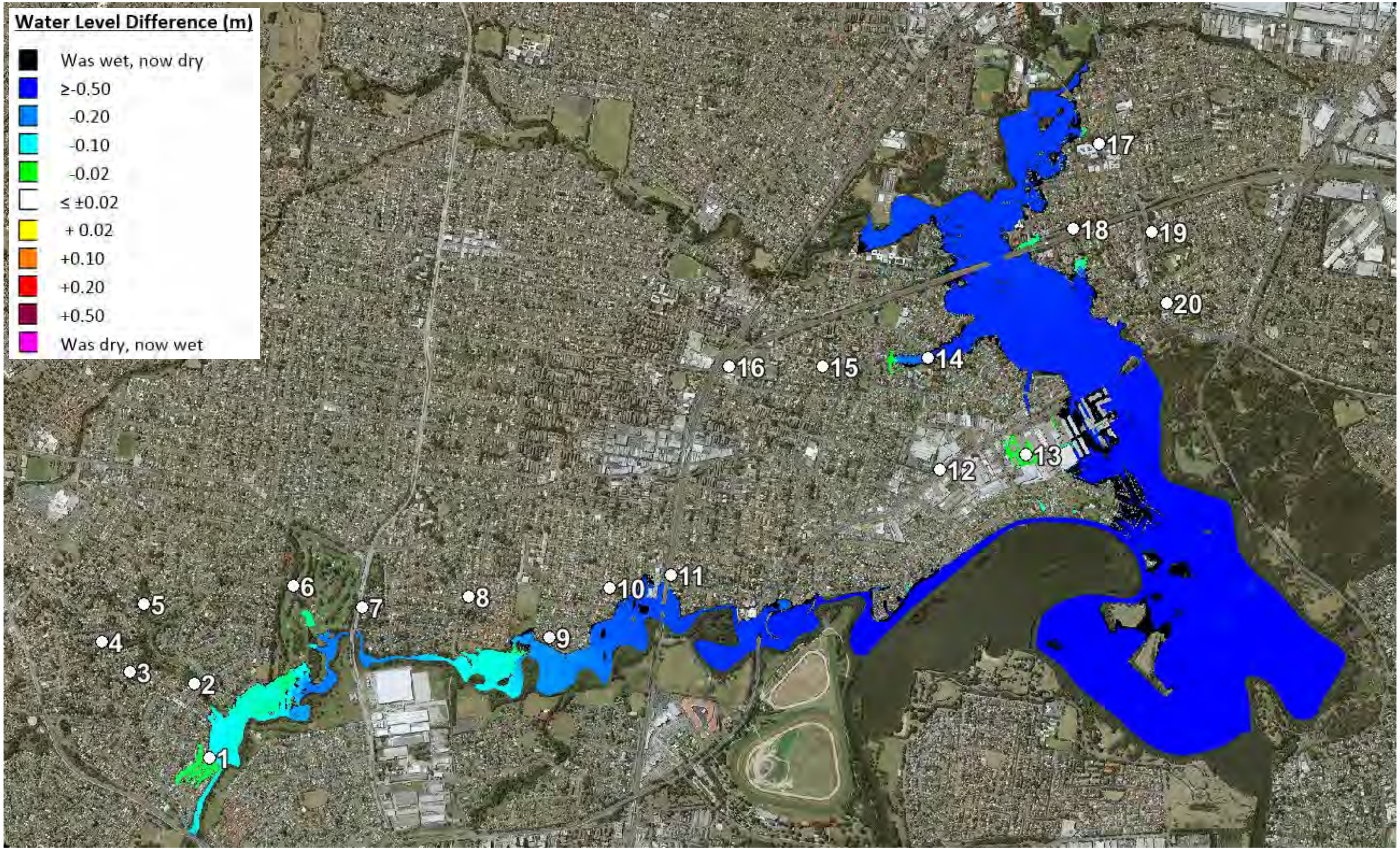


Plate 22 Flood level difference map with lower downstream water levels

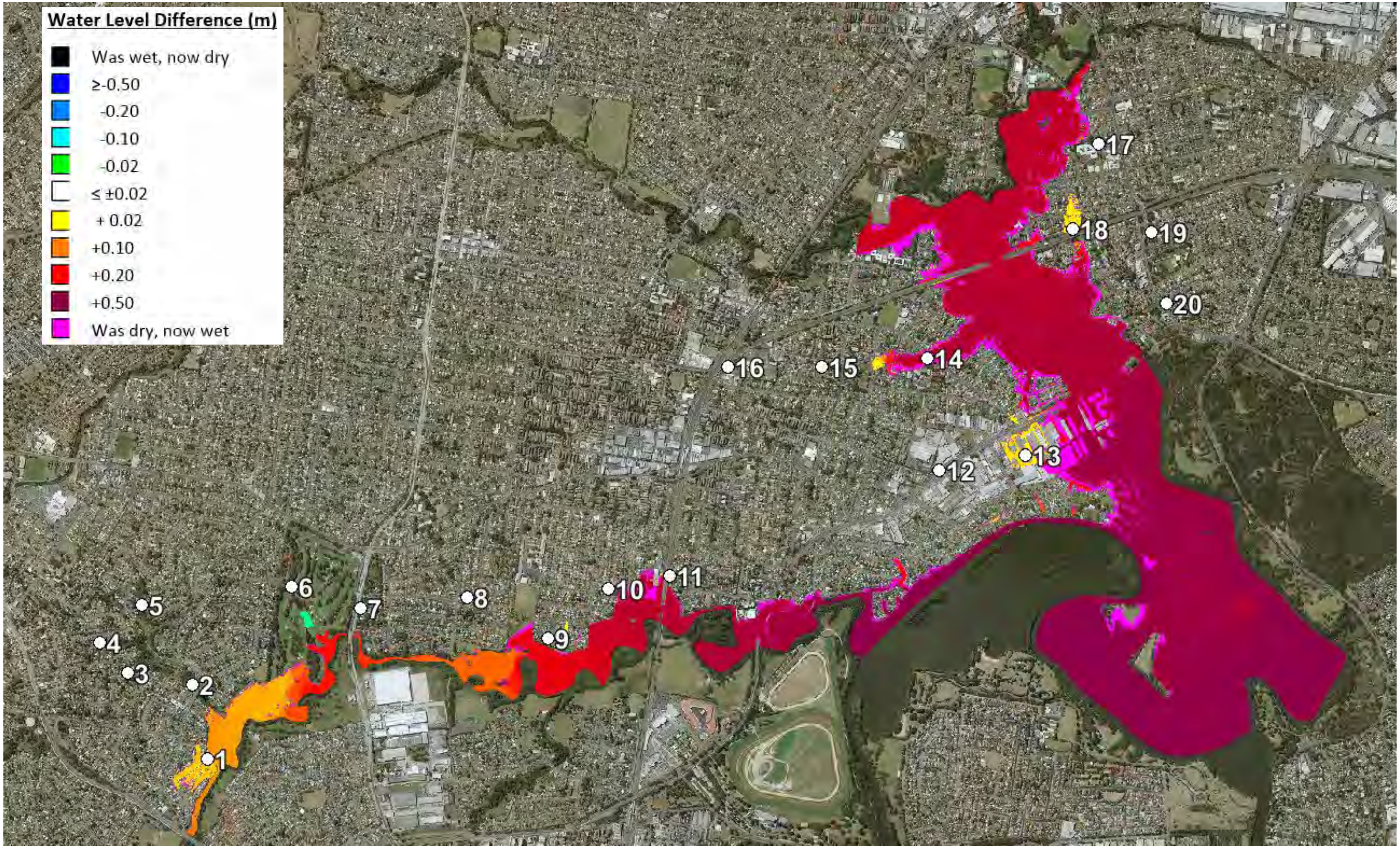


Plate 23 Flood level difference map with higher downstream water level

Overall, it can be concluded that the 1% AEP flood levels across areas lower lying sections of the study area are sensitive to changes in the adopted Prospect Creek, Cabramatta Creek and Georges River water level. However, flood level impacts across the more elevated sections of the catchment are predicted to be negligible.

9 CLIMATE CHANGE ANALYSIS

9.1 Overview

The *'Practical Consideration of Climate Change'* (Department of Environment and Climate Change, 2007) guideline states that rainfall intensities are likely to increase in the future. The NSW Government's *'Climate Change in the Sydney Metropolitan Catchments'* (CSIRO, 2007) elaborates on this further and suggests that annual rainfall is likely to decrease, however, extreme rainfall events are likely to be more intense. It is anticipated that extreme rainfall intensities could increase by between 2% and 24% by 2070 (Department of Environment and Climate Change, 2007). This has the potential to increase the severity of flooding across Cabravale catchment in the future.

To gain an understanding of the potential impact that climate change-induced rainfall intensity increases may have on flood behaviour across the catchment, additional climate simulations were completed. Due to the wide potential variability of future rainfall intensities, the *'Practical Consideration of Climate Change'* (Department of Environment and Climate Change, 2007) recommends that additional simulations should be completed with 10%, 20% and 30% increases in rainfall intensities to quantify the potential impacts associated with climate change. The outcomes of the climate change simulations are presented in the following section.

Although increases in sea level do have the potential to impact on flood levels along Prospect Creek, Cabramatta Creek and the Georges River, the outcomes of the sensitivity analysis documented in the previous chapter determined that the elevated sections of the study area are not impacted by variations in water levels along each of the waterways. Therefore, the potential impacts of sea level rise have not been assessed as part of the current study.

9.2 Rainfall Intensity Increases

The TUFLOW model was used to perform additional simulations including 10%, 20% and 30% increases in 1% AEP rainfall intensities. It should be noted that only the rainfall intensities were altered. That is, inflow boundary conditions along Prospect and Cabramatta Creeks as well as the Georges River water level boundary conditions were not changed.

Peak floodwater levels were extracted from the results of the modelling and were compared against peak water flood levels for 'base' 1% AEP conditions. This allowed water level difference mapping to be prepared showing the magnitude of any change in water levels associated with the increases in rainfall intensity. The difference mapping is presented in **Plate 24**, **Plate 25** and **Plate 26**. The difference maps were also statistically analysed, and the outcomes of the analysis are presented in **Table 17**. **Table 17** provides the flood level differences as a series of percentiles.

Plate 24 Flood level difference map with 10% increase in Rainfall

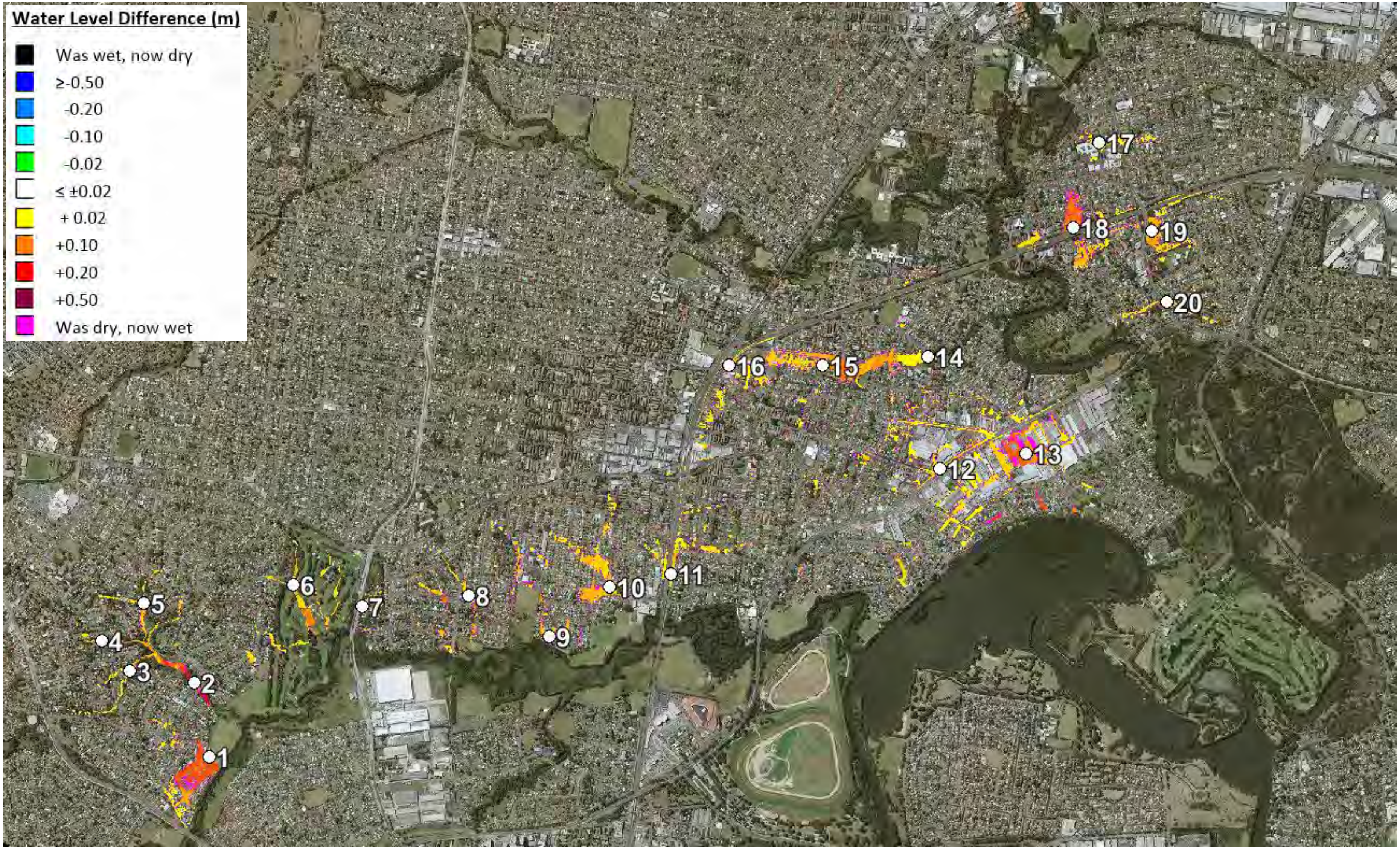


Plate 25 Flood level difference map with 20% increase in Rainfall

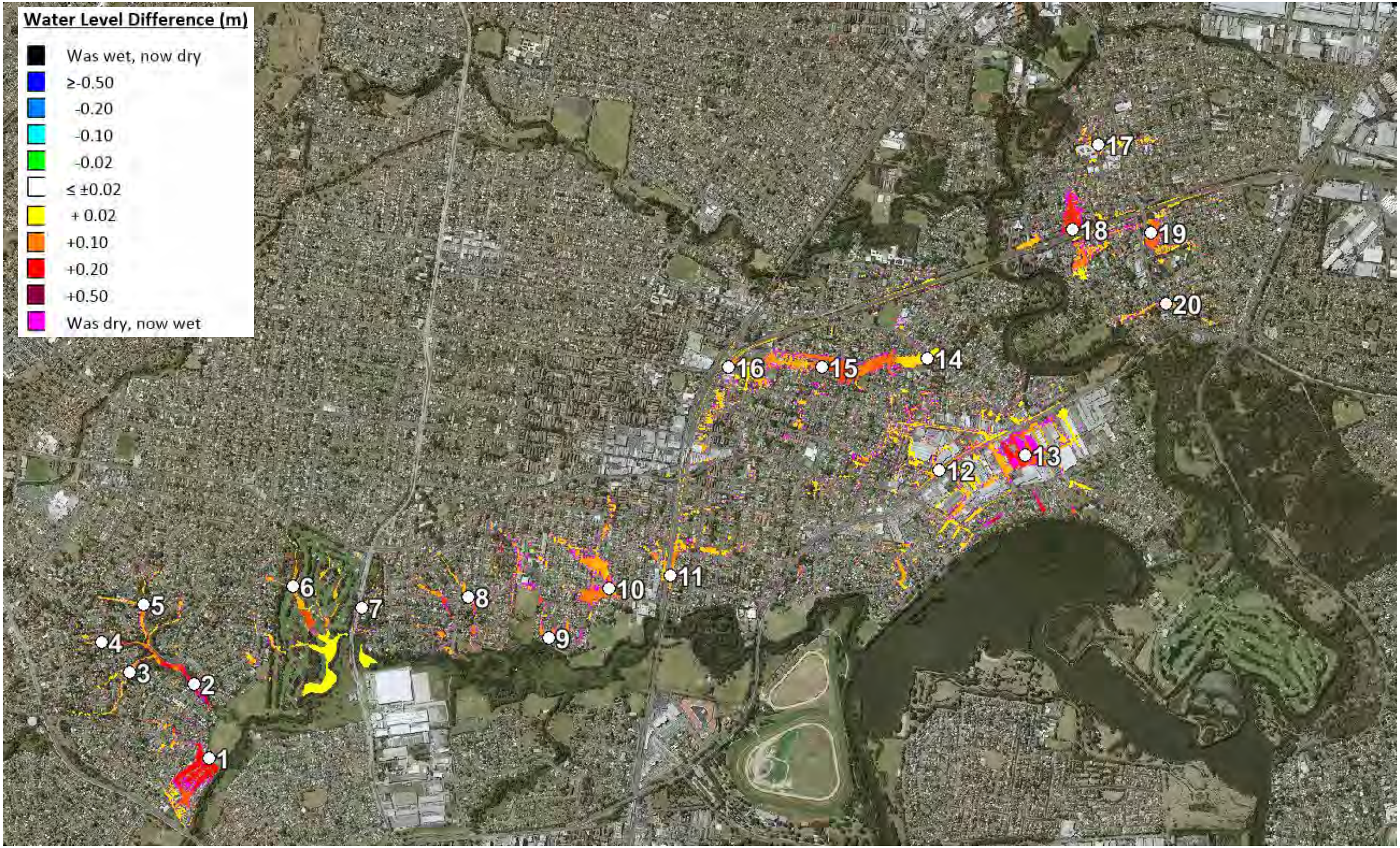


Plate 26 Flood level difference map with 30% increase in Rainfall

Table 17 Percentile Change in 1% AEP Flood Levels Associated with Climate Change

Climate Change Scenario	Percentile Changes in Levels (metres)								
	1st	5th	10th	25th	50th	75th	90th	95th	99th
10% increase in rainfall	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06
20% increase in rainfall	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.05	0.13
30% increase in rainfall	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.08	0.17

Peak 1% AEP flood levels were also extracted from the results of the climate change simulations at a variety of discrete locations across the study area and are presented in **Table 18**. The location of each flood level extraction point is shown in **Plate 24**, **Plate 25** and **Plate 26**.

Table 18 Difference in the 1% AEP Flood Levels and Climate Change Simulation at Various Locations across the Catchment

Location ID	'Base' Water Level (mAHD)	10% Increase in Rainfall		20% Increase in Rainfall		30% Increase in Rainfall	
		Level (mAHD)	Difference (metres)	Level (mAHD)	Difference (metres)	Level (mAHD)	Difference (metres)
1	12.25	11.93	0.07	12.00	0.14	12.06	0.20
2	15.44	15.59	0.11	15.68	0.19	15.74	0.25
3	25.58	25.63	0.04	25.69	0.10	25.74	0.15
4	31.98	31.94	0.02	31.97	0.05	31.99	0.08
5	28.72	28.76	0.04	28.80	0.07	28.83	0.11
6	18.80	18.78	0.04	18.82	0.07	18.85	0.11
7	18.48	18.50	0.02	18.52	0.05	18.54	0.06
8	19.74	19.82	0.06	19.84	0.08	19.87	0.11
9	7.77	7.84	0.04	7.87	0.06	7.89	0.09
10	7.76	7.78	0.03	7.81	0.06	7.84	0.09
11	7.65	7.68	0.03	7.71	0.06	7.74	0.09
12	8.96	9.02	0.03	9.04	0.06	9.06	0.08
13	6.94	7.06	0.10	7.12	0.17	7.16	0.21
14	6.60	6.60	0.01	6.61	0.02	6.62	0.03
15	8.20	8.23	0.04	8.27	0.08	8.30	0.11
16	10.41	10.44	0.03	10.47	0.06	10.50	0.08
17	9.28	9.28	0.01	9.29	0.03	9.31	0.04
18	7.64	7.71	0.06	7.77	0.12	7.82	0.17
19	13.31	13.33	0.04	13.36	0.07	13.40	0.11
20	14.05	14.07	0.02	14.09	0.04	14.10	0.06

The results of the climate change simulations indicate that increases in rainfall intensity do have the potential to increase existing 1% AEP flood levels. Across most areas, the increases are not predicted to exceed 0.1 metres. However, some areas are predicted to experience more significant flood level increases. This includes flood level increases of over 0.3 metres during the 30% increase in rainfall scenario along Prout Creek near the Townview Road culvert.

10 CONCLUSION

This report documents the outcomes of investigations completed to quantify overland and mainstream flood behaviour across the Cabravale study area. It provides information on design flood levels, depths and velocities as well as hydraulic and flood hazard categories for a range of design floods.

Flood behaviour across the study area was defined using a direct rainfall computer model that was developed using the TUFLOW software. The computer model included a full representation of the stormwater drainage system and all bridges and culverts. Major overland flow impediments including buildings and fences as well as road and rail embankments were also included in the model.

The computer model was validated using historic rainfall and reported descriptions of flood behaviour that were provided by the community for floods that occurred in 2012, 2015 and 2016. The model was also verified against alternate modelling techniques.

The calibrated and verified model was used to simulate the design 20%, 5%, 1% and 0.2% annual exceedance probability (AEP) floods as well as the 1 in 10,000 year and Probable Maximum Flood (PMF). The following conclusions can be drawn from the results of the investigation:

- Flooding across the catchment can occur as a result of major watercourses (i.e., Long and Prout Creeks) overtopping their banks, overland flooding when the capacity of the stormwater system is exceeded as well as inundation from elevated water levels in Prospect Creek, Cabramatta Creek and the Georges River.
- Flooding can occur from a variety of different storms and rainfall durations. The most critical flooding across the majority of the study area typically occurs as a result of rainfall bursts that are less than 2 hours in duration. However, longer storm durations will typically produce higher flood levels along Prospect Creek, Cabramatta Creek and the Georges River.
- Many of the stormwater pipes in the area are predicted to have a capacity no greater than the 20% AEP flood. Therefore, during large storms, considerable flow can be concentrated along drainage depressions and overland flow paths.
- Velocity mapping prepared as part of the study indicates that flow velocities may exceed 2 m/s during the 1% AEP flood. However, the higher velocity areas are typically contained to the main creeks. As a result, most areas are only predicted to be exposed to a low provision flood hazard.
- Inundation of over 2,100 properties is predicted at the peak of the 1% AEP flood (out of a total of 7,966 properties located within the study). During the PMF, 3,665 properties are predicted to be inundated. Most of these properties are inundated as a result of elevated water levels within Prospect Creek, Cabramatta Creek and the Georges River.

- A number of roadways are predicted to be overtopped during the 1% AEP flood. This would typically render the roadways impassable for at least 1 hour (but more commonly around 2 hours).

11 References

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12 GLOSSARY

acid sulphate soils
: are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.

annual exceedance probability (AEP)
: the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. Eg, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger events occurring in any one year (see also ARI).

Australian Height Datum (AHD)
: a common national surface level datum approximately corresponding to mean sea level.

average annual damage (AAD)
: depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.

average recurrence interval (ARI)
: the long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.

caravan and moveable home parks
: caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the Local Governments Act.

catchment
: the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.

consent authority
: the council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the council, however legislation or an EPI may specify

a Minister or public authority (other than a council), or the Director General of OEH, as having the function to determine an application.

development	is defined in Part 4 of the Environmental Planning and Assessment Act (*EP&A Act*). infill development: refers to development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. new development: refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	a step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ESD	Ecologically Sustainable Development (ESD) using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act, 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	a range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local

overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood awareness Awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood fringe areas the remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land is synonymous with flood prone land, i.e., land susceptible to flooding by the PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (see flood planning area).

flood mitigation standard the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.

floodplain risk management options the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.

floodplain risk management plan a management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.

flood plan (local) A sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.

flood planning area the area of land below the FPL and thus subject to flood related development controls.

flood planning levels (FPLs) are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans.

flood proofing

a combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.

flood prone land

land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.

flood readiness

Readiness is an ability to react within the effective warning time.

flood risk

potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.

existing flood risk**:** the risk a community is exposed to as a result of its location on the floodplain.

future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas

those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas

those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

freeboard

provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.

hazard

a source of potential harm or a situation with a potential to cause loss. In relation to this study the hazard is flooding which has the potential to cause damage to the community.

Definitions of high and low hazard categories are provided in Appendix L of the *Floodplain Development Manual* (*2005*).

historical flood a flood which has actually occurred.

hydraulics term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

local overland flooding inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

local drainage smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

mainstream flooding inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage councils have discretion in determining whether urban drainage problems are associated with major or local drainage. Major drainage involves:

- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or
- water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or
- major overland flowpaths through developed areas outside of defined drainage reserves; and/or
- the potential to affect a number of buildings along the major flow path.

mathematical / computer models the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

merit approach	the merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well-being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into council plans, policy, and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local flood risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood. <u>minor flooding</u>: Causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. <u>moderate flooding</u>: Low lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. <u>major flooding</u>: Appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	measures that modify either the flood, the property or the response to flooding.
peak discharge	the maximum discharge occurring during a flood event.
probable maximum flood (PMF)	the PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
probable maximum precipitation (PMP)	the PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

probability	A statistical measure of the expected chance of flooding (*see annual exceedance probability*).
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	equivalent to water level (both measured with reference to a specified datum).
stage hydrograph	a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	a plan prepared by a registered surveyor.
TUFLOW	is a 1-dimensional and 2-dimensional flood simulation software. It simulates the complex movement of floodwaters across a particular area of interest using mathematical approximations to derive information on floodwater depths, velocities and levels.
velocity	the speed or rate of motion (*distance per unit of time, e.g., metres per second*) in a specific direction at which the flood waters are moving.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	the horizontal distance in the direction of wind over which wind waves are generated.
XP-RAFTS	is a non-linear runoff routing software. It incorporates subcatchment information such as area, slope, roughness and percentage impervious and is used to simulate the transformation of historic or design rainfall into runoff (i.e., discharge hydrographs).

APPENDIX A

COMMUNITY CONSULTATION

How You Can Help

The computer model developed for the flood study will be calibrated against historic flood information at various locations across the catchment. Therefore, any flood photographs, videos and descriptions of flood depths / heights that you can provide will assist with calibrating the model.

Enclosed with this brochure is a questionnaire that aims to collect as much historic flood information as possible to assist with the model calibration. You are encouraged to complete the questionnaire and return it by the 23rd August 2017. Alternatively, the questionnaire can be completed online via the flood study website:
cabravale.floodstudy.com.au

Image courtesy of Fairfield City Champion

Further Information

To obtain further information on the Cabravale Overland Flood Study or to submit any information that you think may be valuable to the study, please contact:

David Tetley
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney NSW 2000
(02) 8355 5501
dtetley@csse.com.au

Janahan Jivajirajah
Fairfield City Council
PO Box 21
Fairfield NSW 1860
(02) 9725 4249
catchment@fairfieldcity.nsw.gov.au

Alternatively, you can visit the flood study website:
cabravale.floodstudy.com.au

Cabravale Overland Flood Study

Information Brochure

Fairfield City Council is preparing an overland flood study for the Cabravale catchment. This brochure provides an overview of the flood study and outlines how you can help

Introduction

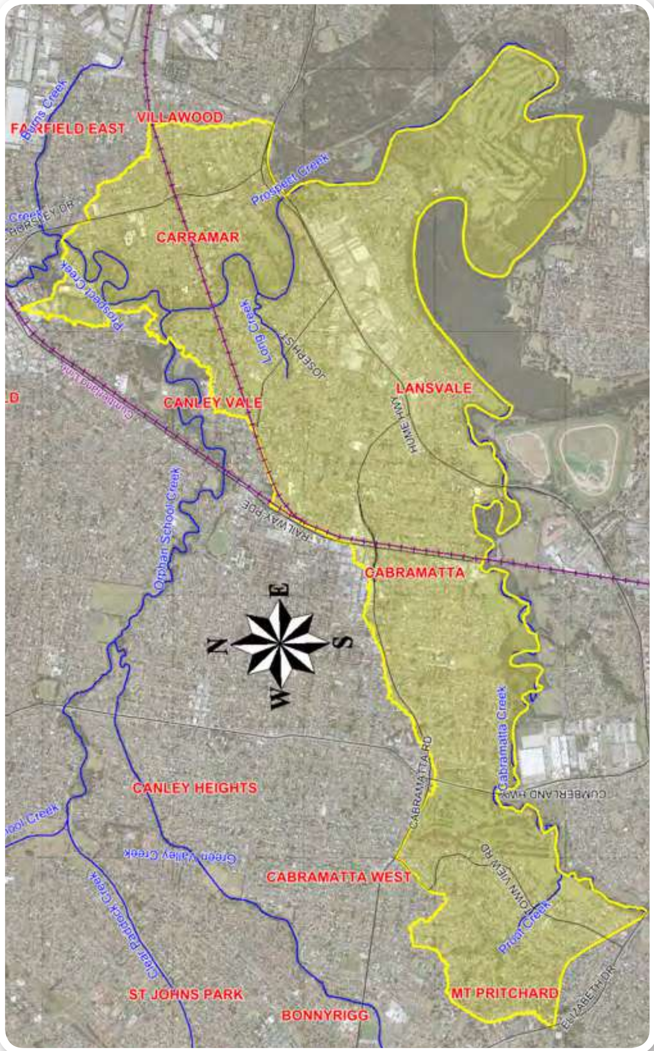
Flooding is the most costly form of natural disaster in Australia. It causes an estimated $314 million worth of damage each year. However, flooding is also one of the most managable natural disasters as we can reasonably predict which areas it will impact.

In an effort to better understand and manage the existing flood risks, Fairfield City Council is preparing an overland flood study for the Cabravale catchment. The catchment area is shown in yellow in the image on the right and includes sections of Carramar, Villawood, Canley Vale, Cabramatta, Lansvale and Mount Pritchard.

During most rainfall events, runoff is carried by the stormwater system into Long, Prout, Prospect or Cabramatta Creeks. However, during periods of heavy rainfall there is potential for the capacity of the stormwater system (underground pipes) to be exceeded and lead to overland flooding. The most recent overland flooding in the catchment occured in June 2016.

Overland flooding can cut roadways and inundate properties. This can result in damage to garages, sheds and homes. It can also place lives at risk. Flooding can also impose a significant financial and emotional burden on individuals and businesses.

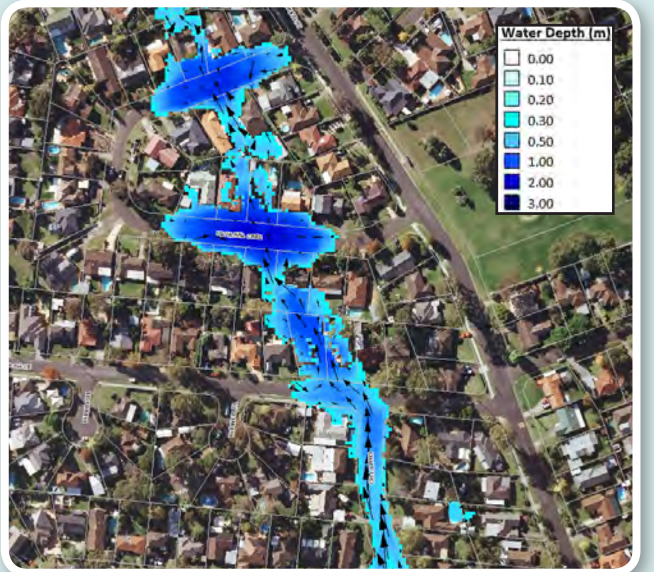
The preparation of a flood study will enable key flooding characteristics such as floodwater depths and speed to be established across the catchment.



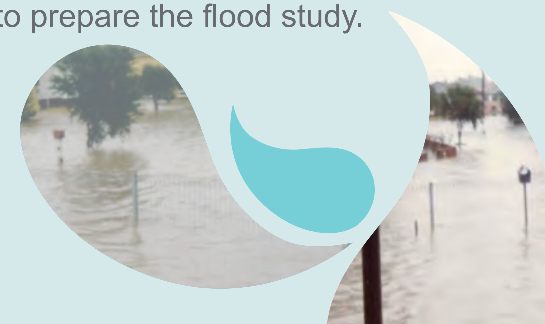
This flood study information will allow Council to confirm the location of flooding problems and identify where flood mitigation measures (e.g. stormwater upgrades) may be best implemented to reduce the impact of flooding on the community. It will also assist with emergency management and guide future development and re-development so that it is compatible with the flood risk.

What is a Flood Study?

The primary objective of the flood study is to identify the nature and extent of the existing flooding problem. This will be primarily achieved through the development of a computer flood model, which will be used to quantify the capacity of the stormwater system and simulate how overland flow would move through the catchment. An example of a floodwater depth and speed map that is produced by a computer flood model is shown below.



Council has commisioned specialist flood consultants, Catchment Simulation Solutions, to prepare the flood study.



Section 3 - Additional Flood Information

1. How fast do floodwaters typically move in your area?
   - ☐ Stays still
   - ☐ Walking pace
   - ☐ Running pace

2. In your opinion, what is the main cause of flooding (e.g., stormwater system blockage, stormwater capacity, obstructions to overland flow - fences, garages)?

3. Do you have any suggestions on ways of reducing the flooding problems?

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

FairfieldCity
Celebrating diversity

Cabravale Overland Flood Study

Questionnaire

This questionnaire has been prepared to assist Fairfield City Council to better understand the flooding "trouble spots" across the Cabravale catchment and to assist in the calibration of a computer flood model that will be developed as part of the Cabravale Overland Flood Study.

The following questionnaire should only take around 10 minutes to complete. Try to answer as many questions as possible and give as much detail as possible (attach additional pages if necessary).

Once complete, please return the questionnaires by the 23rd August 2017 to:

catchment@fairfieldcity.nsw.gov.au

OR

Janahan Jivajirajah
Fairfield City Council
PO Box 21
Fairfield NSW 1860

Alternatively, if you have internet access, an online version of the questionnaire can be completed at: www.cabravale.floodstudy.com.au

Section 1 - General Information

Can you please provide your contact details in case we need to contact you for additional information? Note that answering this question is optional. If you do provide contact details, this information will remain confidential at all times and will not be published (refer to privacy statement at the bottom of this page).

Name: ______________________________

Address: ______________________________

Phone No. ______________________________

Email: ______________________________

Please tick ☑ the best answer to the following questions.

1. What type of property is this?

☐ Residential

☐ Commerical

☐ Industrial

☐ Vacant Land

☐ Other (Please specify:______________________________)

2. What is the occupier status of the property?

☐ Owner occupied

☐ Rental property

☐ Business

☐ Other (Please specify:______________________________)

3. How long have you lived / worked in the area:

(a) At this address? ______________________________

(b) In the Cabravale area? ______________________________

PROTECTING YOUR PRIVACY – The personal information requested on this form will only be used for the Cabravale Overland Flood Study. The supply of this information by you is voluntary. Council is regarded as the agency that holds the information and will endeavour to ensure that this information remains secure, accurate and up-to-date. Access to information is restricted to Council Officers and other authorised people. You may make applications for access to information held by Council. You may also request an amendment to information held by Council. Should you require further information please contact Fairfield City Council.

Section 2 - Flood History

1. As far as you know, has your property ever been affected by flooding?

☐ Yes

☐ No (If you answered No, please go to Question 3 on final page)

2. How were you impacted by flooding (you can select more than one option)?

☐ Traffic was disrupted

☐ My front / back yard was flooded

☐ My garage was flooded

☐ My house was flooded

☐ Other (Please specify): ______________________________

____

____

3. Can you tell us on what dates the flooding occurred and how high the flood waters reached (attach additional pages if you have information on more than 2 floods)?

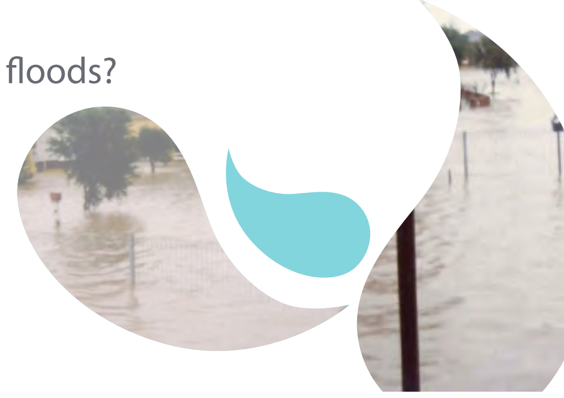
Date of flood(s)	☐ June 2016 ☐ April 2012 ☐ April 2015 ☐ Feb 1990 ☐ Other (please specify)__________	☐ June 2016 ☐ April 2012 ☐ April 2015 ☐ Feb 1990 ☐ Other (please specify)__________
Flood depth/ height, flow direction & location		
Are you confident of the height / depth of the flood?	☐ High (within 5cm) ☐ Medium (within 20cm) ☐ Low (within 50cm)	☐ High (within 5cm) ☐ Medium (within 20cm) ☐ Low (within 50cm)
What time did you observe the flood height / depth?		

4. Do you have any photographs or videos of these (or other) floods?

☐ Yes ☐ No

If you answered Yes, can you provide a copy of these to assist with the computer model calibration?

☐ Yes ☐ No



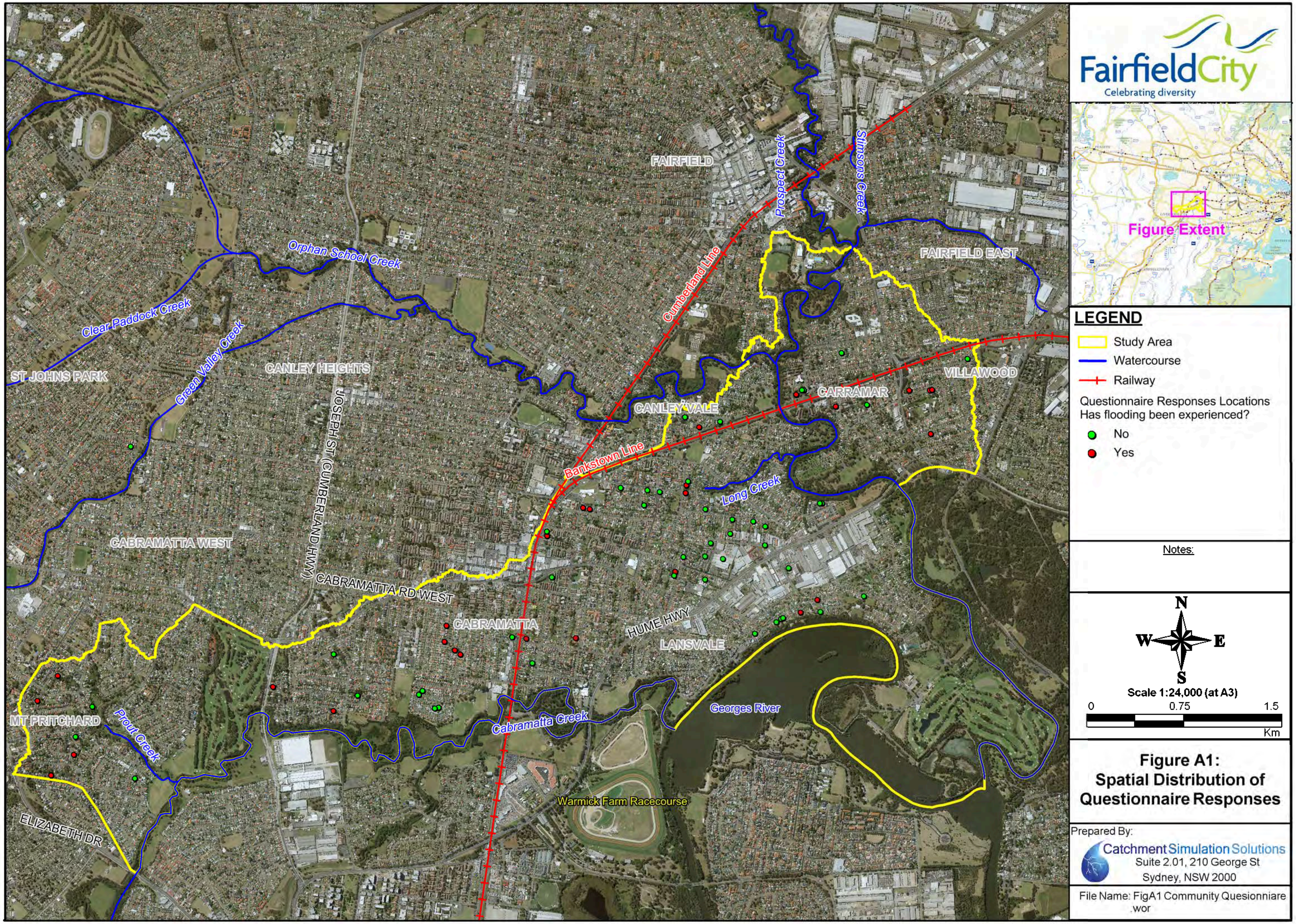


Figure A1: Spatial Distribution of Questionnaire Responses

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigA1 Community Quesionniare .wor

#	Property Type: Residential	Commercial	Industrial	Vacant Land	Other	Please Specify	What is the occupier status of the property: Owner occupied	Rental Property	Business	Other	Please Specific	How long have your lived in area?: Current Address	In the general area?	As far as you know, has your property ever been affected by flooding?	How were you impacted by flooding (you can select more than one option)?: Traffic was disrupted	My front/back yard was flooded	My garage was flooded	My house was flooded	Other	Please specific
1	X						X					14 yrs	14 yrs	Yes	X	X	X			
2	X						X					37 yrs	42 yrs	Yes	X	X	X			
3	X			X		To be rezoned to R4 High Density residential. Planning proposal has been supported by council, awaiting exhibition		X	X			20 yrs	37 yrs	No					X	15 yrs ago cnr of Chaddeston/Hume Hwy was flooded
4	X						X					50 yrs	50 yrs	Yes	X	X	X		X	Basement
5	X						X					20+yrs	36+yrs	No						
6	X						X					44 yrs		No						
7	X						X					17 yrs	30 yrs	No						
8	X						X					31 yrs		Yes						
9	X						X					16 yrs	20 yrs	Yes				X		
10	X						X					30 yrs	30 yrs	No						
11	X						X					50 yrs	50 yrs	No						
12					X	Charity Org	X					14 yrs	14 yrs	No	X					
13	X					Housing NSW		X				17 months		Yes						Back yard flooded
14	X						X					49 yrs		No						
15	X							X				30 yrs		Yes						1998
16	X						X					35 yrs	35 yrs	Yes	X	X			X	Main sewer cover in my backyard spills into backyard every tiome there is a big storm, have to wash down backyard to clean.
17	X						X					15 yrs	72 yrs	No						
18	X						X					1980		No	X				X	Approx 400mm 84
19	X						X					30 yrs	37 yrs	Yes		X	X		X	The whole complex, I live in be flooded each time heavy rain
20	X						X					5 yrs		No						
21	X						X					60yrs		No						
22	X						X					17 yrs	20 yrs	No						
23	X						X					45 yrs		Yes	X					
24	X						X					52 yrs		Yes	X	X	X			
25	X						X					7 yrs	7 yrs	No						
26	X						X					45 yrs	45 yrs	No						
27	X						X					30 yrs	31 yrs	No						
28	X						X					5 yrs	20 yrs	No						
29	X						X					18 yrs	yes	No						
30	X						X					20 yrs	yes	No						
31	X						X					62 yrs	62 yrs	No						
32	X						X					49 yrs		No						
33	X						X					20 yrs		No						
34	X						X					54 yrs		Yes		X			X	We have flat ground
35	X						X					1978	1967	Yes	X	X	X			
36	X						X					8 yrs	8yrs	No						
37	X						X					7 yrs	7 yrs	No						
38	X					Units	X					20 yrs		No					X	No experience of flooding
39	X						X					6 yrs		No						
40	X						X					29 yrs		No						
41	X						X					3.5 yrs	25 yrs	No						
42	X					Town house	X					3 yrs		Yes	X					
43	X							X				16 yrs		No						
44	X						X					30 yrs		No						
45	X						X					47 yrs		No						
46	X						X					10 yrs		Yes	X					
47	X						X					56 yrs		No						
48	X						X					51 yrs		Yes					X	From a previous resident in 1956 there was 2" of water on the ground, nothing since.
49	X						X					20 yrs	25 yrs	No						
50	X						X					12 yrs		No						
51	X						X					3 yrs	10 yrs	No						

#	Can you tell us on what dates the flooding occurred and how high the flood waters reached? Date of floods: Jun-16	Apr-15	Apr-12	Feb-90	Other	Please specify	Flood depth/ height, flow direction, location	Are you confient of the height/ depth of the flood	What time did you observe the flood height/ depth?	Do you have any photographs or videos of these (or other) photos?	If you answered yes, can you provide a copy of these to assist with the computer model calibration?	How fast do floodwater typically move in your area?	In your opinion, what is the main cause of flooding (e.g. stormwater system blockage, stormwater capacity, obstructions to overland flow - fences, garages)?	Do you have any suggestions on ways of reducing the flooding problems?	Do you have any other comments or information that you think would be useful for this investigation?
1							When very heavy rain, water would come up through my tiles about 5cm in garage	High		No		Stays still	Stormwater capacity		
2										Yes			Stormwater system, ditch in road		
3						2002				No			Event that occurred in 2002 due to stormwater capacity.	Upgrades to stormwater infrastructure	
4	X	X	X				Appox. 10-20 cm	Medium	Periods of heavy rain	No		Walking pace	Stormwater, blockage, capacity	NO	NO
5												Walking pace	Fences, blockage		
6												Running Pace	Blockage	Keep storm water drainage clean at all times	
7										No					
8				X						No		Running Pace			
9						2005	About 5cm height inside my house	High	midnight	No		Stays still	Because on that day the heavy rain was non stop all night, the drain outside my house broke and the storm water came to house from the pipe under ground and from the kitchen sink.	Please check the storm water pipe outside and clean up the rubbish frequently, before the rain season come.	
10												Walking pace	Rain	NO	No
11												Running Pace	No flooding has occurred	N/A	I have lived on my premises for 50 years & never experienced any flooding.
12										Yes				Keep street/road side clear of waste, falling leaves, plastice, waste	
13	X						Backyard from neighbour	Low	Morning	No		Stays still	Uneven blocks of land, No backyard stormwater drains, backyard fences have bottom grill blocked/closed by tenants/owners	backyard storm water drains. Stop grills on bottom of fences from been blocked	Notice to - 10A Cumberland St + other residence to remove grill covers form bottom of fences, Mandatory backyard drains - stormwater, trees close to house - gutters blocked.
14												Walking pace	Stormwater capacity	Try clearing Cabramatta creek	
15															
16													Our main concern is for the sewerage overflowing. I think its people connecting stormwater runoff to the sewerage pipes in the houses up the hill from us.	Stopping the above from happening by inspecting connections to the sewerage system where there are reports of problems like ours.	The sewerage overflowing seems to be getting worse. It seems every time there is a large downpour the sewerage will overflow into our backyard. Before it wasn't guaranteed to occur that predictably.
17												Running Pace	Stormwater capacity due to extensive development and covering previous grassy areas with impervious substances	Prevent the laying down of impervious surfaces when it is not required, unless on site retention of water is used in conjunction. Create more rain gardens & swales to deal with run off water from streets. Continue to plant trees/shrubs/grasses in riparian areas of our creeks.	Perhaps some financial incentives could be offered in relation to rates charges in order to encourage residents to maintain green areas around their homes & harvest rain water. Keep high density housing for the CBD immediately adjacent areas to minimise impact of suburban run-off.
18						84'	400mm in the street door step fgromt yard could not get out	High	3 days	No		Running Pace	Blockage due to creek possibly blocked	Remove objects, creek trolleys, rocks, trees, branches, furniture	I wish you well to understand people need to understand the way to build in these areas. Support fining of people doing the wrong thing on a sliding scale of $500 - $5K +.
19	X						All along the street from Bromfield St to Hwy & Lansvale Street	Low	Between 11.00am - 7.00pm	No		Running Pace	Storm water system very old & small size 150mm. Need the new big size stormwater pipe at least 250mm to let the flood run quickly, same pipe building in new suburbs.	Clean the small creeks & rivers from broken trees & rubbish & mud to let easy run the water without flooding. Bigger size of sewerage pipes "250"mm size underground.	Cleaning the rivers & creeks once a month, cut all trees not important around the rivers. Open more channels & direct them torun into the big lakes & rivers.
20															
21															
22												Stays still	Purely just from rain, this area never or rarely ever floods	No.	No
23										No			Clean out creeks, don't pay consultants!	Clean out creeks, don't pay consultants!	Clean out creeks, don't pay consultants!
24						1986	In the culdesac at the bottom of Stonehaven Pde the water reached thigh high approx. 90 cms		Mid afternoon	No					
25							No flood in my area, the only area is Railway & League Club.			No			The stormwater drain was not large enough, & Cabramatta creek burst its banks and engulfed large areas of low land.	I believe that following this flood or the one after the stormwater drain at the end of Stonehaven Pde was considerably enlarged since then although at times it struggles to handle the water flowing down the hill it has never threatened to flood any of the homes in this aread during or after prolonged heavy rain.	The flood in 1986 which at the time was likened to a 50 year folld was caused primarily bu Cabramatta creek bursting its banks and the water around this area rising very quickly. In my opinion no matter how much money councils spend on consultants or studies it will never prevent the sydney basin from flooding n hte event of another 50/100 year flood, rivers & creeks will rise & low lying areas will be affected. Finally I must comment on the map inside your pamphlet, printed sideways with some names upside down on colours resembling a soiled nappy, I hope that the $$$ beingt thrown at your consultants will result in something a whole lot better than a dog's breakfast. I live in hope sir.
26										No			Never seen any flood water in the street	Stormwater blockages	
27										No		Stays still	Heavy rain		
28												Walking pace	Stormwater capacity & gutter blockage together with debris/excessive leaves and rubbish causing blockage to the drains thus impact flooding adversely.	Regular clean up of street gutters, Clear rubbish in the local creeks and waterways. Regular sweep of streets with lots of trees, create more storm water & run off system, manage the trees & roots and curve gutter via regular maintenance/clean up, upgrade storm water system	Our observation is that the following issues are causing an increaase in flooding: Many curve gutters within the Cabravale precinct are full of rubbish blocking & clogging, hence impacting drainage & water movement. We are seeing tree roots on the street causing uplifting of the road curve gutters which the problem seems to not get fixed for a prolonged period. This issue is restricting the free flow of floodwaters. The council shopuld inspect & focus on a plan to improve this situation.
29											No				Ensure that street storm water drains are clear from debris.
30															
31															
32															When there has been a lot of rain and water running down gutters, sometimes the stormwater system blocks & affects toilet system & water flow.
33													When the council sel the dirt roads way back when the bright sparkes, put the drain on the high side whdcih means that water comes in off the street - THANK YOU FOR		
34						1950's	My father had flooding knee high. They had to walk ion the rail line to get around it.		Lasted for days	No		Walking pace	The river can't cope with run off, blocked stormwatrer drains, the natural water course has been changed by developments over many years, cars & other being dumped in the creks & waterways.	Street ckeaning (sweepers) more often to prevent blockage of bottles and other rubbish, levies to catch & slow run off when river breaks its banks, clean out the rubbish from local creeks so that water can flow.	
35						29/04/1988	1 metre water flooded back yard & garage flowing in easterly direction		5:00 PM	Yes	Yes	Walking pace	I have no idea but I understanda that some work has already been done, since 1988 I have not seen that degree of flooding ever since, although smaller more temporary flooding has occurred since.		Could cliamte change be a considering factor? Occasionally sewers appear blocked. I suspect nearby residents are flushing things they shouldn't!
36															
37															
38														Keep waterways clear of plant growth	
39															
40														You would think, bigger storm water pipes, where needed, and more drains.	
41															
42	X				X			Low	8am - Midnight			Walking pace	Nothing.		
43															
44															
45															
46	X							Low				Walking pace	Stormwater system		
47												Walking pace	Cabramatta creek, Prospect River, Georges River, all merging since the lake was formed, we did notice that the height the lake rose was much lower		
48						1986 & 1988	The highest floods observed reached 4 metres below the bank behind 11 Georges River Rd		Day time						I believe Fairfield city records will indicate a solution to the problem, as stated in the 1930 ariqal photographs. Also if there was a dedicated annual programme of clearing the 5 creeks of debris thisw would give a clear flow towards chipping norton lake reducing the risk of local flooding & ultimately flow in a orderly manner down stream to the outfall.
49															
50															
51												Walking pace	Obstructing to overland flow		

#	Property Type						What is the occupier status of the property					How long have your lived in area?		As far as you know, has your property ever been affected by flooding?	How were you impacted by flooding (you can select more than one option)?						Can you tell us on what dates the flooding occurred and how high the flood waters reached?									Do you have any photographs or videos of these (or other) photos?	If you answered yes, can you provide a copy of these to assist with the computer model calibration?	How fast do floodwater typically move in your area?	In your opinion, what is the main cause of flooding (e.g. stormwater system blockage, stormwater capacity, obstructions to overland flow - fences, garages)?	Do you have any suggestions on ways of reducing the flooding problems?	Do you have any other comments or information that you think would be useful for this investigation?
	Residential	Commercial	Industrial	Vacant Land	Other	Please Specify	Owner occupied	Rental Property	Business	Other	Please Specific	Current Address	In the general area?		Traffic was disrupted	My front/back yard was flooded	My garage was flooded	My house was flooded	Other	Please specific	Date of floods						Flood depth/ height, flow direction, location	Are you confient of the height/ depth of the flood	What time did you observe the flood height/ depth?						
																					Jun-16	Apr-15	Apr-12	Feb-90	Other	Please specify									
52	X						X					56 yrs		Yes		X		X		Shed in backyard					X	6/07/2016	Lower 2 rooms, downstairs	High				Running Pace	Stormwater system blockage & also obstruction to overland flow	Find out where the blockage is occuring in stormwater pipe	
53	X						X					1.5 yrs	55 yrs	Yes				X	X	Bottom 2 rooms water leaks through walls when it rains												Stays still	Upgrade storm water systems		
54	X						X					30 yrs	57 yrs	Yes		X	X			Soil erosion subsidance blocked storm water drains on the road storm water 1987 approximate.	X	X	X	X			1.5 meters, natural direction of creek flow to tidal river	High	in the 1980's after buying property, geography storm water ran out of rivers, todes concrete bad planning			X	Storm water creeks cannot handle the volume of water need to be bigger. Bad palnning some land should not been allowed to be built on more concrete - far more storm water run off geography tidal movement down stream.	Do not allow houses to be built in flood zones bigger storm water catchment areas thjat can handle water bank up until todal movements of rivers goes to low tide for water dispersion.	Get people who understand natural water flow & geography creeks, rivers, tidal movements. Increase the stormwater bank up reservoirs away from houses. DO NOT SELL OR APPROVE BUILDING IN FLOOD AREAS.
55	X							X				20 yrs		No																				Storm water upgrades	
56			X						X			1985		No																					
57	X						X					56 yrs		Yes						Rear of backyard along left side of garage from boundary fence to garage concrete slab possibly into garage and water under slab	X				X		Ground was saturated like a bog, water visible in grass, no flow direction as water was at standstill, anytime there is excessive heavy rainfall	Low	During rainfall & after for at leas a week			Stays still	Excess heavy rainfall and very slow drainage, possibly other causes maybe house gutters & down pipes not concreted or not functioning in left boundary neighbours house & yard	We hope your research & studies will be thorough & will find effective solutions.	Possibly it would help to have a thorough investigation & study of the neighbouriong yards to understand if the flooding is worsened or not helped by the neighbouring properties. There seems to be a lack of effective drainage.
58	X						X					65 yrs		Yes		X	X				X	X					8-10 cm West toward prospect creek, backyard	High				Walking pace	About 25 yrs ago, Fairfield Council built a pre-school behind my backyard fence in the gorunds of Carramar public school. They raised the gorund level to build on by about 600mm which damaged the fence & now athe water cannot get away & flows into mine & neighbouring properties.		
59	X							X		Public Housing		8 yrs	8 yrs	Yes	X	X				Carramar Station walkway	X	X	X				45 cms	High	Whilst clearing storm water			Running Pace	Debris throughout gutters, blocking of stormwater in Elm St, run off from neighbouring properties	Regular clearing of gutters/stormwater, more stormwater drainage	Elm St was completely flooded, June 2016. Neighbours & I cleared stormwater but it took at least 90 mins to get decent flow into s/water. Meanwhile, cars were still driving through waters that were up to their front car grills.
60	X						X					32 years		No																					
61	X						X							No																					
62	X						X					32 years	32 years	No																					
63	X						X					5 yrs 7 mths	20+ yrs	No																			Have not seen flood in this area.	No.	
64	X						X					15 years	15 years	No																			N/A	N/A	
65	X									X	Strata Plan 60601	19 yrs	19 yrs	No																			Strata Plan 60601 has no claim from the date the building was built.	No	
66	X						X					18 years and 9 months	Approx 33 years	No																			I have NOT experienced flood since I live at this address for approx. 18+ years	No, thank-you.	
67		X					X							No																					
68	X						X					30 years	30 years	No																					
69	X						X					4yrs		Yes																			I believe the catchment is not flowing quick enough or need more outlet.		
70	X						X						20 years	No		X											1 feet water overflow from storm drain in my front yard	Medium		No		Stays still	Ensure that new dwellings are approved as according to advice we've received from Council, not all constructions need Council approval prior to construction. We currently have a structure adjoining our boundary fence that has no down pipes installed therefore all run off is coming into our yard. There is another structure 2 houses up which should be connected to storm water which may or may not have been done by the owners. While this is not a flood issue in itself, it is part of the problem.	It should be compulsory for down pipes to be connected to the storm water drains to ensure the sewer system is not overloaded. Obviously there is a problem in a flood situation where sewer is illegally connected. We also wonder why Council approves building in known floor prone areas eg the end of Reservoir Road near Elizabeth Drive.	
71	X						X					53yrs	53yrs	No																			Widen Cabramatta Creek where it passes Joe Broad Park near the Florence St entrance. Flooding has occurred in my street and the bottom half is blocked to traffic, but we have access at Parkside Place. Once in about 1987 Parkside Place was flooded and we had to wade out. I have seen people in row boats in the bottom of the street and even on Joe Broad. Last time the wire fence was flattened.		
72	X						X					58 years	58 years	No																				The stormwater drain located outside my property has recently been updated so perhaps that should be looked at as an option within the catchment area	No
73	X						X					19 years	32 years	No																				For over 32 years in my stay, there is no indication of flooding problem.	Knowing area like Carrama which have flooding problem but not on my street. In fact it is too dry for my front lawn.
74	X						X					7 years	7 years	No																				Our property has never had any issues with drainage, run off or flooding since we've been here.	Our property has never had any issues with drainage, run off or flooding since we've been here.
75	X						X					18 years	18 years	Yes					X	The easement on at 13 Edna Ave was blocked causing water to run across my back yard and into the drain on the 17 Edna Ave side of the property							1999 - 2000 water flowed from 13 Edna Ave toward 17 Edna Ave	Medium		No		Running Pace	Storm water blockage from the road drain to 11 and 13 Edna Ave	The road dragon Edna Ave next to 11 Edna Ave has a big opening allowing rubbish to fall into the drain which then causes the pipe to become blocked there is also elbow in the pipe/ drain between 13 and 15 Edna Ave which may be causing one obstruction The pipe at running across 15 Edna ave between the two drains is plastic and doesn't appear to be causing and problems The pipe between the road 11 and 13 Edna Ave is concrete or clay which may also be a cause of blockages	
76	X						X					18 years	18 years	Yes																					
77	X						X					54 years	54 years	Yes		X	X				X						side and rear of property	High		No		Stays still	changes in neighbours properties		
78	X						X					41 years	41 years	Yes	X	X			X	Because the flooding occurs on the road, the houses opposite our house are more affected by yard & garage flooding.		Apr-12					Flow direction north to south; Location on Booyong street on the road and front yards of the houses adjacent to the street; Depth: above the curb onto and into the adjacent properties.	High		Yes		Running Pace	Stormwater capacity & apparent increase in torrential rain;	Reduce the number of concrete front yards (to allow more absorption of water instead of it flowing over the concrete); investigate the capacity of the streets adjacent to Booyong Street; holding tanks or stormwater pond in the park at the top of the street (corner of Booyong & Bolivia); educate drivers about driving at speed through flood waters to reduce the wash that gets pushed on to our property and into garages.	This has occurred many times over the 41 years we have lived at this address, usually once a year after summer thunderstorms or severe hail storms eg April 1991. However, in recent years since about 2012 the frequency has increased to two or three times a year (four this year already), with them being more extensive and taking longer to drain. One of the major issues is the problem created by people driving through the flooding often at speed causing large bow waves, pushing the water up and down driveways and into properties/ houses. The most recent flooding, 7th June 2017, occurred at night and cars drove into the water without realising causing problems for them, stalled cars etc & water being pushed into our properties again. Also in recent events the water flowing across our properties from the streets behind us (Kauri, Gidgee, Brigalow) has become deeper and more torrent than before. The property to the north of us (no.23) has a "river" of water 20cm deep running over it during the flooding events. The drainage of the water from storms down
79	X						X					16	16	No																				drainage. The drains on the roads are useful until flash flooding does happen. The flow through those drains on the roads are far to less and I would suggest putting more drains, not on the roads as this would require a reconstruction of the roads, but a drain besides the creek that are most likely to over flow. The drains should then be directed to areas where the rain water drain system is not over flowing like in areas with low chances of floods. this way, the water can be evenly distributed and cause less chances of one area flooding. You should also introduce flood gates at the mouth of cabramatta creek next to chipping nortan lake atas sussex street next to cabramatta high school is always flooded. flood gates during raining seasons would also help prevent water from overflowing.	

#	Property Type						What is the occupier status of the property					How long have your lived in area?		As far as you know, has your property ever been affected by flooding?	How were you impacted by flooding (you can select more than one option)?						Can you tell us on what dates the flooding occurred and how high the flood waters reached?									Do you have any photographs or videos of these (or other) photos?	If you answered yes, can you provide a copy of these to assist with the computer model calibration?	How fast do floodwater typically move in your area?	In your opinion, what is the main cause of flooding (e.g. stormwater system blockage, stormwater capacity, obstructions to overland flow - fences, garages)?	Do you have any suggestions on ways of reducing the flooding problems?	Do you have any other comments or information that you think would be useful for this investigation?
	Residential	Commercial	Industrial	Vacant Land	Other	Please Specify	Owner occupied	Rental Property	Business	Other	Please Specific	Current Address	In the general area?		Traffic was disrupted	My front/back yard was flooded	My garage was flooded	My house was flooded	Other	Please specific	Date of floods						Flood depth/ height, flow direction, location	Are you confient of the height/ depth of the flood	What time did you observe the flood height/ depth?						
																					Jun-16	Apr-15	Apr-12	Feb-90	Other	Please specify									
80	X							X				2 years	2 years	Yes					1	The road was closed to traffic and pedestrians due to severe flooding under the railway bridge at Sandal Crescent, Carramar. I assume the flooding was due to the overflow at Orphan School Creek which is in close proximity the Sandal Crescent. The entire road under the bridge was flooded.	X						Not sure, but it was severely flooded over two days			No		Stays still	Heavy rainfall over consecutive days causing a sudden increase in stormwater (and not enough capacity to contain it).		
81	X						X					0	31 years	No																				Larger sewage areas. Clearing of drains. Increase tree cutting services. Level off roads and provide adequate drainage.	
82	X						X					13 years	14 years	No																				No	No
83	X						X					32 YEARS	36 YEARS	No																					
84	X						X					55 years		Yes		X									X	16/05/1905	50cm East Front yard	High	About 5-7 days	No		Stays still	Storm water systtem blockage capacity obstruction to overland flow		
85	X						X					20 years		Yes		X					X						From the main sewage of next house No57 when it is big rain, the water was spreading over my half backyard from the fence. Sometimes this flood will stay more 1 week depend the time of the rain weather.	Medium		No		Walking pace	stormwater blockage and capacity. When it was big rain and keeps long days. The water too much		
86	X						X					50 years		No																		Walking pace	River/creek breaking, low land	unblock drains keeping clean as much as possible for water runoff to stop flooding	warning system for residents is area when flooding likely to be expected

APPENDIX B

MANNING'S "N" CALCULATIONS

Manning's 'n' Calculations

Prepared by: D. Tetley **Date:** 23/08/2013
Checked by: **Date:**

The following provide Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach is appropriate for direct rainfall modelling as it can account for the variation in 'n' with respect to flow depth.

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m\ (n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface
n_1 = a correction factor for the effect of surface irregularities
n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)
n_3 = a value for obstructions
n_4 = a value for vegetation on the floodplain
m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type 5 - Grass
Relatively short grass. Occasional tree, fence post or childrens play equipment may also be present.

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

		Base *n* Value	
Bed Material	Median Size of bed material (in millimeters)	Straight Uniform Channel[1]	Smooth Channel[2]
Sand Channels			
Sand[3]	0.2 .3 .4 .5 .6 .8 1.0	0.012 .017 .020 .022 .023 .025 .026	-- -- -- -- -- -- --
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020

Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
2 For indicated material; Chow(1959)
3 Only For Upper regime flow where grain roughness is predominant

Assume "Firm Soil" for manicured grass areas

n_b = 0.025

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Assume "moderate" to cater for undulating terrain across most of the study area

n_1 = 0.006

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

Occasional tree stump or obstruction may be present:

n_3 = 0.004

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is

		timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

Assume grass is equal to or less than 0.05 metres in height

n_4 = 0.065	When water depth is < 0.03m	(water depth less than height of grass)
n_4 = 0.03	When water depth is ~ 0.05m	(water depth equal in height to grass)
n_4 = 0.015	When water depth is ~ 0.07m	(water depth less than twice height of grass)
n_4 = 0.001	When water depth is > 0.1m	(water depth more than twice height of grass)

Final 'n' Value

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

n = 0.1	When water depth is < 0.03m
n = 0.065	When water depth is ~ 0.05m
n = 0.05	When water depth is ~ 0.07m
n = 0.036	When water depth is > 0.1m

Manning's 'n' Calculations

Prepared by: D. Tetley | **Date:** 23/08/2013
Checked by: | **Date:**

The following provide Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach is appropriate for direct rainfall modelling as it can account for the variation in 'n' with respect to flow depth.

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m\ (n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface
n_1 = a correction factor for the effect of surface irregularities
n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)
n_3 = a value for obstructions
n_4 = a value for vegetation on the floodplain
m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type 3 - Trees
Trees (> 2metres in height) with medium to dense undergrowth

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

		Base *n* Value	
Bed Material	Median Size of bed material (in millimeters)	Straight Uniform Channel[1]	Smooth Channel[2]
Sand Channels			
Sand[3]	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--
	.6	.023	--
	.8	.025	--
	1.0	.026	--
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020

Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
2 For indicated material; Chow(1959)
3 Only For Upper regime flow where grain roughness is predominant

Assume "Firm Soil"

n_b = 0.025

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Assume "moderate" to cater for undulating terrain across most of the study area

n_1 = 0.01

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

Many obstructions likely

n_3 = 0.025

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is

		timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

Assume significant undergrowth up to 0.3 m in height, less dense shrubs up to 1.5m & tree branch above 2m

n_4 = 0.1	When water depth is < 0.3m	(Shrubs, trees & undergrowth in contact with flow)
n_4 = 0.05	When water depth is ~ 1.5m	(Shrubs & tree trunks in contact with flow)
n_4 = 0.02	When water depth is >2m	(Tree trunks in contact with flow)

Final 'n' Value

$n = m\,(n_b + n_1 + n_2 + n_3 + n_4)$

n = 0.16	When water depth is < 0.3m
n = 0.11	When water depth is ~ 1.5m
n = 0.08	When water depth is >2.0m

Manning's 'n' Calculations

Prepared by: D. Tetley **Date:** 23/08/2013
Checked by: **Date:**

The following provide Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach is appropriate for direct rainfall modelling as it can account for the variation in 'n' with respect to flow depth.

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m\,(n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface
n_1 = a correction factor for the effect of surface irregularities
n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)
n_3 = a value for obstructions
n_4 = a value for vegetation on the floodplain
m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type 4 - Roads
Concrete kerb & gutter for containing low flows with road pavement at higher stages

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

		Base *n* Value	
Bed Material	**Median Size of bed material (in millimeters)**	**Straight Uniform Channel[1]**	**Smooth Channel[2]**
Sand Channels			
Sand[3]	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--
	.6	.023	--
	.8	.025	--
	1.0	.026	--
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020

Catchment Simulation Solutions

Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
[2] For indicated material; Chow(1959)
[3] Only For Upper regime flow where grain roughness is predominant

Assume "Concrete"

n_b = 0.012

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Relatively minor grades along most roadways

n_1 = 0.002

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

May be garbage bins etc, but assume negligible

n_3 = 0.002

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is

		timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

Assume water contained in gutter initially and then spreads onto road pavement

n_4 = 0.001	When water depth is < 0.04m	(Water contained within gutter)
n_4 = 0.005	When water depth is ~ 0.1m	(Water comes into contact with pavement aggregate)
n_4 = 0.002	When water depth is > 0.15m	(Water well above aggregate/gutter height)

Final 'n' Value

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

n = 0.017	When water depth is < 0.04m
n = 0.021	When water depth is ~ 0.1m
n = 0.018	When water depth is >0.15m

Manning's 'n' Calculations

Prepared by: D. Tetley **Date:** 23/08/2013
Checked by: **Date:**

The following provide Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach is appropriate for direct rainfall modelling as it can account for the variation in 'n' with respect to flow depth.

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m\ (n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface

n_1 = a correction factor for the effect of surface irregularities

n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)

n_3 = a value for obstructions

n_4 = a value for vegetation on the floodplain

m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type 6 - Concrete

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

Bed Material	Median Size of bed material (in millimeters)	Base *n* Value: Straight Uniform Channel[1]	Base *n* Value: Smooth Channel[2]
Sand Channels			
Sand[3]	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--
	.6	.023	--
	.8	.025	--
	1.0	.026	--
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020

Coarse Sand	**1-2**	**0.026-0.035**	**--**
Fine Gravel	**--**	**--**	**.024**
Gravel	**2-64**	**0.028-0.035**	**--**
Coarse Gravel	**--**	**--**	**.026**
Cobble	**64-256**	**0.030-0.050**	**--**
Boulder	**>256**	**0.040-0.070**	**--**

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
[2] For indicated material; Chow(1959)
[3] Only For Upper regime flow where grain roughness is predominant

Assume "Concrete"

n_b = 0.012

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Assume smooth

n_1 = 0

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

Assume minimal obstructions

n_3 = 0.002

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is

		timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

n_4 = 0.02	When water depth is < 0.005m	(Water in contact with aggregate)
n_4 = 0.001	When water depth is > 0.005m	(Water above aggregate height)

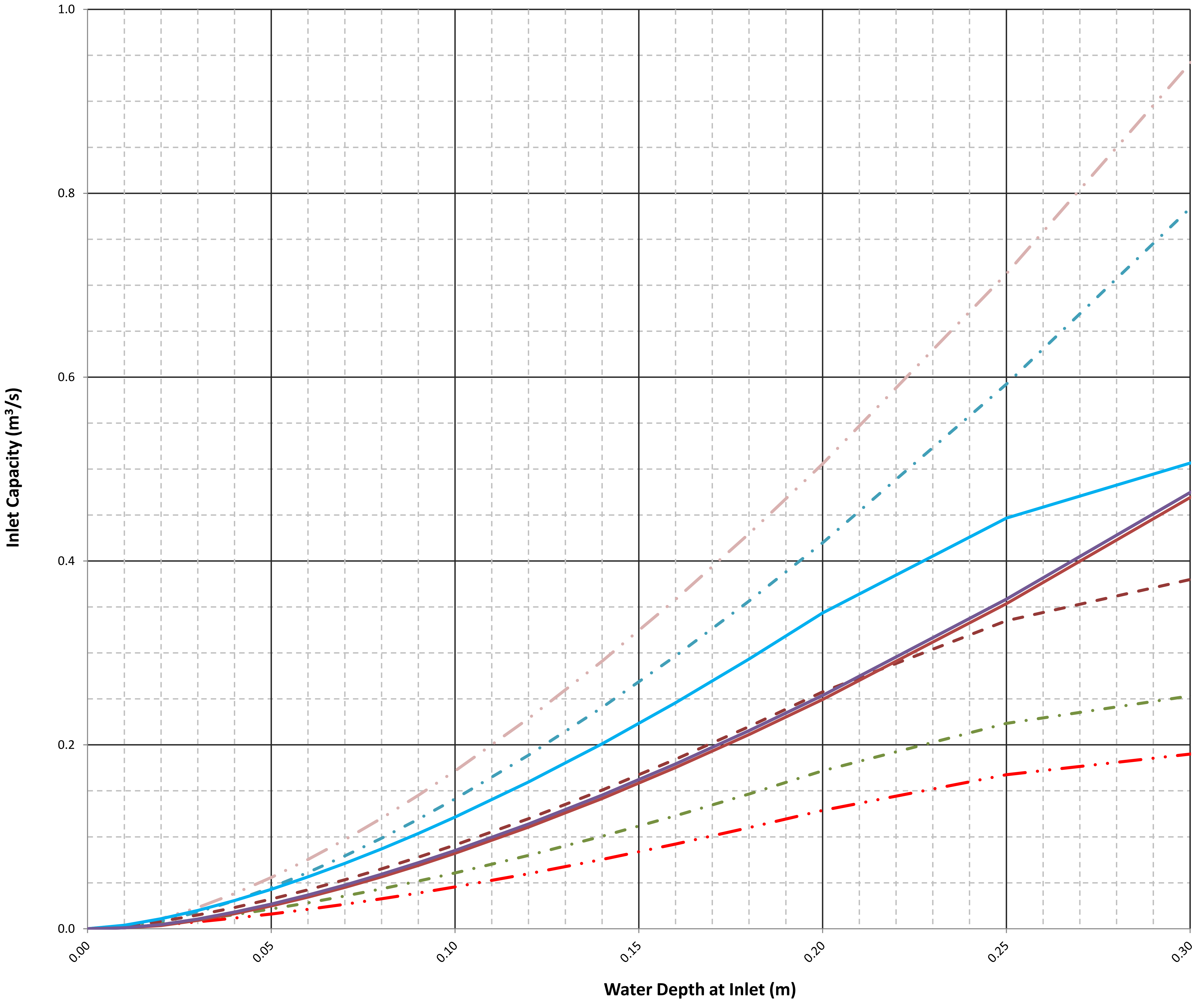
Final 'n' Value

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

n = 0.034	When water depth is < 0.005m
n = 0.015	When water depth is > 0.005m

APPENDIX C

STORMWATER INLET CURVES



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LEGEND

- Combination inlet with 0.9m lintel & 0.9x0.45m grate
- Combination inlet with 1.8m lintel & 0.9x0.6m grate
- Combination inlet with 2.4m lintel & 0.9x0.6m grate
- Kerb inlet with 0.9m lintel
- Kerb inlet with 1.2m lintel
- Kerb inlet with 1.8m lintel
- Kerb inlet with 2.4m lintel
- Inlet with 0.36m2 grate on Kerb
- Inlet with 0.41m2 grate on Kerb

Notes:

Inlet capacity curves do not consider blockage.

Figure C1:
Inlet Capacity Curves for Sag Pits

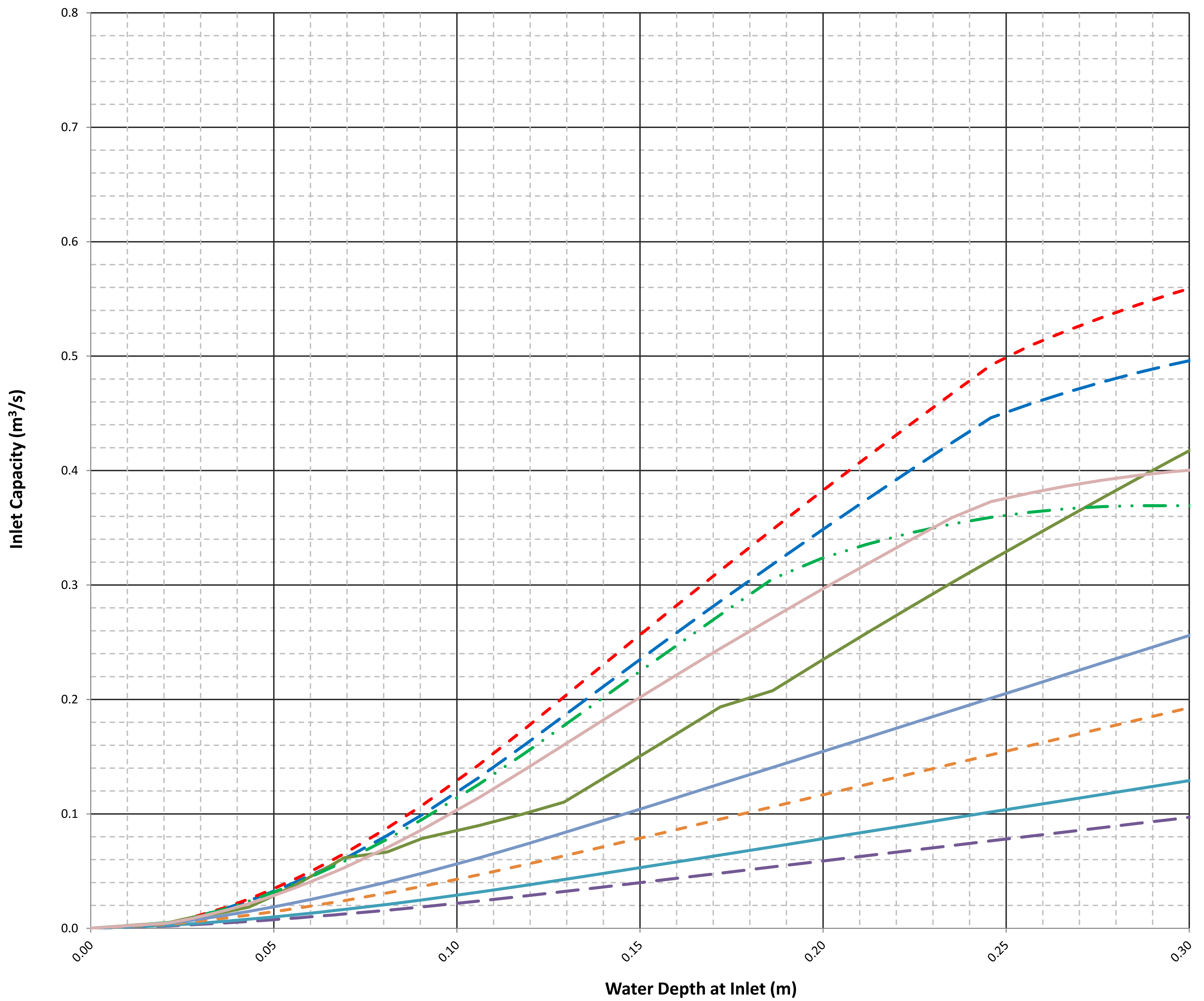
Prepared By:

Catchment Simulation Solutions

Suite 1, Level 2, 210 George Street

Sydney, NSW, 2000

File Name: Inlet Capcacity Curves.xls



LEGEND

- Combination inlet with 0.9m lintel & 0.9x0.45m grate
- Combination inlet with 1.8m lintel & 0.9x0.45m grate
- Combination inlet with 2.4m lintel & 0.9x0.45m grate
- Combination inlet with 2.6m lintel & 0.9x0.45m grate
- Kerb inlet with 0.9m lintel
- Kerb inlet with 1.2m lintel
- Kerb inlet with 1.8m lintel
- Kerb inlet with 2.4m lintel
- Inlet with 0.36m2 grate on Kerb
- Inlet with 0.41m2 grate on Kerb

Notes:
Inlet capacity curves do not consider blockage.

Figure C2:
Inlet Capacity Curves for On Grade Pits

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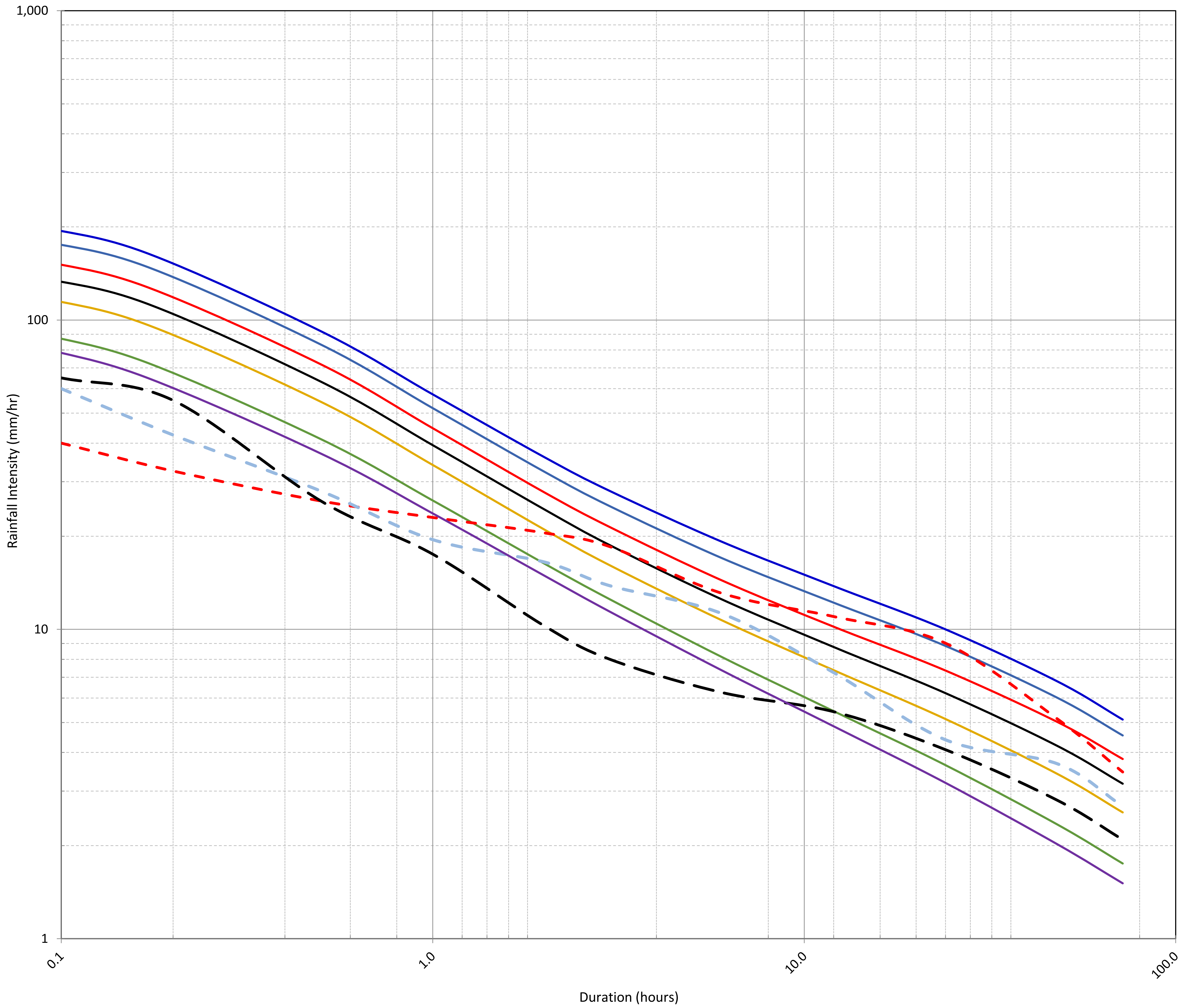
Sydney, NSW, 2000

File Name: Inlet Capcacity Curves.xls

APPENDIX D

COMPARISON BETWEEN HISTORIC AND DESIGN RAINFALL INFORMATION



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LEGEND:

- 1% AEP
- 2% AEP
- 5% AEP
- 10% AEP
- 20% AEP
- 50% AEP
- 2016 Rainfall
- 2015 Rainfall
- 2012 Rainfall
- 63.2% AEP

Notes:
IFD curves are based upon 2016 IFD data

Figure D1: Design Intensity - Frequency - Duration Curves Vs Historic Rainfall

Prepared By:
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File Name: IFD Comparison.xlsx

Appendix E

ARR2016 Assessment

Australian Rainfall and Runoff 1987 Versus 2016 Assessment

Mainstream and overland flooding has historically been defined across the Fairfield City Council Local Government Area based upon hydrologic procedures defined in the 1987 version of *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australian) (referred to herein as ARR1987). In December 2016 a revised version of Australian Rainfall and Runoff was released (Geoscience Australia, 2016) (referred to herein as ARR2016). Therefore, investigations were completed to determine the impact that the revised hydrologic procedures may have on design flood behaviour across the Cabravale study area and determine the most appropriate hydrologic procedures to apply as part of the current flood study.

The outcomes of the investigations are summarised below. It should be noted that only the 1% AEP (1 in 100-year ARI) event was investigated as part of this assessment.

Rainfall Intensity

Point design rainfall intensities for the 1% AEP event were downloaded from the Bureau of Meteorology's 1987 and 2016 IFD webpage. This design rainfall information is presented in **Table 1** for storm durations varying between 10 minutes and 24 hours. The design rainfall intensities were extracted from the IFD grid cell located closest to the centroid of the study area (33.900^{o} south, 150.925^{o} east).

Table 1 1% AEP Point Design Rainfall Intensities

Storm Duration	Rainfall Intensity (mm/hr)	
	1987	2016
10 mins	169	166
15 mins	141	138
20 mins	123	118
30 mins	99.7	92.0
1 hour	67.9	57.5
2 hours	44.9	36.0
3 hours	35.0	28.0
6 hours	22.9	19.2
12 hours	15.1	13.8
24 hours	10.2	10.0

The comparison provided in **Table 1** indicates that the ARR2016 rainfall intensities are between 2 and 20% lower than the ARR1987 intensities, with the average difference being -10%.

Areal Reduction Factors

The design rainfall intensities presented in **Table 1** are strictly only applicable at a point. Therefore, ARR 2016 includes revised areal reduction factors that recognise that there is unlikely to be a uniformly high rainfall intensity across all sections of large catchments. Although ARR 1987 did include areal reduction factors, this largely drew from overseas research.

The areal reduction factor parameters at the study area centroid were downloaded from the ARR2016 data hub (a copy of the information downloaded from the data hub is included at the end of this document). The areal reduction parameters were applied in combination with the study area (11.5 km^2) to the areal reduction equations provided in ARR2016 to develop the areal reduction factors provided in **Table 2**.

Table 2 Areal Reduction Factors

Storm Duration	Reduction Factor	
	1987	2016
10 mins	0.98	0.79
15 mins	0.98	0.82
20 mins	0.98	0.84
30 mins	0.98	0.86
1 hour	0.99	0.89
2 hours	1.00	0.90
3 hours	1.00	0.91
6 hours	1.00	0.95
12 hours	1.00	0.97
24 hours	1.00	0.98

Areal reduction factors were also extracted from Figure 1.6 of ARR1987 and are included in **Table 2**. It is noted that no reduction factors are provided in ARR1987 for durations less than 30 minutes. Therefore, it was assumed that the 30-minute reduction factors also applied for shorter storm durations. It is also noted that it is very difficult to extract precise reductions factors for catchment areas less than 50 km^2 (such as Cabravale) as the areal reduction curves in Figure 1.6 very rapidly converge to 1.0 for small catchment areas.

The factors provided in **Table 2** show that the ARR1987 factors are globally higher than the ARR2016 reduction factors. The most significant differences occur for shorter storm durations. For longer storm durations (e.g., > 12 hours), the differences are generally negligible.

The areal reductions factors summarised in **Table 2** were applied to the point rainfall intensities summarised in **Table 1** to define the design rainfall intensities for application to the Cabravale study area. The areal reduced rainfall intensities are summarised in **Table 3**.

The comparison provided in **Table 3** shows that the lower design rainfall intensities and higher areal reduction factors provided by ARR2016 results in significantly lower design rainfall intensities relative to ARR1987. ARR2016 design rainfall intensities are 19% lower than ARR1987 intensities, on average.

Table 3 Areal Reduced 1% AEP Design Rainfall Intensities

Storm Duration	Rainfall Intensity (mm/hr)	
	1987	**2016**
10 mins	166	131
15 mins	138	113
20 mins	121	99
30 mins	97.7	79.1
1 hour	67.2	51.2
2 hours	44.9	32.4
3 hours	35.0	25.5
6 hours	22.9	18.2
12 hours	15.1	13.4
24 hours	10.2	9.8

Temporal Patterns

One of the most significant differences between ARR2016 and ARR1987 is in the use of storm temporal patterns (i.e., the patterns describing the distribution of rainfall throughout the storm). ARR1987 used a single temporal pattern for each AEP/storm duration while ARR2016 uses 10 temporal patterns for each AEP/storm duration.

The ARR2016 temporal patterns were downloaded from the ARR data hub. In accordance with ARR2016 for catchments with an area less than 75 km^2, the "point" temporal patterns rather than "areal" temporal patterns were selected to describe the temporal variation in rainfall.

A total of ten temporal patterns were applied to the areal reduced rainfall depths for the 1% AEP for each storm duration. This provided a storm database comprising 245 different storms for the 1% AEP event.

Rainfall Losses

ARR2016 also utilises a different approach for defining initial rainfall losses. The ARR1987 approach applies a constant initial loss and continuing loss rate for all storms. As part of previous flood studies, a pervious initial loss of 10mm and a pervious continuing loss rate of 2.5 mm/hr was typically applied.

The ARR2016 approach employs an initial rainfall loss that varies accordingly to the storm severity and duration. The ARR2016 initial rainfall losses are calculated by subtracting median pre-burst rainfall losses from the overall storm loss for the catchment (an overall storm loss of 28mm is defined for the area by ARR2016). The resulting "burst" initial rainfall losses are summarised in **Table 4**. It was noted that no pre-burst rainfall losses are provided on ARR2016 data hub for storm durations less than 1 hour. Therefore, it was assumed that the pre-burst rainfall losses for the 1 hour storm also applied for storm durations less than 1 hour.

Table 4 ARR2016 Initial Rainfall Losses for the 1% AEP flood

Storm Duration	Storm Initial Loss (mm)	Median Pre-burst Depth (mm)	Burst Initial Loss (mm)
10 mins	28	0.3	27.7
15 mins		0.3	27.7
20 mins		0.3	27.7
30 mins		0.3	27.7
1 hour		0.3	27.7
2 hours		0.9	27.1
3 hours		3.0	25.0
6 hours		11.2	16.8
12 hours		20.6	7.4
24 hours		11.4	16.6

As shown in **Table 4**, initial rainfall losses of between 7.4 and 27.7 mm were calculated. In all cases except for the 12-hour storm, the ARR2016 initial rainfall losses are higher than the ARR1987 initial rainfall losses typically adopted as part of previous studies.

Continuing loss rates are applied in ARR2016 in a similar manner to how they were used in ARR1987. However, the values have changed. ARR2016 specifies a continuing loss rate of 1.9 mm/hour for the Cabravale area. This is lower than ARR1987 which recommends a continuing loss rate of 2.5 mm/hour.

Hydrologic Assessment

XP-RAFTS Model Development

As discussed in the previous sections, ARR2016 requires simulation of a large number of storms. The large number of storms prevents the use of the TUFLOW model as a single simulation can take multiple hours or even multiple days. Therefore, a lumped hydrologic model was developed to undertake the ARR2016 hydrologic analysis. The hydrologic model was developed using the XP-RAFTS software. Further details on how the XP-RAFTS model was developed is provided beow.

Subcatchment Parameterisation

The Cabravale study area was subdivided into 366 subcatchments based on the alignment of major flow paths and topographic divides. The subcatchments were delineated with the assistance of the CatchmentSIM software using a 2 metre Digital Elevation Model (DEM). The subcatchment layout is presented in **Figure E1**.

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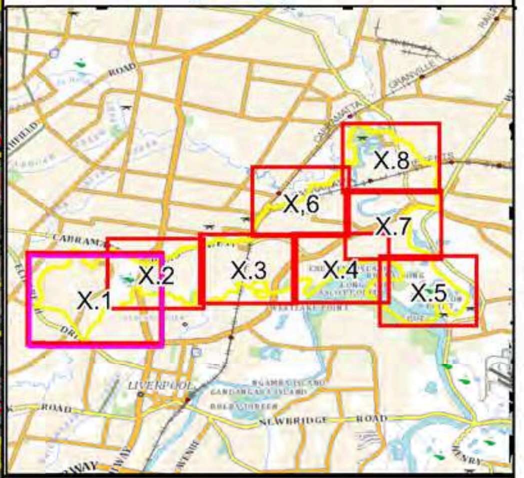

LEGEND

- XP-RAFTS Subcatchment Boundaries
- XP-RAFTS Link
- XP-RAFTS Node

Notes:

N
W E
S

Scale 1:7,000 (at A3)

0 0.2 0.4
Km

Figure E1.1:
XP-RAFTS
Subcatchment Layout

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Sydney, NSW 2000

File Name: FigE1.1 - RAFTS.wor

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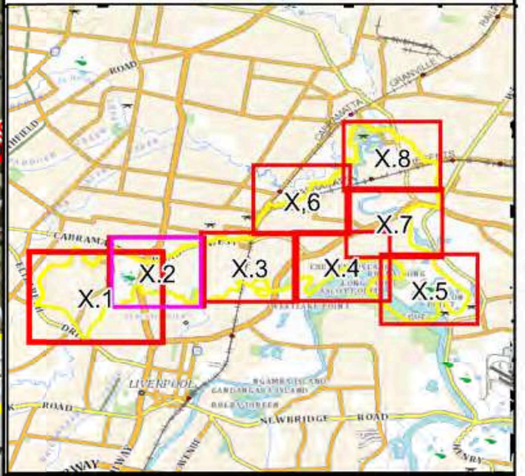

LEGEND

- XP-RAFTS Subcatchment Boundaries
- XP-RAFTS Link
- XP-RAFTS Node

Notes:

N W E S

Scale 1:5,000 (at A3)

0 0.15 0.3 Km

Figure E1.2: XP-RAFTS Subcatchment Layout

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File Name: FigE1.2 - RAFTS.wor

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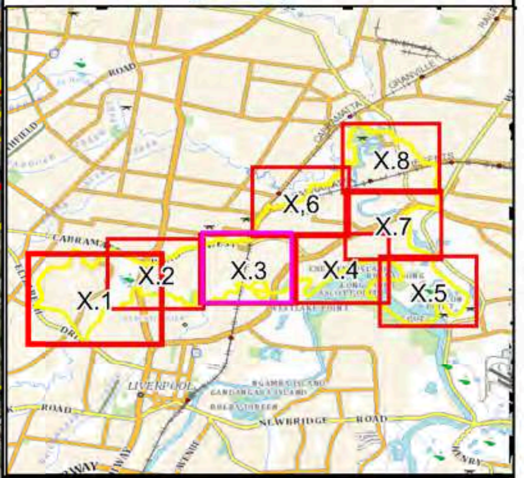

LEGEND

- XP-RAFTS Subcatchment Boundaries
- XP-RAFTS Link
- XP-RAFTS Node

Notes:

N W E S

Scale 1:5,000 (at A3)

0 0.15 0.3 Km

Figure E1.3: XP-RAFTS Subcatchment Layout

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File Name: FigE1.3 - RAFTS.wor

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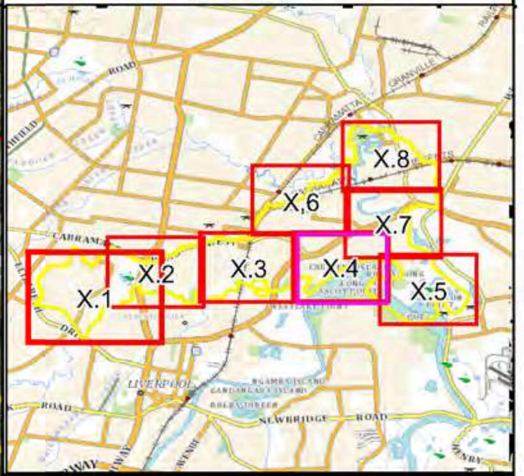

LEGEND

- XP-RAFTS Subcatchment Boundaries
- XP-RAFTS Link
- XP-RAFTS Node

Notes:

N
W E
S

Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure E1.4: XP-RAFTS Subcatchment Layout

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File Name: FigE1.4 - RAFTS.wor

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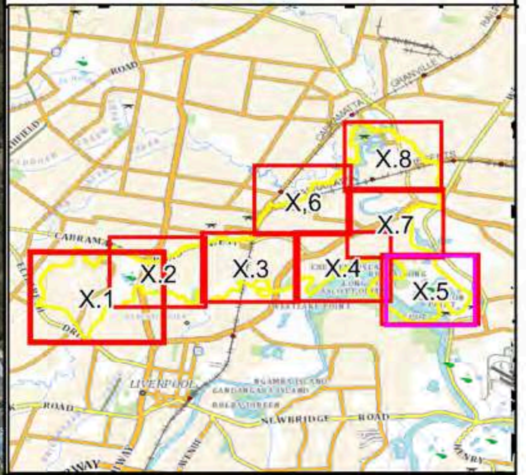

LEGEND

XP-RAFTS Subcatchment Boundaries
XP-RAFTS Link
XP-RAFTS Node

Notes:

N
W E
S

Scale 1:5,000 (at A3)
0 0.15 0.3
Km

**Figure E1.5:
XP-RAFTS
Subcatchment Layout**

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Sydney, NSW 2000

File Name: FigE1.5 - RAFTS.wor

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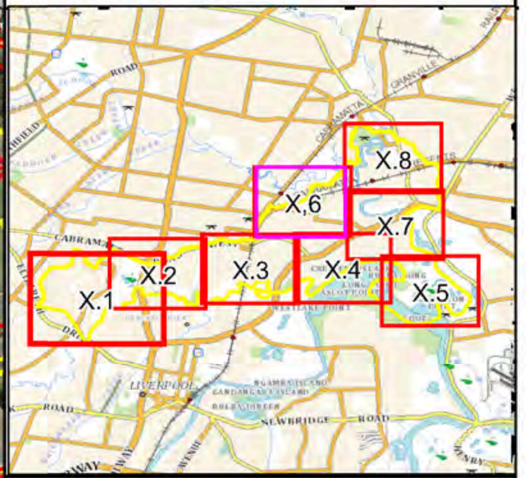

LEGEND

- XP-RAFTS Subcatchment Boundaries
- XP-RAFTS Link
- XP-RAFTS Node

Notes:

N
W E
S

Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure E1.6:
XP-RAFTS
Subcatchment Layout

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File Name: FigE1.6 - RAFTS.wor

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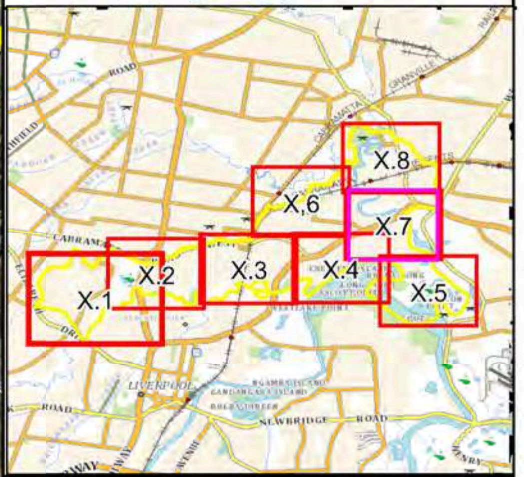

LEGEND

XP-RAFTS Subcatchment Boundaries

XP-RAFTS Link

XP-RAFTS Node

Notes:

N
W
E
S

Scale 1:5,000 (at A3)

0 0.15 0.3

Km

Figure E1.7:
XP-RAFTS
Subcatchment Layout

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Sydney, NSW 2000

File Name: FigE1.7 - RAFTS.wor

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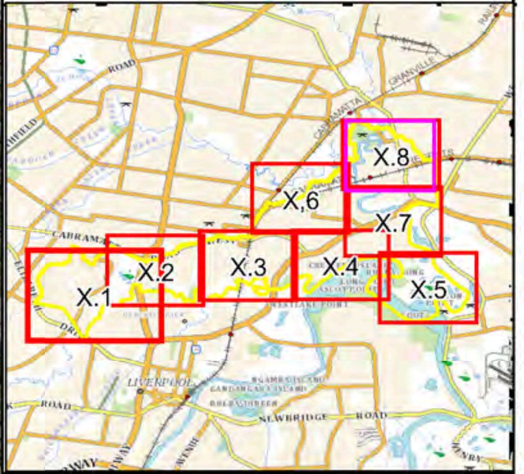

LEGEND

- XP-RAFTS Subcatchment Boundaries
- XP-RAFTS Link
- XP-RAFTS Node

Notes:

N
W E
S

Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure E1.8:
XP-RAFTS
Subcatchment Layout

Prepared By:
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Sydney, NSW 2000

File Name: FigE1.8 - RAFTS.wor

Key hydrologic properties including area and average vectored slope were calculated automatically for each subcatchment using CatchmentSIM. The remote sensing land use outputs (refer **Figure 5**) were used to define the variation in impervious areas and catchment roughness (i.e., pervious "n" values). The percentage impervious and pervious 'n' values that were assigned to each land use are summarised in **Table 4**. The percentage impervious and Manning's 'n' values were subsequently used to calculate a weighted average percentage impervious and pervious 'n' value for each subcatchment.

Table 5 Impervious Percentage and Pervious "n" values

Land Use	Impervious %	Pervious "n"
Buildings	100	0.025
Water	100	0.030
Trees	0	0.100
Grass	0	0.035
Concrete	100	0.015
Road	100	0.018

Each XP-RAFTS subcatchment was subdivided into two sub-areas. The first sub-area was used to represent the pervious sections of the subcatchment and the second sub-area was used to represent the impervious sections of the subcatchment. The division of each subcatchment into pervious and impervious sub-areas allows different rainfall losses and roughness coefficients to be specified, thereby providing a more realistic representation of rainfall-runoff processes from the two different hydrologic systems.

Stream Routing

In addition to local subcatchment runoff, most subcatchments will also carry flow from upstream catchments along the main flow path/watercourses. The flow along these watercourses/flow paths is represented in XP-RAFTS using a "link" between successive subcatchment "nodes".

For this study, the velocity results from a preliminary 1%AEP flood simulation were used in conjunction with the main watercourse length to determine the average travel time for flow along each watercourse (lag = watercourse length / average velocity along watercourse).

Hydrologic Results

ARR2016

The "base" XP-RAFTS model was updated to include each of the 245 1% AEP design storms. Each design storm was routed through the XP-RAFTS model and the peak discharges from the full suite of temporal patterns were reviewed to determine the "critical" temporal pattern for each storm duration.

In accordance with guidance provided in ARR2016, the temporal pattern that generated the closest, but next highest peak discharge to the average discharge, was selected as the "critical" temporal pattern for each subcatchment. The average discharge was calculated based on assessment of the peak discharge generated by all temporal patterns for a particular storm duration.

A review of the results yielded a wide variety of critical durations and temporal patterns across the XP-RAFTS model area (over 200 different critical temporal patterns and critical storm durations varying between 10 mins and 6 hours patterns were identified when considering all 366 subcatchments in the XP-RAFTS model). It was considered that this quantity of storms was still too high to apply to the TUFLOW model. Therefore, the critical temporal patterns and durations were only investigated at 19 "critical" locations. A critical location was defined as a location where the results of preliminary flood simulations showed significant overland flow depths (note that areas immediately adjoining Prospect, Orphan School and Cabramatta Creeks were not included in the critical area assessment as mainstream flooding is more likely to dominate across these areas). The location of each "critical" location is shown in **Plate 1**.

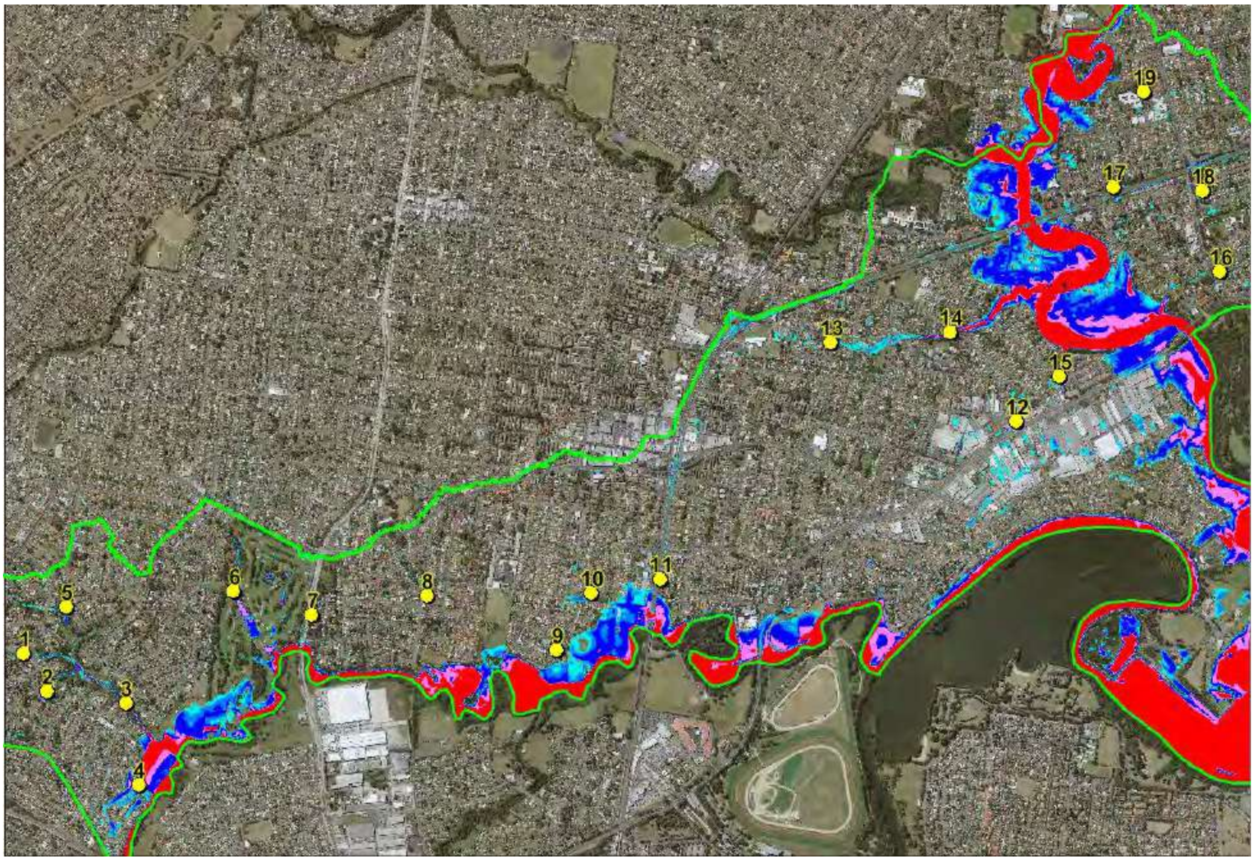


Plate 1 **Locations for critical duration and critical temporal pattern assessment**

Table 6 shows the peak discharges and critical durations at each of the "critical" locations based upon ARR2016. As shown in **Table 6**, once the assessment was restricted to the critical locations only, it showed that the critical durations varied between 10 minutes and 25 minutes (with the 15 minute duration being most common). The following temporal patterns were determined to be the most appropriate to adopt for each storm duration:

- 1% AEP 10 minute storm: temporal pattern number 4363;
- 1% AEP 15 minute storm: temporal pattern number 4397; and,
- 1% AEP 25 minute storm: temporal pattern number 4471.

ARR1987

The XP-RAFTS model was also used to simulate rainfall-runoff processes for the 1% AEP event based upon ARR1987. This involved running a range of different storm durations (10 minutes up to 9 hours) to determine the critical duration at each of the critical locations. In accordance with ARR1987 the critical duration was selected as the storm duration that produced the highest peak 1% AEP discharge at each critical location. Peak discharges and critical storm duration at each of the critical locations are summarised in **Table 6**.

Table 6 Comparison between ARR 1987 and ARR2016 1%AEP peak discharges

Critical Location ID (refer Plate 1)	XP-RAFTS Subcatchment ID	Critical Duration (mins)		Peak 1% AEP Discharge		
		ARR1987	ARR2016	ARR1987	ARR2016	Difference
1	57	90	15	3.54	1.88	-47%
2	45	120	10	2.39	1.28	-46%
3	36	120	15	23.3	11.2	-52%
4	23	120	10	6.57	4.23	-36%
5	60	90	15	3.27	1.75	-46%
6	75	120	15	6.23	2.79	-55%
7	215	90	15	2.35	1.19	-49%
8	86	120	10	2.77	1.63	-41%
9	333	15	15	1.82	1.37	-25%
10	113	120	15	9.84	6.07	-38%
11	246	60	15	9.5	6.39	-33%
12	147	90	15	3.82	2.61	-32%
13	131	120	15	15.0	10.4	-31%
14	276	60	25	25.2	15.7	-38%
15	143	20	25	9.44	6.50	-31%
16	169	90	15	6.07	3.64	-40%
17	177	90	15	4.06	2.92	-28%
18	173	90	25	5.79	3.31	-43%
19	303	90	15	7.11	4.81	-32%

The critical durations presented in **Table 6** shows that the critical durations for ARR1987 vary between 15 minutes and 120 minutes, with the 120 minute storm duration being most common. Accordingly, the critical ARR1987 durations are typically much longer than ARR2016.

Table 6 also shows that the ARR1987 peak 1% AEP discharges are, at all locations, higher than the ARR2016 discharges. The ARR1987 are between 31% and 52% higher than the corresponding ARR2016 discharges (with the average difference being +39%).

Accordingly, the outcomes of the hydrologic assessment show that the revised ARR2016 hydrologic procedures are predicted to generate lower peak 1% AEP discharge estimates for the Cabravale study area. The differences are primarily associated with the lower point design rainfall intensities, higher areal reduction factors and higher initial rainfall losses for ARR2016.

Hydraulic Assessment

ARR2016

To assess the impact that the revised ARR2016 hydrology would have on design flood behaviour, the critical 1%AEP ARR2016 hydrographs for the 10, 15 and 25 minute storm durations were applied to the TUFLOW model.

The rainfall hyetographs for the critical temporal patterns and storm durations were applied directly to the TUFLOW model (i.e., the TUFLOW model was used to simulate the transformation of rainfall into runoff). Rainfall-runoff processes across the mainstream areas (i.e., Cabramatta, Orphan School and Prospect creeks) were simulated using the XP-RAFTS models for the Prospect and Cabramatta Creek catchments (i.e., flow hydrographs were extracted from the XP-RAFTS models and were used to define mainstream inflows into the TUFLOW model). A static tailwater level of 6.8 mAHD adopted for the Georges River (corresponding to the peak 1% AEP Georges River water level river).

The results from the individual TUFLOW model simulations were combined into a final flood envelope for the 1% AEP flood. The TUFLOW results from the Prospect Creek and Cabramatta Creek TUFLOW model simulations were also incorporated into the design flood envelope. However, the raw TUFLOW model results were "filtered" by removing results from areas that were inundated to a depth of less than 0.15 metres and did not form part of an obvious overland flow path. The resulting 1% AEP floodwater depth mapping is provided in **Figure E2**.

ARR1987

The TUFLOW model was also used to simulate the 1% AEP flood based upon the ARR1987 hydrology. This involved applying the ARR1987 critical hyetographs to the TUFLOW model and using the TUFLOW to simulate the transformation of rainfall into runoff and simulate the movement of this runoff across the Cabravale study area. Like the ARR2016 simulation, mainstream inflows were defined using flow hydrographs extracted from the XP-RAFTS model and a static tailwater level of 6.8 mAHD was adopted for the Georges River.

The results from each of the invidious 1% AEP simulations were combined to form a final design flood envelope. The final design flood envelope was also "filtered" using the same process that was employed for the ARR2016 simulation. The resulting floodwater depth results, based upon ARR1987 hydrology, are presented in **Figure E3**.

Hydraulic Impacts

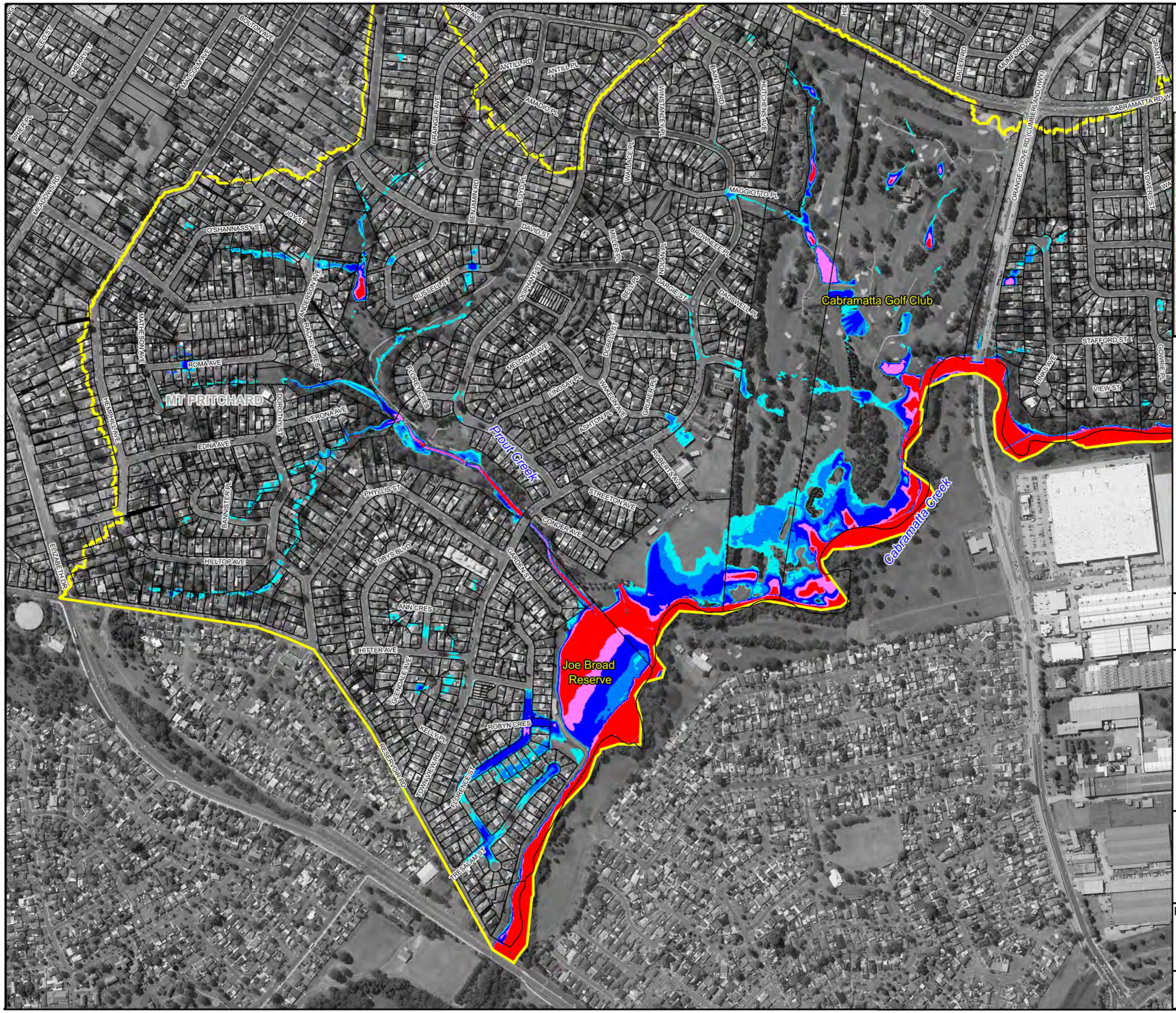
To assist in quantifying the impacts that ARR2016 is predicted to have on peak water levels and extents, flood level difference mapping was prepared. The difference map was prepared by subtracting peak ARR2016 flood levels from the from the ARR1987 flood level. This enabled the magnitude and location of changes in flood level/depths and inundation extent to be quantified. The resulting difference mapping is presented in the attached **Figure E4**.

Figure E4 shows that the ARR2016 will generate lower 1% AEP flood levels across all sections of the Cabravale study area. In the upstream sections of the study area, the flood level differences are typically less than 0.1 metres. However, as the contributing catchment areas increase, the flood level differences start to become more significant. Along the downstream sections of Long

Creek, the flood level differences are predicted to exceed 0.2 metres and along the downstream sections of Prout Creek the differences are predicted to exceed 0.3 metres.

A comparison of the inundation areas shows that the 1% AEP flood with ARR2016 hydrology is predicted to inundate a land area of 4.14 km^2. The 1% AEP flood with ARR1987 hydrology is predicted to inundate a land area of 4.58 m^2. Therefore, ARR2016 is predicted to reduce the amount of inundated land by approximately 10%.

The number of properties within the Cabravale study area inundated using both hydrologic precures was also determined by intersecting the inundation extents with Council's cadastre layer. This determined that the ARR2016 hydrology is predicted to inundate 2,506 properties during a 1% AEP flood. The ARR1987 hydrology is predicted to inundate 3,060 properties.



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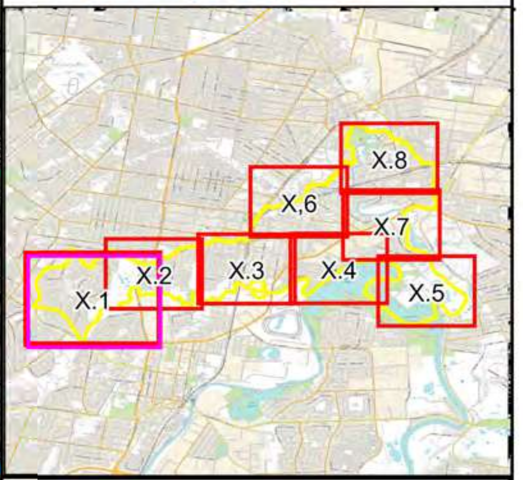


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

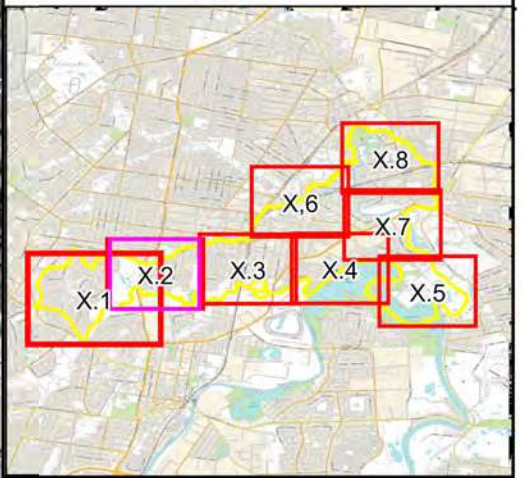
Scale 1:7,000 (at A3)

0 0.2 0.4
Km

Figure E2.1:
1% AEP ARR2016
Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE2.1 - ARR2016 Depths.wor



LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure E2.2:
1% AEP ARR2016
Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE2.2 - ARR2016 Depths.wor

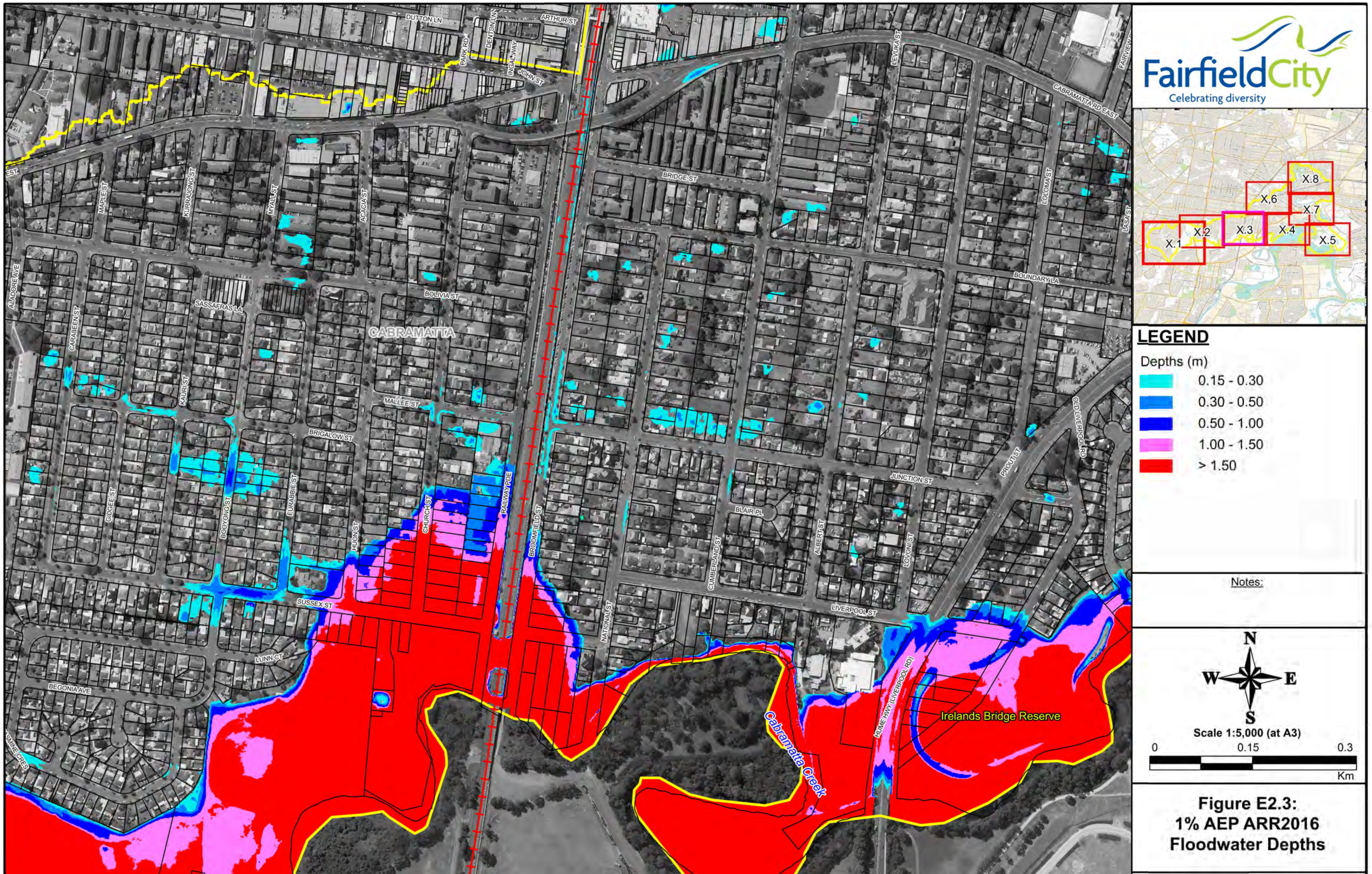


Figure E2.3:
1% AEP ARR2016
Floodwater Depths

Prepared By:
Catchment Simulation Solutions
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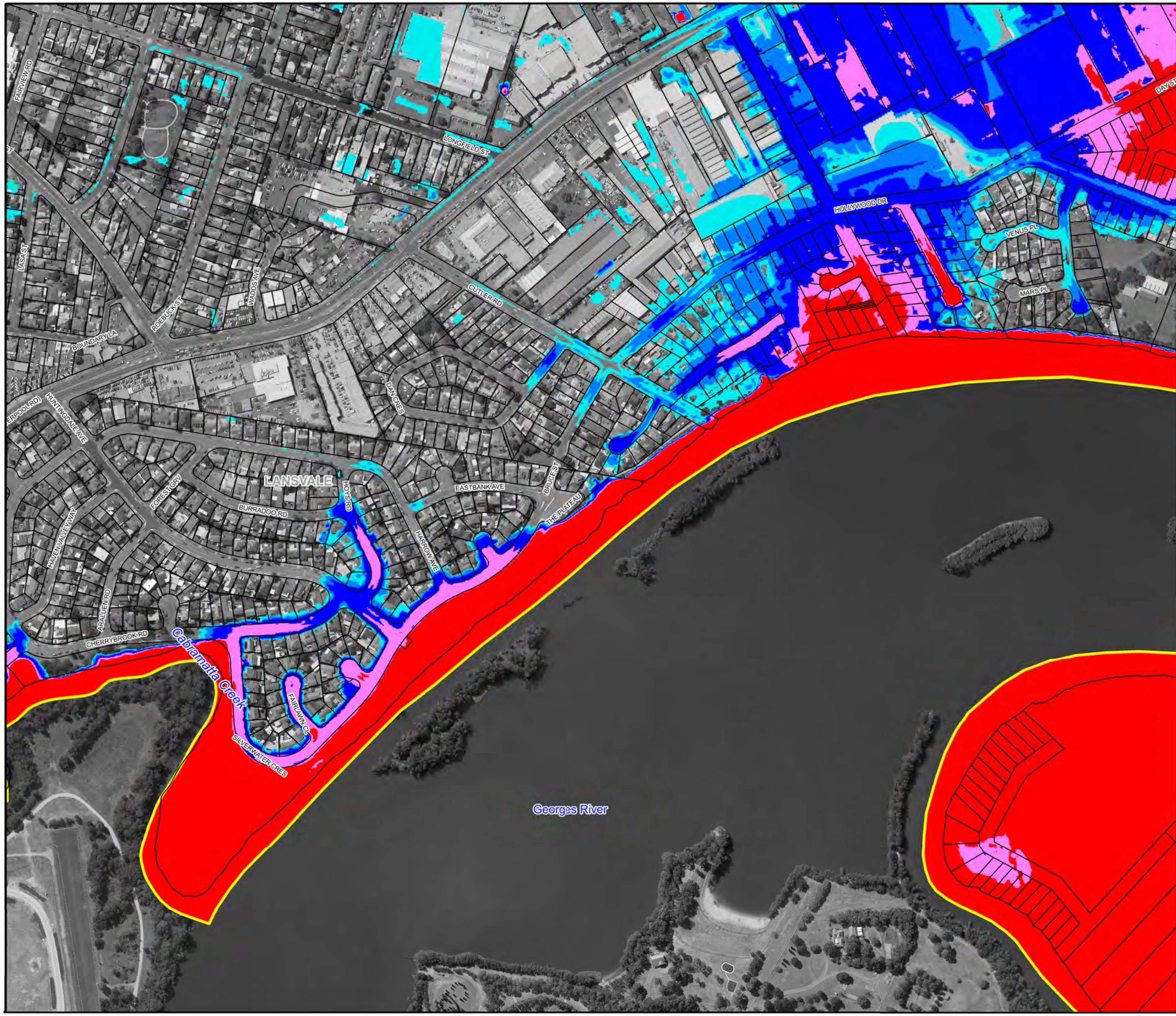
Sydney, NSW 2000

File Name: FigE2.3 - ARR2016 Depths.wor



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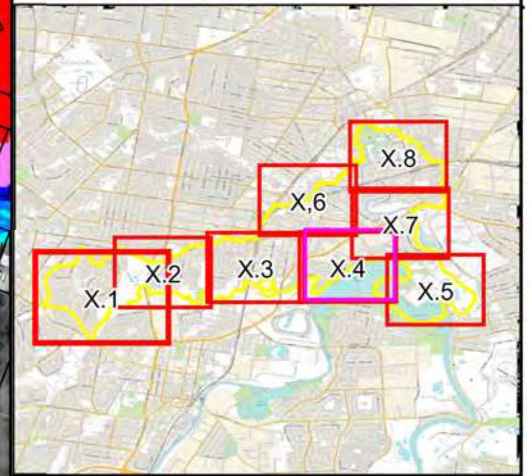


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

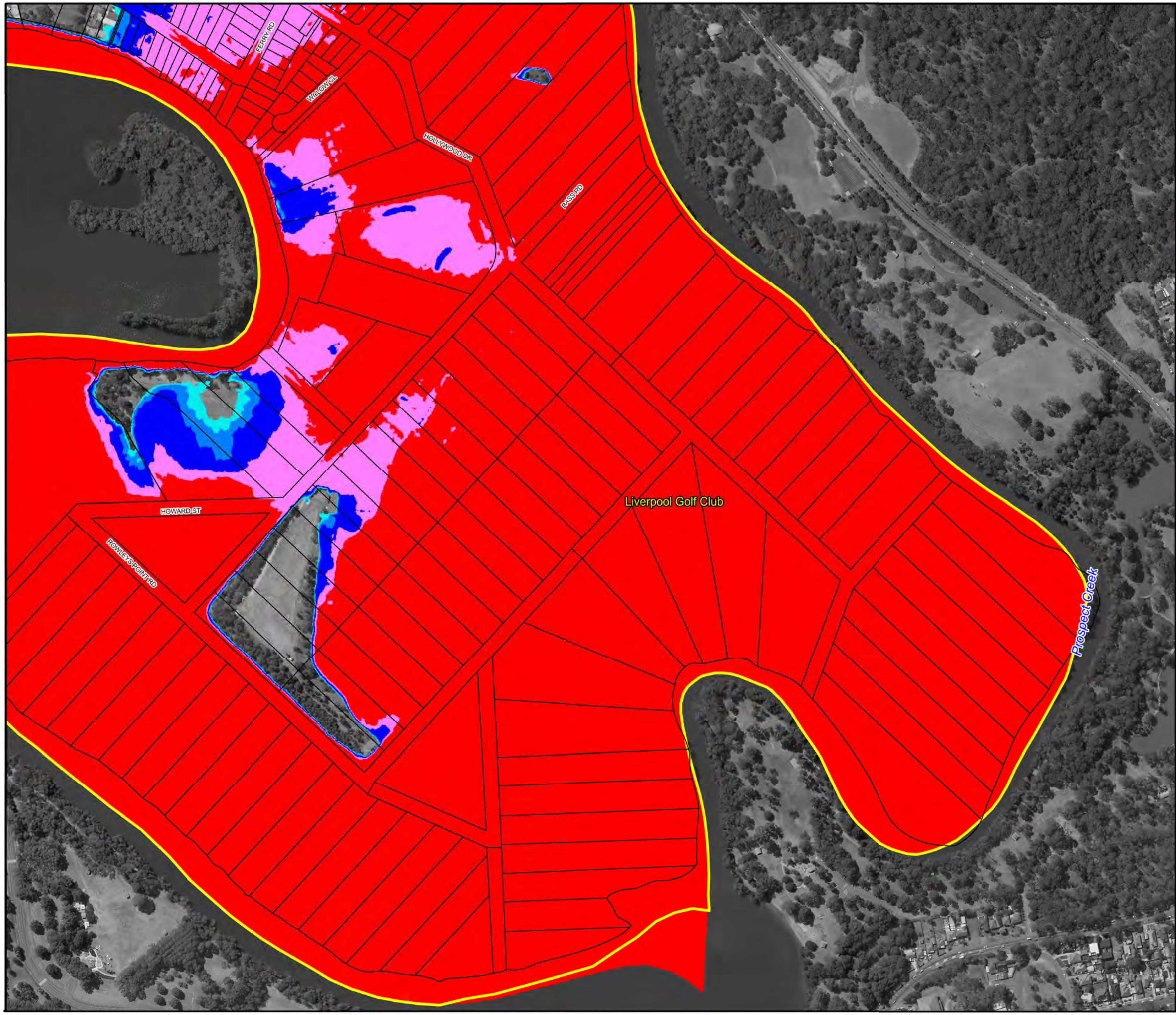
Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure E2.4:
1% AEP ARR2016
Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE2.4 - ARR2016 Depths.wor



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LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N W E S

Scale 1:5,000 (at A3)

0 0.15 0.3 Km

Figure E2.5: 1% AEP ARR2016 Floodwater Depths

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CatchmentSimulationSolutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE2.5 - ARR2016 Depths.wor

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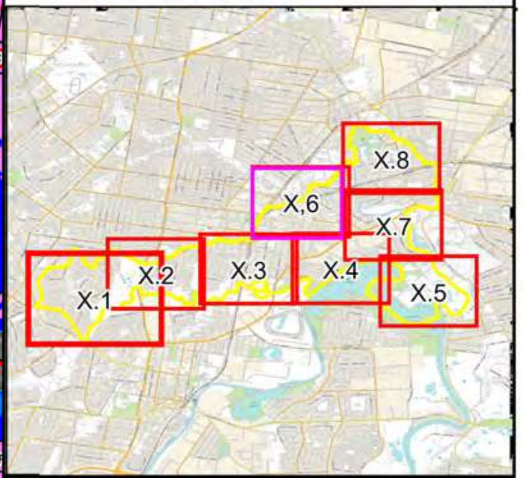


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

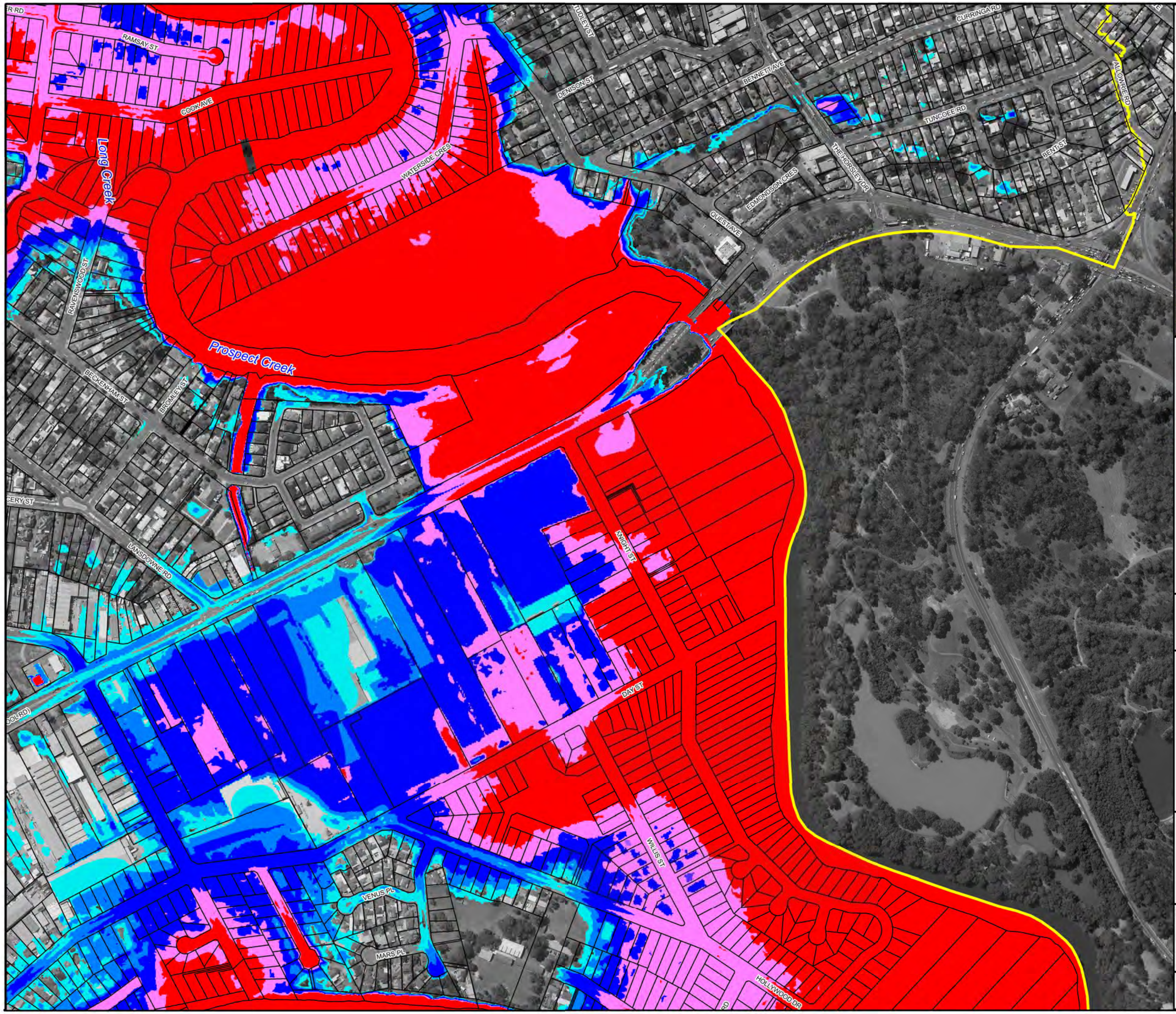
Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure E2.6: 1% AEP ARR2016 Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE2.6 - ARR2016 Depths.wor



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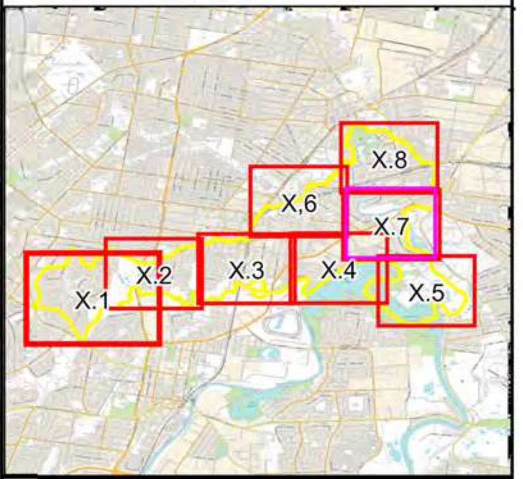


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

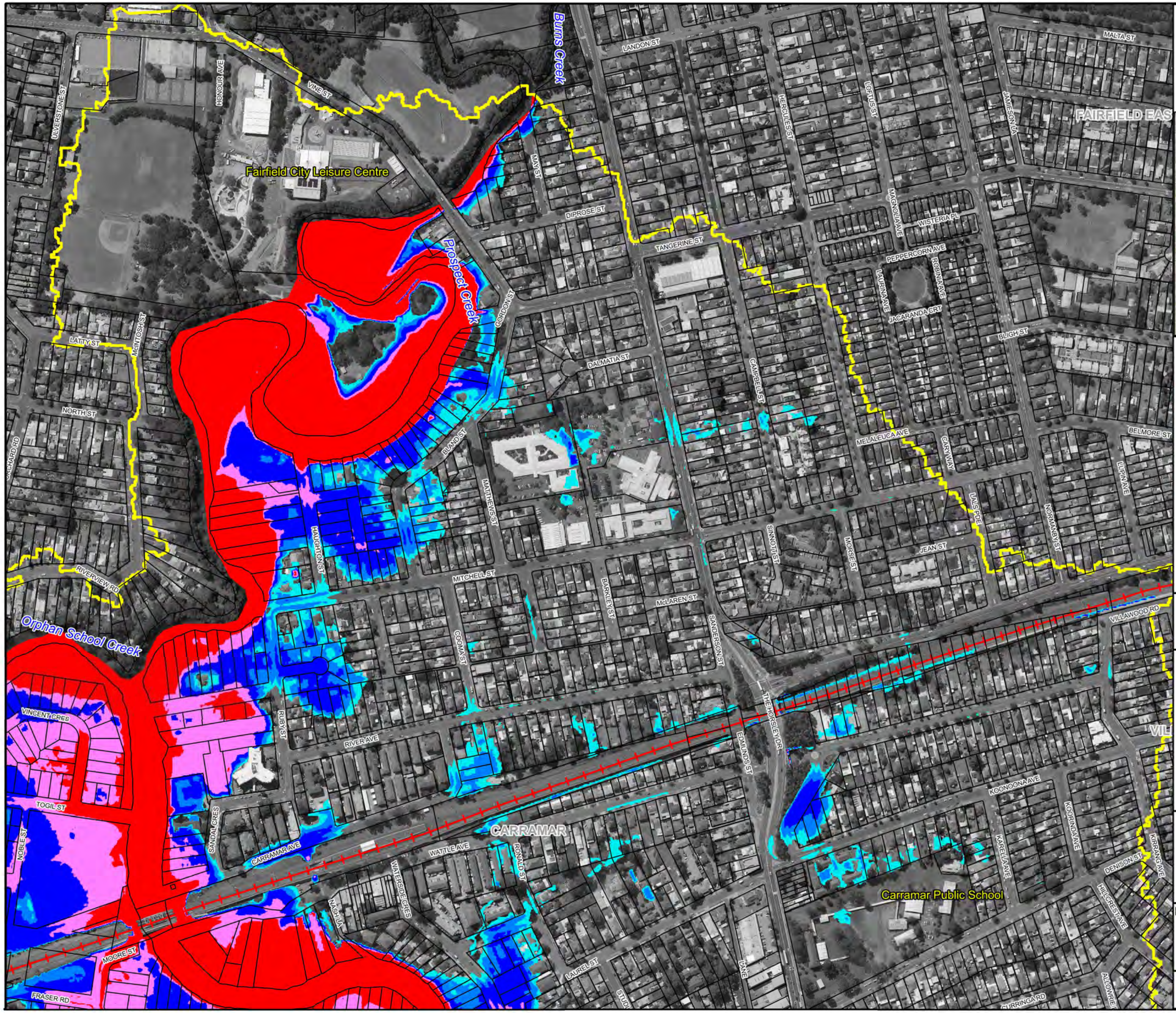
Scale 1:5,000 (at A3)

0 0.15 0.3
Km

**Figure E2.7:
1% AEP ARR2016
Floodwater Depths**

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE2.7 - ARR2016 Depths.wor



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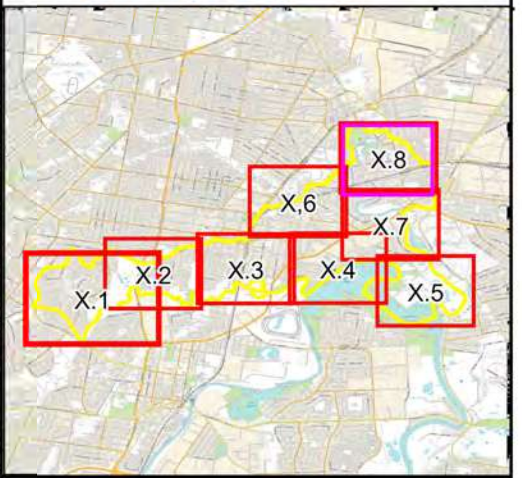


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

Scale 1:5,000 (at A3)

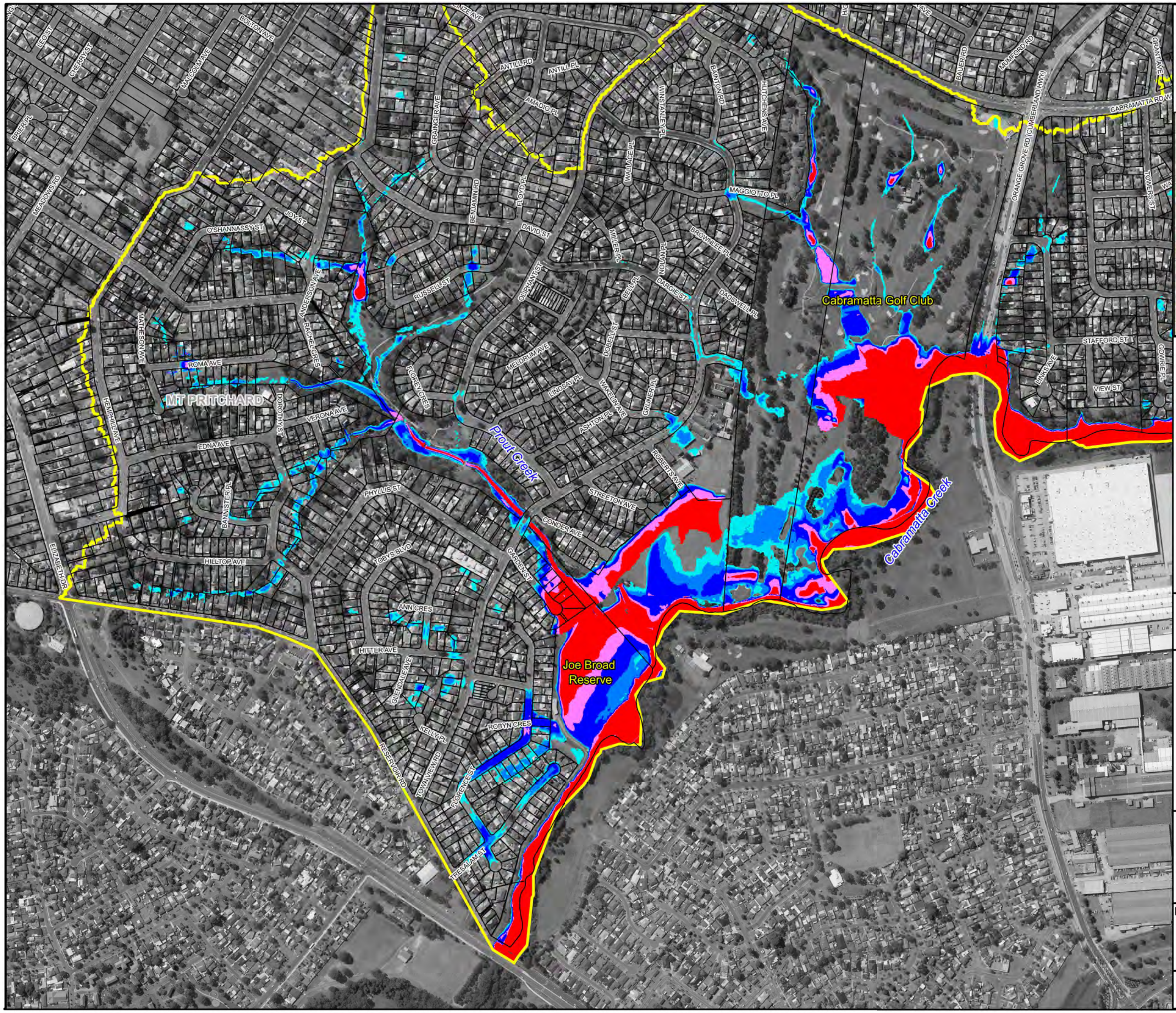
0 0.15 0.3
Km

Figure E2.8:
1% AEP ARR2016
Floodwater Depths

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE2.8 - ARR2016 Depths.wor



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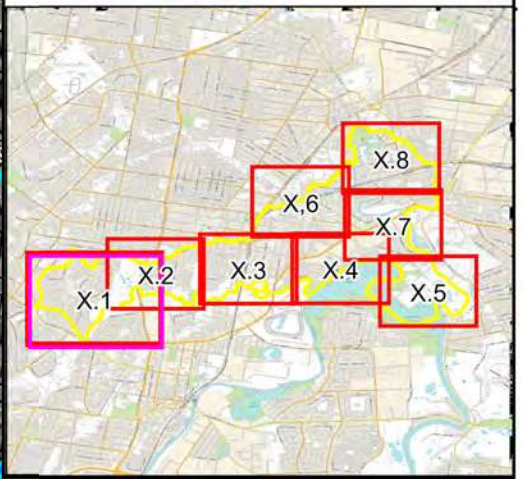


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

Scale 1:7,000 (at A3)

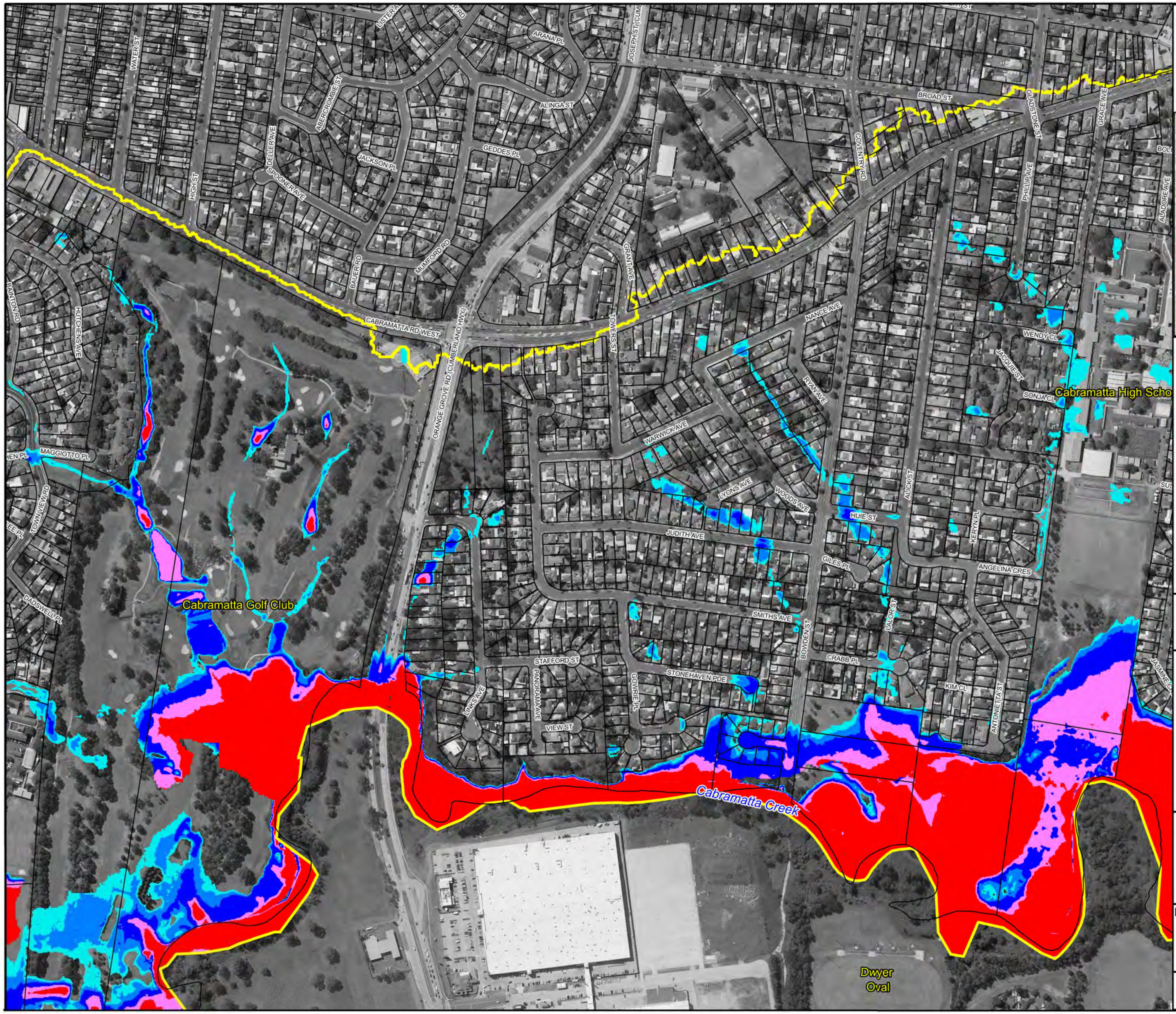
0 0.2 0.4
Km

Figure E3.1:
1% AEP ARR1987
Floodwater Depths

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE3.1 - ARR1987 Depths.wor



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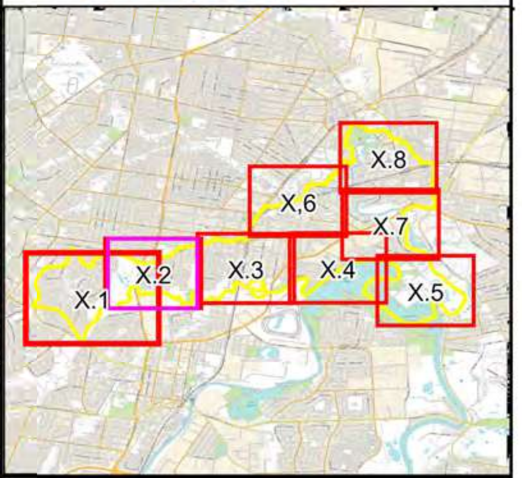


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

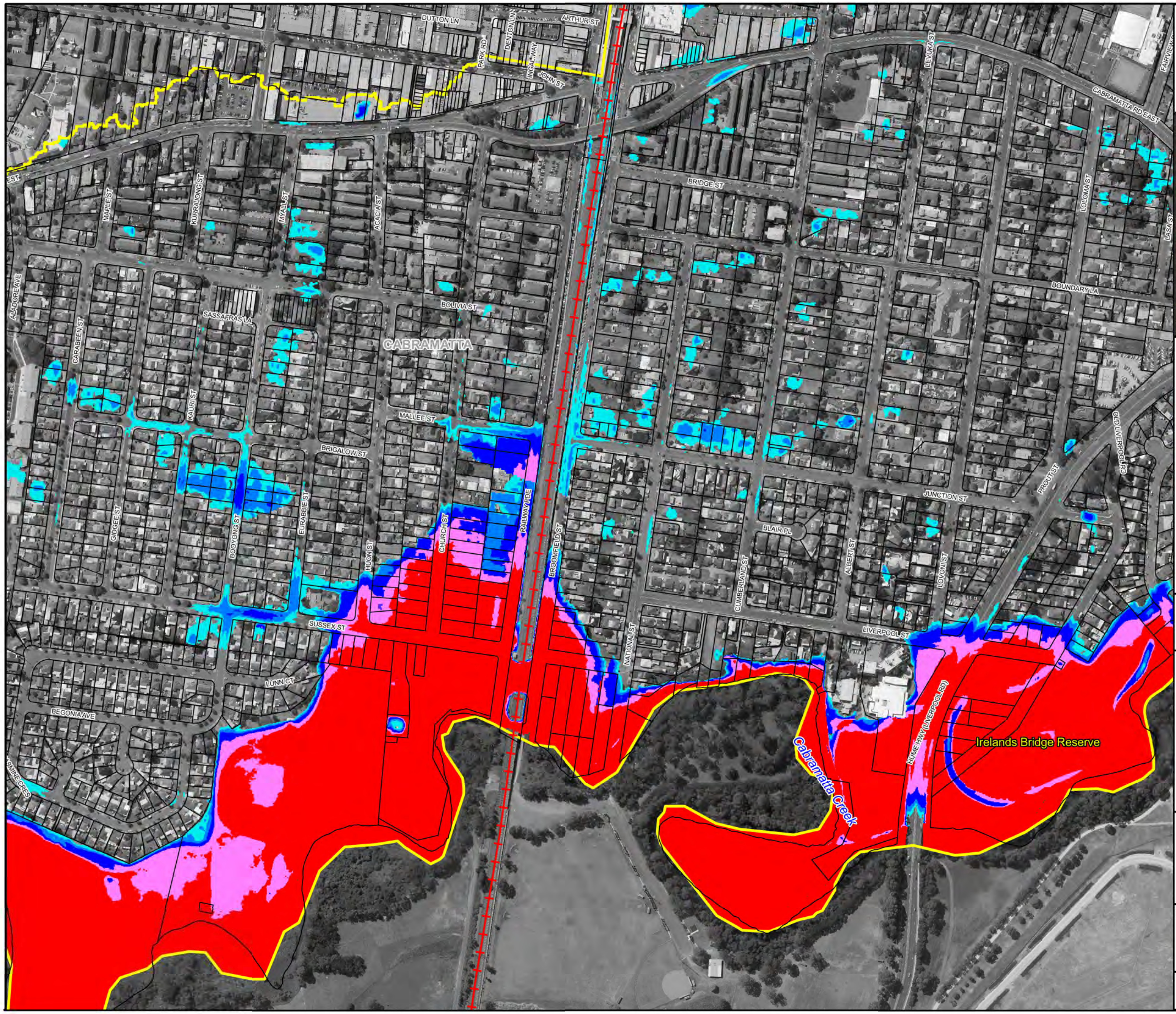
Scale 1:5,000 (at A3)

0 0.15 0.3 Km

Figure E3.2:
1% AEP ARR1987
Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE3.2 - ARR1987 Depths.wor



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X.1 X.2 X.3 X.4 X.5 X.6 X.7 X.8

LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N W E S

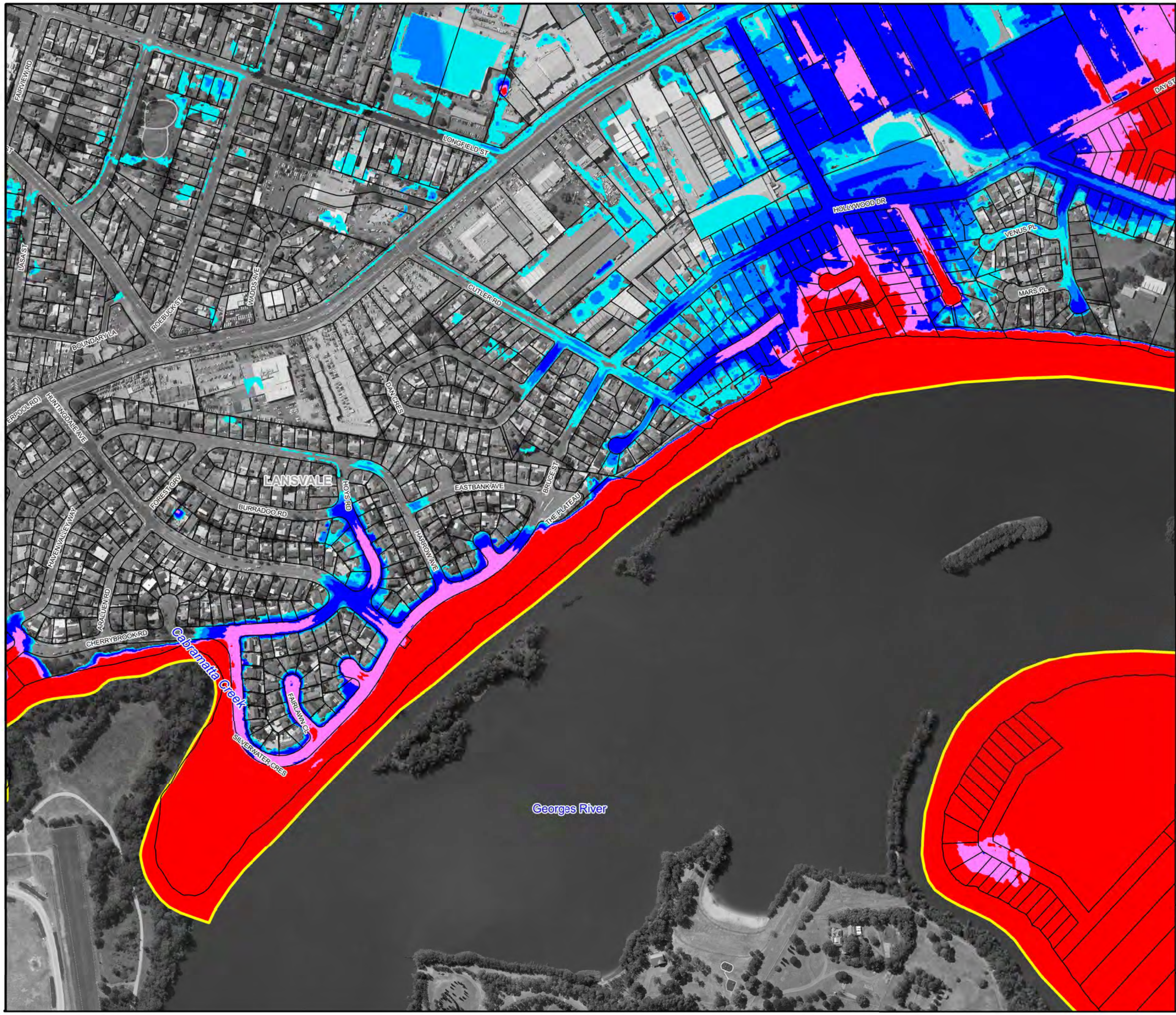
Scale 1:5,000 (at A3)

0 0.15 0.3 Km

Figure E3.3: 1% AEP ARR1987 Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE3.3 - ARR1987 Depths.wor



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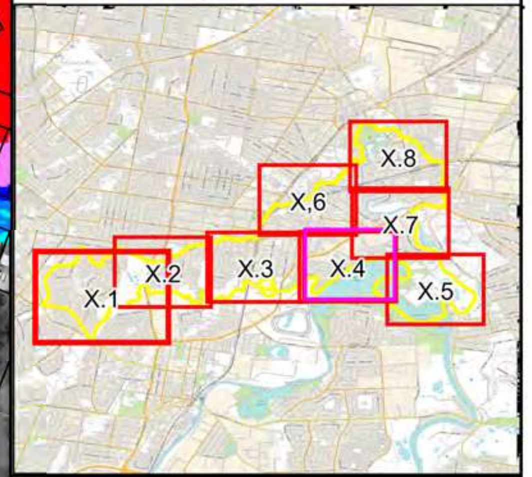


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

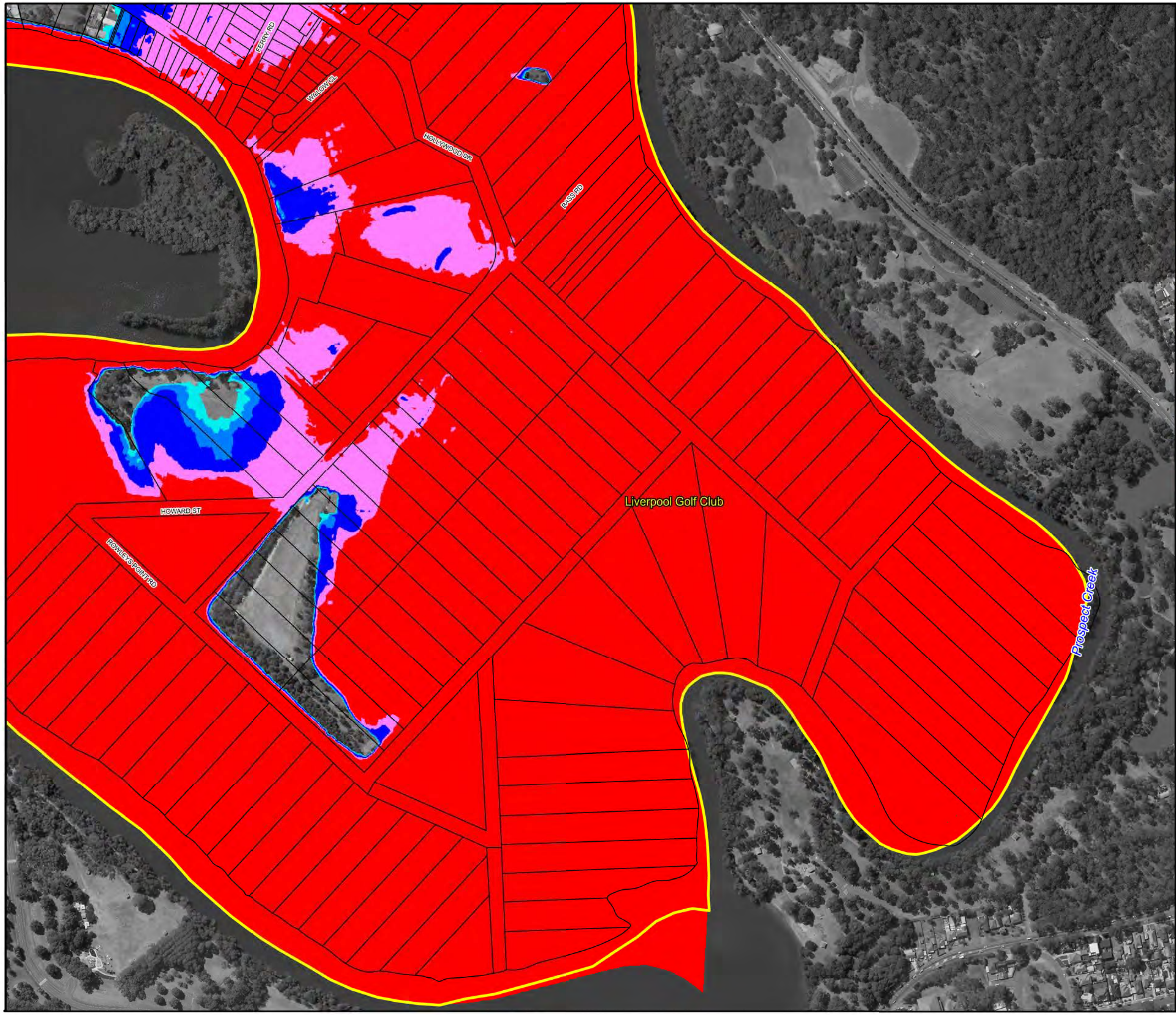
Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure E3.4: 1% AEP ARR1987 Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE3.4 - ARR1987 Depths.wor



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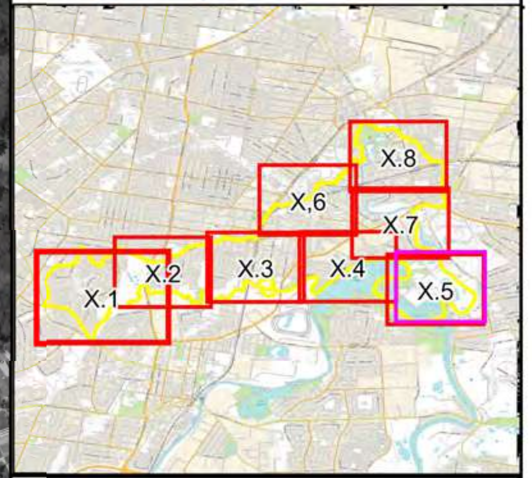


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

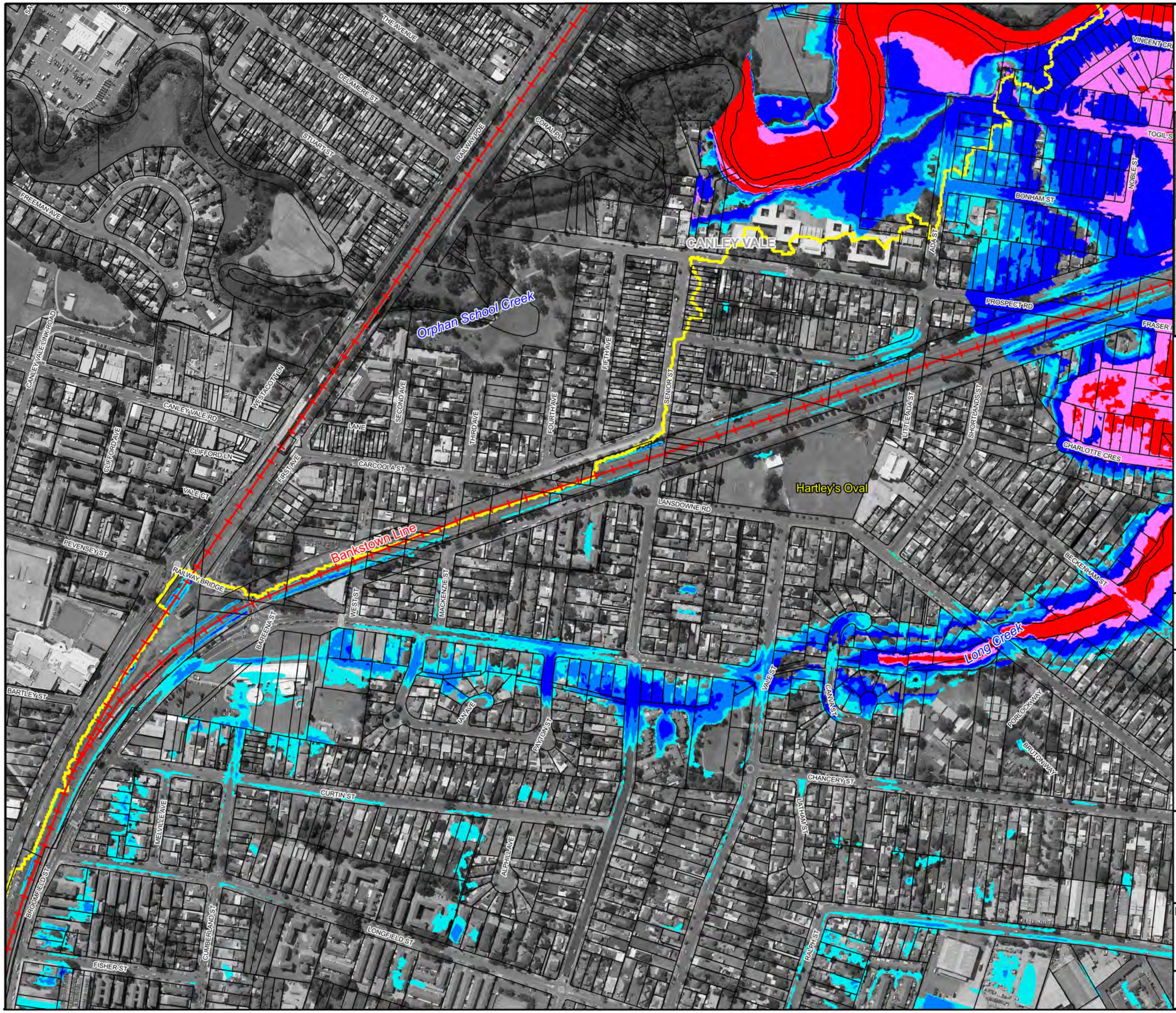
Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure E3.5:
1% AEP ARR1987
Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE3.5 - ARR1987 Depths.wor



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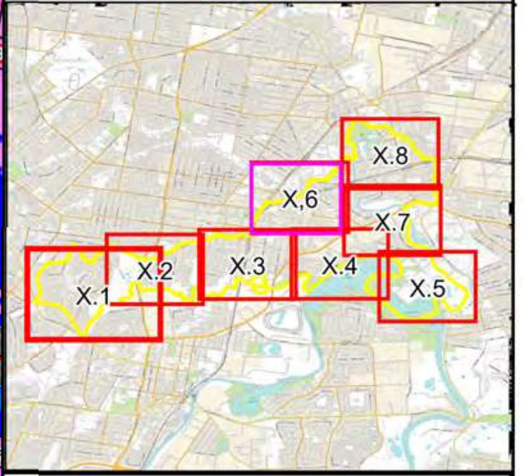


LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

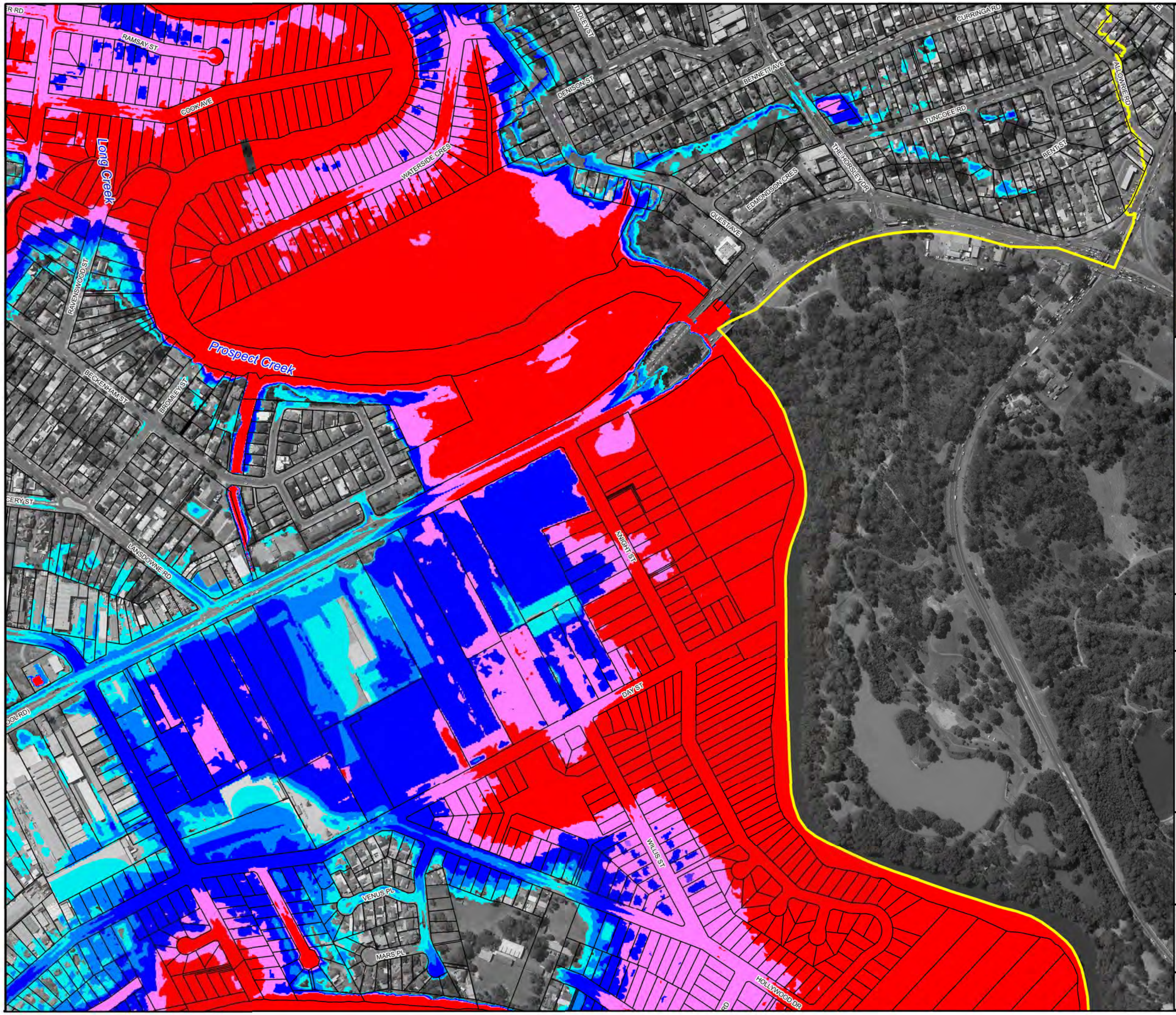
Scale 1:5,000 (at A3)

0 0.15 0.3
Km

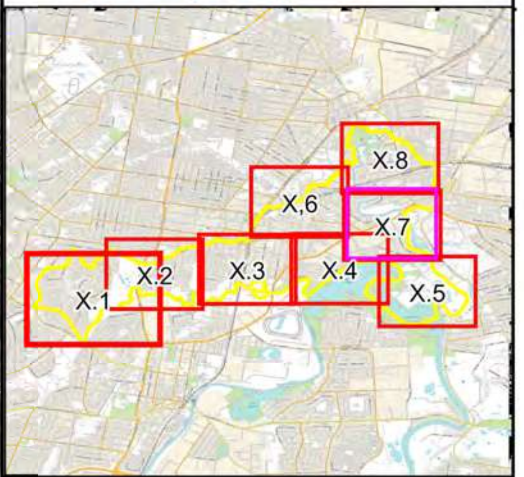
Figure E3.6:
1% AEP ARR1987
Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE3.6 - ARR1987 Depths.wor



Fairfield City
Celebrating diversity



LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

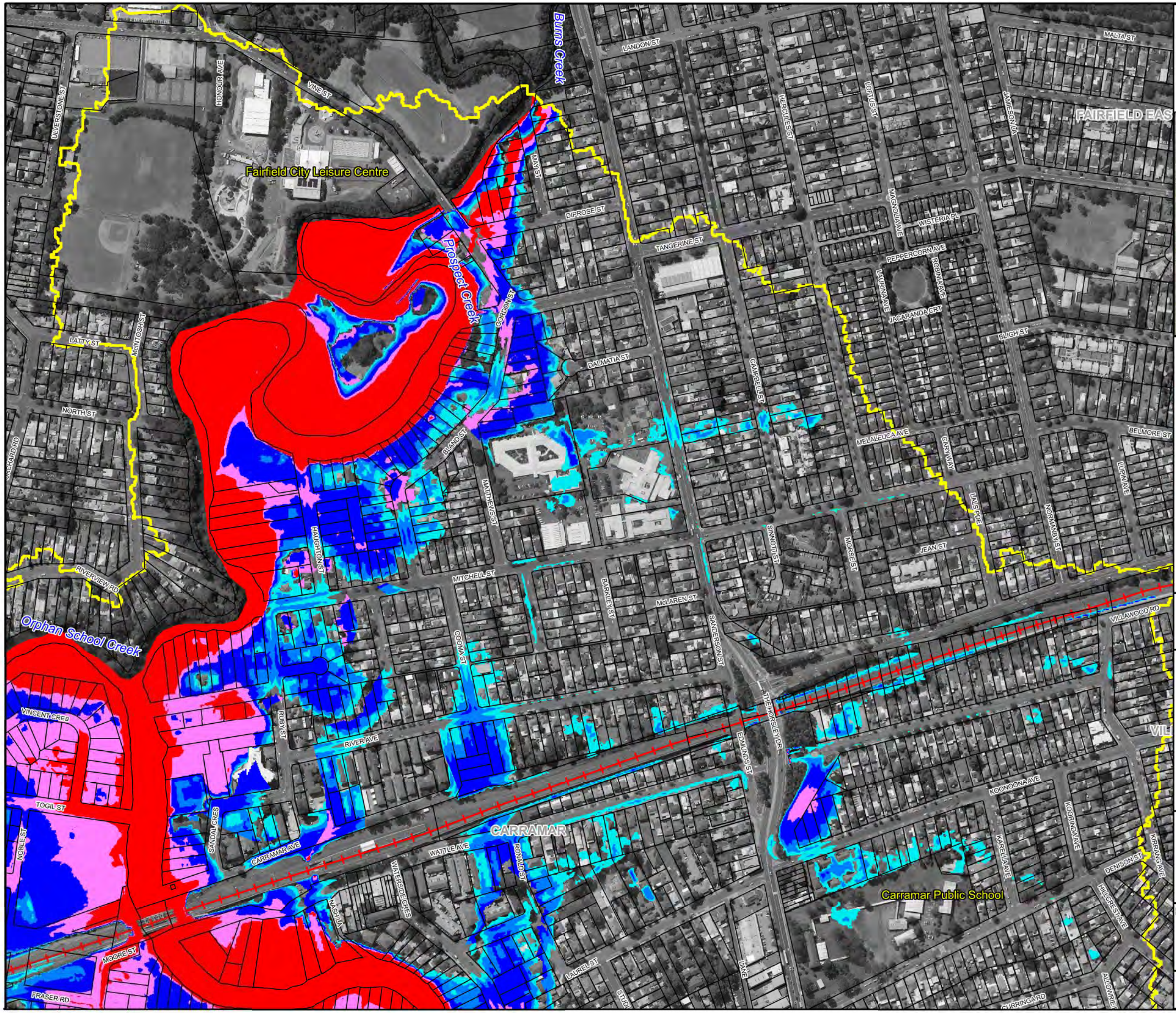
Scale 1:5,000 (at A3)

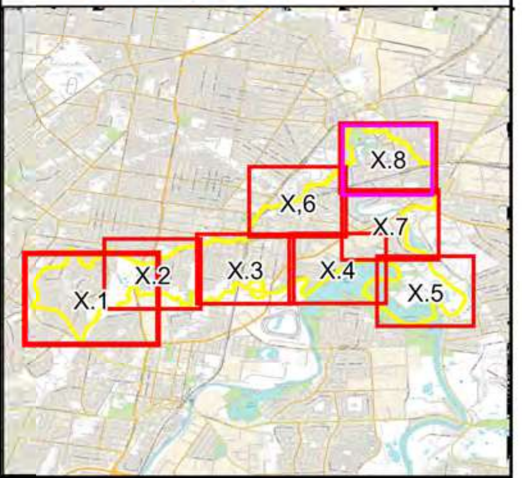
0 0.15 0.3 Km

Figure E3.7:
1% AEP ARR1987
Floodwater Depths

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE3.7 - ARR1987 Depths.wor





FairfieldCity
Celebrating diversity

LEGEND

Depths (m)

- 0.15 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 1.50
- > 1.50

Notes:

N
W E
S

Scale 1:5,000 (at A3)

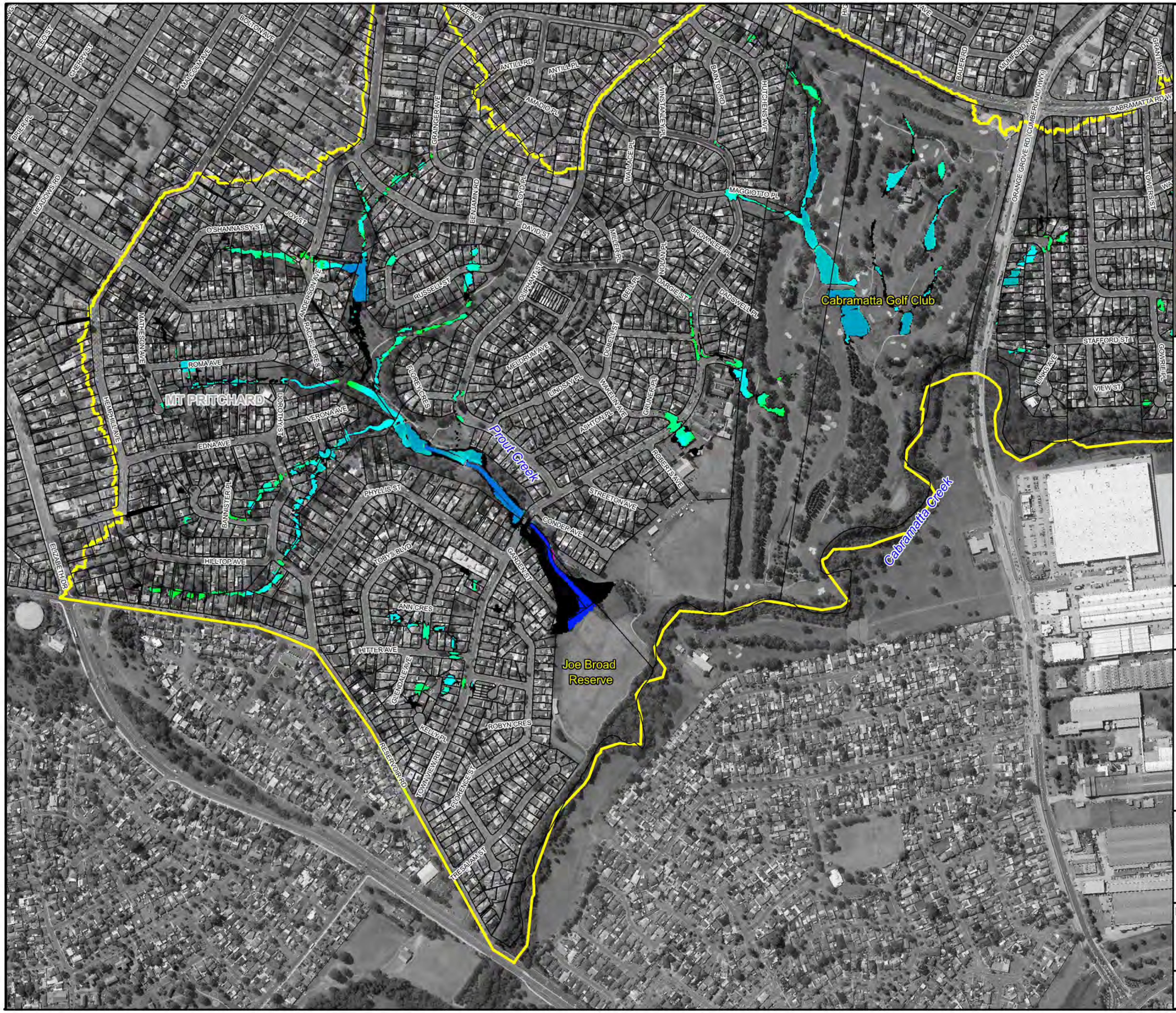
0 0.15 0.3 Km

Figure E3.8: 1% AEP ARR1987 Floodwater Depths

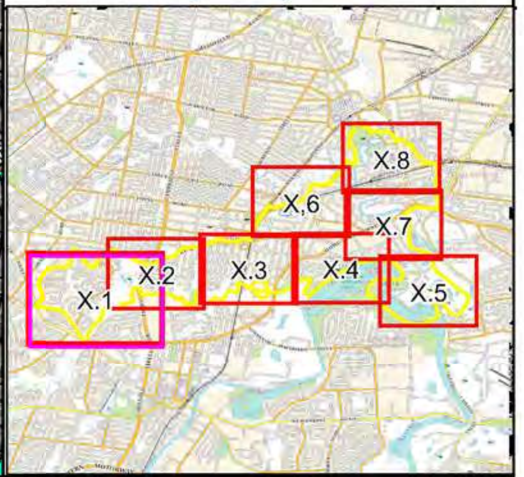
Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE3.8 - ARR1987 Depths.wor



FairfieldCity
Celebrating diversity



LEGEND

Water Level Difference (m)

- 0.50
- 0.20
- 0.10
- 0.02
- No Change
- -0.02
- -0.10
- -0.20
- -0.50
- Previously wet now dry
- Previously dry now wet

Notes:

Differences where calculated by subtracting ARR1987 1%AEP water levels from ARR2016 1%AEP Water Levels

N
W E
S

Scale 1:7,000 (at A3)

0 0.2 0.4
Km

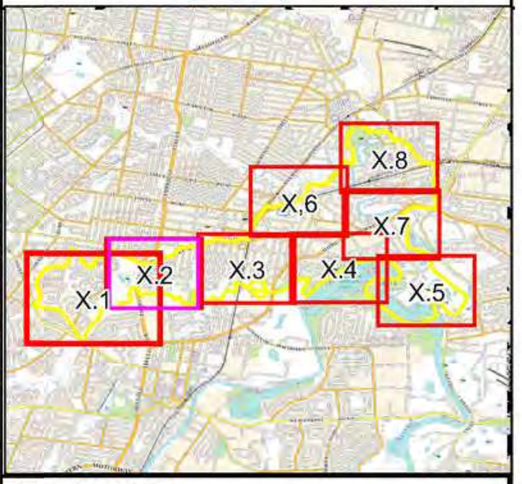
Figure E4.1: Difference Between ARR2016 and ARR1987 1% AEP Water Levels

Prepared By:

CatchmentSimulationSolutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE4.1 - ARR H Diff.wor

Fairfield City
Celebrating diversity



LEGEND

Water Level Difference (m)

- 0.50
- 0.20
- 0.10
- 0.02
- No Change
- -0.02
- -0.10
- -0.20
- -0.50
- Previously wet now dry
- Previously dry now wet

Notes:
Differences where calculated by subtracting ARR1987 1%AEP water levels from ARR2016 1%AEP Water Levels

N W E S

Scale 1:7,000 (at A3)

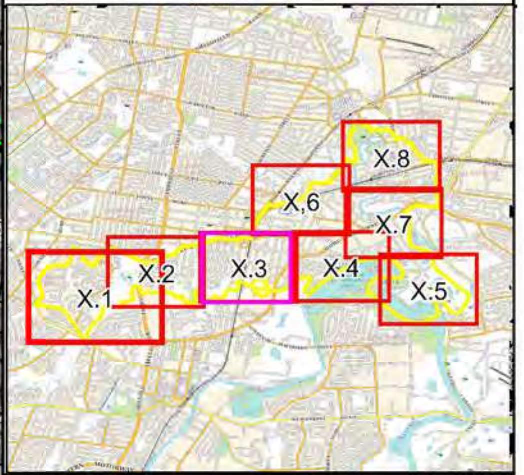
0 0.2 0.4 Km

Figure E4.2: Difference Between ARR2016 and ARR1987 1% AEP Water Levels

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE4.2 - ARR H Diff.wor

FairfieldCity
Celebrating diversity



LEGEND

Water Level Difference (m)

- 0.50
- 0.20
- 0.10
- 0.02
- No Change
- -0.02
- -0.10
- -0.20
- -0.50
- Previously wet now dry
- Previously dry now wet

Notes:

Differences where calculated by subtracting ARR1987 1%AEP water levels from ARR2016 1%AEP Water Levels

N W E S

Scale 1:7,000 (at A3)

0 0.2 0.4 Km

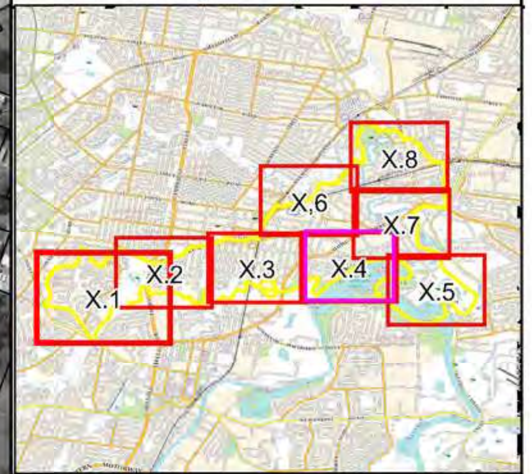
Figure E4.3: Difference Between ARR2016 and ARR1987 1% AEP Water Levels

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE4.3 - ARR H Diff.wor

Fairfield City
Celebrating diversity



LEGEND

Water Level Difference (m)

- 0.50
- 0.20
- 0.10
- 0.02
- No Change
- -0.02
- -0.10
- -0.20
- -0.50
- Previously wet now dry
- Previously dry now wet

Notes:

Differences where calculated by subtracting ARR1987 1%AEP water levels from ARR2016 1%AEP Water Levels

N
W E
S

Scale 1:7,000 (at A3)

0 0.2 0.4

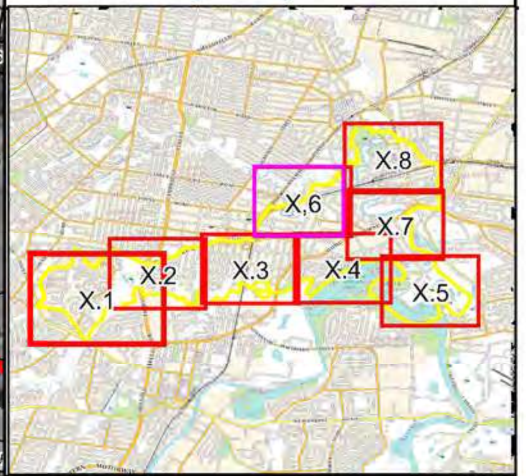
Km

Figure E4.4: Difference Between ARR2016 and ARR1987 1% AEP Water Levels

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE4.4 - ARR H Diff.wor



FairfieldCity
Celebrating diversity

LEGEND

Water Level Difference (m)

- 0.50
- 0.20
- 0.10
- 0.02
- No Change
- -0.02
- -0.10
- -0.20
- -0.50
- Previously wet now dry
- Previously dry now wet

Notes:

Differences where calculated by subtracting ARR1987 1%AEP water levels from ARR2016 1%AEP Water Levels

N W E S

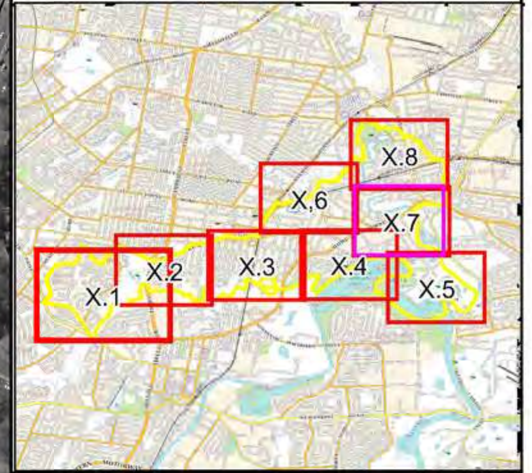
Scale 1:7,000 (at A3)

0 0.2 0.4 Km

Figure E4.6: Difference Between ARR2016 and ARR1987 1% AEP Water Levels

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE4.6 - ARR H Diff.wor



LEGEND

Water Level Difference (m)

- 0.50
- 0.20
- 0.10
- 0.02
- No Change
- -0.02
- -0.10
- -0.20
- -0.50
- Previously wet now dry
- Previously dry now wet

Notes:

Differences where calculated by subtracting ARR1987 1%AEP water levels from ARR2016 1%AEP Water Levels

Scale 1:7,000 (at A3)

0 0.2 0.4 Km

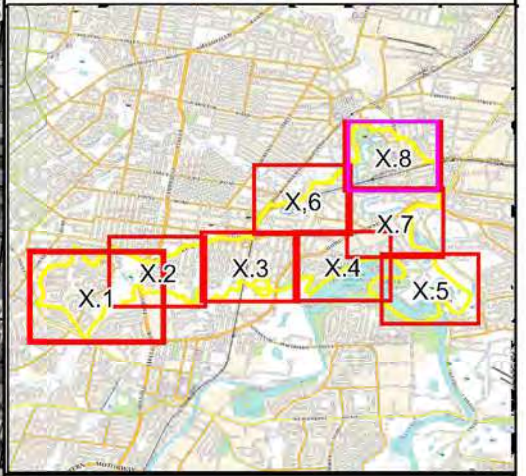
Figure E4.7: Difference Between ARR2016 and ARR1987 1% AEP Water Levels

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE4.7 - ARR H Diff.wor

Fairfield City
Celebrating diversity



LEGEND

Water Level Difference (m)

- 0.50
- 0.20
- 0.10
- 0.02
- No Change
- -0.02
- -0.10
- -0.20
- -0.50
- Previously wet now dry
- Previously dry now wet

Notes:
Differences where calculated by subtracting ARR1987 1%AEP water levels from ARR2016 1%AEP Water Levels

N
W E
S

Scale 1:7,000 (at A3)
0 0.2 0.4 Km

Figure E4.8: Difference Between ARR2016 and ARR1987 1% AEP Water Levels

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigE4.8 - ARR H Diff.wor

Summary

The outcomes of this assessment have determined that ARR2016 will produce some notable reductions in design discharges, flood levels and flood extents when compared with ARR1987 for the 1% AEP flood. The differences are primarily associated with the lower point design rainfall intensities, higher areal reduction factors and higher initial rainfall losses for ARR2016.

Although the magnitude of the reported reductions in flood discharges and levels may not transfer across to other AEPs, a review of the ARR2016 point rainfall intensities for the 20% and 5% AEP shows reductions relative to ARR1987. Therefore, it is likely that ARR2016 will generate lower discharges/levels for these other events as well.

As application of ARR2016 is relatively new and its application is yet to be fully tested, it is considered more appropriate to adopt the more conservative ARR1987 hydrology to define design flood behaviour as part of the current study.

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	150.95
Latitude	-33.895
Selected Regions	
River Region	
ARF Parameters	
Temporal Patterns	
Areal Temporal Patterns	
Interim Climate Change Factors	

Region Information

Data Category	Region
River Region	Sydney Coast-Georges River
ARF Parameters	SE Coast
Temporal Patterns	East Coast South

Data

River Region

division	South East Coast (NSW)
rivregnum	13
River Region	Sydney Coast-Georges River

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v1

ARF Parameters

Long Duration ARF

$$Areal\ reduction\ factor = Min\left\{1, \left[1 - a\left(Area^b - c\log_{10}Duration\right)Duration^{-d} + eArea^f Duration^g\left(0.3 + \log_{10}AEP\right) + h10^{iArea\frac{Duration}{1440}}\left(0.3 + \log_{10}AEP\right)\right]\right\}$$

Zone	SE Coast
a	0.06
b	0.361
c	0.0
d	0.317
e	8.11e-05
f	0.651
g	0.0
h	0.0
i	0.0

Short Duration ARF

$$ARF = Min\left[1, 1 - 0.287\left(Area^{0.265} - 0.439\log_{10}(Duration)\right).Duration^{-0.36} + 2.26 \text{ x } 10^{-3} \text{ x } Area^{0.226}.Duration^{0.125}\left(0.3 + \log_{10}(AEP)\right) + 0.0141 \text{ x } Area^{0.213} \text{ x } 10^{-0.021\frac{(Duration-180)^2}{1440}}\left(0.3 + \log_{10}(AEP)\right)\right]$$

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v1

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

Note: These losses are only for rural use and are NOT FOR USE in urban areas

Storm Initial Losses (mm)	28.0
Storm Continuing Losses (mm/h)	1.9

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v1

Temporal Patterns

code	ECsouth
Label	East Coast South

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v2

Areal Temporal Patterns

code	ECsouth
arealabel	East Coast South

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v2

BOM IFD Depths

Click here to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v2

Median Preburst Depths and Ratios

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	1.0 (0.038)	1.0 (0.029)	1.0 (0.025)	1.0 (0.022)	0.6 (0.012)	0.3 (0.005)
90 (1.5)	0.6 (0.02)	1.2 (0.03)	1.5 (0.035)	1.9 (0.038)	1.1 (0.019)	0.5 (0.008)
120 (2.0)	0.0 (0.0)	0.6 (0.015)	1.1 (0.022)	1.5 (0.027)	1.2 (0.018)	0.9 (0.013)
180 (3.0)	1.5 (0.039)	1.4 (0.029)	1.4 (0.024)	1.3 (0.021)	2.3 (0.031)	3.0 (0.037)
360 (6.0)	2.3 (0.045)	5.6 (0.087)	7.9 (0.104)	10.0 (0.116)	10.7 (0.105)	11.2 (0.098)
720 (12.0)	1.5 (0.022)	4.6 (0.052)	6.7 (0.063)	8.7 (0.07)	15.5 (0.105)	20.6 (0.123)
1080 (18.0)	1.4 (0.018)	5.7 (0.052)	8.6 (0.065)	11.3 (0.073)	15.4 (0.083)	18.5 (0.088)
1440 (24.0)	0.0 (0.0)	4.1 (0.033)	6.8 (0.045)	9.4 (0.052)	10.5 (0.049)	11.4 (0.047)
2160 (36.0)	0.0 (0.0)	1.7 (0.011)	2.8 (0.015)	3.8 (0.018)	5.2 (0.02)	6.2 (0.021)
2880 (48.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.003)	1.7 (0.005)
4320 (72.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v2

10% Preburst Depths

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
90 (1.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
120 (2.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
180 (3.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
360 (6.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
720 (12.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1080 (18.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1440 (24.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2160 (36.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2880 (48.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4320 (72.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v2

25% Preburst Depths

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
90 (1.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
120 (2.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
180 (3.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
360 (6.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
720 (12.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1080 (18.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1440 (24.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2160 (36.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2880 (48.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4320 (72.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v2

75% Preburst Depths

min (h)\AEP (%)	50	20	10	5	2	1
60 (1.0)	16.7 (0.633)	14.6 (0.43)	13.2 (0.337)	11.9 (0.268)	10.2 (0.2)	9.0 (0.159)
90 (1.5)	13.7 (0.455)	14.9 (0.387)	15.7 (0.353)	16.4 (0.327)	17.2 (0.297)	17.9 (0.277)
120 (2.0)	11.2 (0.34)	18.0 (0.426)	22.4 (0.461)	26.7 (0.485)	24.8 (0.387)	23.3 (0.327)
180 (3.0)	19.9 (0.524)	32.5 (0.668)	40.8 (0.726)	48.8 (0.763)	36.8 (0.493)	27.8 (0.334)
360 (6.0)	23.3 (0.471)	38.0 (0.589)	47.7 (0.633)	57.0 (0.659)	65.5 (0.64)	71.8 (0.625)
720 (12.0)	21.0 (0.317)	30.1 (0.336)	36.2 (0.34)	42.0 (0.339)	53.2 (0.36)	61.6 (0.369)
1080 (18.0)	22.3 (0.283)	33.4 (0.305)	40.7 (0.31)	47.7 (0.31)	55.5 (0.3)	61.3 (0.293)
1440 (24.0)	14.3 (0.161)	24.5 (0.196)	31.2 (0.206)	37.7 (0.211)	40.9 (0.19)	43.2 (0.178)
2160 (36.0)	6.1 (0.059)	13.2 (0.088)	17.9 (0.098)	22.4 (0.103)	33.4 (0.128)	41.6 (0.141)
2880 (48.0)	2.8 (0.024)	4.7 (0.028)	6.0 (0.03)	7.3 (0.03)	16.5 (0.056)	23.4 (0.071)
4320 (72.0)	0.0 (0.0)	0.4 (0.002)	0.7 (0.003)	1.0 (0.004)	7.2 (0.022)	11.9 (0.032)

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v2

90% Preburst Depths

min (h)\AEP (%)	50	20	10	5	2	1
60 (1.0)	38.9 (1.472)	39.1 (1.151)	39.2 (1.001)	39.4 (0.888)	43.5 (0.849)	46.6 (0.824)
90 (1.5)	39.8 (1.325)	47.2 (1.227)	52.0 (1.174)	56.7 (1.13)	62.3 (1.071)	66.4 (1.032)
120 (2.0)	57.7 (1.747)	72.1 (1.71)	81.7 (1.679)	90.8 (1.647)	88.5 (1.382)	86.8 (1.22)
180 (3.0)	57.3 (1.507)	67.7 (1.393)	74.6 (1.327)	81.2 (1.271)	101.2 (1.355)	116.1 (1.395)
360 (6.0)	53.6 (1.083)	79.3 (1.228)	96.3 (1.277)	112.6 (1.3)	119.8 (1.172)	125.2 (1.09)
720 (12.0)	47.2 (0.712)	71.8 (0.801)	88.0 (0.827)	103.6 (0.837)	113.6 (0.769)	121.1 (0.725)
1080 (18.0)	45.4 (0.575)	62.3 (0.57)	73.5 (0.56)	84.2 (0.547)	102.5 (0.556)	116.3 (0.556)
1440 (24.0)	35.5 (0.4)	46.3 (0.37)	53.5 (0.353)	60.3 (0.337)	75.4 (0.351)	86.6 (0.356)
2160 (36.0)	33.5 (0.323)	40.5 (0.271)	45.1 (0.247)	49.5 (0.228)	71.1 (0.272)	87.2 (0.296)
2880 (48.0)	16.3 (0.142)	18.1 (0.109)	19.2 (0.094)	20.3 (0.083)	53.9 (0.184)	79.0 (0.239)
4320 (72.0)	15.5 (0.121)	24.7 (0.131)	30.7 (0.132)	36.5 (0.132)	39.9 (0.12)	42.5 (0.114)

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v2

Interim Climate Change Factors

Values are of the format temperature increase in degrees Celcius (% increase in rainfall)

	RCP 4.5	RCP6	**RCP 8.5**
2030	**0.892 (4.5%)**	0.775 (3.9%)	**0.979 (4.9%)**
2040	**1.121 (5.6%)**	1.002 (5.0%)	**1.351 (6.8%)**
2050	**1.334 (6.7%)**	1.28 (6.4%)	**1.765 (8.8%)**
2060	**1.522 (7.6%)**	1.527 (7.6%)	**2.23 (11.2%)**
2070	**1.659 (8.3%)**	1.745 (8.7%)	**2.741 (13.7%)**
2080	**1.78 (8.9%)**	1.999 (10.0%)	**3.249 (16.2%)**
2090	**1.825 (9.1%)**	2.271 (11.4%)	**3.727 (18.6%)**

Layer Info

Time Accessed	13 December 2017 04:45PM
Version	2016_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values

APPENDIX F

PMP & EXTREME RAINFALL CALCULATIONS

GSDM CALCULATION SHEET

LOCATION INFORMATION

Catchment Cabravale Area 11.50 km^2

State New South Wales Duration Limit 6.0 hrs

Latitude 33.8966^{0}S Longitude 150.9446^{0}E

Portion of Area Considered:

Smooth, **S** = 0.00 (0.0 - 1.0) Rough, **R** = 1.00 (0.0 - 1.0)

ELEVATION ADJUSTMENT FACTOR (EAF)

Mean Elevation 12.5 m

Adjustment for Elevation (-0.05 per 300m above 1500m) 0.00

EAF = **1.00** (0.85 – 1.00)

MOISTURE ADJUSTMENT FACTOR (MAF)

MAF = **0.70** (0.40-1.00)

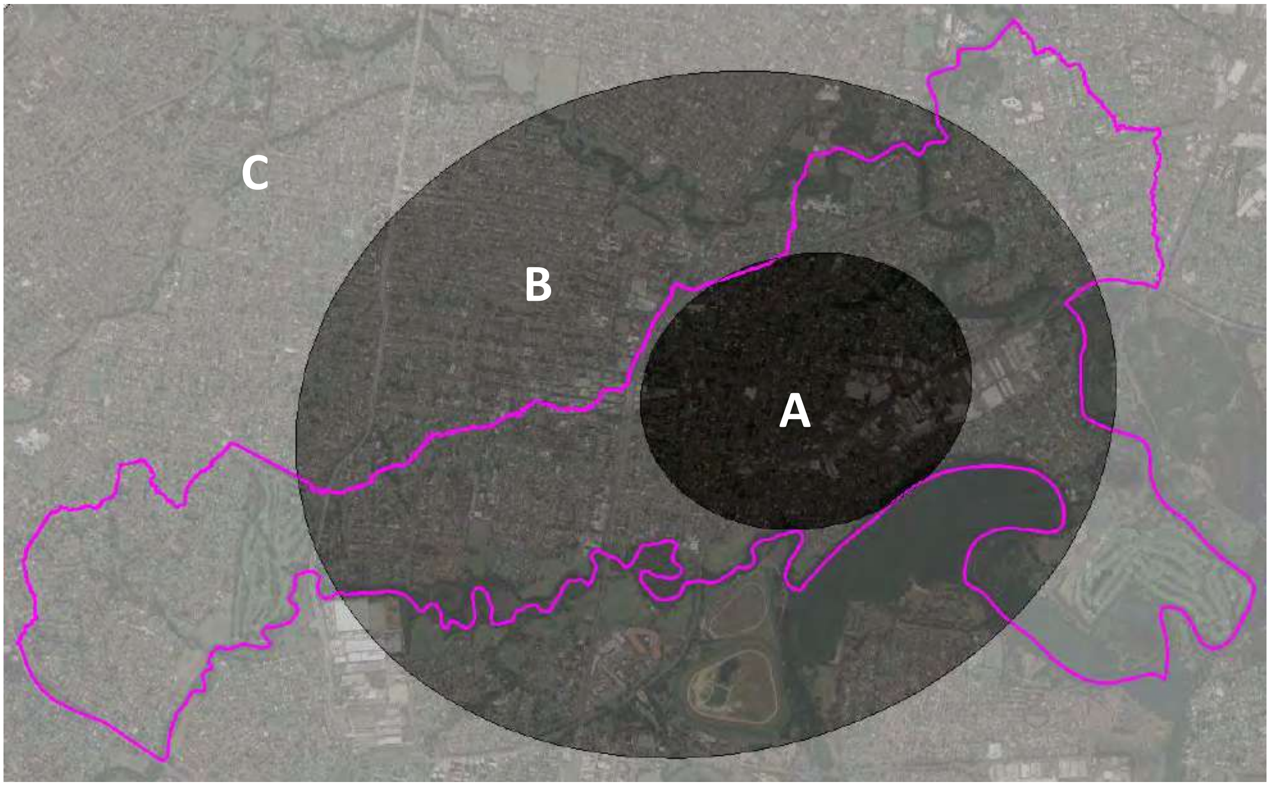
PMP VALUES (mm)

Duration (hours)	Initial Depth -Smooth (D_S)	Initial Depth -Rough (D_R)	PMP Estimate = (D_SxS + D_RxR) x MAF x EAF	Rounded PMP Estimate (nearest 10 mm)
0.25	212	212	148	150
0.50	312	312	218	220
0.75	392	392	274	270
1.00	462	462	324	320
1.50	527	591	414	410
2.00	591	693	485	490
2.50	629	763	534	530
3.00	661	835	584	580
4.00	728	957	670	670
5.00	783	1052	736	740
6.00	830	1118	782	780

Prepared By D. Tetley Date 25/10/2017

Checked By C. Ryan Date 07/01/2018

GSDM SPATIAL DISTRIBUTION



GSDM SPATIAL DISTRIBUTION

DURATION = 0.25 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km^2)	Rainfall Volume between Ellipses (mm.km^2)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	232	163	417	417	163
B	4.00	6.56	218	153	1003	586	147
C	3.69	10.25	212	148	1519	516	140
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 0.50 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km^2)	Rainfall Volume between Ellipses (mm.km^2)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	336	235	604	604	235
B	4.00	6.56	320	224	1472	868	217
C	3.69	10.25	312	218	2236	764	207
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 0.75 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	425	298	764	764	298
B	4.00	6.56	406	284	1867	1103	276
C	3.69	10.25	392	274	2811	944	256
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 1.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	493	345	886	886	345
B	4.00	6.56	474	332	2177	1291	323
C	3.69	10.25	462	324	3319	1142	310
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 1.5 Hours							
Ellipse	Catchment Area Between Ellipse (km²)	Catchment Area Enclosed by Ellipse (km²)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km²)	Rainfall Volume between Ellipses (mm.km²)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	636	445	1143	1143	445
B	4.00	6.56	608	425	2792	1649	412
C	3.69	10.25	591	414	4244	1452	394
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 2.0 Hours							
Ellipse	Catchment Area Between Ellipse (km²)	Catchment Area Enclosed by Ellipse (km²)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km²)	Rainfall Volume between Ellipses (mm.km²)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	744	521	1337	1337	521
B	4.00	6.56	712	498	3272	1935	484
C	3.69	10.25	693	485	4975	1703	462
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 2.5 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	822	575	1476	1476	575
B	4.00	6.56	784	549	3603	2127	532
C	3.69	10.25	763	534	5477	1875	508
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 3.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	902	631	1619	1619	631
B	4.00	6.56	858	601	3945	2325	582
C	3.69	10.25	835	584	5993	2048	555
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 4.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km^2)	Rainfall Volume between Ellipses (mm.km^2)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	1031	721	1851	1851	721
B	4.00	6.56	983	688	4519	2668	667
C	3.69	10.25	957	670	6867	2348	636
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 5.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km^2)	Rainfall Volume between Ellipses (mm.km^2)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	1136	795	2040	2040	795
B	4.00	6.56	1081	757	4969	2929	733
C	3.69	10.25	1052	736	7548	2579	699
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 6.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.57	2.57	1201	841	2157	2157	841
B	4.00	6.56	1148	804	5277	3120	780
C	3.69	10.25	1118	782	8022	2745	744
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

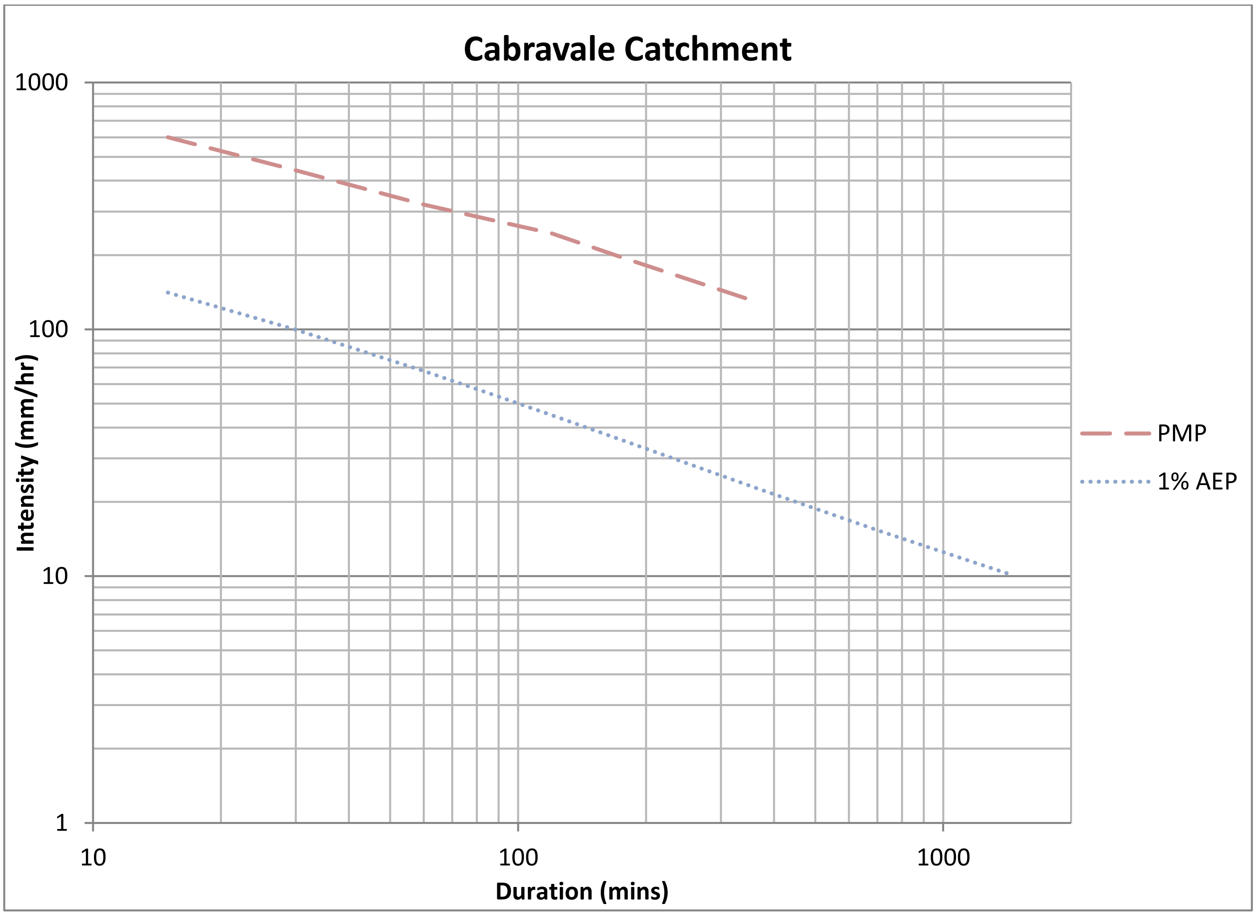
ESTIMATION OF 0.2% AEP AND 1 IN 10,000 YEAR RAINFALL

Overview

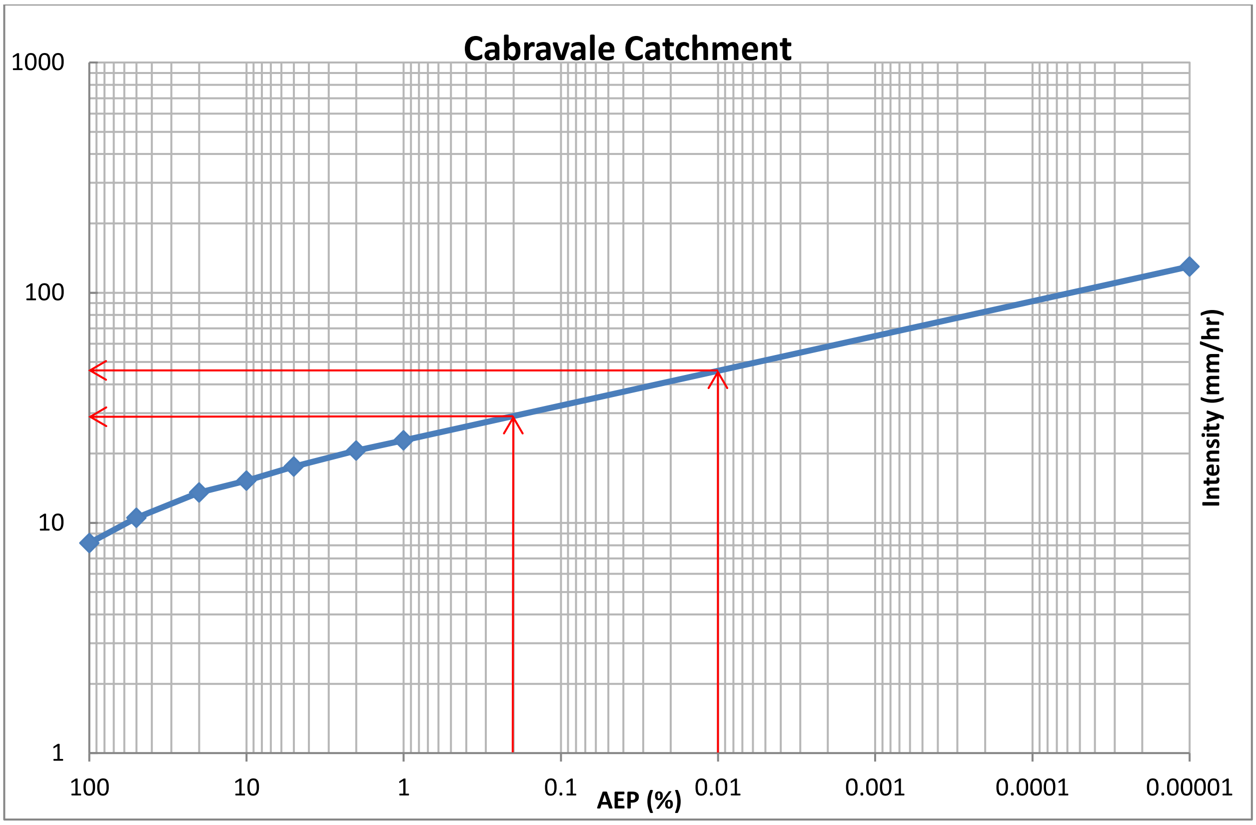
The 0.2% AEP and 1 in 10,000 year rainfall were estimated as part of the Cabravale Catchment Flood Study. The calculations were completed in accordance with procedures set out in 'Australian Rainfall & Runoff- A Guideline to Flood Estimation' (Engineers Australia, 1998) for extreme rainfall. A summary of the calculation technique is provided below.

Calculations

The 1% AEP rainfall intensities were plotted on a chart for a range of different storm durations. The Probable Maximum Precipitation intensities were also included on the chart. A nominal ARI of 10,000,000 years was adopted for the PMP in accordance with Chapter 8 of the Bureau of Meteorology's Generalised Short Duration Method (GSDM) for catchments with areas of less than 100 km^2 (Bureau of Meteorology, 2003). The resulting chart is provided below.



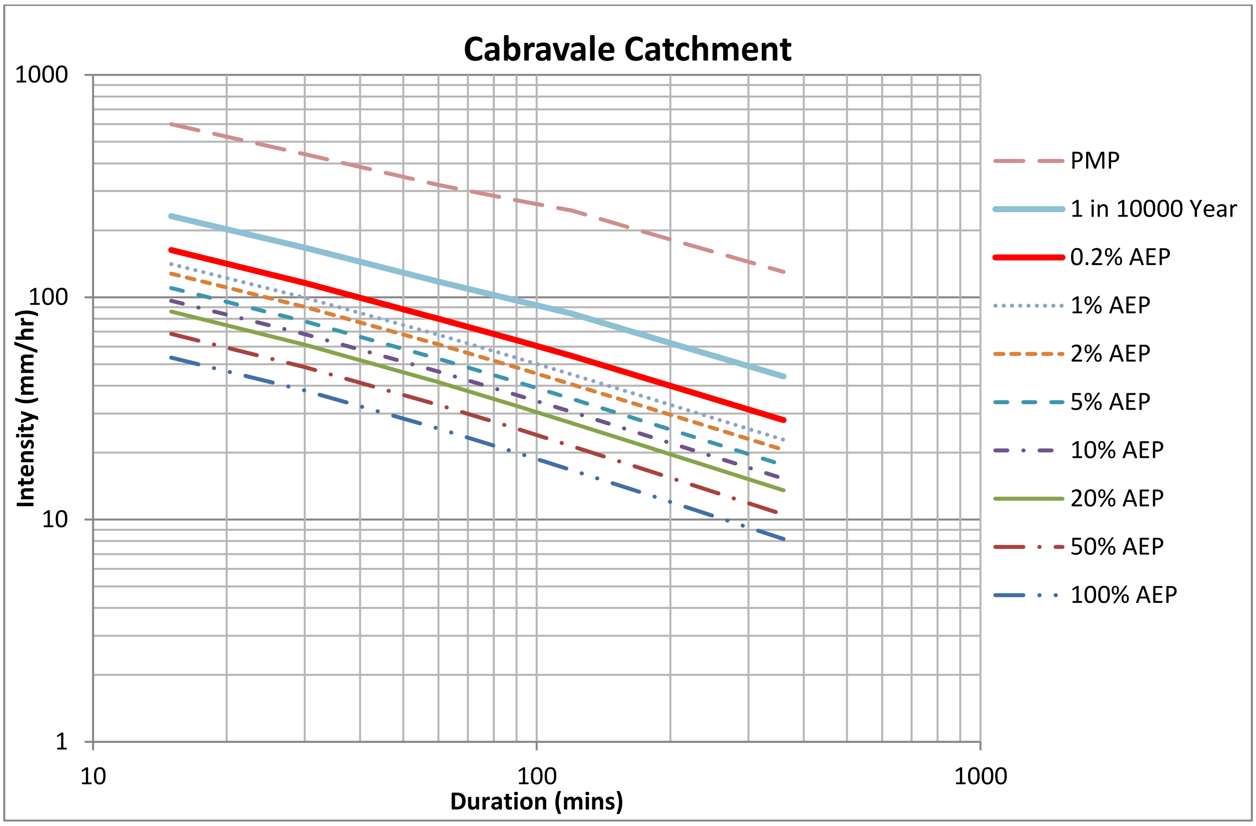
The 6 hour rainfall intensities were extracted from the above charts and were plotted against ARI. The resulting chart is presented below (note: log scales are applied to both X and Y axis).



6 hour rainfall intensities for the 0.2% AEP and 1 in 10,000 year events were extracted from the above chart. This produced the following 6 hour intensity values:

- 0.2% AEP, 6 hour intensity = 28 mm/hr
- 1 in 10,000 year, 6 hour intensity = 44 mm/hr

The 0.2% AEP and 1 in 10,000 year, 6 hour rainfall intensities were included on the original IFD chart and a line was drawn from this point parallel to the 1% AEP and PMF IFD lines (refer blue and red lines in chart below). The blue line represents the 0.5% AEP storm, and the red line represents the 0.2% AEP storm.

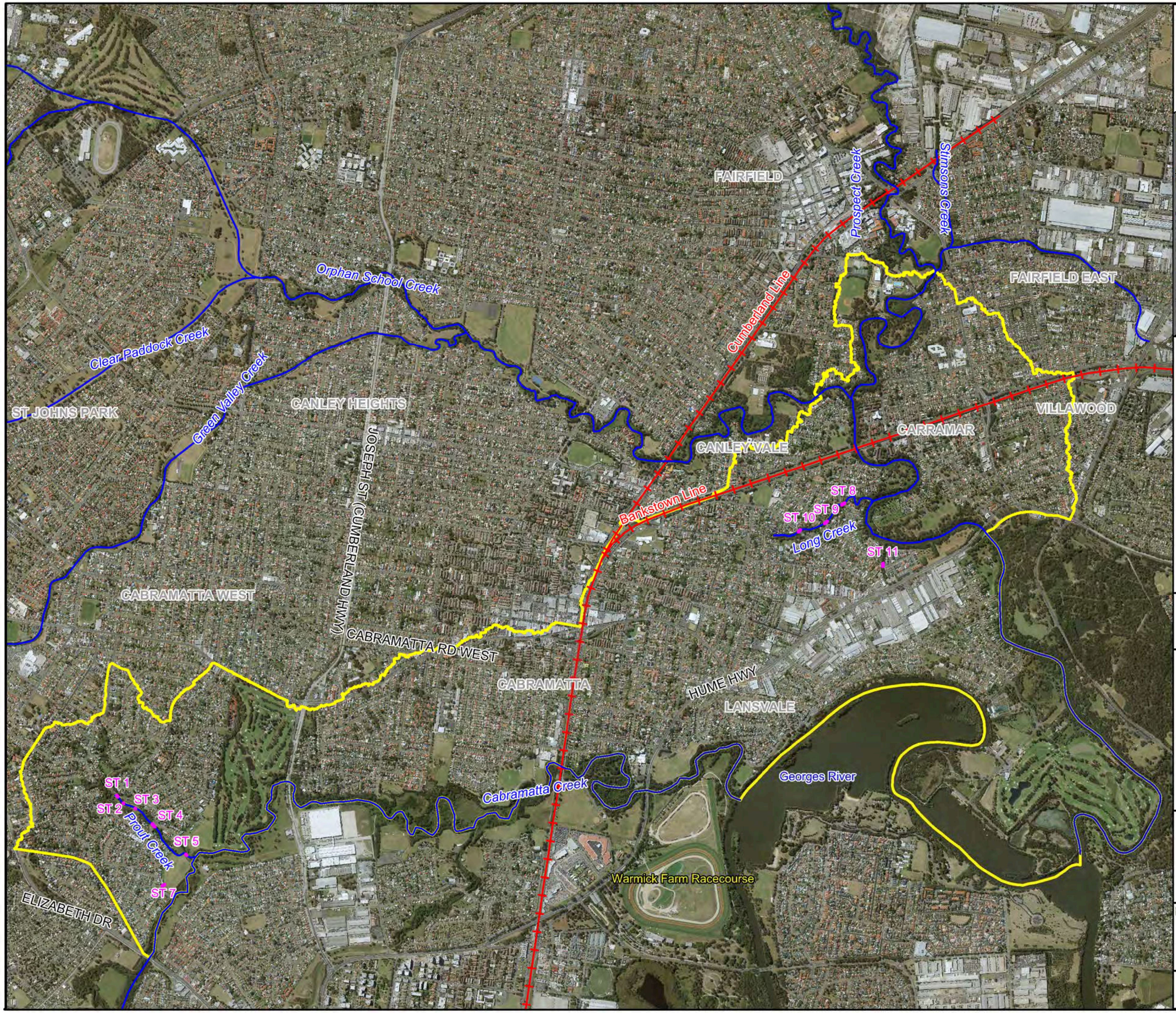


The 0.2% AEP and 1 in 10,000 year intensities were subsequently extracted from the chart for a range of durations:

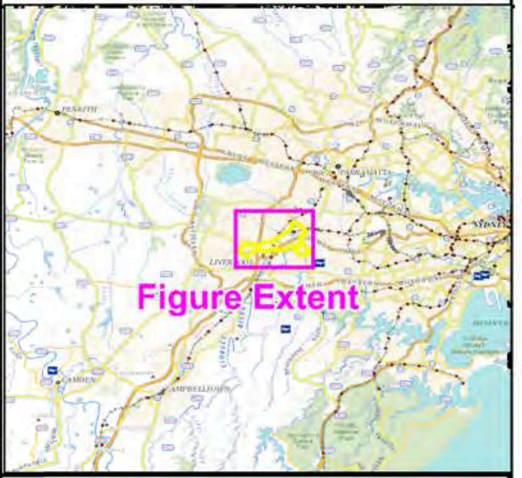
Storm Duration	**0.2% AEP Intensity** (mm/hr)	**1 in 10,000 Year Intensity** (mm/hr)
15 mins	163	232
30 mins	116	167
1 hour	80	118
2 hours	55	84
3 hours	43	66
6 hours	28	44

APPENDIX G

BLOCKAGE CALCULATIONS



FairfieldCity
Celebrating diversity



LEGEND

Study Area

Hydraulic Structure

Notes:

N
W E
S

Scale 1:24,000 (at A3)

0 0.75 1.5 Km

Figure G1: Hydraulic Structure Locations

Prepared By:

Catchment Simulation Solutions
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Sydney, NSW 2000

File Name: FigG1 - Hydraulic Structure Locations.wor

STRUCTURE BLOCKAGE ASSESSMENT

Cabravale Flood Study

Structure ID	Roadway	Waterway	Structure Type	Inverts		Structure Dimensions			Land Use Across Upstream Catchment	Max. L10 (m)	Control Dimension	Main Stream Slope (%)	Debris Availability (L, M, H)	Debris Mobility (L, M, H)	Debris Transportability (L, M, H)	Debris Potential	Debris Potential at Structure	Adjustment for AEP			Design Blockage Level		
				Upstream	Downstream	Dia/Width /Span	Height	Cells / Spans										AEP >5%	AEP 5%-0.5%	AEP < 0.5%	AEP >5%	AEP 5%-0.5%	AEP < 0.5%
ST 1		Prout Creek	Pipe Culvert	17.45	17.14	0.75	N/A	1	100% Urban	1.50	W<L	3%	L	M	L	**LML**	Low	Low	Low	Medium	25%	25%	50%
ST 2		Prout Creek	Pipe Culvert	16.25	16.18	0.9	N/A	1	100% Urban	1.50	W<L	2%	L	M	L	**LML**	Low	Low	Low	Medium	25%	25%	50%
ST 3		Prout Creek	Pipe Culvert	15.40	15.25	0.9	N/A	1	100% Urban	1.50	W<L	3%	L	M	L	**LML**	Low	Low	Low	Medium	25%	25%	50%
ST 4	TOWN VIEW RD	Prout Creek	Pipe Culvert	12.50	12.33	1.55	0.9	2	100% Urban	1.50	L<W<3L	3%	L	M	L	**LML**	Low	Low	Low	Medium	0%	0%	10%
ST 5		Prout Creek	Pipe Culvert	7.13	7.09	0.75	N/A	1	100% Urban	1.50	W<L	1%	L	M	L	**LML**	Low	Low	Low	Medium	25%	25%	50%
ST 6		Prout Creek	Pipe Culvert	6.48	6.45	1.5	N/A	1	100% Urban	1.50	L<W<3L	1%	L	M	L	**LML**	Low	Low	Low	Medium	0%	0%	10%
ST 7	ROBYN CRES		Pipe Culvert	10.28	9.94	0.45	N/A	4	100% Urban	1.50	W<L	1%	L	M	L	**LML**	Low	Low	Low	Medium	25%	25%	50%
ST 8	MOORE ST	Long Creek	Pipe Culvert	1.27	1.15	1.8	N/A	1	100% Urban	1.50	L<W<3L	1%	L	M	L	**LML**	Low	Low	Low	Medium	0%	0%	10%
ST 9	BECKENHAM ST	Long Creek	Pipe Culvert	2.29	2.18	1.8	N/A	2	100% Urban	1.50	L<W<3L	1%	L	M	L	**LML**	Low	Low	Low	Medium	0%	0%	10%
ST 10	LANSDOWNE RD	Long Creek	Pipe Culvert	3.69	3.59	1.8	N/A	2	100% Urban	1.50	L<W<3L	1%	L	M	L	**LML**	Low	Low	Low	Medium	0%	0%	10%
ST 11	BECKENHAM ST	Long Creek	Box Culvert	3.20	3.19	2.44	1.5	2	100% Urban	1.50	L<W<3L	2%	L	M	L	**LML**	Low	Low	Low	Medium	0%	0%	10%

APPENDIX H

TUFLOW REVIEW REPORT

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Our Ref: DW: L.N20969.002.Review.docx

5 February 2018

Catchment Simulation Solutions
Suite 2.01
210 George Street
Sydney
NSW 2000

Attention: David Tetley

Dear David

RE: CABRAVALE OVERLAND FLOOD STUDY - TUFLOW MODEL REVIEW

Thank you for inviting BMT to undertake a review of the Cabravale TUFLOW model developed by Catchment Simulation Solutions for Fairfield City Council.

Catchment Simulation Solution provided BMT with the control and input files for a TUFLOW model (Cabravale_~e1~_~e2~_~s1~_~s2~.tcf), along with a modelling report and the results files from the 1% AEP simulation (for selected durations).

BMT has reviewed the provided information and details of our review are documented in the sections below.

TUFLOW Control Files

BMT undertook a review of use of commands within the control files (tcf, ecf, tef, tbc, tgc) of the model. The following observations have been made:

Use of Command: GIS Projection Check == WARNING

This command should be set to error (as per TUFLOW default). 16 input files have generated a warning in relation to this command (Warning 0305 – Projection of .mif file is different to that specified by the MI Projection == Command).

Often this error can be generated by various input files having different bounds. This can be resolved by using the **MI Projection Check Ignore Bounds == ON.**

Input files with different projections may not correctly snap together.

Use of Command: Bed Resistance Cell Sides == AVERAGE n or AVERAGE M or MAXIMUM n

This is not an actual TUFLOW command. The model has applied **AVERAGE n** to the model, however, the default option is **INTERROGATE**. The **INTERROGATE** option provides a higher resolution sampling of material values compared with just sampling at cell centres (as used in the **AVERAGE n** option). Prior to **INTERROGATE** being the default, the **AVERAGE M** option was the default as the average would be skewed to the smaller Manning's value. The higher resolution sampling is particularly useful in modelling urban areas where frequent and large changes in Manning's 'n' values occur.

Use of Command: Interpolate ZUVH ALL

The TUFLOW manual does not recommend the use of this command unless converting a Mike21 flood model (which only has a cell centre elevations).

The **Interpolate ZUVH ALL** option will result in all ZU, ZV and ZH points being interpolated based on the surrounding ZC values, rather than using the points defined by any **READ GRID** or **READ GIS** commands. Its location in the tgc file (after all topography layers have been read) will result in the removal on any 'thin' zlines from the model, including those defined in the ridge and levee layers.

Comparison of Model to Report

BMT undertook a consistency check to confirm the provided model (and the inputs contained within) are consistent with the reporting of the hydraulic model. The following observations have been made:

Model Version

The TUFLOW model has been run with TUFLOW_2017-09-AC-iDP_w64 not 2016-04-AD as referenced in the report

Manning's 'n' Inconsistencies

Depth varying Manning's 'n' values are applied to the different land uses. A check of the Manning's 'n' values used in the model (based on those reported by the tlf) and documented in the report showed an inconsistency for two land uses (Material 3 – Trees, and Material 6 – Roads). A comparison of the values is shown in Table 1 (Trees) and Table 2 (Roads). In particular, the Manning's 'n' value of 0.650 applies to trees in the TUFLOW is unusually high.

Table 1 Material 3 (Trees) – Manning's 'n' Comparison

Depth	Report Values	TUFLOW Model
<0.3	0.160	0.035
1.5	0.110	0.650
>2.00	0.080	0.080

Table 2 Material 6 (Roads) – Manning's 'n' Comparison

Depth	Report Values	TUFLOW Model
<0.04	0.017	0.017
0.1	0.021	0.021
>0.15	0.020	0.018

Building Footprints

The report states that the elevation contained within the building footprints were raised to the floor level (assumed to be 300 mm above the ground level) and that once the water level entered the house, the manning's 'n' value of 1.0 was adopted. This is inconsistent with the depth varying Manning's 'n' values applied to buildings (where a value of 1.0 is applied once the depth at the building exceed 1.0 metres).

TUFLOW Log File Check

BMT reviewed the various warnings that were recorded in the TUFLOW log file during the model initialisation. A summary of the various warnings (including some additional comments) are detailed below.

XY: WARNING 1317

The water level line is being ignored as it doesn't cross a 1D network channel (only valid for WLLs with 2 vertices) or snap to a vertex on the 1D network as required for a WLL with three or more vertices.

Ensure WLL snaps to a 1D network channel object or crosses a channel (only if using a 2 vertex WLL)

XY: WARNING 1036

This warning is issued due to the Manning's 'n' values being specified on both the channel and from either the upstream and/or downstream cross sections. A review of the adopted Manning's 'n' values is recommended.

XY: WARNING 2122 (8 occurences)

This warning is issued when a 1D pit or node does not connect to an active cell within any 2D domain, and therefore the link to the 2D domain has been ignored. A review of the pit location and/or the model extent is recommended.

XY: WARNING 1100 (7 Occurrences)

This warning is issued where a 1D structure's invert/bed lies below the bed of the primary upstream and/or downstream channel. A review of the 1D topography and structure inverts/dimensions is recommended to ensure the input data is correct

TUFLOW Model Structure

BMT has reviewed the general model structure of the model and the following observations are made:

- A number of hx lines include the 's' flag. The 's' flag is a legacy, and is no longer recommended for use.
- A number of hx lines include the 'z' flag. The use of the 'z' flag on the hx lines is not recommended unless checking the reason for the elevation discrepancy between the invert of 1d and 2d cell centre elevation.
- Thick z lines should be used along the hx alignment. A breakline is recommended along the 1d-2d boundary interface to ensure that the 2d cell elevations are consistent with the levee or spill crest of the 1d channel. The omission of these z lines may result in premature interaction between the 1d channel and 2d floodplain.
- There are a number of buildings identified in the Manning's 'n' layer which are not assigned to a z shape (used to lift the terrain to the flood level). As the model is a direct rainfall model, all buildings will have some degree of inundation.

- There is an HX line across 'land cells' at confluence of DrainX and XS-5. The resultant boundary cells that exist within the 'land' area of the 1d channel may result in a model instability.
- A number of bridge structures do not include a length. Whilst not needed for the computations, the inclusion of a length is used to determine the nodal storage for the 1d elements, and the presence of a normal amount of nodal storage can help improve model stability.
- All bridges in Cabramatta Creek have identical form loss coefficients applied (0.2 applied below the soffit level, 2.0 above the soffit level). A form loss of 2.0 being applied above the deck level is unusually high. Typically, a value of 1.56 is used for the deck structure, with above the deck varying from 0.0 to 0.5 depending on the railing configuration.

Review of Model Simulation

BMT has reviewed the results of the model simulation (the 15 min, 60 min and 120 min durations) and the following observations are made:

- Volume errors (as a % of Volume In + Out) are all within the acceptable range (+/- 1%)
- The 60 min and 120 min storm durations have 722 and 216 1D negative depths respectively. These negative depths should be reviewed and amended as required (they may be related to a reduced nodal storage attached to some of the structures)
- Based on a sample of 1D results, there are some channels which are demonstrating unstable flow behavior (including Cab_1101R and Cab_10.2B)

Recommendations

BMT recommends the following actions following our review of the Cabravale TUFLOW model:

- Change the following commands in the control files:
  - GIS Projection Check == ERROR (not Warning)
  - Bed Resistance Cell Sides == INTEROGATE (not AVERAGE n)
  - Remove Interpolate ZUVH ALL Command
- Review applied Manning's 'n' values for Material 3 (trees) and address inconsistency between report and model.
- Review Manning's 'n' approach for buildings to ensure consistency between model and report.
- Review and action (as required) the warning messages identified in the model initialisation.
- Review the application of the hx lines in the 1d-2d linking – in particular the use of the 's' and 'z' flags and consider the use of a thick z lines along the alignment of a hx line.
- Review and action (as appropriate) the representation of the bridges with regard to the applied loss coefficients and the lack of storage applied (due to 0 length being attributed to the object).
- Review and action (as appropriate) the 1D negative depths, particularly if they regularly occur at a single location within the model.

If you have any questions regarding the information contained within this review, please don’t hesitate to contact the undersigned.

Yours Faithfully
BMT

Daniel Williams
NSW Flood Lead

Appendix I

Field Verification

LOCATION:
Tobys Blvd to Hitter Ave and Townview Rd, Mt Pritchard

PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

COMMENT:
Trapped low points in roadways causing flow to pond and then spill through properties towards drainage reserve, **retain in mapping**.

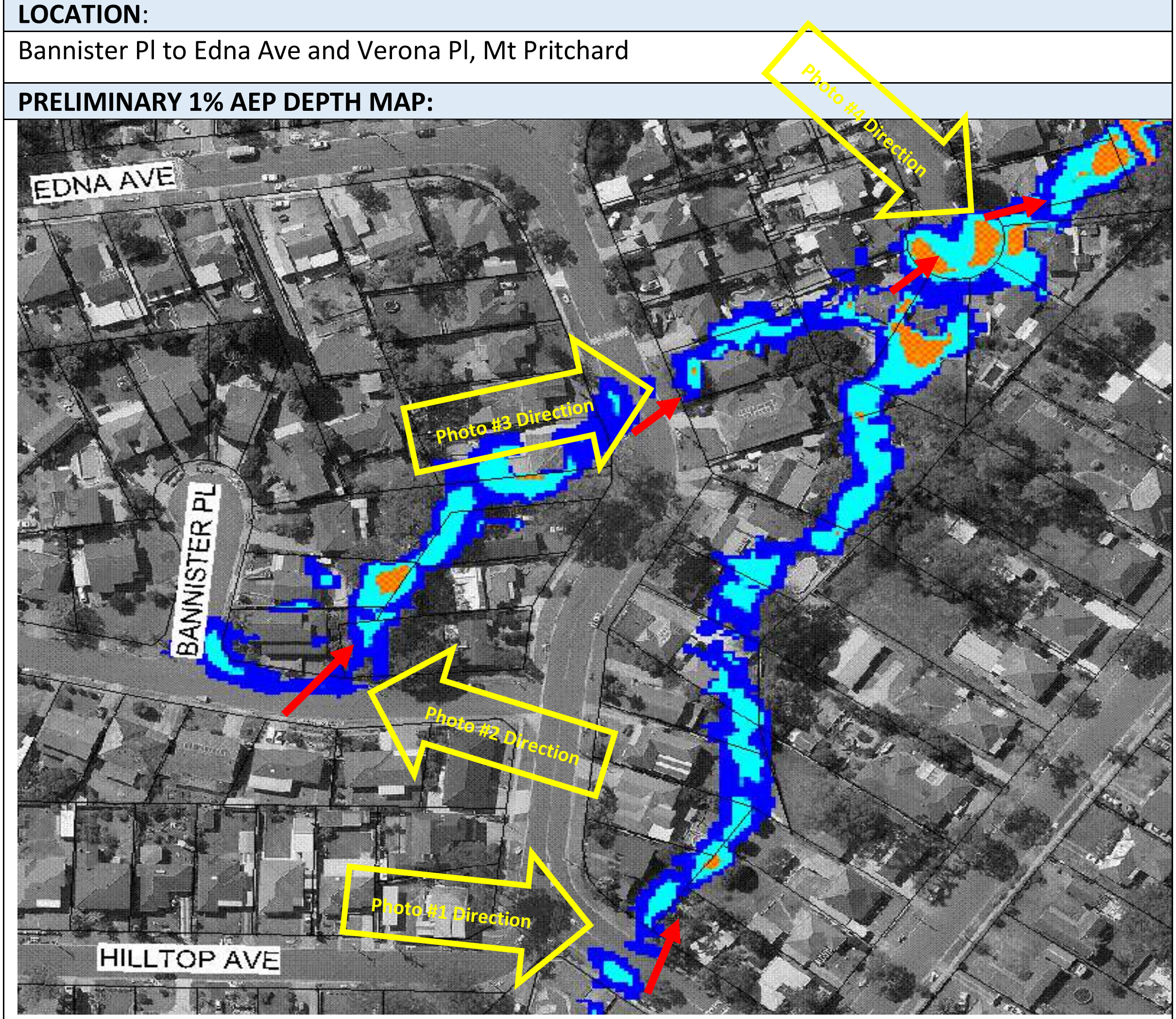
LOCATION:
Hilltop Ave to Edna Ave, Mt Pritchard
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION:

COMMENT:
Terrain lowers towards the rear of properties and spills onto Edna Ave. **Retain in mapping**.

LOCATION:
Bannister Pl to Edna Ave and Verona Pl, Mt Pritchard

PRELIMINARY 1% AEP DEPTH MAP:



GOOGLE© STREET VIEW OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

GOOGLE© STREET VIEW OF LOCATION #4:

COMMENT:
Low Points in terrain, water builds up on roadway and spills through. **Retain in mapping**.

LOCATION:
Matheson Ave to Roma Ave, Mt Pritchard

PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:

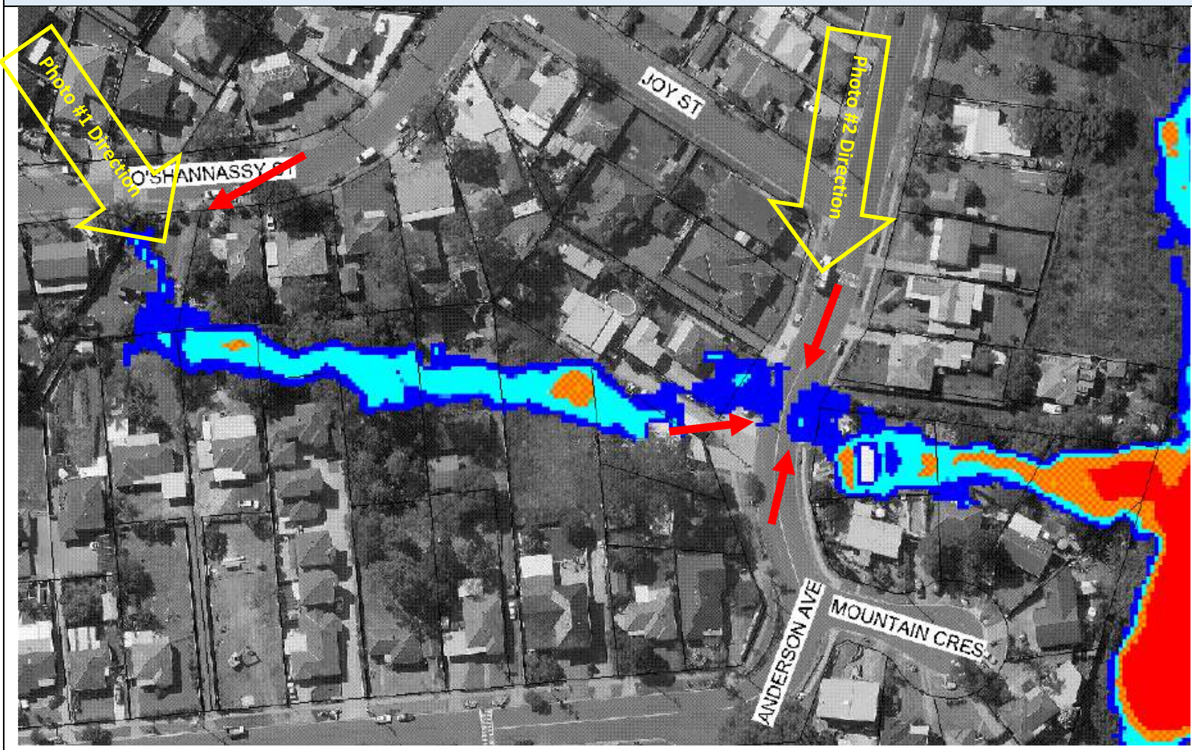
GOOGLE© STREET VIEW OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

GOOGLE© STREET VIEW OF LOCATION #4:

PHOTOGRAPH OF LOCATION #5:

COMMENT:
Trapped low points in roadways causing flow to pond and then spill through properties towards drainage reserve, **retain in mapping**.

LOCATION:
O'Shannassy St to Anderson Ave, Mt Pritchard
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:


PHOTOGRAPH OF LOCATION #2:

COMMENT:
Trapped low points in roadways causing flow to pond and then spill through properties towards drainage reserve, **retain in mapping**.

LOCATION:
Grainger Ave to David St, Mt Pritchard

PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:

PHOTOGRAPH OF LOCATION #2:

PHOTOGRAPH OF LOCATION #3:

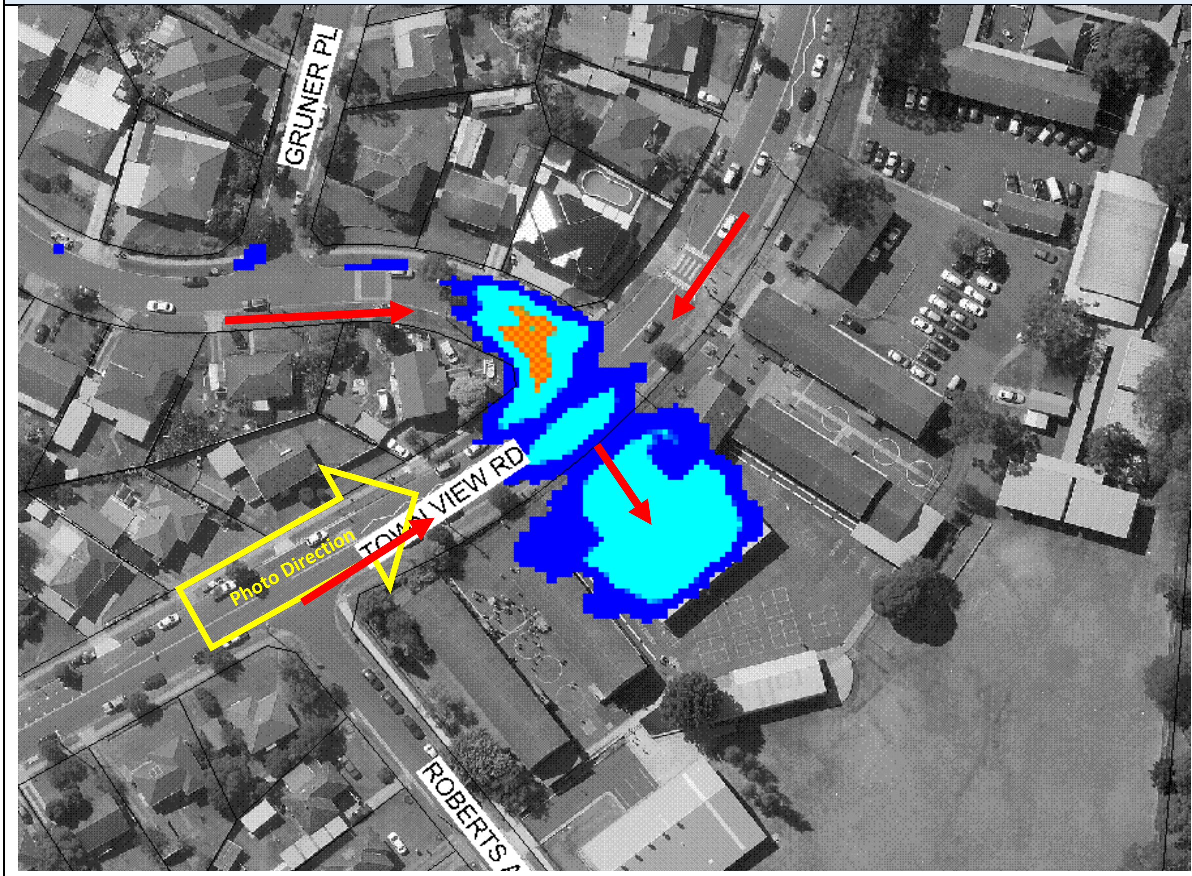
COMMENT:

Trapped low points in roadways causing flow to pond and then spill through properties towards drainage reserve, **retain in mapping**.

LOCATION:
Russell St, Mt Pritchard
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION:

COMMENT:
Trapped low point in roadways causing flow to pond and then spill through property, **retain in mapping**.

LOCATION:
Townview Rd, Mt Pritchard
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION:

COMMENT:
Trapped low point in roadways causing flow to pond and then spill through Mt Pritchard East Public School, **retain in mapping.**

LOCATION:
Links Ave, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION:

COMMENT:
Trapped low point in roadways causing flow to pond and then spill through properties, **retain in mapping.**

LOCATION:
Lyons Ave to Judith Ave and Smiths Ave, Cabramatta

PRELIMINARY 1% AEP DEPTH MAP:

PHOTOGRAPH OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

COMMENT:
Trapped low points in roadways causing flow to pond and then spill through properties, **retain in mapping**.

LOCATION:
Nance Ave to Bowden St and Huie St, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:

PHOTOGRAPH OF LOCATION #3:

COMMENT:
Trapped low points in roadways causing flow to pond and then spill through properties, **retain in mapping**.

LOCATION:
Crabb Pl, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:

PHOTOGRAPH OF LOCATION:

COMMENT:
Trapped low point in roadways causing flow to pond and then spill through properties towards drainage reserve, **retain in mapping.**

LOCATION:
Alick St to Wendy Cl and Sonja Cl, Cabramatta

PRELIMINARY 1% AEP DEPTH MAP:

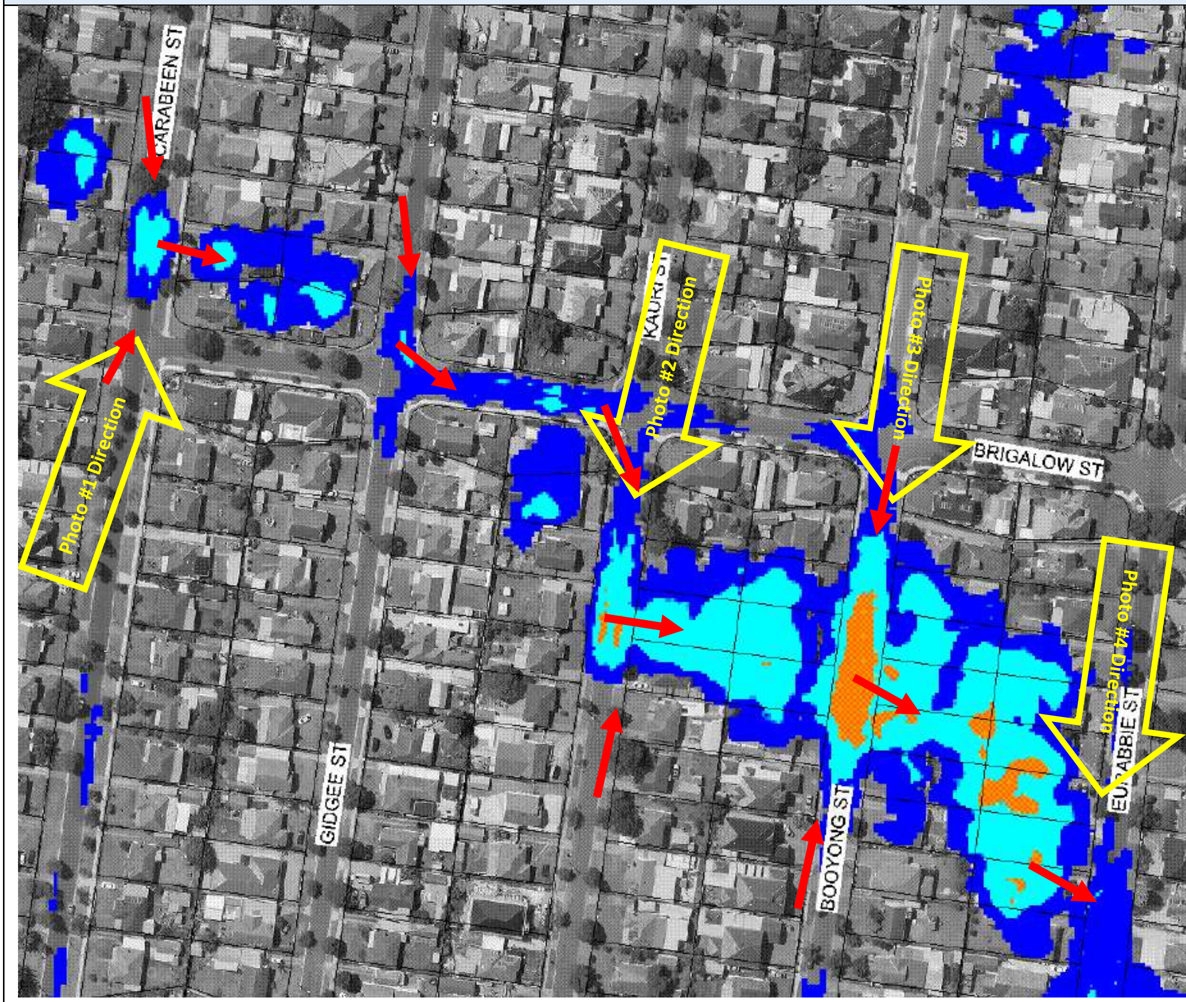
GOOGLE© STREET VIEW OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:

PHOTOGRAPH OF LOCATION #3:

PHOTOGRAPH OF LOCATION #4:

COMMENT:
Low Points in terrain, water builds up on roadway and spills through properties. Small wall on boundary of Cabramatta High School keeps majority of water on streets before spilling into school grounds. **Retain in mapping**.

LOCATION:
Carabeen St to Kauri St, Booyong St and Eurabbie St, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:


GOOGLE© STREET VIEW OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

GOOGLE© STREET VIEW OF LOCATION #4:

COMMENT:
Low Points in terrain, water builds up on roadway and spills through properties. **Retain in mapping**.

LOCATION:
Myall St across Bolivia St, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:

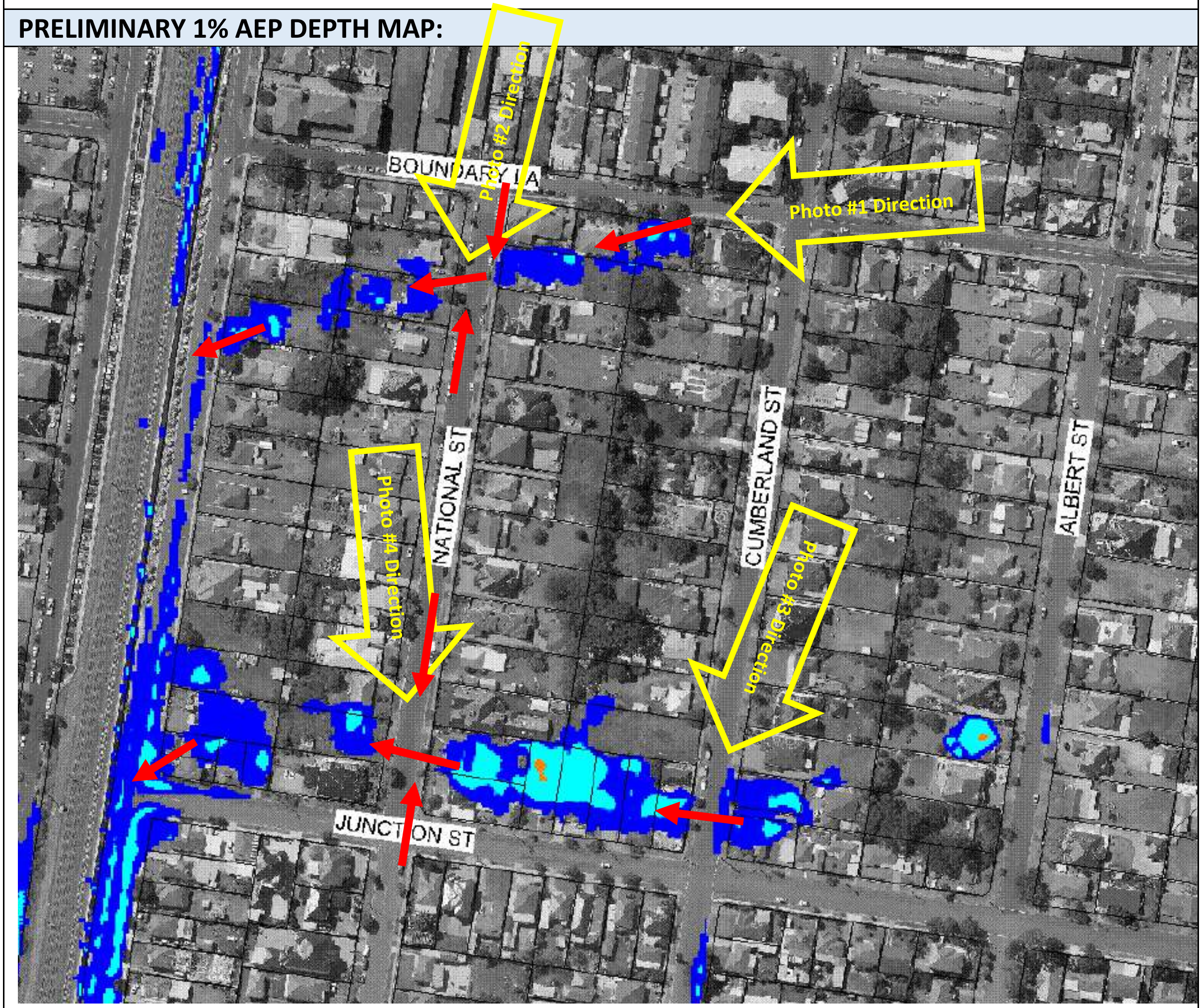

PHOTOGRAPH OF LOCATION #2:

COMMENT:
Trapped low points in roadways causing flow to pond and then spill through properties towards reserve, **retain in mapping**.

LOCATION:

Cumberland St and Boundary Ln to National St, Cabramatta

PRELIMINARY 1% AEP DEPTH MAP:



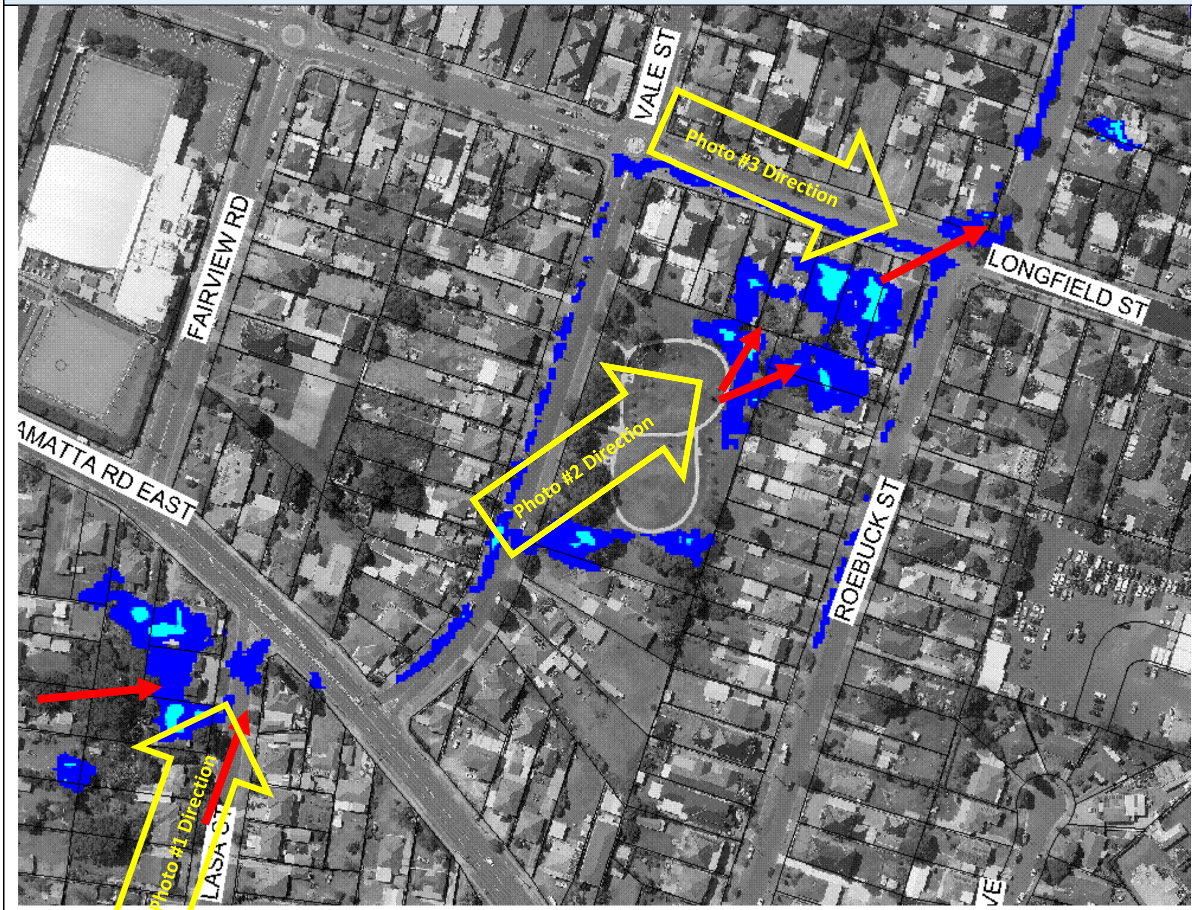
GOOGLE© STREET VIEW OF LOCATION #1:

PHOTOGRAPH OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

GOOGLE© STREET VIEW OF LOCATION #4:

COMMENT:
Low Points in terrain, water builds up on roadway and spills through properties. Raised intersections cause flow to move through properties instead of along roadways. **Retain in mapping**.

LOCATION:
Lasa St to Roebuck St and Longfield St, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:

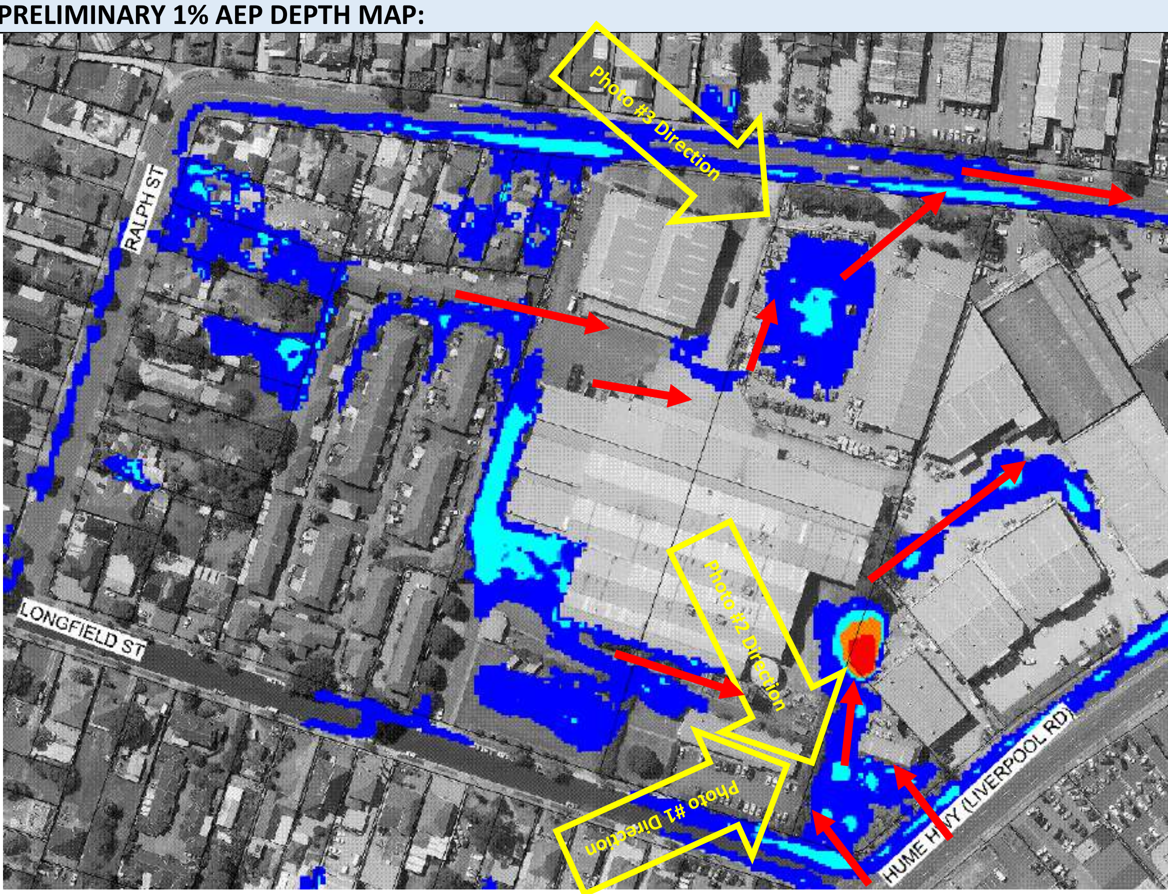

PHOTOGRAPH OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

COMMENT:

Water flows through properties. Elevated intersections cause flow to pass through properties instead of roadways. Elevated edge around park contains some water until sufficient ponding occurs and water continues to spill through further properties, **retain in mapping.**

LOCATION:
Hume Highway to Ralph St, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:



PHOTOGRAPH OF LOCATION #1:

PHOTOGRAPH OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

COMMENT:
Water flows through properties. Elevated intersections cause flow to pass through properties instead of roadways, **retain in mapping.**

LOCATION:
Fisher St to Longfield St and Curtin St, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:

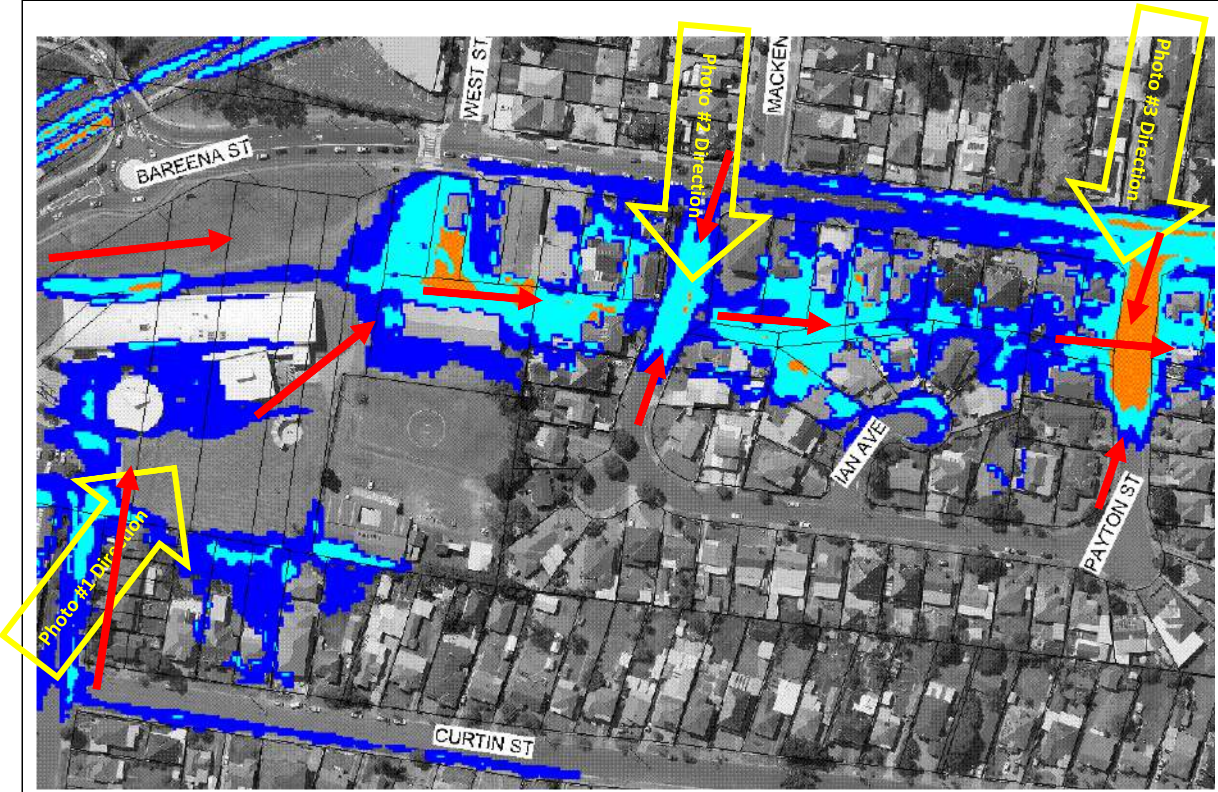
GOOGLE© STREET VIEW OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

COMMENT:
Water flows through properties. Elevated intersections cause flow to pass through properties instead of roadways, **retain in mapping.**

LOCATION:
Curtin St to Payton St, Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:



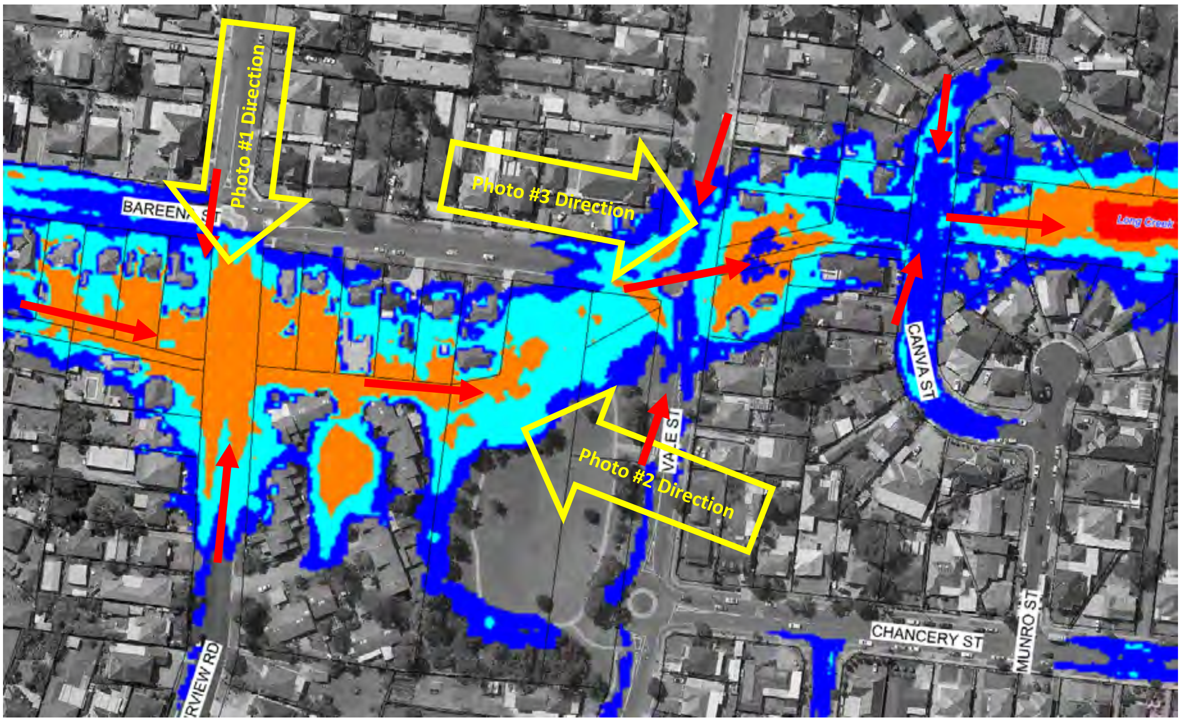
PHOTOGRAPH OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

COMMENT:
Water flows through properties, **retain in mapping.**

LOCATION:
Payton St to formal Long Creek channel (Canva St), Cabramatta
PRELIMINARY 1% AEP DEPTH MAP:

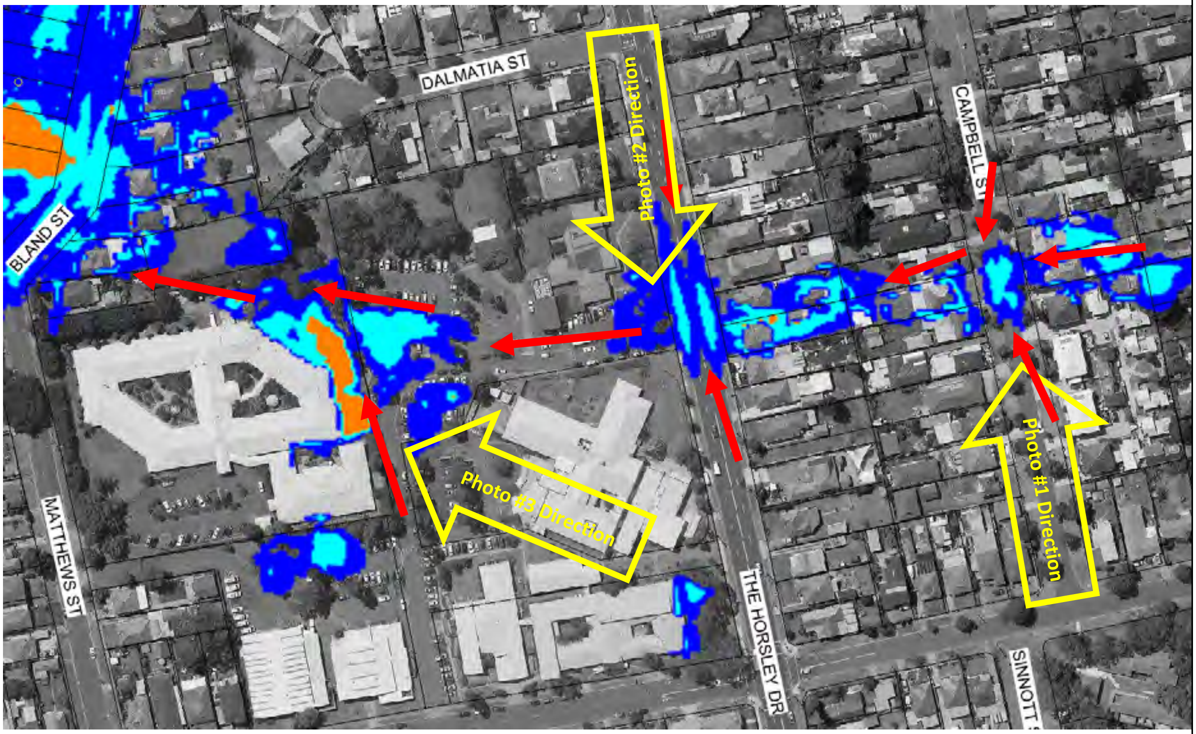


GOOGLE© STREET VIEW OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:

GOOGLE© STREET VIEW OF LOCATION #3:

COMMENT:
Water flows through properties, **retain in mapping.**

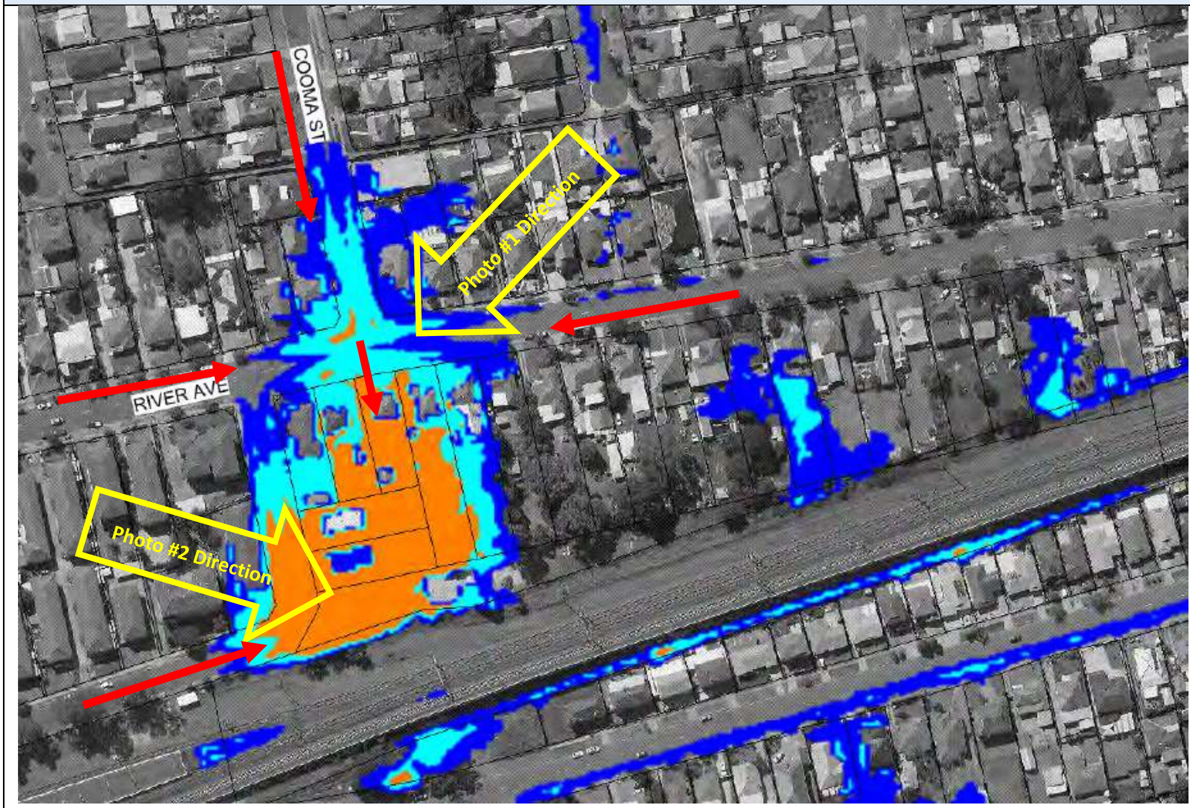
LOCATION:
Campbell St, Fairfield East to Bland St, Carramar
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:


PHOTOGRAPH OF LOCATION #2:

PHOTOGRAPH OF LOCATION #3:

COMMENT:

Water flows through properties, **retain in mapping.**

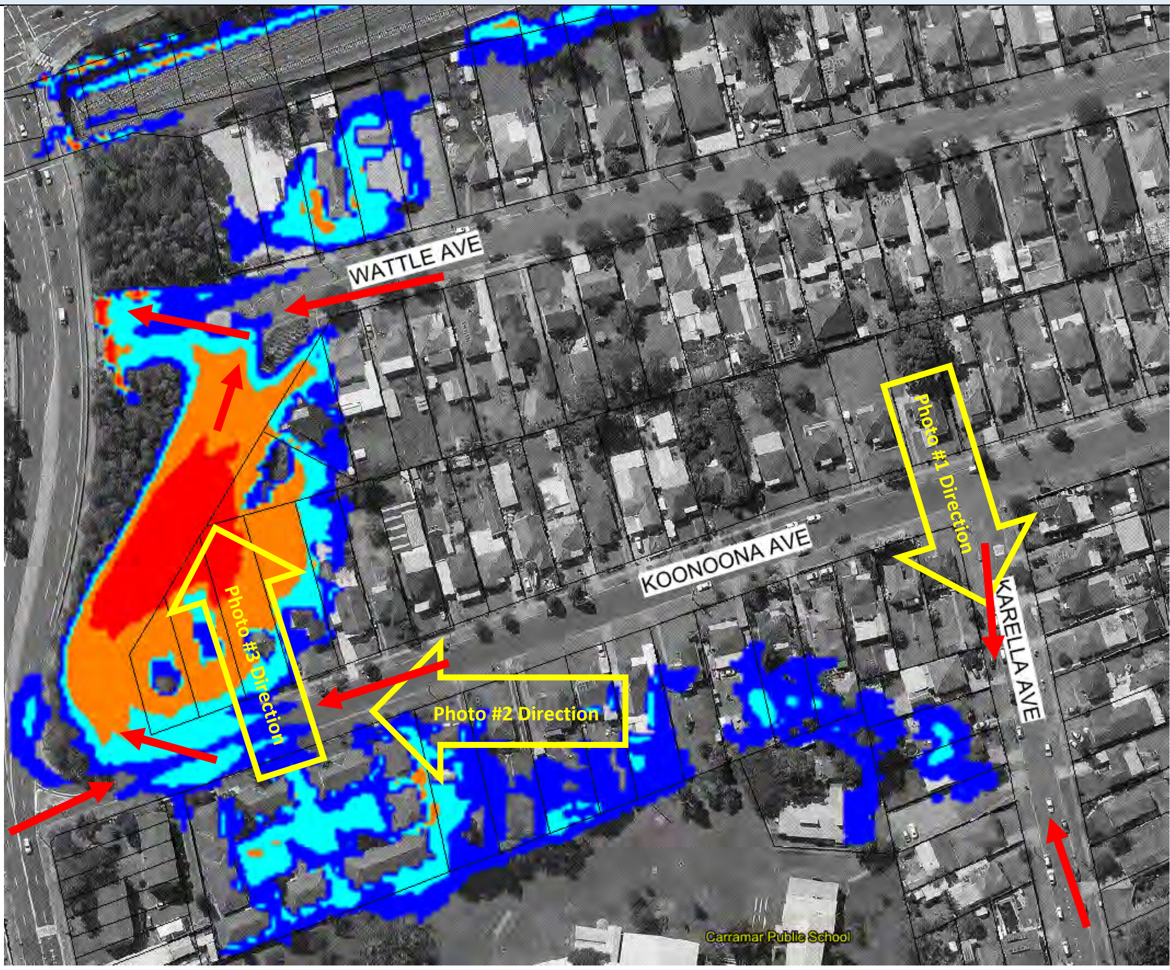
LOCATION:
Intersection of River Ave and Cooma St, Carramar
PRELIMINARY 1% AEP DEPTH MAP:

PHOTOGRAPH OF LOCATION #1:


PHOTOGRAPH OF LOCATION #2:

COMMENT:
Trapped low point in roadways causing flow to pond and then spill through properties towards railway line which acts as significant impediment due to a high embankment. Water can only drain through the stormwater system from this area and so significant ponding occurs. R**etain in mapping.**

LOCATION:
Karella Ave to Wattle Ave, Villawood

PRELIMINARY 1% AEP DEPTH MAP:



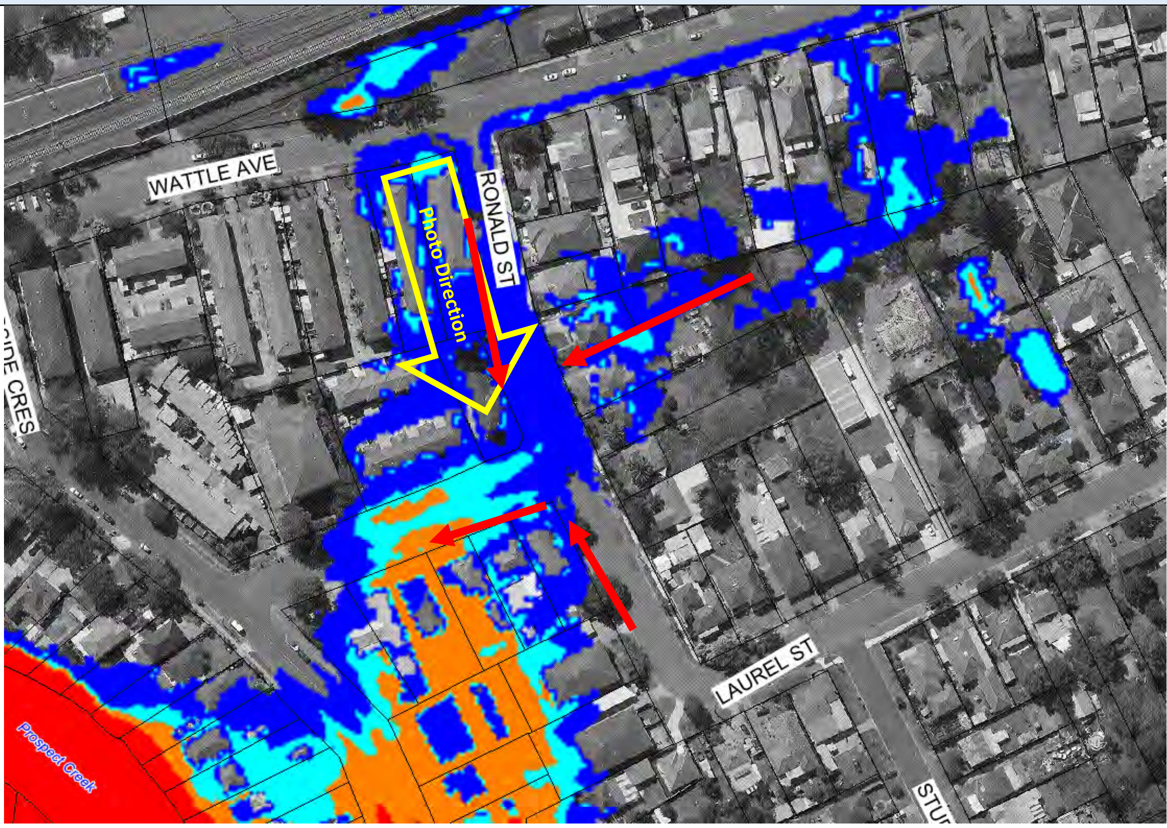
GOOGLE© STREET VIEW OF LOCATION #1:

PHOTOGRAPH OF LOCATION #2:

PHOTOGRAPH OF LOCATION #3:

COMMENT:

Water flows into low sag location on Elm St, ponds to a sufficient depth before spilling onto Wattle Ave and through the roadway underpass, **retain in mapping.**

LOCATION:
Wattle Ave to Ronald St, Villawood
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION:

COMMENT:
Trapped low point in roadways causing flow to pond and then spill through properties towards drainage reserve, **retain in mapping.**

LOCATION:
Tuncoee Rd to Horsley Dr, Carramar
PRELIMINARY 1% AEP DEPTH MAP:

GOOGLE© STREET VIEW OF LOCATION #1:

GOOGLE© STREET VIEW OF LOCATION #2:


GOOGLE© STREET VIEW OF LOCATION #3:


PHOTOGRAPH OF LOCATION #4:

COMMENT:
Water flows through properties, eventually ponding upstream of The Horsley Drive where the stormwater system drains it away, **retain in mapping.**

APPENDIX J

PUBLIC EXHIBITION COMMENTS & RESPONSES

Cabravale Overland Flood Study - Public Exhibition Comments and Responses

#	Comments	Response
1	They have not been the strata managers of this property since 2020. Remove them from being contacted.	Noted. No further action required
2	They have not been the strata managers of this property since 2021. Remove them from being contacted.	Noted. No further action required
3	Never had a problem with water. Why high risk? Council approved the flats behind. Council was sent a video. Water came into the property from the road, but when as soon as the rain stopped. He asked went were the pipes going to be done. Why is No.6 Carramara Avenue not high risk. Strongly objects against the high risk for his property.	Indentified as high risk as property adjoins a roadway "sag" point which is predicted to be cut early in the flood and, therefore, presents evacuation difficulties. However, velocities are very low indicating evacuation on foot would be possible. High precinct classification modified to medium risk
4	Information couriosity. If there is anything she can do let her know.	Primarily impacted by mainstream flooding from Propsect Creek. Very little that can be done at proeprty scale. No further action taken
5	Just wanted to have a chat. Need drainage in Fairview Road and Vale Street. Advised me of a boat tied to power pole in the 1986 flood. Payton Sttreet did not flood in 1986 or 1988. Some flooding in 1964. Railway Parade up near the bowling club was 3-4 feet under water.	Impacted by local overland flooding rather than mainstream flooding which was more promiment in 1986/1988. Falls within low risk precinct indicating low hazard flows even during the 1% AEP flood
6	Rang & left a message. She left two e-mails detailing past local issues. Council subsequently spoke with the property owner : sag pit in front of property always blocks, water coming down street excessive, need another stormwater pit in front of No. XX Curringa Street.	Council advised that they will put this request to Council's Watermanagement Plan including requesting a street sweeper, and a CCTV.
	Council explained the low risk precinct and she asked some insurance questions. She goes to a broker for insurance.	Noted. No further action required
	Just adding more information to this morning's email. My mother Mrs XXX XXXX was the previous owner. That is why I am aware of the previous history and I have resided here for many years. I received a letter from Fairfield City Council dated 2 November 2022 regarding the above mentioned study. I seek some clarification as to why my property at XX Curringa Road Villawood was identified as a low risk precinct. Yes there has been water run off coming from an overflowing drain situated out the front of number XX Curringa Road. When this drain overflows the water pools on my driveway and also on an extra drain installed on footpath of number XX to take this excess water away. If the rain is heavy or hail blocks this drain then it overflows and runs down my driveway and the side of my house. I might point out that situation got worse after Curringa Road was redone and the height if the road lifted. At the time our old driveway had to be removed and a new driveway installed by whoever did this work. There is a definite low point on the drain side of my driveway and when we had concerns after completion, the second drain was put in on the footpath. Our concerns re this sutuation were raised at the time but to no avail and no more could be done. I feel that the installation of a second drain further up the street to catch some if the cutter flow up higher might help. As I am situated at the bottom of a hill. This year following heavy rain in February there was minor flooding in my yard which did enter part of the house. I don't think Council or whoever has control of these drains have done enough to fix stormwater pipes and clear them regularly from tree roots in the area. At the bottom of Curringa Road near Horsley Drive these drains are blocked with grass and leaves and never been cleaned by either Council or the home-owners living there. I would like to discuss with you the ramifications of my property being identified and also my insurance ramifications. I feel that the lifting of the height of Curringa Road and making it higher has caused a problem not of my making but bad planning by Council at the time. I am not sure when these works were carried out, at a guess maybe sometime between 2006 and thereafter. Your records would indicate this. I did send an email regarding this situation in the beginning but never heard back from Council and unfortunately I am unable to find a copy and no longer working at company from which I sent it.	Experiences tend to support flood modelling outputs (i.e., realtively shallow local overland/drainage issues). Potential for drainage upgrades can be explored as part of future floodplain risk management study. Inundation mapping and flood risk precincts appears to be reasonable/consistent with observations. Therefore, no further action taken.
7	Phone call: Mrs XXXX was not concerned just wanted to say they feel better since Council put in the basins. I advised her that this study is different to that of the Cabramatta Creek study.	Noted. No further action required
8	Just wanted to know about the overland flood study. Heavily affected by Prospect Creek. He did not know it was flood affected. His solicitor did not advise him. Already treated under VHR scheme.	Noted. No further action required
9	Received a Ms XXX XXX letter. Advised it was a glich in the mail merge.	Noted. No further action required
10	Advised there is some pits blocking in the high risk zone, adjacent to his property. He will put a letter into mail@fairfieldcity.nsw.gov.au to City Assets Branch tpo keep the pits clear.	Noted. Property located near a "sag" point where blockage does have the potential to havea notable impact on drainage performance. Therefore, regular maintenance is highly recommended.
11	Just after information. Council advised the Georges River will take precedent over the Cabravale Overland Flood study.	Noted. No further action required
12	Was not concerned. Council advised that Propsect Creek would take precedent over the Cabravale Study. He mentioned that they have not really flooded since 1996, it came up to the front yard. They use the laneway to evacuate. The house is raised.	Noted. No further action required
13	Was OK with the information. Just advised that they do not get informed by the SES to evacuate and it would be good to get their cars out. The SES do baracade the road.	Noted. Potentially for Council to reach out to SES to determine if opportunities for a SMS/message service to advise of impending road closures
14	e-mail about the letter only and what are the planning controls. Advised Council seeking to remove planning controls above the FPL.	Noted that Council has not opted in to new LEP Clause 5.22 which currently prevents application of controls above the FPL. However, this may change in the future
15	I spoke about the study. I explained the 1% AEP area and PMF area. He had a flood study done 2016 (Drains/Tuflow) that can be made available if the consultant wants it. Can also go on site if consultant wants to. There is a square of high risk (looks like the house envelope) - can the consultant check this out as it is inconsisitant with other high risk areas? He has never flooded (but the report mapping is comparible to Council's results).	The available terrain information shows that the ground elevation drops away around the footprint of the dwelling. This produces localised areas of higher velocity and deeper water around the buildings. As it stands, the current building is built well above this area so would not be exposed to a high risk. High risk precinct modified to medium risk
16	e-mailed the electricity grid to Council. And their Local government flood response material.	Noted. No further action required
17	Was concerned that there is no SES emergancy reponse to evacuate. The text comes through after they have flooded. The car is relied upon for going to work, shopping, children to schools..etc. Where is the early warning system? Ie like QLD	Noted. Potentially for Council to reach out to SES to determine if opportunities for a SMS/message service to advise of impending road closures and evacuation orders
18	Council spoke to XXX about the flood study. He also brought up speaking with other Council representatives in the past. He is available to speak with at any time. No contact from the SES about any potential flooding. Lots of water comes from Robyn Crescent. He is well versed about when to move the car as he has been there since 1977.	Noted. Potential for Council to reach out to SES to determine if opportunities for a SMS/message service to advise of impending road closures and evacuation orders
19	XXXX was concerned about the future zoning for high rise. I advised XXXX that the light blue was low risk precinct and Council is seeking exemptions for low risk precinct areas	Agreed. The low risk precinct should not significant reduce development potential of site (i.e., development will just need to comply with appropriate conctrols)
	e-mailed that gave a detailed history of flooding along Prospect Creek.	Property impacted by mainstream flooding from Prospect Creek, which is documented seperately from the current study which is focused on local overland flooding. Suggest Council keep contact details on file for any future updated of the Prospect Creek study

#	Comments	Response
20	Asked: What is overland flooding? What is the definition of “overland”?	Overland flooding is inundation from local runoff rather than inundation from water overtopping the bank of a defined watercourse. It most commonly occurs in urban catchments when the capacity of the local stormwater system is exceeded. The term "overland" refers to movement across land. This could be by walking (e.g., overland travel) or, in this case, the movement of water across land that is normally dry.
	Asked: What is the main source of stormwater flows?	All urbanised catchment expereince stormwater runoff, although more stormwater runoff occurs in catchment with larger impervious areas (e.g., roads, concrete) as there is less opportunity for infiltration of rainfall
21	Just wanted information about her affectation: Low risk precinct. Concerned that she will have insurance problems.	Council advised to read insurance policy and speak with insurance company, or change. No further action required
22	XXXX has not seen it flood.	Council advised that the the house was included as part of house raising for Prospect Creek . House floor level is 0.5m above the 1%AEP flood. The overland flooding will not be above the mainstream flood level. No further action required
23	Advised the flooding comes from Phyliss/Edna St intersection as there is no drainage.	Council advised that the FRMS&P will look at problem areas to see if anything can be done
	He had a private local study carried out.	Council advised that this was because Council did not have any formal study at that time.
24	Went to a Council organised event 20 years ago. House raising, levee wall, detention basin - nothing has happened.	Council explained these measures were for Prospect Creek flooding. This is a different study - verland flooding is the water getting to the creek so will not benefit from these types of measures.
25	Has had 300mm of water through back yard. Street sweeper required as leaves block pits. Bigger pipes may help the flooding. Sink holes near the shops in Myall/Bolivai streets need to be fixed.	Appears to be an overland flow path running through the rear yards of these properties. High risk categorisation associated with potential evacuation difficulties (roadway sag point located in front). However, considered that evacuation on foot would be possible. High risk classification modified to medium risk
26	Wanted to speak about he did not get a letter.	Council advised him he is outside of the PMF that’s why he did not receive a letter.
27	Spoke about the risk precincts that affect the property. He has never flooded.	Council advised him that we may have not had the 100 year flood yet (and property is only marginally impacted by inundation during the 100 year/1% AEP flood in any case). Council advised the next step is the FRMS&P for any works.
28	XXXX sent an e-mail regarding a recent knock down rebuild (previously considered medium risk precinct) and how the new high risk classification might impact on future development plans (e.g., granny flat)	Council advised that previous flood risk classification was based on Cabramatta Creek. The current study focusses on overland flooding. The applicable development controls for the high risk classification are included in Chapter 11 of the Fairfield DCP 2013
29	XXX wanted to fill his land to get to the levee height so that a granny flat can be built.	Council advissd that if everyone filled their land it would increase the existing flood level and granny flats are not allowed in high risk precincts as it would promote more people living in high flood risk areas. Filling could be explored but would need to be modelled to confirm any potential for adverse impacts. Council's current VHR scheme is $81K. He can potentially do it as an ower builder but has to contract out specalist roles.
30	Never had water in property in the past 49 years. No. XX Florence has had water entering the property. The road does get flooded but it subsides quickly.	Property not predicted to be inundated during the 1% AEP flood which tends to confirm experiences. However, due to the road flooding, evacuation is an issue, which is why it falls within the high precinct classification
31	I object to having my property classified as low-risk when it should rightfully be no risk. Please amend the data for 89 Lansdowne Rd, Canley Vale NSW 2166. The LIDAR is wrong.	Review of PMF water level results completed relative to LiDAR. This does confirm water levels in the road would not be sufficiently high to extend into the property in question. Low risk categorisation removed from property
32	Caller left message. Council tried to return call twice. No further corrspondance received	Noted. No further action required
33	Hi My property at XX Florence St Mt Pritchard I have owned since 1997. The property has been through 1 in 20 year flood 1 in 50 year flood 1 in 100 year flood 1 in a 500 year flood 1 in a 1000 year flood. It has also been through some of the heaviest rainfall ever recorded in the surrounding suburbs and the suburb of Mt Pritchard. My property has withstood all the above without concern. My property has never been listed on Fairfield Council list of houses and commercial buildings potentially affected by the 100 year flood in Cabramatta Creek updated report October 2004. The properties that are listed are only 5 . 8,9,10,11 & 21 Also in this report recommended works for Tresalam St and the correction works for the bend in Cabramatta Creek to facilitate better water flow was there an outcome ???? Can you please update on all if any works that have been undertaken by any government dept since 1997.	It's unlikely floods of the magnitudes stated have been experienced within a ~25 year period. Stated observations of no/limited inundation are also inconsistent with observations of a neighbouring property This study is concerned with overland flooding rather than flooding from Cabramatta Creek (Council provided a response regarding what mitigation measures have been implemented in that regard). 1% AEP inundation mapping for this project shows at least half of the property remaining clear of floodwaters. However, the roadway fronting the property is lower and would be cut by more than 1m depth of water (evacuation by vehicle or by walking would not be possible. Therefore, the high risk classification is considered appropriate given the evacuation difficulties
34	Mr XXX advised the SES response time needs to improve ie. early warning. He relies on his own obsevations and a creek height recorder. Live creek data. In the recent floods he has had water under his house. The house has been raised by council.	Noted. Potential for Council to reach out to SES to determine if opportunities for a SMS/message service to advise of impending road closures and evacuation orders
35	Mr XXX had described various options to reduce flooding.	Noted. Recommend that email is kept on Council file and is used to inform future floodplain risk management study
36	XXX wanted to know if he could build a garage in the high risk precinct.	Does not impact on study. No further action taken
37	My recommendation is for council to financially help residents to reduce flood risk and it’s impact on people and property by: - Requesting the NSW Government to increase it’s house raising funding from $70K due to the more than tripling in building cost since that scheme amount was introduced - Council to also contribute financially by cutting planning and building permit charges for houses that are planning to be raised in Medium to High Flood Risk precincts. - Council to provide upon request, free of charge, a Section 10.7 (5) Planning Certificate, for all properties in Medium to High Flood Risk precincts. Please advise if you can recommend the above points to Council for formal adoption.	For Council consideration. Does not impact on current study. No further action taken
38	Raise objection to the draft Cabravale Overland Flood Study. Primarily the depiction of our land in MAP Figure 33.7 which shows our land shaded in pink while the adjoining property at 11-13 Knight Street is shaded in blue - Medium risk. It is clear from this map that it has not taken into consideration the topography of the land especially considering both properties are the same level (AHD) and have similar characteristics. We therefore request a review of the study considering this discrepancy and request our property be placed or considered as medium risk since it has the same or similar levels and characteristics as the adjoining land. Our land as well as those surrounding us have operated as industrial land for a long time and as long as risks are mitigated or there are strategies in place there is no reason why these properties cannot continue. It is highly unreasonable of council to prevent property owners from continuing their business on their land when it is existing and continuing.	Property is already identified as high risk precinct in Georges River Flood Risk Precinct map. Therefore, current study will not change this classification. 1% AEP and PMF depths maps show similar inundation depths at the front of this property and neighbouring properties. However, 11 and 13 have slightly more elevated ground levels at the rear of the property. The high risk classification is a result of the significant inundation depths (i.e., ~1m during 1% AEP flood) within Knight St that would cut access before the peak of the flood (i.e., evacuation issues are the reason for the high classification). 11 and 13 Knight St are not included as "high"as the higher ground at the rear of the property would allow for temporary refuge. Risk precincts will not impact on current land use / business operations. However, it will assist in ensuring that appropriate controls are applied should the property be re-developed in the future (i.e., building back in a more resilient manner). It will also help to ensure that this area is identified as a "problem area" which can be addressed as part of the future FRMS.

#	Comments	Response
39	How will the overland flood study affected her insurances?	Property is primarily impacted by Georges River / Prospect Creek flooding and these studies have been available for multiple years. Therefore, insurance premiums should already reflect this flood information (i.e., current study should not increase premiums)
40	The property owner asked what the blue areas were. He also asked if the consultant can check that the two dark blue areas are correct. He has never flooded at these locations, even in the last heavy storms.	Council advised him that the dark blue was medium risk (100 year flood) and the light blue was low risk (PMF/a very rare flood). Council also advised him that those stoms weren't the 100 year storm, they were around the 20 year flood. Consultant reviewed the medium flood risk areas and the LiDAR information showed ~0.3m deep topographic depressions in these areas that would serve to trap falling rain. However, it also appears the the site includes private stormwater drainage infrastructure in this area that was not included in the flood model that would assist in draining these areas. Therefore, it is likely the flood risk is over-stated and the medium flood risk areas can be removed. However, it is noted that part of the site already falls within a medium flood risk precinct for Prospect Creek.