BROWN

Cooks River Overland Flood Study

Volume 1: Report

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August 2016
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Prepared for Burwood Council

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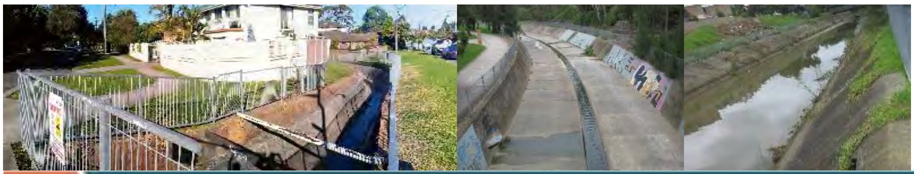

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Executive Summary

Introduction

This Flood Study has been prepared by Brown Consulting, on behalf of Burwood Council. The purpose of this study is to investigate the behaviour of overland flows of the area within Burwood Council local government area (LGA) located within the catchments that drain to the Cooks River.

The study area for this investigation is the section of the Cooks River catchment that is located within Burwood Council LGA. This catchment area of 1.84 square kilometres drains from Liverpool Road, in the north; Coronation Parade, in the west; to Cooks River, in the south. The main subcatchment within the study area drains to the Sydney Water owned Henley Park Stormwater Channel, referred to in this report as the Cooks River feeder channel.

Study Requirements

The study will provide advice to Burwood Council that will assist in their decision making for control and assessment of development potential. The Cooks River Overland Flood Study has been developed with the specific focus to provide Burwood Council with the information required to effectively achieve their planning outcomes.

The study will incorporate aspects of the data collection and flood study phases of the floodplain risk management process, obtaining new data and, as well as making use of the findings of previous investigations and studies.

Methodology

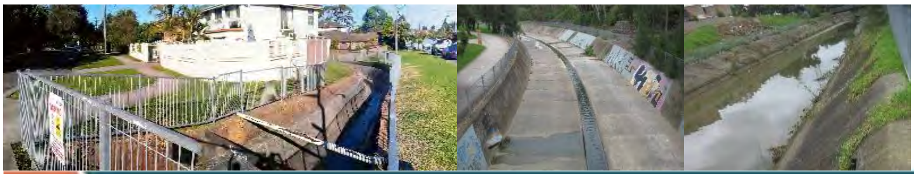
This investigation used the application of rainfall directly onto the grid of the two-dimensional hydraulic model within the *TUFLOW* flood modelling software (Build 2013-12-AA), using the *SMS* interface (Version 11.1). This methodology is known as the direct rainfall approach or 'rainfall on the grid'. This approach removes the need for a separate hydrological modelling package.

Results and Study Outcomes

The Cooks River Overland Flood Study has described flood behaviour in the study area resulting from existing conditions. The study involved the development of a two-dimensional flood model for catchment of the Cooks River feeder channel, also referred to as the Henley Park Channel. The study provides advice and mapping to Burwood Council to assist with decision making for controlling and assessing development potential. The study has:

- Involved the preparation and hand-over to Burwood Council of suitable models of the catchment and floodplain to define flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area
- Presented maps of flood levels, depths, velocities, flows and flood extents within the study area
- Presented maps of provisional hydraulic categories and provisional hazard categories
- Determine provisional residential flood planning levels and defined the flood planning area
- Prepared preliminary emergency response classifications for communities
- Assess the sensitivity of flood behaviour to the potential effects of climate change, such as increases in rainfall intensities and sea level rise
- Provide flood advice for use in a subsequent Floodplain Risk Management Study.

The property tagging maps presented in Volume 2 show that a large number of properties, 346 lots in total within the catchment lie within the Flood Planning Area. These properties will require development controls to manage the risk posed by flooding.



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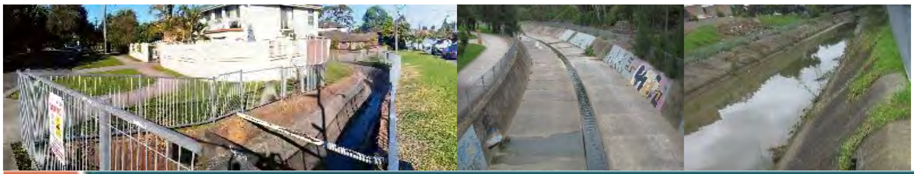


1. Introduction

This Flood Study has been prepared by Brown Consulting, on behalf of Burwood Council. The purpose of this study is to investigate the behaviour of overland flows of the area within Burwood Council local government area (LGA) that is located within the catchments that drain to the Cooks River. This report outlines flooding issues within the catchment and includes descriptions of:

» The physical characteristics of the catchment

» The existing flooding issues review of the existing available flood study information

» The flood planning context for this study

» The methodology used to collect data for use in the study

» The hydrologic and hydraulic modelling undertaken to determine flood levels within the catchment, including validation and calibration of the models

» The results of the modelling and sensitivity analysis

» Preliminary flood planning levels for the catchment

» The impact of potential climate change on flooding within the catchment

This report discusses the impacts of flooding resulting from the 5, 10, 20, 50, 100 and 200 year Average Recurrence Interval (ARI) storm events, along with the Probable Maximum Flood (PMF).

1.1 Background

Burwood Council LGA is located in the inner western suburbs of Sydney. The council area covers approximately 7.26 square kilometres and is home to a population of 32,423 (ABS 2011). Burwood LGA is bordered to the north by Canada Bay Council, to the east by Ashfield Council, to the south by Canterbury Council and to the west by Strathfield Council.

This flood study has been commissioned by Burwood Council to determine flood behaviour within the section of the Burwood LGA that drains to the Cooks River. This study is required to define flood behaviour in the catchment for existing conditions and to address possible future variations due to potential climate change scenarios.

1.2 Description of Study Area

The study area for this investigation is the catchment of the Cooks River that is located within Burwood Council LGA, shown on Figure 1 and in Volume 2 of this report on the *Map 1 – Study Area*. This catchment has an area of 1.84 square kilometres drains from Liverpool Road in the north, Coronation Parade in the west, to Cooks River in the south. The main subcatchment within the study area is drains to the Henley Park Stormwater Channel, referred to in this report as the Cooks River feeder channel. The Cooks River feeder channel has an area of approximately 1.24 square kilometres and drains in a north–south direction where it leaves the Burwood LGA, flowing into the Canterbury LGA across Burwood Road.

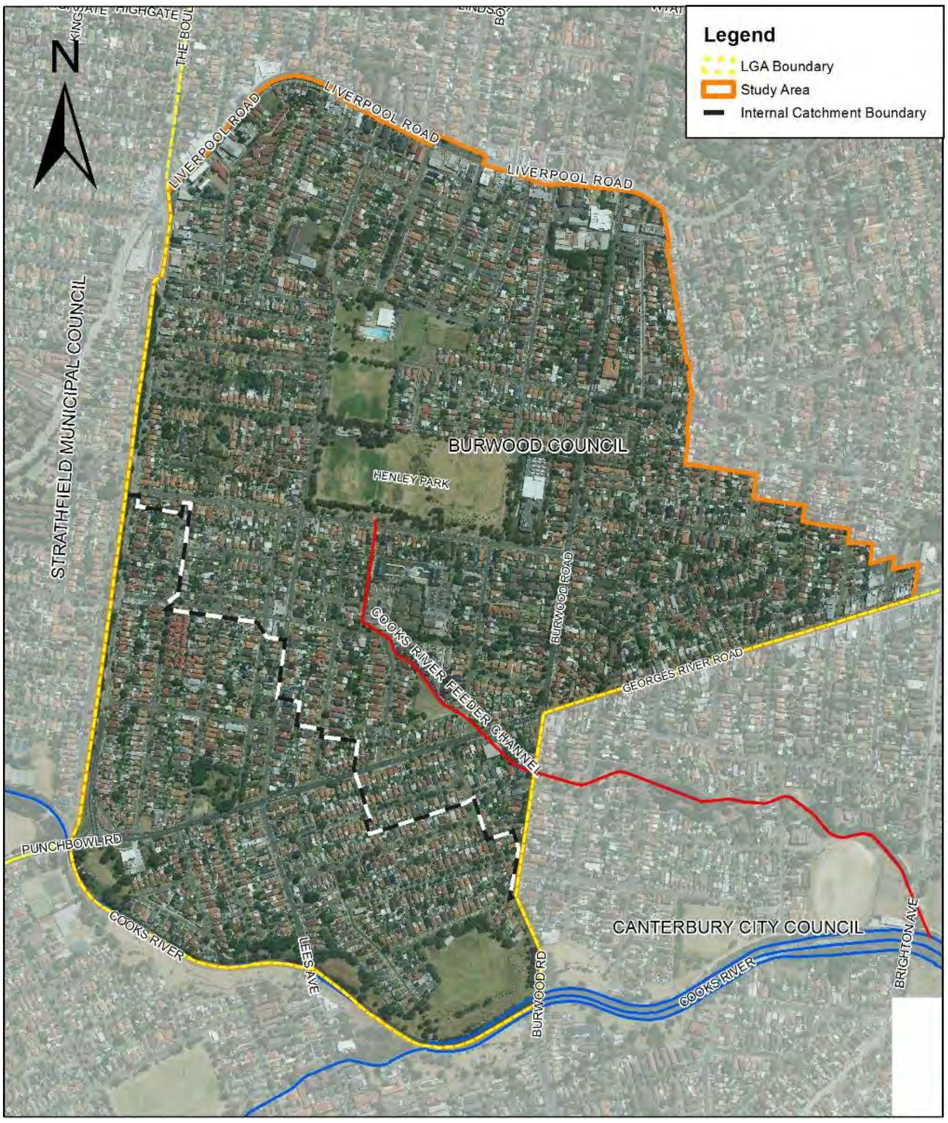
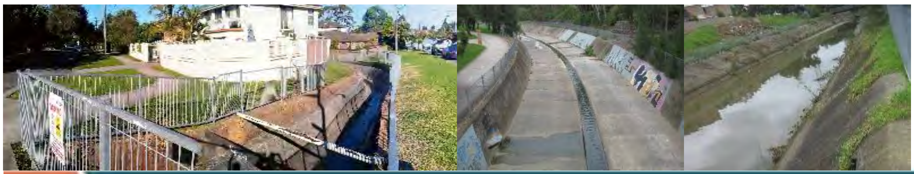


Figure 1 – Cooks River catchment study area

There are nine smaller sub-catchments, six of which drain directly to the Cooks River, with the remaining three draining to the Cooks River feeder channel through Canterbury LGA. The subcatchment layout is presented in Volume 2 of this report on the *Map 2*. The six Cooks River feeder channel sub-catchments drain from Tangarra Street in the north and Weil Avenue in the east to separate outlets along the river between Georges River Road and Burwood Road. The three sub-catchments drain into the Canterbury LGA join the Cooks River feeder channel are located in the eastern



section of the study area. These sub-catchments cross Georges River Road, draining south through Canterbury LGA before joining the channel.

Land use within the Cooks River catchment within Burwood LGA is mostly residential. Retail and commercial premises are located along Liverpool Road in the north of the catchment and Georges River Road in the southern area of the catchment, as well as along Coronation Parade in the west.

Several parks are located within the catchment including Henley Park, Grant Park and Cooinoo Reserve located in the middle reaches of the Cooks River feeder channel catchment. Walsh Avenue Reserve, Whiddon Reserve, Browns Reserve and Flockhart Park are located along the Cooks River. Henley Park is notable as the only park within Burwood LGA designed to function as a stormwater detention basin. The park was re-constructed in the 1990s, with drainage surcharge pits and an earth embankment along the southern boundary (Mitchell Street) to function as a detention basin to manage stormwater flows. This basin has an approximate volume of 4500 m^3. The park also provides the informal name to the Cooks River feeder channel.

The concrete-lined Cooks River feeder channel was originally built around 1929 and varies in width (from 3–4 metres), and depth (1.5–3 metres) from Henley Park to the outlet at the boundary of Burwood LGA. The channel is owned and managed by Sydney Water from the northern boundary of Henley Park in Shelley Street.

The channel, shown in Volume 2 of this report on the *Map 1 – Study Area,* drains north–south under Henley Park, becoming an open channel south of Mitchell Street. The open channel drains southwards to the Burwood Council Depot, where it runs through a curved underground section, emerging on the south side of Tangarra Street East at Rawson Street. Downstream of this point, the drain becomes an open channel approximately 2.5–3 metres wide that winds to Burwood Road, passing under Stanley Street, Georges River Road and Burwood Road.

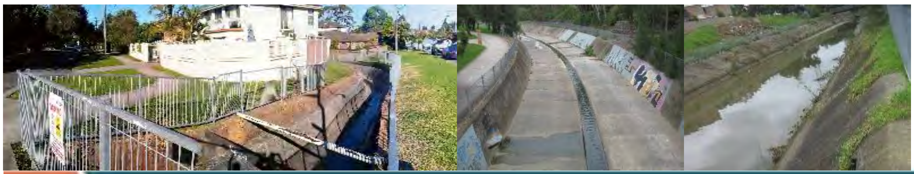
1.3 Study Objectives

The objective of the Cooks River Overland Flood Study is to define flood behaviour in the study area resulting from existing conditions. The study includes the development of a two-dimensional flood model for catchment of the Henley Park Channel.

The study will provide advice to Burwood Council that will assist their decision making for controlling and assessing development potential. The Cooks River Overland Flood Study has been developed with the specific focus to provide Burwood Council with the information they require to effectively achieve their planning outcomes.

The key objectives of the study are to:

- Prepare suitable models of the catchment and floodplain to define flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area
- Prepare maps of provisional hydraulic categories and provisional hazard categories
- Determine provisional residential flood planning levels and flood planning area
- Prepare preliminary emergency response classifications for communities
- Assess the sensitivity of flood behaviour to the potential effects of climate change, such as increases in rainfall intensities and sea level rise
- Provide flood advice for use in a subsequent Floodplain Risk Management Study.



2. Flood Study Planning Context

2.1 Previous Investigations

Flood information has been obtained from Burwood Council for the purposes of developing this report. This information has been obtained from the following sources:

- Robinson GRC Consulting (2002) *Hydraulic Study and On-site Detention Modelling for Burwood Council Catchments*
- Brown Consulting (2004) *Stormwater Drainage Infrastructure Review — Burwood Council Local Government Area*
- Sydney Water (2009) *Cooks River Catchment Mainstream Flood Study Results*
- Webb, McKeown & Associates (1998) *Drainage Feasibility Study at Tangarra Street, Croydon Park*

Robinson GRC Consulting (Note that in 2003, Robinson GRC Consulting merged with WP Brown and Partners, now Brown Consulting) prepared the *Hydraulic Study and On-site Detention Modelling* for Burwood Council Catchments from 2000 to 2002. The primary objective of this study was to develop a computer model to assess flood behaviour for the 100 year rainfall event and from this determine insufficiencies in the drainage system, as well as identify overland flow paths that occurred to an unfavourable frequency. The study covered an area of 7.2 square kilometres with the identified catchments of:

1. St Lukes Catchment
2. Dobroyd Centre North
3. Powells Creek
4. Dobroyd South
5. Cooks River
6. Exile Bay
7. William Street Catchment

A comprehensive survey of the levels of all pits in the study catchments was undertaken by Rose Atkins & Associates as part of this study in June 2000, including obtaining additional survey data for the pit and pipe system. A substantial portion of the field work was done using Global Positioning System (GPS) measurements with theodolites being used in areas where tree cover prevented GPS from being employed. Survey information was supplied to the Robinson GRC modellers in two formats. The first was a spreadsheet giving Integrated Survey Grid (ISG) coordinates and Australian Height Datum (AHD) levels. The second was a series of *AutoCAD* files that were combined into a single drawing showing cadastral data, the drainage system supplied by Council, and the locations and levels surveyed.

In addition to the Robinson GRC 2002 and Sydney Water 2009 studies, Brown Consulting have prepared the *Stormwater Drainage Infrastructure Review for Burwood Council* in 2004. This report involved hydrologic and hydraulic modelling of Burwood Council's stormwater drainage systems, aimed at determining flooding impacts of new developments in the Burwood local government area. The study focused on surface overflows, with models adjusted for increases in impervious area associated with future developments, and the corresponding overflow rates were determined. Flow rates increased in general, and slightly increased flooding occurred at trouble spots identified in the earlier study, but the increases were not sufficient to cause flooding at new locations.

2.2 Regulatory Framework

This section outlines:

- » The legislative framework within which the flood study has been prepared
- » Policies and guidelines applicable to the study
- » Introduces the planning objectives and outlines how the study will be used by Burwood Council.

Local Government Act 1993

This Act creates local governments and grants them the power necessary to perform their functions, among which are the management, development, protection, restoration, enhancement and conservation of the environment of the area the local government is responsible for, in a manner that is consistent with and promotes the principles of ecologically sustainable development. The *Local Government (Ecologically Sustainable Development) Act 1997* amended the *Local Government Act* so that ecologically sustainable development, including the sustainable use of resources, is now a guiding operational principle.

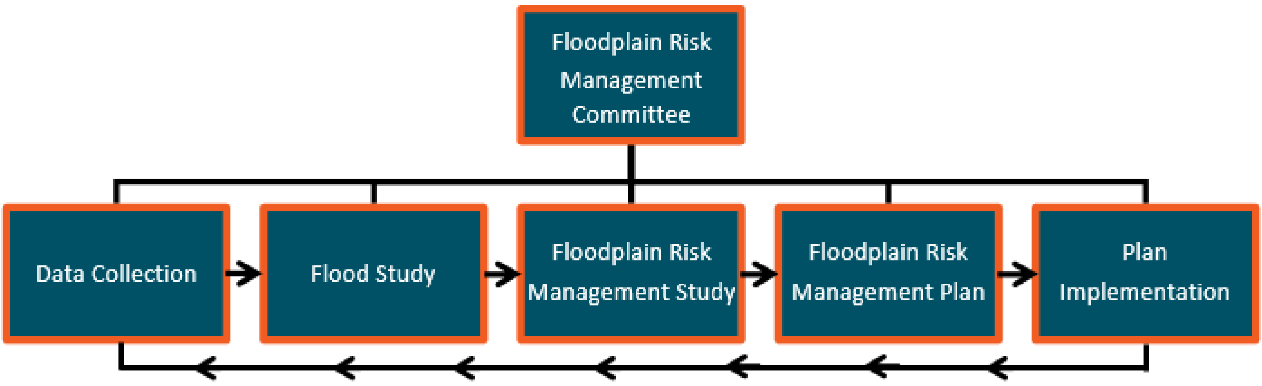
The *NSW Floodplain Development Manual: the management of flood liable land* relates to the management of flood liable land in accordance with Section 733 of the *Local Government Act*. Section 733 states that a council does not incur any liability in respect of any advice furnished in good faith relating to the likelihood of any land being flooded.

NSW Floodplain Development Manual: the management of flood liable land

The *Floodplain Development Manual* has been produced by the New South Wales Government to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property. The document is intended to guide councils in the development and implementation of detailed local floodplain risk management plans. The manual, for residential developments, suggests a freeboard of 0.5 metres for a 100 year flood event.

This manual supports the NSW Government's Flood Prone Land Policy in providing for the development of sustainable strategies for managing human occupation and use of floodplains based on a risk management hierarchy of avoidance, minimisation and mitigation. The manual provides the framework for councils to implement this policy, considering the cost and benefits associated with occupation of floodplains in an integrated approach.

The NSW *Floodplain Development Manual: the management of flood liable land* relates to the management of flood liable land in accordance with Section 733 of the *Local Government Act*. This process is outlined in Figure 2, recreated from the manual.



From *NSW Floodplain Development Manual: the management of flood liable land*

Figure 2 – The floodplain risk management process

Data Collection – Compilation of existing data and collection of additional data.

Flood Study – Defines the nature and extent of the flood problem, in technical rather than map form.

Floodplain Risk Management Study – Determines options in consideration of social, ecological and economic factors relating to flood risk.

Floodplain Risk Management Plan – Council publicly exhibits the preferred options from the studies. The Floodplain Risk Management Plan is subject to responses and subsequent revision. Council formally approves the Plan after public exhibition

Plan Implementation – Council undertakes measures including mitigation works, planning controls, flood warnings, flood readiness and response plans, environmental rehabilitation along with ongoing data collection and monitoring.

The study will incorporate aspects of the data collection, flood study phases making use of the findings of previous investigations, studies and management plans.

Australian Rainfall and Runoff

Engineers Australia (The Institution of Engineers, Australia) publish Australian Rainfall and Runoff to provide guidance on the application of stormwater and flooding design procedures and values along with analysis of likely accuracies. This document is in the process of being updated, with guidance on specific aspects of provided in the form of various projects. These guidance documents, Projects 11 and 15, have been used in the preparation of this flood study.

Environmental Planning and Assessment Act 1979

This Act is the primary piece of land use and planning legislation in New South Wales. It allows for the creation, at various levels of government, of environmental planning instruments to control land use and planning. State environmental planning policies, regional environmental plans, local environment plans (LEPs), development control plans (DCPs), and council codes and policies can all be established under the Act.

When property is sold in NSW the vendor must attach to the contract documents a copy of a certificate issued by the local council under Section 149(2) of the Act. Certificates issued under Section 149 of the *Environmental Planning and Assessment Act 1979* provide details to prospective property purchasers about zonings and other council policies which may affect the land. This is referred to as a *Section 149(2) Certificate* and contains a list of matters prescribed under Schedule 4 of the *Environmental Planning and Assessment Regulation 2000.* The *NSW Floodplain Development Manual* recommends that councils should only provide information on flood development controls where these controls are imposed by council policies in accordance with the requirements of the *Local Government Act 1993*.

Additional information on flooding can be provided by councils under Section 149(5) of the Act. This information can be from flood studies or historical flood events and is at the discretion of council to provide. The *NSW Floodplain Development Manual* states that 'to become fully aware of flood risk prospective purchasers need to rely upon the use of information provided on planning certificates under both Sections 149(2) and 149(5) of the Act, using either planning certificates or other appropriate means'.

Details of flood behaviour outlined in this flood study will form the basis of the information provided by Council on the Section 149(2) and (5) Certificates. This information includes tagged properties and flood planning levels.

NSW Government Sea Level Rise Policy Statement.

To support sea level rise adaptation, the NSW Government has prepared a *Sea Level Rise Policy Statement* that sets out the Government's approach to sea level rise, the risks to property owners from coastal processes and assistance that Government provides to councils to reduce the risks of coastal hazards. The statement includes sea level planning benchmarks which have been developed to support consistent consideration of sea level rise in land-use planning and coastal investment decision-making.

3. Available Data

3.1 Data Sources

The data adopted in the study has been summarised in Table 1, which lists the types and format of the data utilised for the flood modelling undertaken for this investigation.

Table 1 – Summary of data sources

Data Description	Data Sourced	Data Processed
Urban Drainage Network Location and level of stormwater drainage pits. Levels and internal dimensions of stormwater drainage pipes	GIS - *MGA94* (Burwood Council) *DRAINS* - *ISG* (Brown Consulting) *AutoCAD* - *ISG* (Brown Consulting 2004) *AutoCAD* - *MGA* (Brown Consulting 2013)	*DRAINS* *TUFLOW* (1D)
Aerial Photography	ECW dated Jan 2011 (Burwood Council)	*ArcGIS* *TUFLOW* – Spatial Roughness
Cadastre	GIS (shp) – *MGA94* (Burwood Council)	*ArcGIS*
Ground Levels from ALS Data	GIS (xyz) – *MGA94* (Burwood Council)	*ArcGIS* *TUFLOW* (2D)
Design Rainfall	IFD (Burwood Council)	*DRAINS* *TUFLOW* (DRG)

Topographic and rainfall data has been obtained from Burwood Council, with detailed information on pipe and channels surveyed by Brown Consulting. Discussion of these data sources and the use of data is provided in Sections 3.2 to 3.6.

3.2 Topographic Data

Airborne Light Detection and Ranging (LiDAR) survey of the catchment and its immediate surroundings was provided for the study by Burwood Council on behalf of Sydney Water. This data was collected from February to June 2008 by AAMHatch. This data typically has accuracy in the order of:

» +/- 0.15 metres (for 68% confidence level) in the vertical direction on clear, hard ground
» +/- 0.5 metres in the horizontal direction.

The accuracy of the Aerial Laser Scanned (ALS) data can be influenced by the presence of open water or vegetation at the time of the survey. From this data, a triangular irregular network (TIN) was generated by combining ALS data with the ground survey data by Brown Consulting. This TIN formed the basis of the two-dimensional hydraulic modelling for the study, from which the Digital Elevation Model (DEM) was sampled to form the two-dimensional grid.

3.3 Pit and Pipe System

Brown Consulting surveyors were engaged as part of this study to 'ground-truth', or perform a physical check, of the pit and pipe survey data that was supplied by Burwood Council from their Geographic Information System (GIS). This was required to ensure an accurate representation of current conditions within the model. The data checked as part of this investigation included the survey undertaken by Brown Consulting in 2004 as part of their Stormwater Infrastructure Review. This review determined that there were some pits and pipes which have been either modified or added into the reticulation system since 2004 and required updating to ensure accuracy of the model.

Brown Consulting's survey identified and survey a total of twenty-three pits as part of this investigation. This additional or updated data was merged with the 2004 survey and transformed from Integrated Survey Grid (ISG) to Map Grid of Australia (MGA) coordinate systems.

A previous *DRAINS* model that was constructed of the Cooks River catchment by Brown Consulting (2004) was used as a base hydrological verification model as a part of this study. Catchments for this model are proved in Volume 2 on *Map 2*. The *DRAINS* network and catchments were updated to incorporate the additional surveyed pits to achieve more up-to-date and accurate modelling. The updated *DRAINS* model was imported into *TUFLOW* as one-dimensional hydraulic elements.

3.4 Cross Section Data for Open Channels

The Cooks River Catchment central drainage system is predominately concrete-lined, trapezoidal, open channel extending from the tributary outfall on the Cooks River extending upstream to Mitchell Street. The open channel linked together with culverts at road crossings and property crossings where it is closed conduit.

Detailed survey was undertaken by Brown Consulting of the open channel reach of the drainage system including all culvert internal dimensions and cross sectional profiles. Cross sections were generated from the TIN prepared by the surveyor at changes in profile shape and vertical geometry and imported into *TUFLOW* as one-dimensional elements linked to the two-dimensional grid.

The Cooks River feeder channel cross section survey data taken by Brown Consulting's surveyors is provided in Appendix A, along with surveyed details of bridges and culverts along the channel.

3.5 Design Rainfall Data

Design rainfall data was obtained from Burwood Council's *Intensity Frequency Duration* data as supplied by Council for recurrence intervals up to and including the 100 year ARI rainfall event. The 200 year rainfall event was extrapolated from the Burwood IFD using the methodology from *AR&R* (2001). The Probable Maximum Precipitation (PMP) estimates were developed using the methodology in the *Generalised Short Duration Method* published by the Bureau of Meteorology (BoM, 2003).

Rainfall intensities for the 100 year recurrence interval events were taken Burwood Council's Intensity Frequency Duration data as supplied by Burwood Council. Rainfall temporal patterns were developed from Australian Rainfall and Runoff 1987 (*ARR* 1987). Burwood Council is located within Zone 1, shown on Figure 3.

Figure 3 – *AR&R* rainfall zones

Temporal patterns were used to develop incremental rainfall depths, in millimetres, for each time period of the storm event. Storms from 15 minutes to two hours duration were split into 5 minute intervals, 3 and 4.5 hour events into 15 minute intervals, with the 6 hour events and longer split into half hour intervals. Temporal patterns and rainfall depths for each storm event used in the modelling are presented in Appendix B.

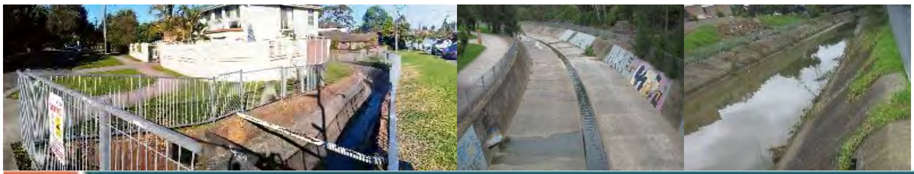
Rainfall depths and temporal patterns for the Probable Maximum Flood (PMF) were developed using the Bureau of Meteorology *Generalised Short Duration Method (GSDM).* Rainfall patterns were developed for the 15, 30, and 45 minute events, the 1, 2.5, 3, 4, 5 and 6 hour events.

No spatial variation in rainfall pattern was modelled as part of this investigation. The catchment size of 1.84 square kilometres does not require areal reduction to be applied, with *Australian Rainfall and Runoff* (2001) recommending that lumped rainfall models are suitable for catchments up to 4.0 square kilometres.

This investigation assumed rainfall probability neutrality with recurrence interval, i.e. that the rainfall event with a probability of 1 in 100 years (1% Annual Exceedance Probability [AEP]) generates the flood event with a probability of 1 in 100 years.

3.6 Community Consultation

Community consultation was carried out by Brown Consulting to obtain information on historical flooding events which may have occurred. Information requested include water levels, inundated properties and the direction of flows. Comparing these first hand observations with the results of the model helps to assess its validity to a certain extent. The feedback received from the community consultation outlined four properties that had encountered flooding in the past and has been used in the validation process and is discussed in detail in Section 5.2.



4. Methodology

This investigation used the application of rainfall directly onto the grid of the two-dimensional hydraulic model within the *TUFLOW* flood modelling software (Build 2013-12-AA), using the *SMS* interface (Version 11.1). This methodology is known as the direct rainfall approach or 'rainfall on the grid'. This approach removes the need for a separate hydrological modelling package.

In traditional flood modelling, separate hydrological and hydraulic models are constructed. The hydrological model has inputs of rainfall, area losses and roughness within a lumped or partially distributed sub-catchment, calculating runoff hydrographs for modelled storm events. This hydrograph is then applied to the hydraulic model, which performs flow calculations based on hydraulic features to develop estimations of flood behaviour across the study area.

In the direct rainfall approach, the hydrological model is incorporated into the hydraulic modelling process and distributed throughout the entire catchment. The hydrological routing is undertaken in the distributed two-dimensional model, rather than in a lumped hydrological package.

4.1 Hydrologic and Hydraulic Model

4.1.1 Model software

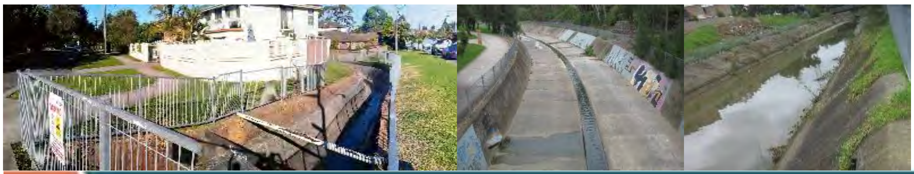
This modelling investigation used the *TUFLOW* flood modelling software (Build 2013-12-AA), using the *SMS* interface (Version 11.1).

4.1.2 Model geometry

The *TUFLOW* model was based on a single set of elevation data, or *Z* points, which was constructed from ALS data provided by Burwood Council at a grid resolution of 0.5 metres. These Z point layers were used to generate a 2.5 metre grid model which covered the entire study area. The 2.5 metre grid was used for all model scenarios within the calibration and validation stage including the 5, 20 and 100 year events in addition to the sensitivity runs. This grid resolution was selected by trialling a range of grid sizes arriving at an optimum grid size that represents the urban nature of the catchment while still achieving an acceptable run time and level of numerical stability. The orientation of the grid was adjusted to align with the majority of property boundaries and road alignment within the catchment; to optimise accuracy of modelling between buildings and through one/two-dimensional interfaces. The delineation of individual catchments within the model in presented in Volume 2 on *Map 2 – Individual Urban Catchment Delineation*.

4.1.3 Modelling of one-dimensional structures

The Cooks River catchment is a heavily urbanised area consisting primarily of low-rise one to two story residential properties. The primary waterway within the catchment is the Cooks River feeder channel, a concrete lined channel. This channel has been represented as a one-dimensional domain of the model using a combination of culverts and open channels linked to the two-dimensional grid. The pit and pipe network was also created within in the one-dimensional domain using the data supplied by Council as well as the updated pits surveyed by Brown Consulting. The reticulated storm water drainage pits have been modelled in accordance with the recommendations *in Australian Rainfall and Runoff Project 11 – Blockage of Hydraulic Structures – Stage 2 Report* (Engineers Australia, 2013) with a 100% blockage for pipes smaller than 450 millimetre diameter and 50% blockage applied for pipes greater than 450 millimetres in diameter. No blockage has been applied to the major culverts in the base case. Sensitivity of the modelling to blockage has been considered in the sensitivity analysis discussed in Section 8.



4.1.4 Approach to representing building obstructions

Examination of the flow paths in the results of the preliminary modelling indicated that there were a number of overland flow paths which flow through properties between buildings. The ALS data supplied by Burwood Council was processed before being provided, to include only ground points and excluded building structures, i.e. it represented the ground surface only and did not include buildings. The buildings do provide an obstruction to overland flow paths in these areas and need to be appropriately represented within the two-dimensional overland flow.

The update to *Australian Rainfall and Runoff* currently being prepared by the Institution of Engineers Australia includes two documents that provide guidance on incorporation of building obstructions: *Project 15: Two Dimensional Modelling in Urban and Rural Floodplains* and *Project 15: Two Dimensional Simulations In Urban Areas Representation of Buildings in 2D Numerical Flood Models*. These documents recommend completely removing building from models where rainfall volumes within building footprints are not significant.

The approach taken to model the obstructions in this flood study involved creating an opened ended line boundary around the building envelope, leaving the downstream edge of the property open to maintain hydrological continuity by allowing rainfall applied to grid within the building footprint to travel out. An example of the results that are produced through the use of this approach is presented in Figure 4, with the arrows indicate the direction of flows and the lines represent the line building boundaries.

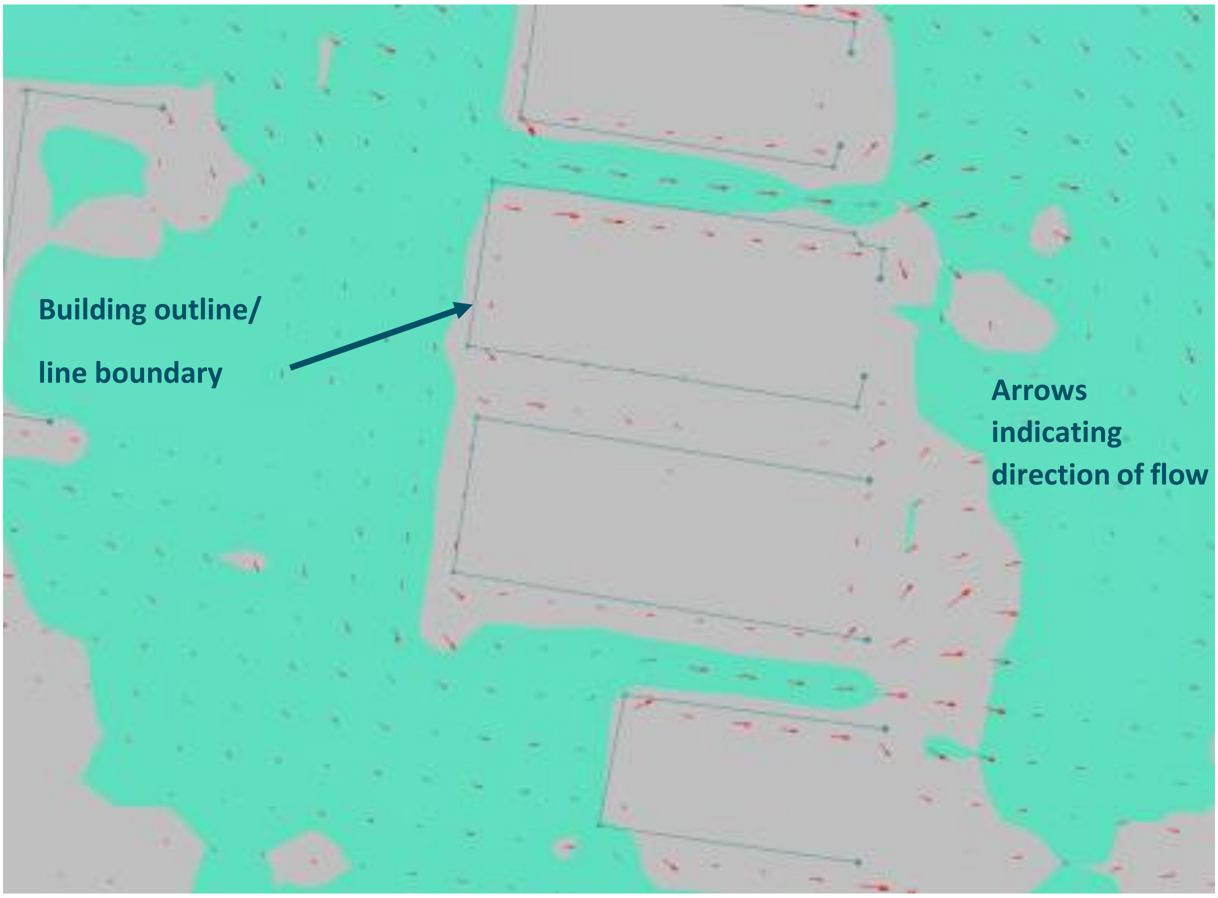
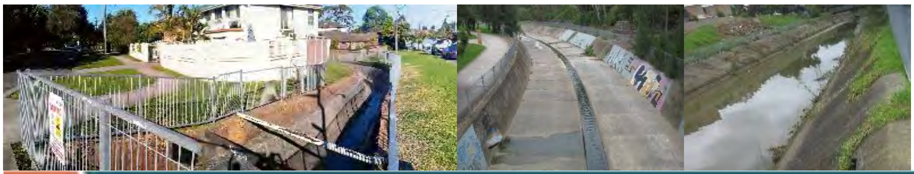


Figure 4 – Approach to modelling building obstructions in *TUFLOW*

The downstream edge of the building was determined by initial model runs without buildings and with fully enclosed building footprints. This approach incorporates the hydraulic obstruction of the buildings, while retaining the rainfall volume that falls within the building footprint.



4.1.5 Land use categorisation mapping

Spatially varying hydraulic roughness and hydrological losses were modelled within the *TUFLOW* model by categorisation and mapping of land uses within the catchment. This involves dividing the study area into surface categories by digitising recent aerial photography supplied by Burwood Council, and assigning each surface category its own parameters. The parameters adopted are summarised in Table 2.

Table 2 – Summary of parameters for various surface categories

Land Use Type	Manning's 'n' Coefficient	Initial Loss (mm)	Continuing Loss (mm/hr)
Bitumen Roads/ Car parks	0.02	1.0	0.0
Buildings	0.02	1.0	0.0
Pervious areas of yards and parks	0.04	5.0	2.5

The spatial distribution throughout the catchment of the three surface categories used in the modelling is shown in Figure 5 and in Volume 2 on *Map 3 – Spatial Distribution of Roughness Values*.

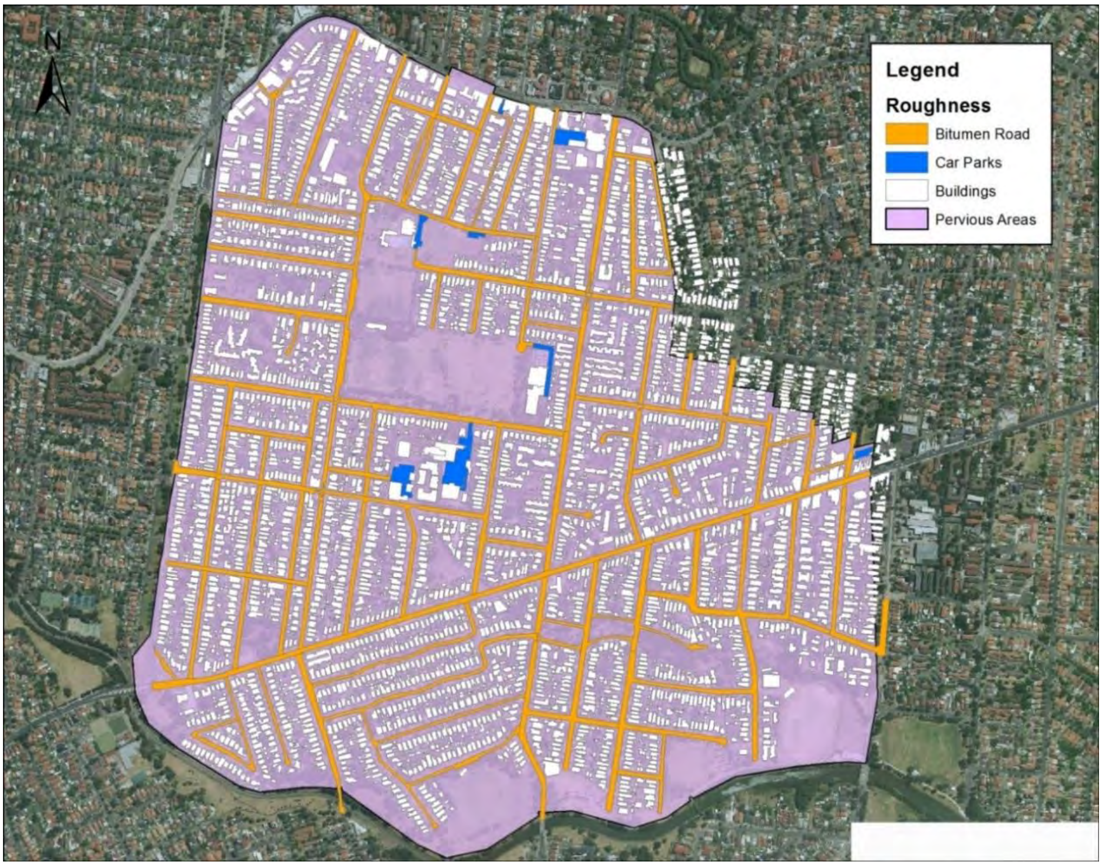
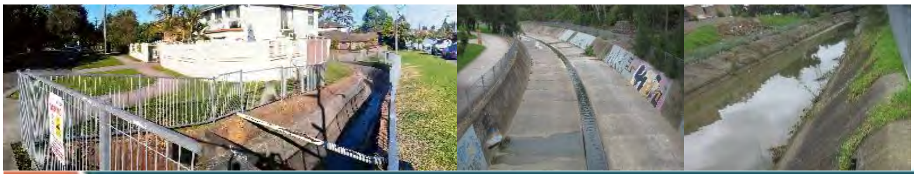


Figure 5 – Spatial representation of surface categories

The buildings category, shown in white, covers a large proportion of the catchment, indicating that the approach to modelling obstructions provided in Section 4.1.4 requires this area to be taken into consideration for flow volume generation.



4.1.6 Model boundary conditions

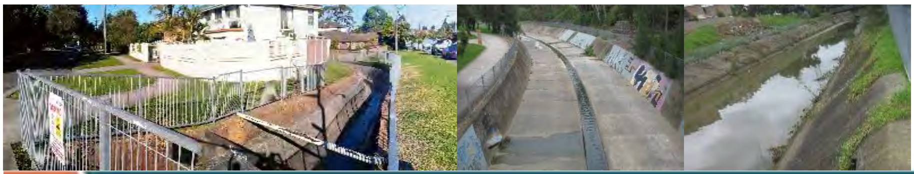
The rainfall over the catchment was applied using the rainfall–on–the–grid method which applies the specified rainfall depths over time to all cells within the study area. The rainfall intensities used were from the Burwood Council and *AR&R* (1987) temporal patterns to obtain the time-intensity distributions.

The downstream boundary conditions adopted for both one-dimensional and two-dimensional domains were all located along the northern bank of the Cooks River. The one-dimensional pipes and two-dimensional overland flow boundary conditions adopted a computed water surface elevation versus flow which uses a set water surface slope for all elevations to calculate normal depth. The slopes were calculated using the ALS data that was supplied by Burwood Council along the primary flow paths out of the catchment. A fixed water surface downstream one-dimensional and two-dimensional boundary condition was adopted for the sensitivity analysis adopting the 100 year flood level in the Cooks River.

4.1.7 Preliminary modelling and refinement

Preliminary modelling, using the available data, was carried out to refine the model and to select the location of flow paths and identify locations within the catchment from which results would be exported for design runs. These reporting locations, or 'history stations' were selected in consultation with Burwood Council to provide details of hydraulic features or flooded properties. These locations are discussed in detail in Section 0 and shown in Volume 2 on *Map 4 – Stations and Hotspot Locations*.

The results of the model were refined by exclusion of flows of depth less than 0.15 metres. This process, also referred to as 'nulling', is required to remove areas of flooding and ponding not considered reportable. Flood depths less than 0.15 metres have been nulled for this map, resulting in the appearance of ponds along roads. Flows shallower than 0.15 metres are outside the levels of accuracy of the methodology used to carry out this investigation. This nulling of flows below 0.15 metres is recommended in the *Floodplain Development Manual.* It should be noted that the accuracy of the LiDAR used in this investigation is quoted in the Intergovernmental Committee on Surveying and Mapping *LiDAR Acquisition Specifications and Tender Template (Version 1.0, November 2010)* as 68% confidence interval within ± 0.15 metres and 95% confidence interval within ± 0.3 metres.



5. Model Calibration and Validation

The Cooks River Feeder Channel catchment does not have a record of historical flood levels. There are no flow measuring stations located within the catchment, with historic flood information available sought through the community consultation, discussed in Section 5.2. The information available through the community consultation questionnaire only provided qualitative and descriptive information with regards to past flooding and was used only as a tool to qualitatively verify the nature of flooding as accounted by residents.

5.1 Comparison With Previous Studies

Analysis of the results produced from the *DRAINS* modelling updated from the 2004 *Stormwater Drainage Infrastructure Review* by Brown Consulting (2004) has been compared with flows generated across history stations in the *TUFLOW* modelling. A summary of comparison flows for 5 year and 100 year events are provided in Table 3.

Table 3 – Comparison of *DRAINS* and *TUFLOW* modelling results.

Location	5y ARI Peak Flow (m^3/s)		100y ARI Peak Flow (m^3/s)	
	DRAINS	*TUFLOW*	*DRAINS*	*TUFLOW*
Cobden St	2.5	2.2	4.1	3.8
Burwood Rd (U/S)	0.8	0.7	1.4	1.0
Baker St	3.5	1.5	6.0	2.3
Llangollan Ave	0.8	0.6	1.4	1.0
Shelley St (into park)	7.4	6.7	11.6	11.9
Anne St	4.3	0.6	7.2	0.9
Short St	2.6	4.6	4.6	8.8
Park inflow (U/S)	12.5	7.3	21.3	17.7
Basin inflow (U/S) from north-east	15.3	16.8	25.3	30.9
Basin inflow from west (Portland St)	3.9	1.5	7.5	3.0
Basin combined total inflow	19.1	18.3	32.9	33.9
Basin outflow (D/S)	6.1	10.1	18.9	28.8
Stiles St (inflow)	5.3	7.1	18.3	18.3
Stiles St (Cnr Kingsbury)	0.0	2.8	0.0	12.3
Kingsbury (infront of property No.9)	0.0	0.4	0.0	2.2
Kingsbury channel O/L flow to channel	5.6	5.3	18.9	8.8
Kingsbury culvert	10.7	8.7	25.2	14.1

Location	5y ARI Peak Flow (m^3/s)		100y ARI Peak Flow (m^3/s)	
	DRAINS	*TUFLOW*	*DRAINS*	*TUFLOW*
O/L flow west Of 2a Tangarra St East	0.0	0.1	0.0	5.8
Rawson St	2.8	2.7	5.4	13.9
Stanley St culvert	13.8	13.3	28.5	37.5
O/L flow to 47 Stanley St	0.0	0.1	0.0	1.6
Georges River Rd culvert	14.7	13.9	29.1	35.2
Burwood Rd culvert	16.1	14.5	31.0	36.0
Windsor Ave culvert	16.8	14.7	30.8	38.3
O/L flow at Linthorn Ave	0.0	0.1	0.0	0.1
Hampton St culvert	22.4	17.9	42.1	44.5

The results in Table 3 show the peak flow rates generated in *TUFLOW* match closely to the peak flows generated in *DRAINS* in the majority of locations. Differences in the modelled results relate to variability in distribution of separated flows. This is particularly evident in locations such as Baker Street, Anne Street, the basin outflow, Stiles Street, Kingsbury channel and culvert, Tangarra Street and Rawson Street. These differences are the result of the overland flow paths assumed in the *DRAINS* not being consistent with the flow paths developed in *TUFLOW* using the rainfall–on–the–grid method, which is based on the ALS data. It should be noted that continuity is maintained at critical confluence points, with flows being consistent between the two modelling approaches.

5.2 Community Consultation

Community consultation was carried out by Brown Consulting to obtain information on historical flooding events. Information requested from residents within the study area included water levels, inundated properties and the direction of flows. These first hand observations have been compared with the results of the TUFLOW modelling to assess the validity of the results. Feedback received from the community consultation outlined four properties that had encountered flooding in the past. Information on flooding from these four properties has been used in the validation process. The Community Consultation Report is provided in Appendix C, with property locations show in Volume 2 on *Map 5 – Community Consultation Results*.

Property 1

The resident of described incidence of the drainage grate blocking located on the footpath. In such cases overflow is directed through their front gate just in front of the property. Flows entering the property generally pond up in the front garden; however the flood levels did not over top the front step. Figure 6 shows the peak results of the model in a 20 year 2 hour event, it can be noticed that there is a significant volume of water flowing through the front yard of the property. The flows early on in the storm concur with the description given by the resident, however as the magnitude of flows increase, flows overtop the crest threshold of the front yard and flow around the building and along the side yard. Only a qualitative comparison is possible in this situation as no flood levels were recorded.

Property 2

The resident described water reaching the backdoor and then flowing through the carport on the north side of the property in a flood event approximately 50 years ago and no known dates of occurrence could be provided. Flooding was described as ponding up in the rear yard from the channel, however didn't inundate habitable areas. Figure 6 shows Property 2, highlighted which exhibits similar conditions to that described, however it is understood that there has been substantial changes to the channel and redevelopment of the site and adjoining properties since the reported occurrence.

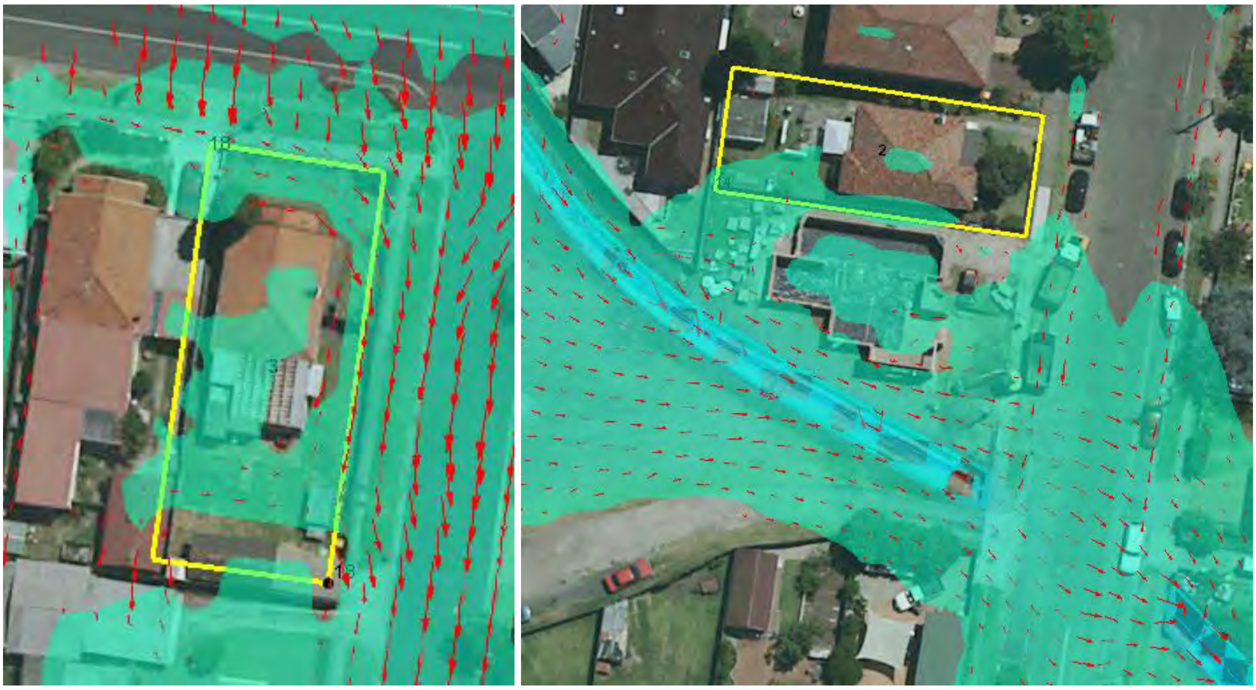


Figure 6 – *TUFLOW* modelling results for Property 1 (left) and Property 2 (right)

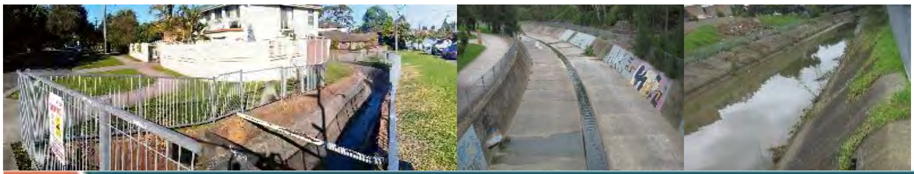
Property 3

The owners of Property 3 reported they observed flooding on their property during heavy rainfall, especially in their garage. They also noted that the land was very flat around the property and it is on the low end of the street. Figure 7 shows the peak flood depth after a 100 year 2 hour storm. There is some pooling of water in the garage area as well as in the front yard which to an extent correlates with the description given by the owner, which would not be classified as overland flow in the context of this study as it is not greater than 0.15 metres.

Property 4

The owner of Property 4 reported flooding both on his property as well as the neighbour's property which occurred sometime in the early 1970's, with actual dates unknown. The resident described a flood which exceeded the floor level on the neighbour's property however not on the property in question. The results of the 100 year 2 hours storm exhibit a similar outcome where inundation of the neighbouring property is clearly evident in Figure 7, with the dwelling of Property 4 located within the flood fringe. The flooding on the neighbouring property shows the floor level inundated by 0.1-0.15 metres. The dwelling has been substantially modified since the flooding occurred and currently only provides a qualitative verification as to the historical nature of flooding within the vicinity of the dwelling.

Figure 7 – *TUFLOW* modelling results for Property 3 (left) and Property 4 (right)



6. Design Event Modelling

6.1 Overview

There are two basic approaches available to determining design flood levels:

- **Flood frequency analysis** – based upon a statistical analysis of the flood events
- **Rainfall and runoff modelling** – design rainfalls are processed by hydrologic and hydraulic computer models to produce estimates of design flood behaviour.

A complete homogenous record of flood levels and flows over a number of decades is not available for the Cooks River feeder channel catchment, meaning that the flood frequency approach could not be applied in this investigation. A rainfall and runoff modelling approach using *DRAINS* model and rainfall–on–the–grid in *TUFLOW* was adopted for this study to calculate design flows in the *TUFLOW* hydraulic model, which determines design flood levels, flows and velocities.

6.2 Critical Duration

Modelling of the 100 year event was undertaken to determine the critical storm duration for the catchment and subcatchment areas. Design storm durations from 15 minutes to 12 hours were modelled, using temporal patterns from *AR&R* (1987).

The modelling calculated that a combination of the 25 minute, 90 minute and 2 hour design storm durations were critical across the whole catchment for the 100 year event. The 2 hour storm duration was predominantly the critical storm duration for the majority of the catchment for the 100 year event. For mapping purposes, the peak flood results adopted in the mapping was achieved by running the full duration of storms in *TUFLOW* and applying the maximum of all durations at each individual cell due to the spatial variability of critical storm duration.

6.3 Downstream Boundary Conditions

In addition to runoff from the catchment, downstream areas can also be influenced by high water levels in the Cooks River. Consideration must therefore also be given to accounting for the joint probability to coincident flooding from both catchment runoff and backwater effects.

A full joint probability analysis to consider the interaction of these two mechanisms is beyond the scope of this study. It is accepted practice to estimate design flood levels in these situations using a 'peak envelope' approach that adopts the highest of the predicted levels from the two mechanisms. The effects of backwater flooding was modelled as a part of the sensitivity analysis discussed in Section 8.

6.4 Modelling of Blockages

The effect of blockage of hydraulic structures has been investigated in accordance with the recommendations on Engineers Australia, (2013) *Australian Rainfall and Runoff: Revision Projects Project 11: Blockage of Hydraulic Structures (Stage 2)*. A detailed discussion of the impact of blockages on flood behaviour is discussed in the Sensitivity Analysis in Section 8.1.5 and Appendix E.

7. Flood Mapping Results and Discussion

The results maps from this study are presented in *Volume 2: Flood Mapping* which presents the following results from the modelling of design storm events:

- Peak flood depths and level contours
- Peak flow rates
- Peak flood velocities
- Provisional Flood Hazard Categorisation
- Hydraulic categorisation
- Burwood Council’s preference for Provisional Hydraulic Categorisation
- Preliminary flood emergency response classification of communities.

Discussion of the results of the flood modelling presented on these maps is provided in Section 7.1. The flood profile of the Cooks River feeder channel and flood stage hydrographs for the 5, 10, 20, 50, 100 and 200 year events, along with the PMF is presented in Appendix D.

7.1 Summary of Results

Peak flood levels, depths and flows at key selected locations within the catchment are summarised in Sections 7.1.1–7.1.7. These key locations coincide with the history stations adopted in the sensitivity analysis discussed in Section 8 and also major road crossings of the main channel. The location of the selected key locations is shown in Figure 8 and in Volume 2 on *Map 4 – Station Locations and Hotspots*.

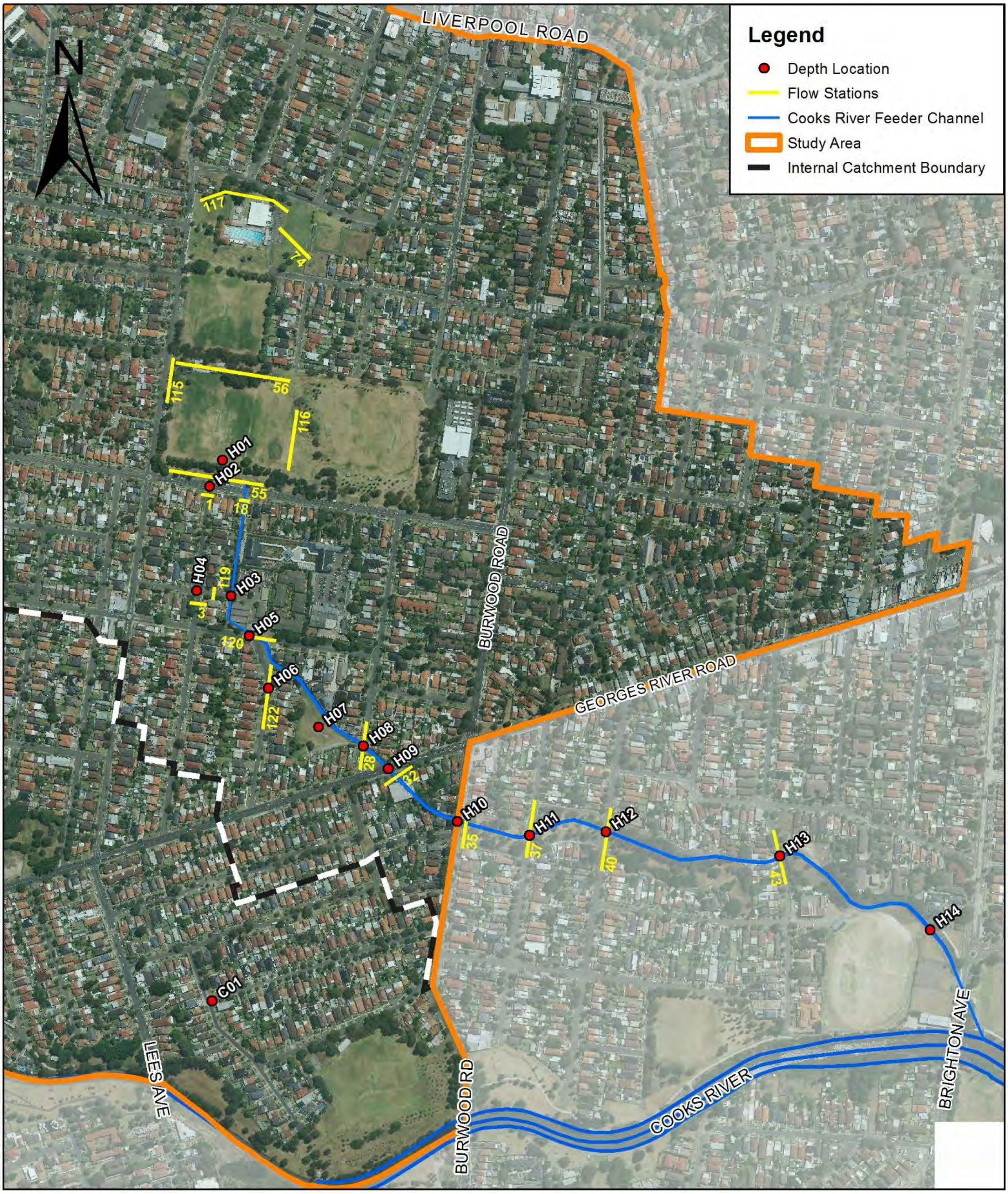


Figure 8 – Location of modelling history stations

7.1.1 Peak flood depths and level contours

Peak flood depths and flood surface elevation contours for the Cooks River catchment are presented in Volume 2 of this report on:

- » *Map 6 – 5 year peak depth* (5y.D)
- » *Map 7 – 10 year peak depth* (10y.D)
- » *Map 8 – 20 year peak depth* (20y.D)
- » *Map 9 – 50 year peak depth* (50y.D)
- » *Map 10 – 100 year peak depth* (100y.D) (also presented on Figure 9)
- » *Map 11 – 200 year peak depth* (200y.D)
- » *Map 12– PMF peak depth* (PMF.D.)

The results presented on the maps in Volume 2 indicate that flooding occurs within Henley Park 7.2.1 and along the Cooks River feeder channel. Flooding occurs downstream of Henley Park in the area at the intersection of Tangarra Street East and Stiles and Lennartz Streets, discussed in Section 7.2.2, including the Burwood Council Works Depot. This flooding is primarily within the road reserve for events up to the 10 year event, with properties inundated during the 20, 50, 100, 200 events.

Flooding upstream of Henley Park is primarily limited to the road reserves for the 5, 10 and 20 year events, with property flooding occurring during the 50, 100 and 200 year events between Ann Street and Henley Park, as well as upstream of Shelley Street.

Flooding within the sub-catchments that drain directly to the Cooks River occurs within properties but is mostly limited to the road reserve for 5, 10, 20 50 and year 100 year events, with the exception of flooding of properties at the intersection of Yandarlo and Trelawney Streets for the 5 year and less frequent events, discussed in 7.2.5.

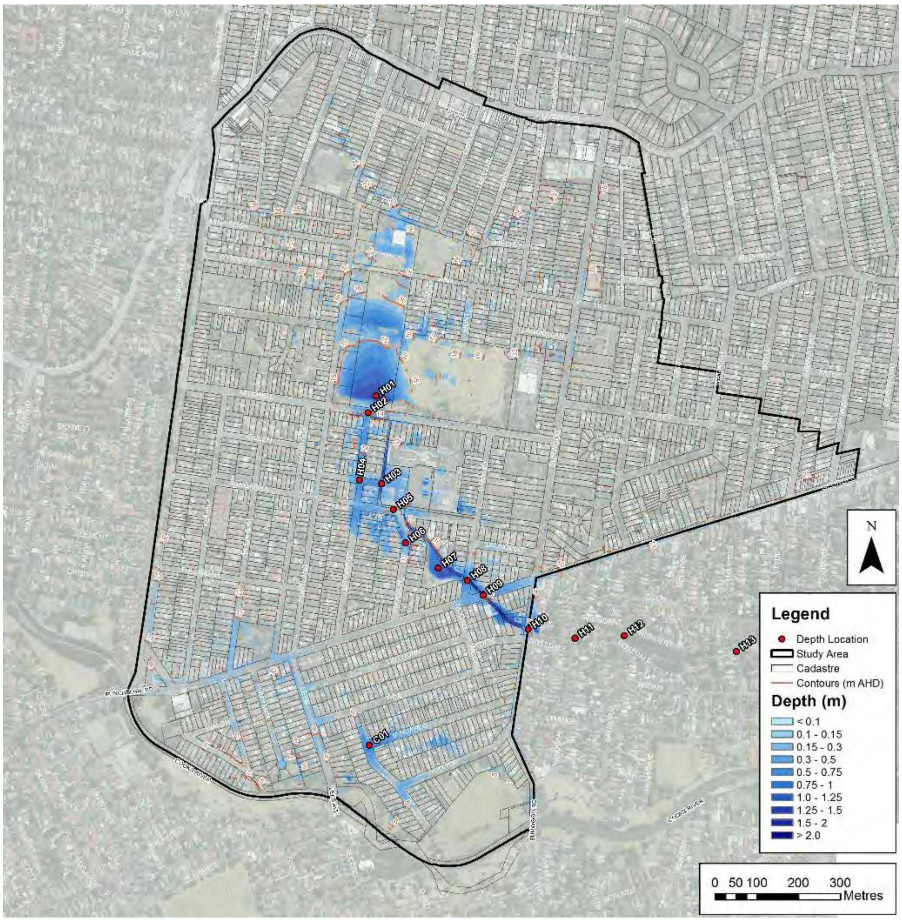
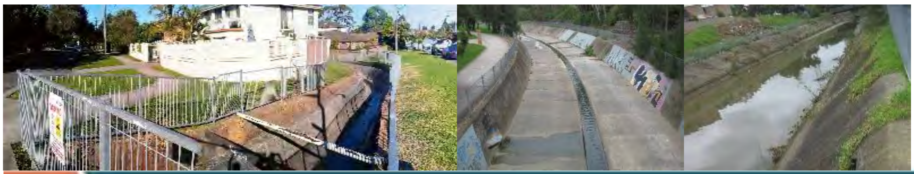


Figure 9 – Peak flood depths for the 100 year storm (refer to *Map 10 – 100 year peak depth* (100y.D) in Volume 2)



A tabulated summary of peak flood depth and level results at key locations for 5 year to 200 year and PMP design storms are provided in Table 4.

Table 4 – Peak flood levels (m AHD) and depths (m) at key locations

Station	Location	Type	5y ARI	10y ARI	20y ARI	50y ARI	100y ARI	200y ARI	PMF
H01	Henley Park detention basin	Level (m AHD)	14.72	14.77	14.82	14.86	14.90	14.94	15.32
		Depth (m)	1.36	1.41	1.46	1.50	1.54	1.57	1.96
H02	Mitchell St	Level (m AHD)	13.80	13.82	13.85	13.87	13.89	13.92	14.18
		Depth (m)	0.10	0.12	0.15	0.17	0.19	0.22	0.55
H03	Kingsbury St - channel	Level (m AHD)	12.08	12.20	12.34	12.42	12.48	12.54	13.08
		Depth (m)	0.15	0.28	0.41	0.49	0.56	0.61	3.26
H04	Kingsbury St - Stiles St	Level (m AHD)	12.37	12.42	12.47	12.51	12.56	12.61	13.23
		Depth (m)	0.23	0.27	0.32	0.37	0.42	0.46	1.14
H05	Tangarra St East	Level (m AHD)	11.89	11.90	11.93	11.96	11.99	12.02	12.36
		Depth (m)	0.04	0.05	0.07	0.11	0.13	0.17	0.49
H06	Rawson St	Level (m AHD)	11.00	11.03	11.07	11.10	11.13	11.17	11.78
		Depth (m)	0.19	0.22	0.25	0.29	0.32	0.35	0.99
H07	Park U/S Stanley St	Level (m AHD)	9.32	9.50	9.64	9.75	9.85	9.94	10.77
		Depth (m)	0.64	0.82	0.96	1.07	1.17	1.26	2.08
H08	Stanley St	Level (m AHD)	9.17	9.37	9.48	9.58	9.65	9.71	10.49
		Depth (m)	0.29	0.49	0.60	0.69	0.77	0.83	1.69
H09	Georges River Road	Level (m AHD)	9.22	9.30	9.38	9.44	9.49	9.53	10.12
		Depth (m)	0.09	0.17	0.25	0.31	0.36	0.40	1.02
H10	Burwood Road	Level (m AHD)	8.19	8.29	8.37	8.41	8.43	8.44	8.75
		Depth (m)	0.01	0.11	0.18	0.23	0.25	0.26	0.60

The results in Table 4 indicate that maximum overland flow depths occur in the detention basin within Henley Park and the small park upstream of Stanley Street. These peak results are for the range of storm durations, with events of different durations causing peak flow depths at locations throughout the catchment.

Stage hydrographs, showing modelled flood surface elevation during design storm events for selected locations in Table 4 are provided in Appendix D.

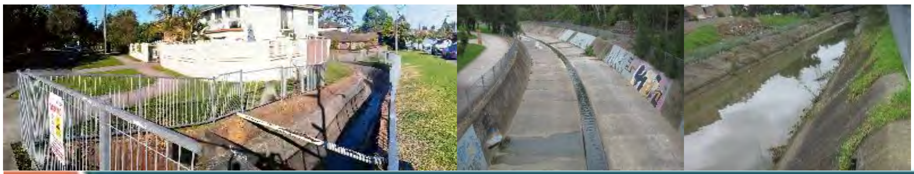
7.1.2 Peak flow rates

Peak flow rates generated in the *TUFLOW* modelling have been reported from locations throughout the catchment for the peak 5, 10, 20, 50, 100 and 200 year events, along with the PMF and are provided in Table 5. The location of the *TUFLOW* stations is presented in Volume 2 on *Map 4 – Stations and Hotspot Locations*.

Table 5 – Peak flows (m^3/s) at key locations

Location	*TUFLOW* Station Id	5y ARI	10y ARI	20y ARI	50y ARI	100y ARI	200y ARI	PMF
Shelley St (into park)	117 & 74	6.1	7.4	8.9	9.1	10.4	11.8	43.6
Henley Park basin inflow (U/S) From north-east	56 & 116	16.4	19.5	24.2	26.8	30.5	34.4	120.6
Henley Park basin inflow from west (Portland St)	115	1.7	1.9	2.3	2.8	3.4	3.9	17.3
Henley Park basin combined total inflow	**-**	**18.0**	**21.4**	**26.5**	**28.1**	**33.9**	**38.3**	**137.9**
Henley Park basin outflow (D/S) (Us Mitchell St)	55	13.2	17.5	23.0	28.1	33.3	38.2	129.5
D/S Mitchell St	18	4.4	6.6	7.0	8.2	9.5	10.4	16.6
Stiles St (Inflow)	1	8.2	10.8	13.8	16.8	20.0	22.3	32.5
Kingsbury channel O/L flow	119	5.6	6.7	7.6	8.3	8.7	9.2	18.5
Stiles St (Cnr Kingsbury) (outflow)	3	3.5	5.5	8.2	10.9	13.6	16.3	53.2
Tangarra St East culvert	120	10.4	12.6	15.0	17.1	19.2	21.3	52.9
Rawson St	122	3.2	4.9	8.1	12.1	15.3	18.4	94.9
D/S Stanley St culvert	30	14.4	16.6	20.5	24.3	28.0	31.9	79.6
D/S Georges River Rd culvert	32	13.7	15.4	18.4	21.2	24.1	27.1	146.6
D/S Burwood Rd culvert	35	14.2	17.8	23.0	28.2	33.2	38.6	155.4

The results in Table 5 indicate that the basin in Henley Park does not appear to reduce peak flow rates for events of greater magnitude than the 50 year event. These peak results are for the range of storm durations, with events of different durations causing peak flow rates at locations throughout the catchment.



7.1.3 Peak flood velocities

Peak flood velocities categorised into bands for the Cooks River catchment are presented in Volume 2 of this report on:

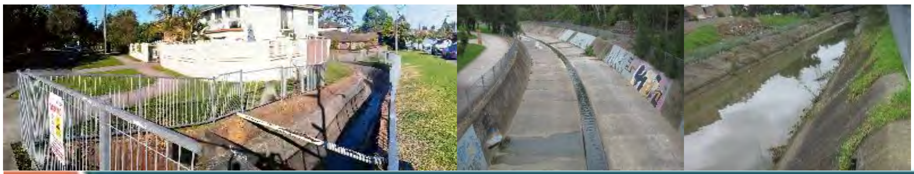
- *Map 13 – 5 year peak velocity* (5y.V)
- *Map 14 – 10 year peak velocity* (10y.V)
- *Map 15 – 20 year peak velocity* (20y.V)
- *Map 16 – 50 year peak velocity* (50y.V)
- *Map 17 – 100 year peak velocity* (100y.V)
- *Map 18 – 200 year peak velocity* (200y.V)
- *Map 19 – PMF peak velocity* (PMF.V).

The results presented on the maps in Volume 2 indicate that highest flow velocities occurs within the Cooks River feeder channel and along Shelley Street and Stiles Street. The tabulated summary of peak velocities within the open channel and overtopping structures for 5 year to 200 year and PMP design storms is presented in Table 6.

Table 6 – Peak velocities (m/s) in open channel

Location	Type	5y ARI	10y ARI	20y ARI	50y ARI	100y ARI	200y ARI	PMF
D/S Mitchell St	Open Channel	2.0	2.2	2.2	2.4	2.6	2.8	2.9
U/S Tangarra St East	Open Channel	1.8	1.9	1.9	1.9	1.9	1.9	2.4
Tangarra St East	Culvert	5.2	5.7	5.9	6.0	6.1	6.2	6.3
D/S Tangarra St East	Open Channel	2.7	2.9	3.1	3.2	3.3	3.5	3.8
U/S Stanley St	Open Channel	1.6	1.6	1.6	1.5	1.5	1.5	6.5
Stanley St	Culvert	3.6	3.6	3.6	3.6	3.5	3.5	6.3
U/S Georges River Rd	Open Channel	1.7	1.7	1.7	1.9	2.0	2.1	2.7
Georges River Rd	Culvert	4.1	4.2	5.5	5.6	5.7	5.9	6.5
D/S Georges River Rd	Open Channel	1.6	1.6	1.7	1.7	1.9	2.1	3.1
U/S Burwood Rd	Open Channel	1.6	1.7	1.9	2.2	2.5	2.8	4.2
Burwood Rd	Culvert	4.1	4.2	5.4	5.5	5.6	5.7	6.8
D/S Burwood Rd	Open Channel	2.2	2.2	2.3	2.4	2.5	2.6	4.4

The results in Table 6 and in Volume 2 on *Maps 13–19* indicate that the highest flow velocities occur within the culverts under roads. These velocities are relatively high, up to approximately 6.0 metres per second. These peak results are for the range of storm durations, with events of different durations causing peak flow velocities at locations throughout the catchment.



7.1.4 Provisional Flood Hazard Categorisation

Hazard categories were determined in accordance with Appendix L of the *NSW Floodplain Development Manual*, the graphical representation of this categorisation methodology is shown in Figure 10. For the purposes of this report, the transition zone shown in yellow on Figure 10 has been classified as high hazard.

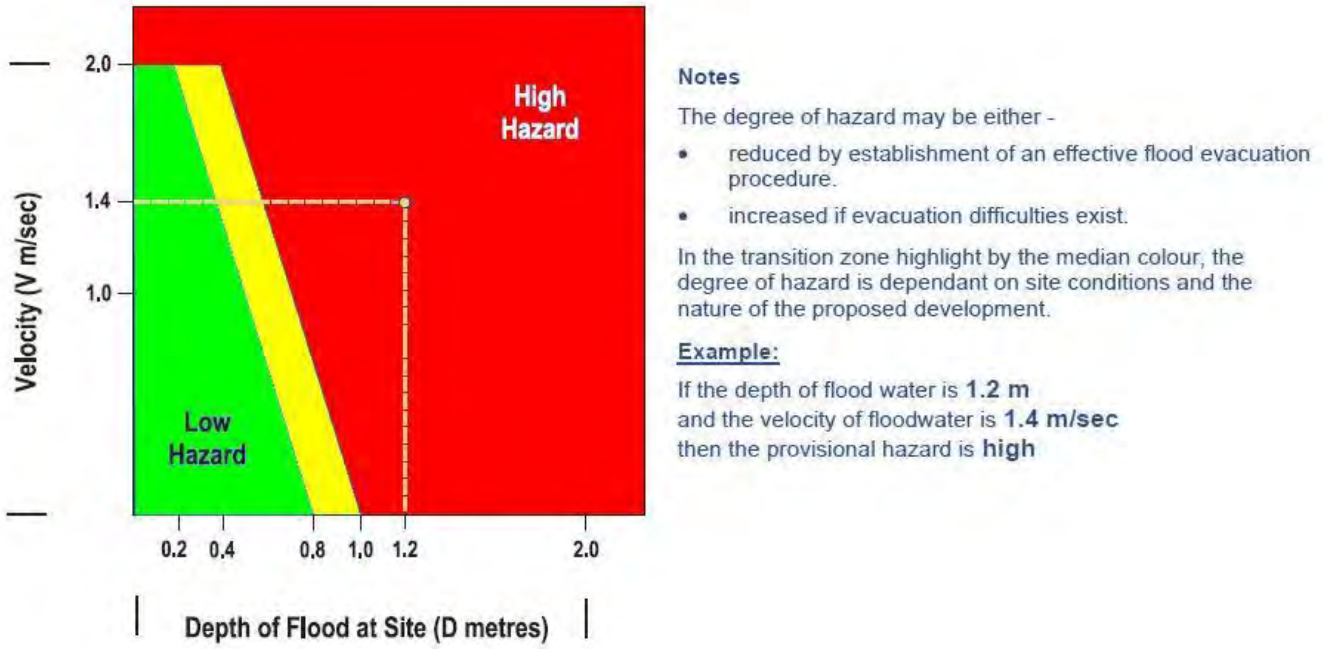


Figure 10 – Provisional Hydraulic Hazard Categories (Figure L2 from *NSW Floodplain development manual* (2005))

Maps of provisional flood hazard categorisation in the Cooks River catchment are presented in Volume 2 of this report on:

- *Map 20 – 5 year Provisional Flood Hazard Categorisation* (5y.PHFC)
- *Map 21 – 10 year Provisional Flood Hazard Categorisation* (10y.PHFC)
- *Map 22 – 20 peak Provisional Flood Hazard Categorisation* (20y.PHFC)
- *Map 23 – 50 year Provisional Flood Hazard Categorisation* (50y.PHFC)
- *Map 24 – 100 year Provisional Flood Hazard Categorisation* (100y.PHFC)
- *Map 25 – 200 year Provisional Flood Hazard Categorisation* (200y.PHFC)
- *Map 26 – PMF Provisional Flood Hazard Categorisation* (PMF.PHFC).

The results presented on the maps in Volume 2 indicate that areas provisionally categorised as High Hazard occurs within the Cooks River feeder channel and along Shelley Street and Stiles Street, increasing in extent for events from the 5 year to the 200 year.

7.1.5 Provisional Hydraulic Categorisation

Provisional hydraulic categories of flooding, namely floodway, flood storage and flood fringe, are described in the *Floodplain Development Manual* (NSW State Government, 2005). The manual does not provide a technical definition of hydraulic categorisation that would be suitable for all catchments, with different approaches are used by different consultants and authorities, based on the specific features of the study catchment in question.

For this study, flood categories were defined by the following criteria, which correspond in part with the criteria proposed by Howells *et. al*. (2003):

Floodway is defined as areas where:

- the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s AND peak velocity > 0.25 m/s, or
- peak velocity > 1.0 m/s and peak depth > 0.15 metres
- The remainder of the floodplain is either Flood Storage or Flood Fringe

Flood Storage comprises areas outside the floodway where peak depth > 0.5 metres

Flood Fringe comprises areas outside the Floodway where peak depth < 0.5 metres.

Maps of provisional flood categorisation in the Cooks River catchment are presented in Volume 2 of this report on:

- *Map 27 – 5 year Provisional Hydraulic Categorisation* (5y.FC)
- *Map 28 – 10 year Provisional Hydraulic Categorisation* (10y.FC)
- *Map 29 – 20 peak Provisional Hydraulic Categorisation* (20y.FC)
- *Map 30 – 50 year Provisional Hydraulic Categorisation* (50y.FC)
- *Map 31 – 100 year Provisional Hydraulic Categorisation* (100y.FC)
- *Map 32 – 200 year Provisional Hydraulic Categorisation* (200y.FC)
- *Map 33 – PMF Provisional Hydraulic Categorisation* (PMF.FC).

The results presented on the maps in Volume 2 indicate that areas provisionally categorised as floodway occurs within the Cooks River feeder channel and along Shelley Street and Stiles Street, increasing in extent for events from the 5 year to the 200 year. The main areas of flood storage is Henley Park within the Cooks River feeder channel catchment, as well as the intersection of Yandarlo and Trelawney Streets in the sub-catchments that drain directly to Cooks River.

7.1.6 Burwood Council's Preference on Provisional Hydraulic Categorisation

Councils are increasingly moving away from the practice of defining Floodway, Flood Storage and Flood Fringe, as the mapping of Flood Fringe may allow landowners to bypass a Council Development Application and instead apply to a private certifier, under the 2008 Exempt and Complying SEPP. In order to avoid this, a 'Low Risk' and 'High Risk' classification was adopted where:

- **High Risk** corresponds with areas classified as Floodway and Flood Storage
- **Low Risk** corresponds with areas classified as Flood Fringe.

This method of hydraulic categorisation is Burwood Council's preferred method. Maps of provisional hydraulic categorisation in the Cooks River catchment are presented in Volume 2 of this report on:

- *Map 34 – 5 year Provisional BC Hydraulic Categorisation* (5y.BCHC)
- *Map 35 – 10 year Provisional Hydraulic Categorisation* (10y. PHC)
- *Map 36 – 20 peak Provisional Hydraulic Categorisation* (20y. PHC)
- *Map 37 – 50 year Provisional Hydraulic Categorisation* (50y. PHC)
- *Map 38 – 100 year Provisional Hydraulic Categorisation* (100y. PHC)
- *Map 39 – 200 year Provisional Hydraulic Categorisation* (200y. PHC)
- *Map 40 – PMF Provisional Hydraulic Categorisation* (PMF. PHC).

The results presented on the maps in Volume 2 indicate that areas provisionally categorised as High Risk occurs within the Cooks River feeder channel and along Shelley Street and Stiles Street, increasing in extent for events from the 5 year to the 200 year. The main areas of high risk are Henley Park within the Cooks River feeder channel catchment, as well as the intersection of Yandarlo and Trelawney Streets in the sub-catchments that drain directly to Cooks River.

7.1.7 Preliminary flood emergency response classification of communities

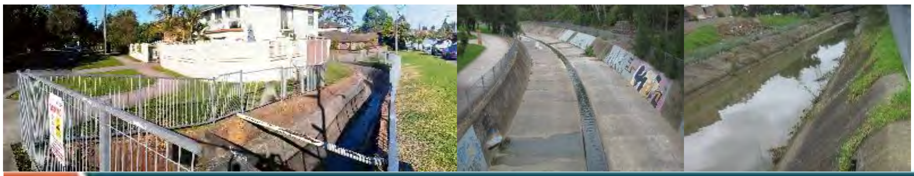
The *NSW Floodplain Development Manual* requires flood studies address the management of continuing flood risk to both existing and future development areas. As continuing flood risk varies across the floodplain so does the type and scale of emergency response problem and therefore the information necessary for effective Emergency Response Planning (ERP).

Classification provides an indication of the vulnerability of the community in flood emergency response and identifies the type and scale of information needed by the State Emergency Services (SES) to assist in emergency response planning (ERP).

Criteria for determining flood response plan classifications and an indication of the emergency response required for these classifications are provided in the *Floodplain Risk Management Guideline, 2007 (Flood Emergency Response Planning: Classification of Communities).* This guideline summarises the response required for areas of different classification. These may vary depending on local flood characteristics and resultant flood behaviour, i.e. in flash flooding or overland flood areas.

The criteria for classification of floodplain communities are generally more applicable to riverine flooding where significant flood warning time is available and emergency response action can be taken prior to the flood. In urban areas like the Cooks River catchment, flash flooding from local catchment and overland flow will generally occur as a direct response to intense rainfall without significant warning. For most (if not all) flood affected properties in the catchment, remaining inside the building is likely to present less risk to life than attempting to drive or wade through floodwaters, as flow velocities and depths are likely to be greater in the roadway.

The guideline recommends ERP Classification be undertaken for the 100 year event, along with the PMF. These are presented in Volume 2, on *Map 41* (100y.FERP) and *Map 42* (PMF.FERP). Areas that are likely to be isolated due to floodwater and contain properties that are likely to be inundated were classified as either Low Flood Island (LFI) or Low Trapped Perimeter (LTP) Areas. These high priority areas include properties the Cooks River feeder channel and Stiles Street. The areas classified as *Rising Road Access* are likely to be inundated but have roads rising uphill and away from the rising floodwaters. Therefore, residents should not be trapped unless they delay evacuation from their homes.



7.2 Flood Affected Locations

7.2.1 Henley Park

Henley Park is notable as the only park within Burwood LGA designed to function as a stormwater detention basin. The park, shown on Photograph 1, was re-constructed in the 1990s, with drainage surcharge pits and an earth embankment along the southern boundary (Mitchell Street) to function as a detention basin to manage stormwater flows.

Photograph 1 – Henley Park, looking east from Portland Street

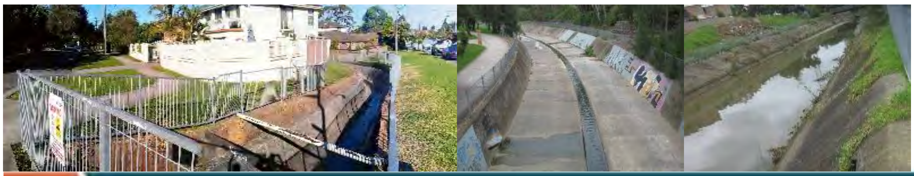
This flood affected land is zoned RE1 Public Recreation on *Burwood Council Local Environment Plan* (LEP) 2012 and is used for sporting fields. The park also contains Enfield Aquatic Centre and the Henley Park Amenities Complex, both of which are inundated during the 100 year flood event.

The stage hydrographs, presented in Appendix D, indicate that the flood depth in Henley Park is estimated to be greater than 1.5 metres in the 100 year event. The results in Table 5 indicate that the basin in Henley Park does not appear to reduce peak flow rates for events of greater magnitude than the 50 year event.

7.2.2 Tangarra Street East, Rawson Street, Lennartz/Stiles Street, Kingsbury Street

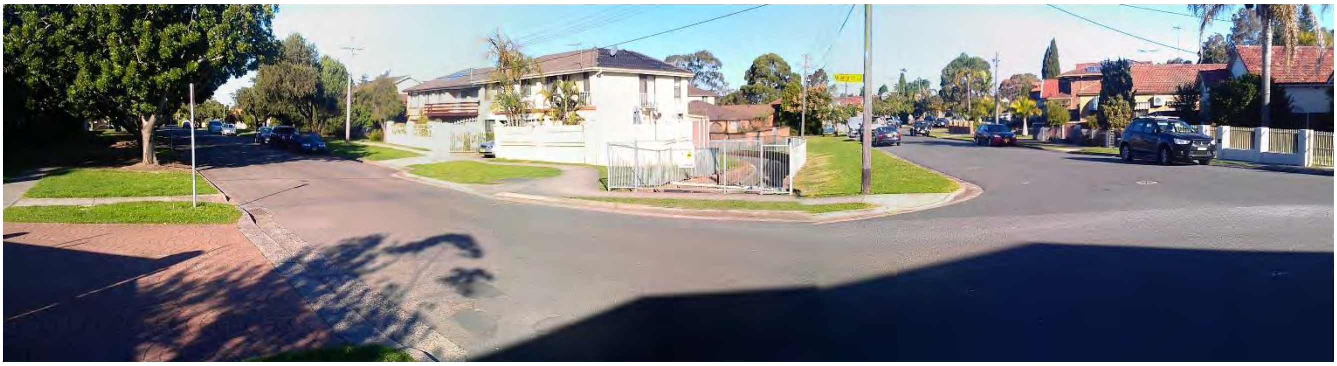
This location, downstream of Henley Park, is inundated by overland flooding and mainstream flooding. The intersection of Tangarra Street East and Lennartz/Stiles Streets (shown on Photograph 2) is a trapped low point that takes overflow from Henley Park, flowing north–south down Stiles Street through the intersection with Kingsbury Street.

Photograph 2 – Intersection of Tangarra Street East and Lennartz/Stiles Street, looking south-east



There is no overland flow route along roads from the intersection shown in Photograph 2, with flood water travelling through properties located in the block bounded by Lennartz Street, Tangarra Street East and Rawson Street.

The Cooks River feeder channel has a sharp left-hand turn facing downstream at Tangarra Street East, where it becomes a covered channel. The covered concrete channel takes two almost 90° turns within the length of approximately 70 metres before becoming an open channel at the intersection of Tangarra Street East and Rawson Street, shown looking downstream on Photograph 3. This curving channel geometry reduces the hydraulic efficiency and is a factor in flooding at this location. The channel then passes between No. 9 Tangarra Street and No. 8 Rawson Street, travelling through open land to Stanley Street, which is discussed in Section 7.2.3.



Photograph 3 – Intersection of Tangarra Street East and Rawson Street, looking south-east along Cooks River feeder channel

The Webb, McKeown & Associates report prepared in 1998 noted information from the householder at No. 8 Rawson Street that the channel alongside this property had overtopped twice in the previous thirteen years. The event on 2 January 1996, was estimated to approximately correspond to a 50 year recurrence interval rainfall event at Enfield, although this storm was less severe in surrounding areas.

The results of the modelling presented in Table 4 indicate that the peak depths at this flood location vary within the roads between 0.13 metres at Tangarra Street East and 0.42 metres at the intersection of Kingsbury Street and Stiles Street. Flooding at Rawson Street, shown on Photograph 3, is calculated at 0.35 metres in the 100 year event.

7.2.3 Stanley Street and Georges River Road

A small park, approximately 1.2 hectares, is located in the block between Stanley Street, Rawson Street, Tangarra Street East and Georges River Road. This park, shown on Photograph 4 acts as a detention basin and was the subject of the 1998 Webb McKeown investigation.

Photograph 4 – Cooks River feeder channel and park between Stanley and Rawson Streets, looking south-east

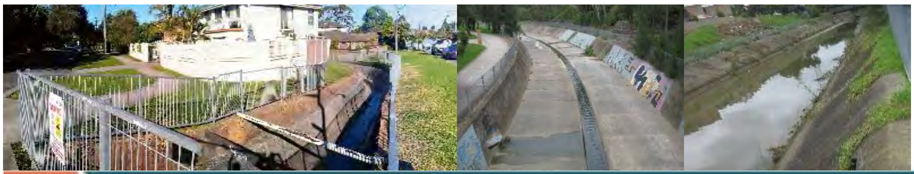
The Webb, McKeown study estimated that 45 and 47 Stanley Street would be subject to above-floor flooding in a 100 year ARI flood. Flooding at this location, presented in Table 4, is calculated at up to 1.17 metres deep in the 100 year event.

The intersection of Georges River Road and Stanley Street is shown in Photograph 5. In the flood of 2 January 1996, Stanley Street was reported to be flooded to a depth of 0.4 m.

Photograph 5 – Cooks River feeder channel and park between Stanley Street and Georges River Road, looking north-west

The Cooks River feeder channel passes under Stanley Street with a clearance of only 1.27 metres under the road slab. The capacity of the channel and its adjoining overbank area, is significantly reduced by the Stanley Street roadway, resulting in flooding occurring more frequently at this point along the channel than at any other location in Burwood LGA.

The modelling indicates that water levels in the channel will exceed the capacity of the culvert under Stanley Street for events greater than the 5 year recurrence interval, resulting in flow crossing Stanley Street, re-entering the channel and then flowing under Georges River Road.



7.2.4 Burwood Road

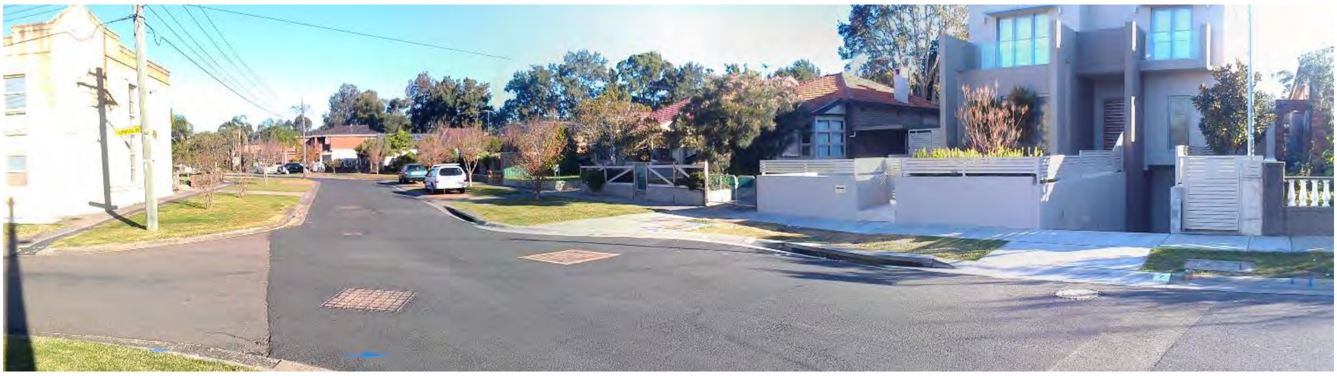
The Cooks River feeder channel is highly constricted between Georges River Road and Burwood Road, as shown in Photograph 6.

Photograph 6 – Cooks River feeder channel, viewed from Burwood Road, looking north-west

The modelling indicates that in the 100 year event, flow in this area of the channel backs up along Georges River Road, flowing north-east to the intersection with Burwood Road, flowing south and re-joining the channel at the point at which it leaves Burwood LGA. The results in Table 4 show that the flood depth at Burwood Road in the 100 year event is 0.25 metres.

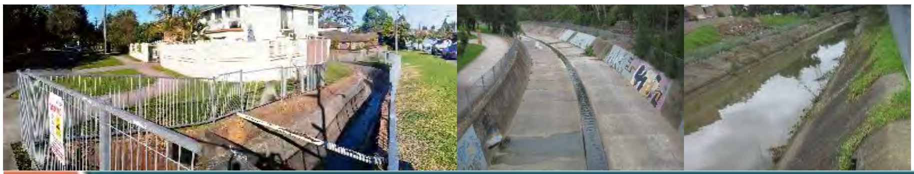
7.2.5 Intersection of Trelawney and Yandarlo Streets

Flooding occurs at the intersection of Trelawney and Yandarlo Streets, shown on Photograph 7, as a result of a trapped low point.



Photograph 7 – Intersection of Trelawney and Yandarlo Streets, looking south-west

Of particular concern at this location is the driveway entrance to a basement car park, shown on the right-hand side of Photograph 7. This basement car park entrance is at the location of the mapped hotspot and does not appear to have flooding protection. Historical aerial photographs indicate that this building has been recently constructed, between 2010 and 2011.



8. Sensitivity Analysis

8.1 Parameter Sensitivity

A sensitivity analysis of the Cooks River catchment model was run to investigate the effect of varying range of different scenarios and parameters. All sensitivity runs used the 100 year ARI 2 hour design storm which was identified as the critical storm duration of the main channel which is the reach most sensitive to parameter changes. The following was tested for sensitivity analysis:

» Downstream Boundary Condition with 100 year ARI Cooks River Flood Levels.
» Initial Loss +/-10%
» Continued Loss +/- 10%
» Pit Ku Loss Parameter +/-20%
» Manning’s ‘n’ roughness parameter +/-20%
» Blockage scenario with 20% blockage in pit inlet capacity (reduced from 50%)
» Blockage scenario with 100% blockage in pit inlet capacity and 50% blockage applied to major culverts
» Blockage scenario with 100% blockage in pit inlet capacity and 100% blockage applied to major culverts
» Climate Change +10%, +20% and +30% in rainfall intensity

These sensitivity scenarios were undertaken for the 100 year ARI 2 hour rainfall event with results provided in Appendix E, maps provided in Volume 3, with a brief summary in Sections 8.1.1 to 8.1.5. A more detailed discussion of the modelled climate change scenarios in detail in Section 8.2.

8.1.1 Boundary condition sensitivity

The sensitivity analysis using flood level data from the Cooks River Flood Study (Sydney Water, 2009) showed the backwater effect of the peak 100 year flood event for the Cooks River extends into the Cooks River feeder channel, it does not influence flood levels within the Burwood Council LGA. This analysis indicates that in the event of the peak of the 100 year event for the overall Cooks River coinciding with the peak from the Cooks River feeder channel, which is feasible as both peaks occur for the 2 hour event, there would be no backwater effects within Burwood LGA.

8.1.2 Initial and continuing losses sensitivity

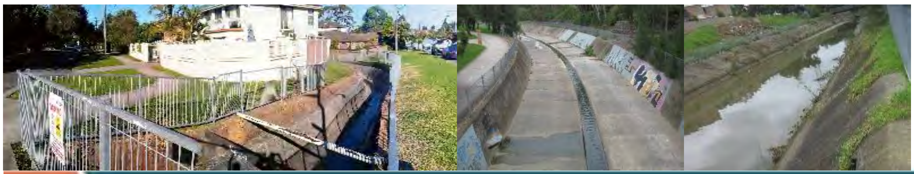
The result of sensitivity analysis shows the *TUFLOW* model is not sensitive to initial loss and continued loss parameters where the resulting difference in analysed flood surface level varied by less than 0.01 metres in the majority of the scenarios tested.

8.1.3 Pit Ku loss sensitivity

The result of sensitivity analysis shows the *TUFLOW* model is not sensitive to variations in the pit Ku loss parameter where the resulting difference in analysed flood surface level varied by less than 0.01 metres in the majority of the scenarios tested.

8.1.4 Manning’s ‘n’ roughness sensitivity

The result of sensitivity analysis shows the *TUFLOW* model is not sensitive to Manning’s ‘n’ where the resulting difference in analysed flood surface level varied by less than 0.01 metres in the majority of the scenarios tested. The results in Table E10 and Table E11 in Appendix E indicate that the largest variation in flow depth is of the order of 0.04 metres.



8.1.5 Blockage sensitivity

Flood levels adjacent to the main central channel are sensitive to blockage of culvert crossings, particularly upstream of culverts. Flood levels increase by as much as 0.2 metres for 50% blockage and 0.3 metres for 100% blockage. This is attributable to a large component of the 100 year event conveyance being contained within the channel. A blockage factor has been applied to all design runs in determining Flood Planning Levels and Flood Planning Area such that any incidence of total blockage is appropriately contained within any freeboard provision for properties which may be affected by a blockage scenario is appropriately identified in the analysed flood extents.

8.2 Climate Change Sensitivity Analysis

The effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) are having on the average earth surface temperature is a point of variable scientific opinions and is constantly under research. The extent of any permanent climatic or sea level change can only be established with certainty through scientific observations over several decades.

Current Climate Change research indicated that there is a likelihood of climate change and sea level rise as a result of increasing greenhouse gasses. In this regard, the following points can be made:

- Greenhouse gas concentrations continue to increase
- Global sea level has risen about 0.1 metres to 0.25 metres in the past century
- Many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

With the uncertainty of the probable effect of climate change with respect to flooding, it is necessary to investigate and consider the possible causes on flood levels.

8.2.1 Rainfall increase

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however this information is not of sufficient accuracy for use as yet (NSW State Government, 2007).

In light of this uncertainty, the NSW State Government (2007) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered which has been adopted in this study.

The results of the climate change scenario modelling is presented in Volume 3 on the following maps:

- *Map S.18* (CC.01) for sensitivity difference to a 10% increase in rainfall
- *Map S.19* (CC.02) for sensitivity difference to a 20% increase in rainfall
- *Map S.20* (CC.03) for sensitivity difference to a 30% increase in rainfall.

The tabulated summary of differences in flows resulting from the modelled climate change scenarios are presented in Table 7, showing changes in flood depth, and Table 8 showing changes in flow rates.

Table 7 – Results of sensitivity analysis for climate change scenarios - 100 year ARI flood depths

Location	Depth Location	100 year ARI Flood Depth	Difference in Flood Depth (m)		
			Climate Change +10% Rainfall	Climate Change +20% Rainfall	Climate Change +30% Rainfall
Detention basin	H01	1.52	0.03	0.06	0.09
Mitchell St	H02	0.17	0.03	0.06	0.11
Kingsbury St - Channel	H03	0.52	0.06	0.1	0.15
Kingsbury St - Styles St	H04	0.11	0.03	0.06	0.08
Tangarra St East	H05	0.30	0.02	0.05	0.09
Rawson St	H06	1.13	0.08	0.15	0.22
Park U/S Stanley St	H07	0.72	0.06	0.11	0.16
Stanley St	H08	0.32	0.05	0.08	0.12
Georges River Road	H09	0.24	0.02	0.03	0.04
Burwood Road [D/S limit of LGA]	H10	0.32	0.06	0.1	0.15
Windsor Ave	H11	2.83	0.1	0.18	0.26
Balmoral Ave	H12	0.33	0.13	0.23	0.35
Hampton St	H13	2.70	0.09	0.18	0.26
Small Bridge U/S Brighton Ave	H14	0.39	0.04	0.08	0.12

The results presented in Table 7 indicate that flood depths within the length of the Cooks river feeder channel located within Burwood LGA are not affected by a 10% increase in rainfall. Rainfall increases of 20 and 30% do increase flows within the channel, by up to 0.15 metres, reaching as far upstream as the location of the flooding hotspot at Kingsbury Street, discussed in Section 7.2.2.

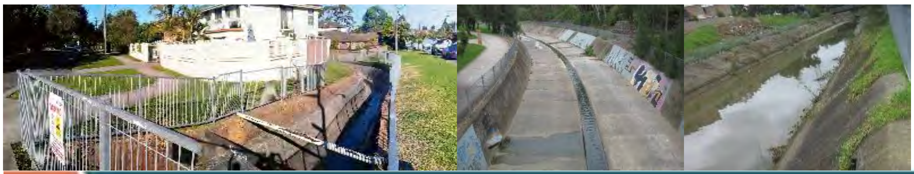


Table 8 – Results of sensitivity analysis for climate change scenarios - 100 year ARI flows

Location	ID	100 year ARI Flow	Difference in Flow (m^3/s)		
			Climate Change +10% Rainfall	Climate Change +20% Rainfall	Climate Change +30% Rainfall
Shelley St (into park)	117 & 74	9.7	1.1	2.2	3.3
Basin inflow (U/S) from north-east	56 & 116	30.3	3.3	6.7	10.2
Basin inflow from west (Portland St)	115	3.3	0.5	1.0	1.5
Basin outflow (D/S) (Mitchell St)	55	33.1	4.5	8.7	13.0
D/S Mitchell St	18	9.4	0.8	1.6	2.6
Stiles St (inflow)	1	20.0	2.8	4.4	6.5
Kingsbury channel O/L flow to channel	119	9.0	0.4	0.7	0.9
Stiles St (Cnr Kingsbury) (outflow)	3	13.3	2.4	4.8	7.3
Tangarra St East culvert	120	21.0	1.9	3.7	5.7
Rawson St	122	14.0	2.7	5.5	8.6
Stanley St	30	28.9	3.3	6.5	9.7
Georges River Rd	33	23.0	4.2	8.2	12.0
Burwood Rd	35	30.4	5.3	10.8	16.4
Windsor Ave	37	38.7	6.0	11.4	17.2
Balmoral Ave	40	39.9	5.9	12.2	18.5
Hampton St	43	44.4	7.1	10.5	16.6

The areas most affected by climate change are immediately adjacent to the Cooks River feeder channel. The difference analysis shows an overall incremental increase of up to approximately 0.1 metres, 0.2 metres and 0.2 metres for the +10%, +20% and +30% rainfall intensities respectively with localised increases of up to 0.3 metres for the +30% rainfall intensities.

8.2.2 Sea level rise

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009. This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (NSW State Government, 2009) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010*.

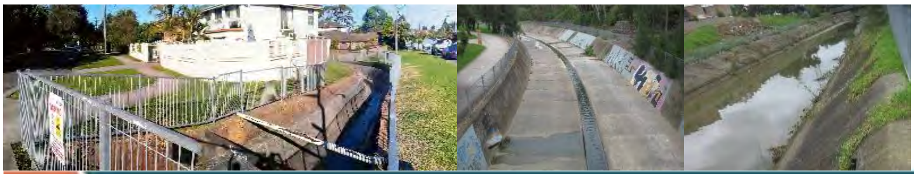
The Policy Statement says:

> *'Over the period 1870-2001, global sea levels rose by 20 centimetres, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… However, the 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible'* (NSW State Government, 2009)

In light of this uncertainty, the NSW State Government's advice is subject to periodical review. As of 2012 and after the commencement of this flood study, the NSW State Government withdrew endorsement of sea level rise predictions but still require sea level rise to be considered. At the commencement of this flood study the benchmarks required Council to plan for projected sea level rise of 0.4 metres by 2050 and 0.9 metres by 2100 (NSW State Government, 2010), relative to 1990 levels.

This study includes only the drainage network draining to the Cooks River. Through the course of the study, the invert level of the main channel of the Cooks River feeder channel was surveyed at approximately 5 metres AHD at the Burwood Council LGA boundary (the downstream limit of the mapping) which is well above the height of influence from projected sea level rise. Consideration of the effects of sea level rise in the mainstream flooding of the Cooks River was outside the scope of this study. As such, additional sensitivity runs for sea level rise for local overland flood analysis was not warranted.

The sensitivity analysis using flood level data from the Cooks River Flood Study (Sydney Water, 2009) is discussed in Appendix E and shown in Volume 3 on *Maps S.6* to *S.8*. The results of the analysis indicated that the backwater effect of the Cooks River extends into the Cooks River feeder channel downstream of the study area and does not influence flood levels within the Burwood Council LGA.



9. Preliminary Flood Planning Areas – Property Tagging

Land use planning is considered to be one of the most effective means of minimising flood risk and damages from flooding. In NSW, flood risk is managed strategically as part of development control by:

- Selection of a flood risk level to be used for planning, usually the 100 year flood event
- Modelling of the selected flood event to determine the flood level
- Determination of the Flood Planning Level (FPL), which is the flood level of the selected flood event plus an appropriate freeboard, or safety factor, usually 0.5 metres
- Mapping of the Flood Planning Area (FPA), which is the land below the Flood Planning Level (FPL)

In the planning context, the Flood Planning Area is land that is subject to flood related development controls and the Flood Planning Level is the minimum floor level applied to new developments within the Flood Planning Area.

The process of defining FPAs and FPLs is somewhat complicated by the variability of flow conditions between mainstream and local overland flow, particularly in urban areas. The more traditional approaches typically having been developed for riverine environments and mainstream flow.

Defining the area of flood affectation due to overland flow (which by its nature includes shallow flow) often involves determining at which point it becomes significant enough to classify as ‘flooding’. The difference in peak flood level between events of varying magnitude may be minor in areas of overland flow, such that applying the typical freeboard can result in a FPL greater than the Probable Maximum Flood (PMF) level.

The FPA should include properties where future development would result in impacts on flood behaviour in the surrounding area and areas of high hazard that pose a risk to safety or life. Further to this, the FPL is determined with the purpose to decrease the likelihood of over-floor flooding of buildings and the associated damages.

The *Floodplain Development Manual* suggests that the FPL generally be based on the 100 year event plus an appropriate freeboard. The typical freeboard cited in the manual is that of 0.5 metres; however it also recognises that different freeboards may be deemed more appropriate due to local conditions. In these circumstances, some justification is called for where a lower value is adopted.

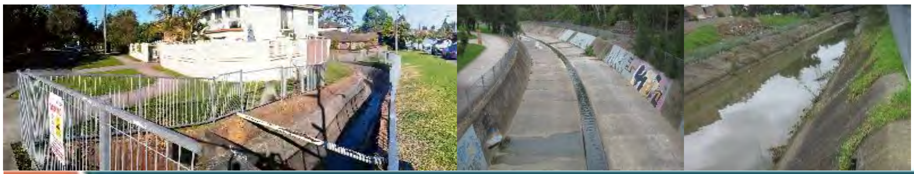
Further consideration of flood planning areas and levels are typically undertaken as part of the Floodplain Risk Management Study where council decides which approach to adopt for inclusion in the Floodplain Management Plan.

9.1 Methodology and Criteria

The methodology used in this report is consistent with that adopted in a number of previous studies in the Burwood LGA including the Dobroyd Canal Flood Study (WMA, 2013). It divides flooding between main stream flooding and overland flooding using the following criteria:

- Mainstream flooding: Any percentage of the cadastral area is affected by mainstream flooding in the 100 year event. This has been defined as the peak flood level within the open channel section of Cooks River feeder channel plus a 0.5 metre freeboard, with the level extended perpendicular to the flow direction.
- Overland flooding: Greater than or equal to 10% of the ‘active’ cadastral area is affected by the 100 year peak flood depth of greater than 0.15 metres. The ‘active’ cadastral area was considered to be the cadastral area excluding the building area that was modelled as impermeable.

In situations where a cadastral lot is subject to both mainstream flooding and overland flooding, the mechanism that produces the highest Flood Planning Level is given precedence, although both levels have been provided.



9.2 Flood Planning Area Mapping

Property tagging maps are presented in Volume 2 on the following maps:

- *Map 43* (OF.TAG) for overland flooding for the 100 year peak event
- *Map 44* (MF.TAG) for mainstream flooding from the Cooks River feeder channel for the 100 year peak event plus 0.5 metres freeboard
- *Map 45* (CR.TAG) for flooding for the Cooks River 100 year peak flood plus 0.5 metres freeboard
- *Map 46* (LOT.TAG) for the amalgamated property tagging map.

The property tagging maps presented in Volume 2 show that a large number of properties within the catchment lie within the Flood Planning Area and will require development controls to manage the risk posed by flooding.

The number of tagged residential and commercial properties within the Cooks River catchment within Burwood LGA are:

- Overland flooding – 265 lots (total)
- Mainstream flooding – 170 lots (total)
  - Mainstream and overland flooding – 113 lots
  - Mainstream only – 57 lots.
- Cooks River flooding – 38 lots (total)
  - Cooks River and overland flooding – 14 lots
  - Cooks River only – 24 lots.
- Total tagged lots – 346 lots

Including parks and other non-residential and commercial lots, a total of 370 lots are tagged as flood affected.

9.2.1 Overland flooding

The total of 256 lots tagged as affected by overland flooding are shown on *Map 43* in Volume 2. These tagged lots are located in the flooding hotspots discussed in Section 7.2 and other areas, with properties experiencing greater depths of inundation generally having higher percentage of area flooded.

9.2.2 Mainstream flooding

A total of 170 lots are identified on *Map 44* in Volume 2 as being affected by mainstream flooding from the Cooks River feeder channel. Of these 170 lots, 57 lots are only impacted by inundation from flows in the feeder channel, also referred to as fluvial flow, not from overland flows from upstream catchment, also referred to as pluvial flow or runoff. All of these lots tagged as affected by mainstream flooding are located between Henley Park and the Burwood–Canterbury LGA boundary at Burwood Road.

9.2.3 Cooks River flooding

Flooding from the Cooks River (fluvial flooding) inundates a total of 38 lots, including parks, shown on *Map 45*. From this total, 24 lots are inundated from the Cooks River only and not from overland flows from upstream catchment. The majority of these lots impacted by flooding in Cooks River have property boundaries on the river or adjacent reserves, with 6 lots on Walsh Avenue, 1 lot on Fountain Avenue and 8 lots on Lees Avenue not bordering the river or an adjacent reserve.

9.2.4 Total tagged properties

The amalgamated property tagging map, *Map 46* in Volume 2, shows the total number of 346 properties with the study area that are subject to planning controls as a result of flooding.

The *NSW Floodplain Development Manual* recommends that councils should only provide information on flood development controls where these controls are imposed by council policies in accordance with the requirements of the *Local Government Act 1993*. This information is provided in a *Section 149(2) Certificate* and contains a list of matters planning matters, including flooding, as prescribed under Schedule 4 of the *Environmental Planning and Assessment Regulation 2000.*

Additional information on flooding can be provided by councils under Section 149(5) of the Act. This information can be from flood studies or historical flood events and is at the discretion of council to provide. The *NSW Floodplain Development Manual* states that 'to become fully aware of flood risk prospective purchasers need to rely upon the use of information provided on planning certificates under both Sections 149(2) and 149(5) of the Act, using either planning certificates or other appropriate means'.

Details of the flood behaviour and flood planning requirements will form the basis of the information provided by Council on the Section 149(2) and (5) Certificates. This information will be provided to properties tagged on *Maps 43–46* by Council in the form of prescribed flood planning levels.

9.3 Additional Data Requirements for Property Tagging

In order to more accurately assess the potential impacts of flooding at the properties tagged on *Maps 43–46*, additional information will be required by Council. This information includes additional survey of property features, in particular building locations and flood elevations. This additional information, or 'ground truthing' will be used to refine the modelling, and findings of this flood study, and may result in properties no longer being tagged and subjected to flood planning controls. This additional information will be required at the Floodplain Risk Management Study stage of the project, outlined in Section 2.2.

10. Conclusion and Recommendations

10.1 Summary of Study Outcomes and Conclusion

The Cooks River Overland Flood Study has described flood behaviour in the study area resulting from existing conditions. The study involved the development of a two-dimensional flood model for catchment of the Cooks River feeder channel, also referred to as the Henley Park Channel.

The study provides advice and mapping to Burwood Council to assist with decision making for controlling and assessing development potential. The study has:

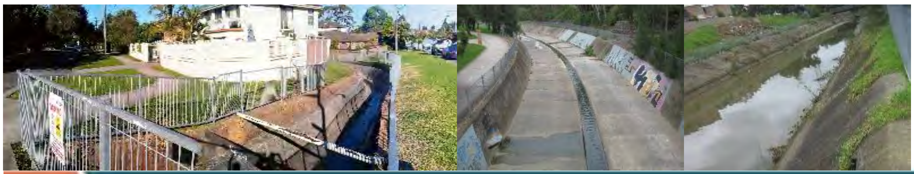
- Involved the preparation and hand-over to Burwood Council of suitable models of the catchment and floodplain to define flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area
- Presented maps of flood levels, depths, velocities, flows and flood extents within the study area
- Presented maps of provisional hydraulic categories and provisional hazard categories
- Determine provisional residential flood planning levels and flood planning area
- Prepared preliminary emergency response classifications for communities
- Assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.
- Provide flood advice for use in a subsequent Floodplain Risk Management Study.

The property tagging maps presented in Volume 2 show that a large number of properties within the catchment lie within the Flood Planning Area and will require development controls to manage the risk posed by flooding.

10.2 Recommendations of this Study

Effective management of flood risk can only be successful if a broad and integrated range of flood management measures are planned and implemented. Flood management measures need to address existing and future flood risks, as well as manage any residual or continuing risk once these measures have been implemented. Flood risk management measures need to address risks to life, property and safety.

The Floodplain Risk Management Study and Plan for the Cooks River catchment within Burwood Council LGA will involve a more detailed identification of areas that require further investigation and of potential options for management of flood risk.



11. Acknowledgements

Brown Consulting acknowledge the assistance of Burwood Council staff in carrying out this study, as well as the NSW Government (Office of Environment and Heritage) and the residents of the Cooks River Tributary Catchment who have participated in the community consultation process.

This study was jointly funded by Burwood Council and the NSW Office of Environment and Heritage.

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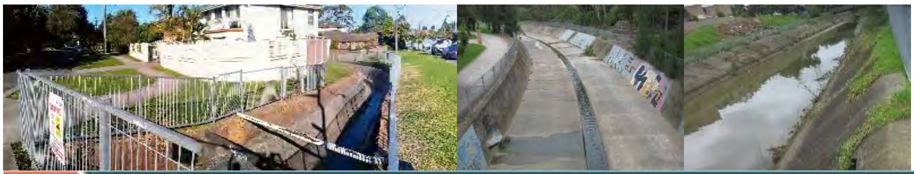
13. Glossary of Terms

Afflux	The rise in water level upstream of a hydraulic structure such as a bridge or culvert, caused by losses incurred from the hydraulic structure.
Australian Height Datum	National survey datum corresponding approximately to mean sea level.
Annual Exceedance Probability	The chance of a flood of a given size or larger occurring in any one year, generally expressed as percentage probability. For example, a 100 year ARI flood is a 1% AEP flood. An important implication is that when a 1% AEP flood occurs, there is still a 1% probability that it could occur the following year.
Average Recurrence Interval	Is the long term average number of years between the occurrence of a flood as big as, or larger than the selected flood event.
Catchment	The catchment at a particular point is the area of land which drains to that point.
Design floor level	The minimum (lowest) floor level specified for a building.
Design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year or 1% probability flood). The design flood may comprise two or more single source dominated floods.
Development	Existing or proposed works which may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
Discharge	The rate of flow of water measured in terms of volume over time. It is not the velocity of flow which is a measure of how fast the water is moving rather than how much is moving. Discharge and flow are interchangeable.
Digital Terrain Model	A three-dimensional model of the ground surface that can be represented as a series of grids with each cell representing an elevation (DEM) or a series of interconnected triangles with elevations (TIN).
Effective warning time	The available time that a community has from receiving a flood warning to when the flood reaches their location.
Flood	Above average river or creek flows which overtop banks and inundate floodplains.
Flood awareness	An appreciation of the likely threats and consequences of flooding and an understanding of any flood warning and evacuation procedures. Communities with a high degree of flood awareness respond to flood warnings promptly and efficiently, greatly reducing the potential for damage and loss of life and limb. Communities with a low degree of flood awareness may not fully appreciate the importance of flood warnings and flood preparedness and consequently suffer greater personal and economic losses.
Flood behaviour	The pattern / characteristics / nature of a flood.
Flooding	The State Emergency Service uses the following definitions in flood warnings: » *Minor flooding:* causes inconvenience such as closing of minor roads and the submergence of low level bridges » *Moderate flooding:* low-lying areas inundated requiring removal of stock and/or evacuation of some houses. Main traffic bridges may be covered.

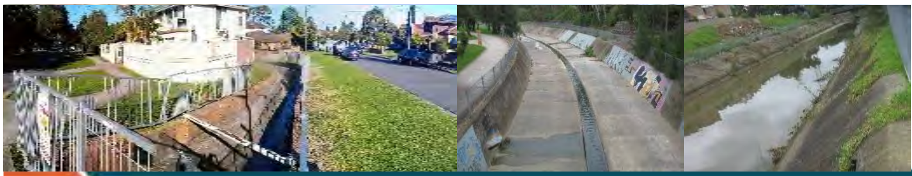
	» *Major flooding:* extensive rural areas are flooded with properties, villages and towns isolated and/or appreciable urban areas are flooded.
Flood frequency analysis	An analysis of historical flood records to determine estimates of design flood flows.
Flood fringe	Land which may be affected by flooding but is not designated as a floodway or flood storage.
Flood hazard	The potential threat to property or persons due to flooding.
Flood level	The height or elevation of flood waters relative to a datum (typically the Australian Height Datum). Also referred to as 'stage'.
Flood liable land	Land inundated up to the probable maximum flood – flood prone land.
Floodplain	Land adjacent to a river or creek which is inundated by floods up to the probable maximum flood that is designated as flood prone land.
Flood Planning Levels	Are the combinations of flood levels and freeboards selected for planning purposes to account for uncertainty in the estimate of the flood level.
Flood proofing	Measures taken to improve or modify the design, construction and alteration of buildings to minimise or eliminate flood damages and threats to life and limb.
Floodplain Management	The coordinated management of activities which occur on flood liable land.
Floodplain Management Manual	A document by the NSW Government (2001) that provides a guideline for the management of flood liable land. This document describes the process of a floodplain risk management study.
Flood source	The source of the flood waters.
Floodplain Management	A set of conditions and policies which define the benchmark from
Standard	which floodplain management options are compared and assessed.
Flood standard	The flood selected for planning and floodplain management activities. The flood may be an historical or design flood. It should be based on an understanding of the flood behaviour and the associated flood hazard. It should also take into account social, economic and ecological considerations.
Flood storages	Floodplain areas which are important for the temporary storage of flood waters during a flood.
Floodways	Those areas of the floodplain where a significant discharge of flow occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if they are partially blocked, would cause significant redistribution of flood flows, or a significant increase in flood levels.
Freeboard	A factor of safety usually expressed as a height above the flood standard. Freeboard tends to compensate for the factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
Geographical Information System	A form of computer software developed for mapping applications and data storage. Useful for generating terrain models and processing data for input into flood estimation models.



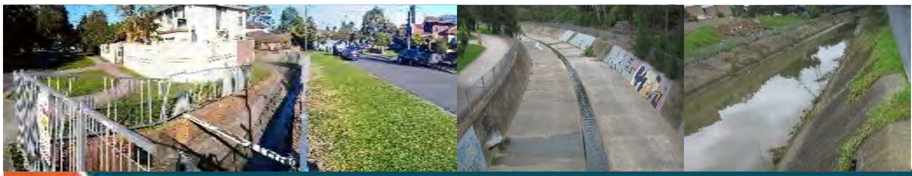
High hazard	Danger to life and limb; evacuation difficult; potential for structural damage, high social disruption and economic losses. High hazard areas are those areas subject to a combination of flood depth and flow velocity that are deemed to cause the above issues to persons or property.
Historical flood	A flood which has actually occurred – Flood of Record.
Hydraulic	The term given to the study of water flow in rivers, estuaries with coastal systems.
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrology	The term given to the study of the rain-runoff process in catchments.
Low hazard	Flood depths and velocities are sufficiently low that people and their possessions can be evacuated.
Management plan	A clear and concise document, normally containing diagrams and maps, describing a series of actions that will allow an area to be managed in a coordinated manner to achieve defined objectives.
Map Grid of Australia	A national coordinate system used for the mapping of features on a representation of the earths surface. Based on the geographic coordinate system 'Geodetic Datum of Australia 1994'.
Peak flood level, flow or	The maximum flood level, flow or velocity occurring during a flood
velocity	event.
Probable Maximum Flood	An extreme flood deemed to be the maximum flood likely to occur at a particular location.
Probable Maximum Precipitation	The greatest depth of rainfall for a given duration meteorologically possible over a particular location. Used to estimate the probable maximum flood.
Probability	A statistical measure of the likely frequency or occurrence of flooding.
Runoff	The amount of rainfall from a catchment which actually ends up as flowing water in the river of creek.
Stage	Equivalent to water level above a specific datum- see flood level.
Stage hydrograph	A graph of water level over time.
Triangular Irregular Network	A mass of interconnected triangles used to model three-dimensional surfaces such as the ground (see DTM) and the surface of a flood.
Velocity	The speed at which the flood waters are moving. Typically, modelled velocities in a river or creek are quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.

Appendices

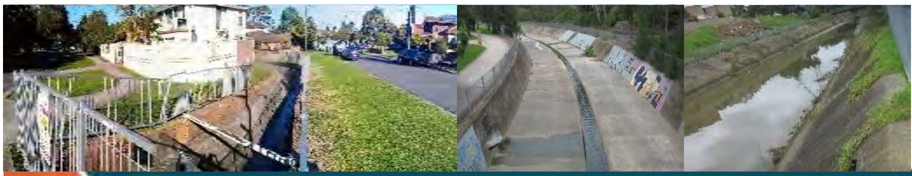
Smart Consulting



Appendix A Cooks River Feeder Channel Surveyed Cross Section Data



Appendix B Rainfall Intensity and Temporal Pattern Data



Appendix C Community Consultation

Appendix C – Community Consultation

Overview

As part of the flood study, computer models describing the flooding behaviour will be built. In order to establish the accuracy of such models, observations from the public on observed flooding behaviour were obtained. Brown Consulting's methodology of public consultation and the data collected from mail out surveys are summarised in the report. The process of community consultation is summarised below.

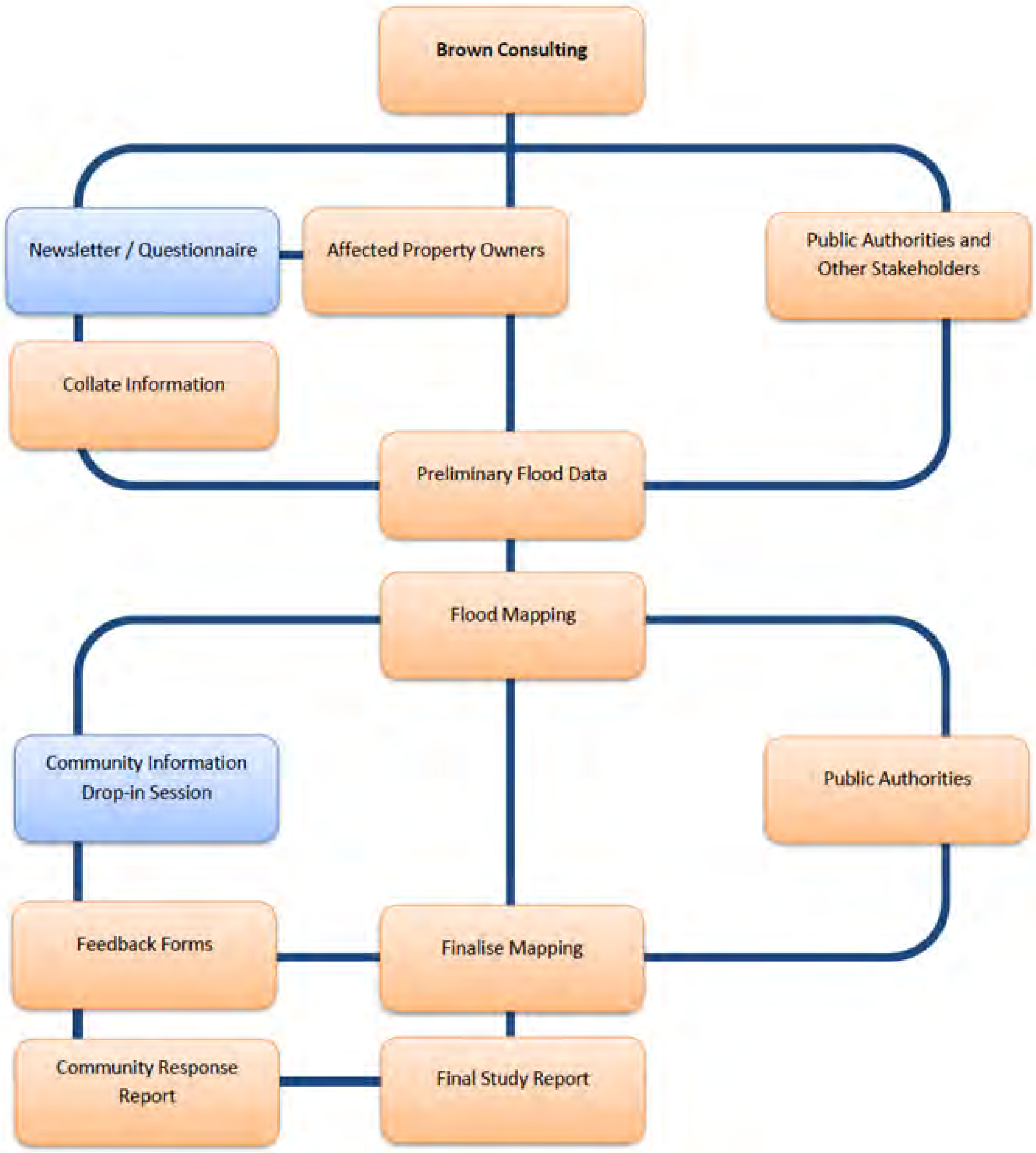


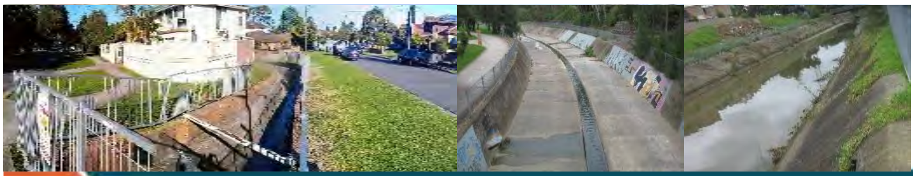
Figure C11 – Flow chart of community consultation in the project proceedings

Survey Design and Methodology

For the initial community consultation Brown Consulting formulated a 'Newsletter and Questionnaire' which was designed to be sent out to residents. The aim of this was to seek to acquire specific historical data and evidence from flood affected residents. Information that was collected included respondents contact details, whether they were a residential property or non-residential property and the time they have lived at the address. More flood specific details were requested including whether they had ever experienced a flooding event. If they answered yes the respondents was also asked to provide the date of the event, at what height the flood reached in relation to their floor level and secondly the flood level on the rest of the property. The residents also had the ability to comment on any other flood experiences. Respondents were asked to provide any photographs of the flooding in hard copy or digital formats.

400 newsletter/questionnaires were delivered through a letter box drop; in areas that are considered may be flood prone in the suburb of Croydon Park. The properties that were included in the letter box drop are highlighted in yellow on the map below. Out of the 400 questionnaires that were delivered only 15 were returned, which is a low response rate to the study. However, the 15 responses that were returned held information and observations on flooding experiences. These responses were analysed and the data from them used for to format flood mapping, tables and the comments recorded.

Figure C12 – Aerial photo of the study area with properties for the letter box drop



Summary of Results Received

From the fifteen returned questionnaire one third of the responses had an issue related to flooding in the past. The location of the respondents is displayed in the map below with green representing flooding experienced and blue representing no flooding experienced. Out of these five respondents that had an issue related to flooding in the past, four expressed a flooding event and one described flood prevention. All five described the flood events, not with specific dates but with more general descriptions such as 'approximately 60 years ago' or did not provide clear flood heights. An example of this is 'flooding occurs when it rains really heavy'.

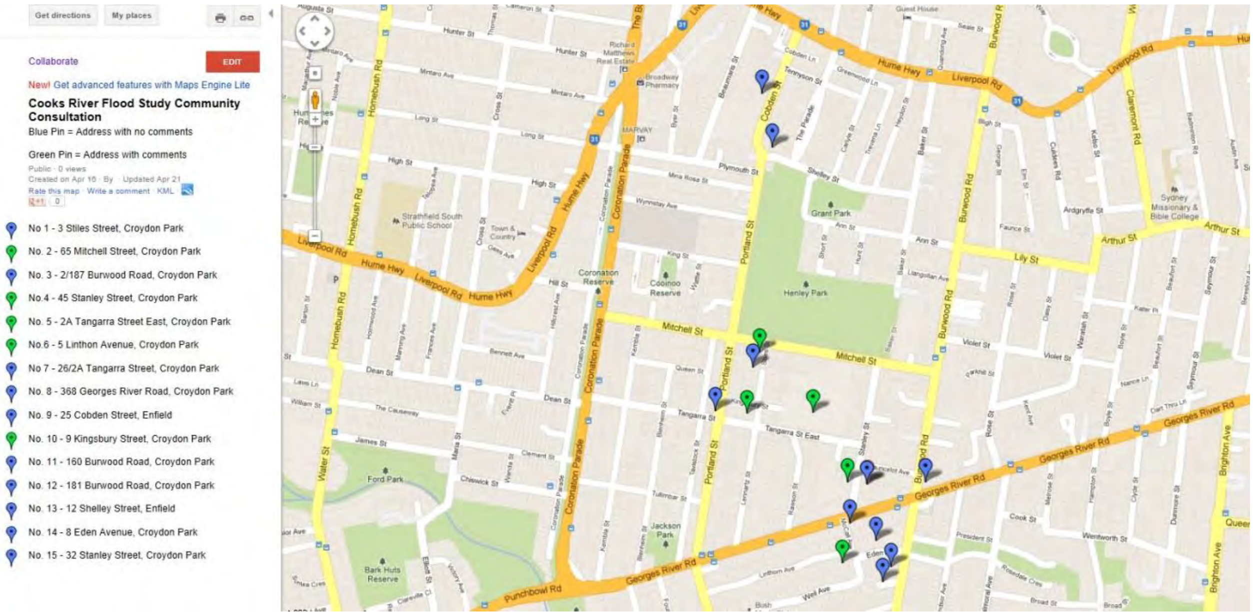
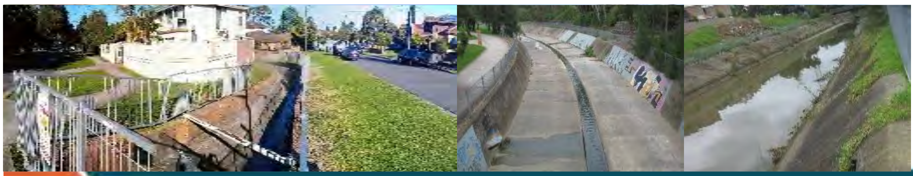


Figure C13 –Map depicting the locations of respondents to the survey

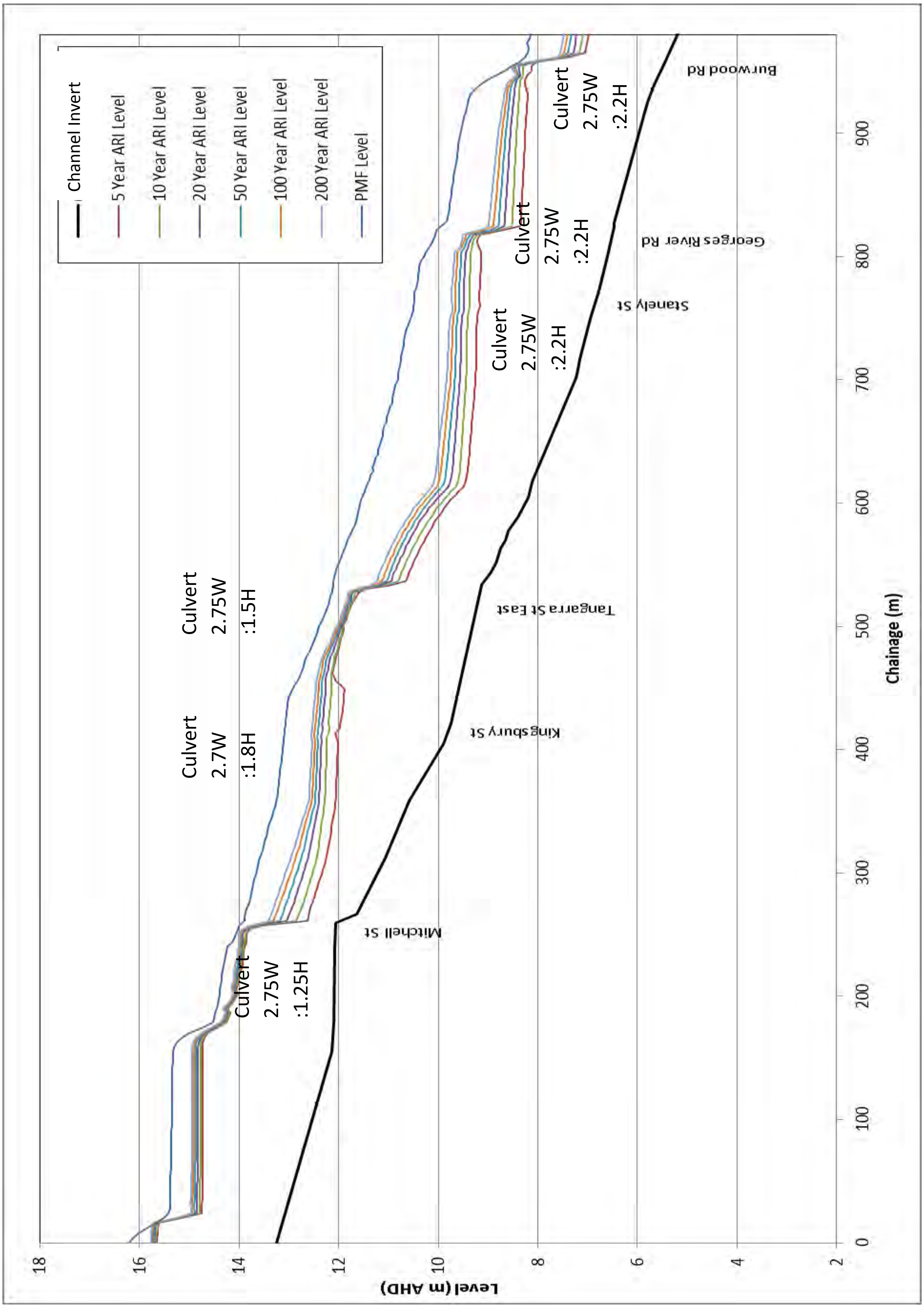
The comments received are included in the table below. Most of the comments could not describe the actual height the water reached or provide photographs of the water levels on their property. In summary, these results displayed that these inundations are more localised drainage issues only and do not have a widespread issue.

Table C9 – Table describing the issues and comments from the newsletter/questionnaire

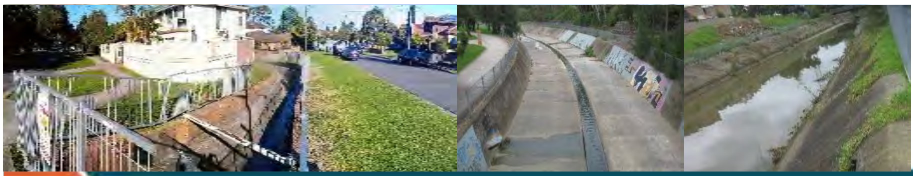
Reference Number	Issue	Comments
1	Nil	
2	Flooding	Flooding occurs 'when it rains really heavy' The water level has not been above the floor level; however it did reach the top of the front step
3	Nil	
4	Flooding	Approximately 60 years ago the water level reached 'Just below the floor level' beneath the house and across the rest of the property.
5	Flooding	'Each time there is reasonable rainfall the pump under the building car park is automatically activated o pump out water from under the building'. The regular use of the pump is a concern for the residents and further development.
6	Flooding	Flooding occurs after heavy rain, more specifically the garage. Issues that were related to the flooding included: 1. That the land is fairly flat so the run off is 'poor' 2. The property is on the low lying side of the street To compensate for this issue the owners have since raised the back yard level.
7	Nil	
8	Nil	
9	Nil	
10		
11	Nil	
12	Nil	
13	Nil	
14	Nil	
15	Nil	



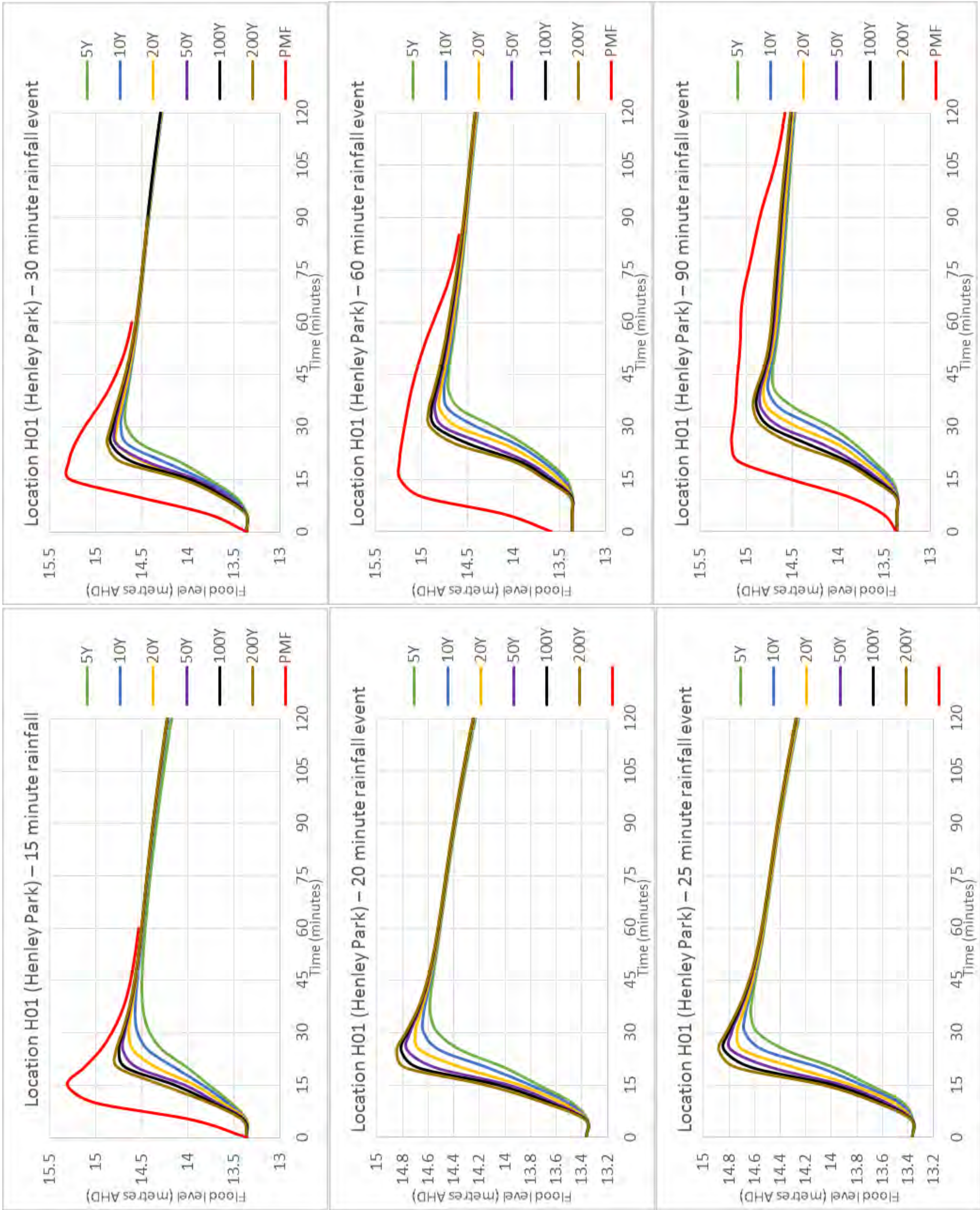
Appendix D Flood Profiles and Stage Hydrographs

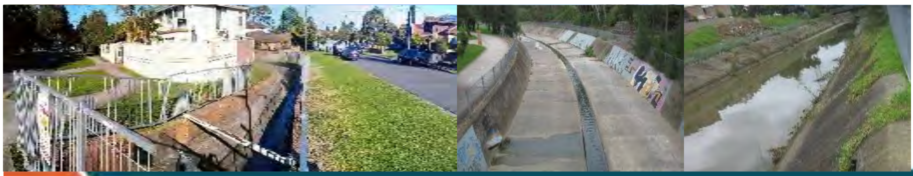


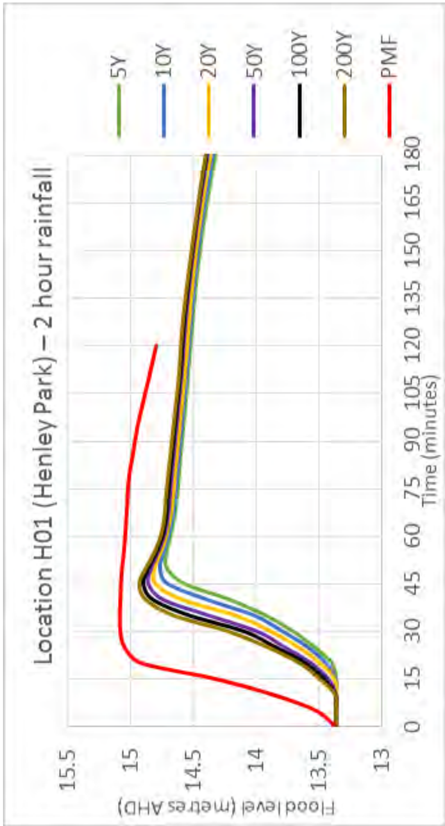
Channel Invert
5 Year ARI Level
10 Year ARI Level
20 Year ARI Level
50 Year ARI Level
100 Year ARI Level
200 Year ARI Level
PMF Level
Culvert 2.75W :1.25H
Culvert 2.7W :1.8H
Culvert 2.75W :1.5H
Culvert 2.75W :2.2H
Culvert 2.75W :2.2H
Culvert 2.75W :2.2H
Mitchell St
Kingsbury St
Tangarra St East
Stanely St
Georges River Rd
Burwood Rd
Level (m AHD)
Chainage (m)
18
16
14
12
10
8
6
4
2
0
100
200
300
400
500
600
700
800
900

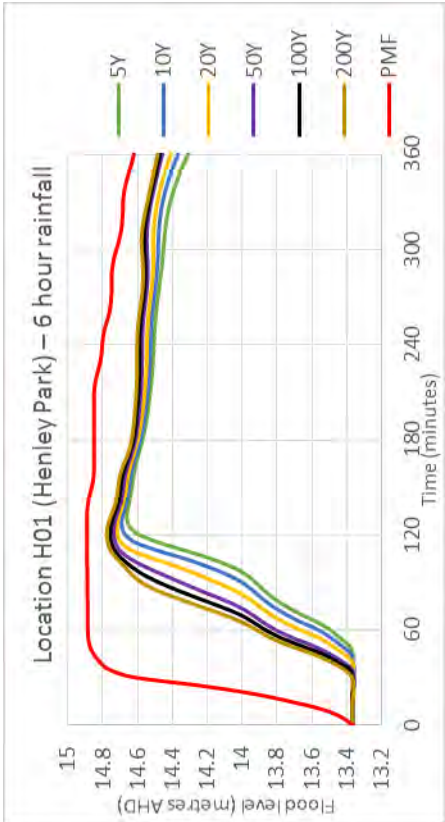


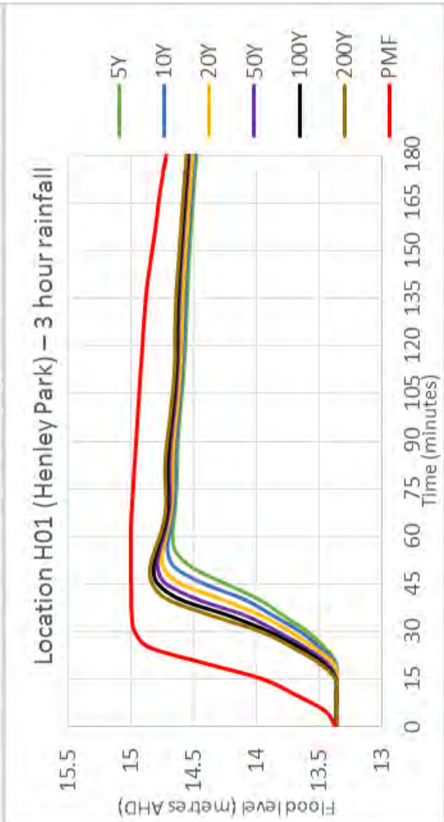
Stage Hydrographs – H01 – Henley Park

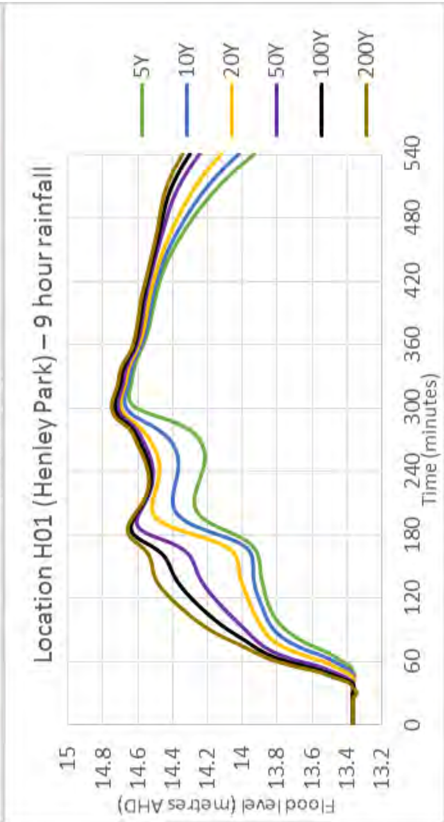


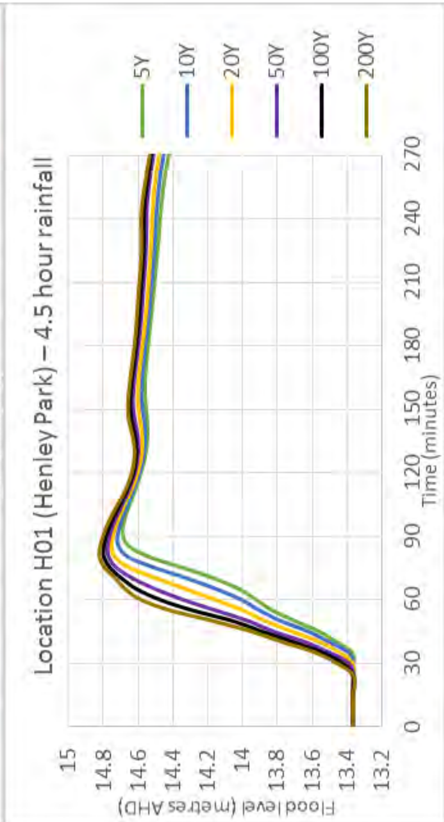


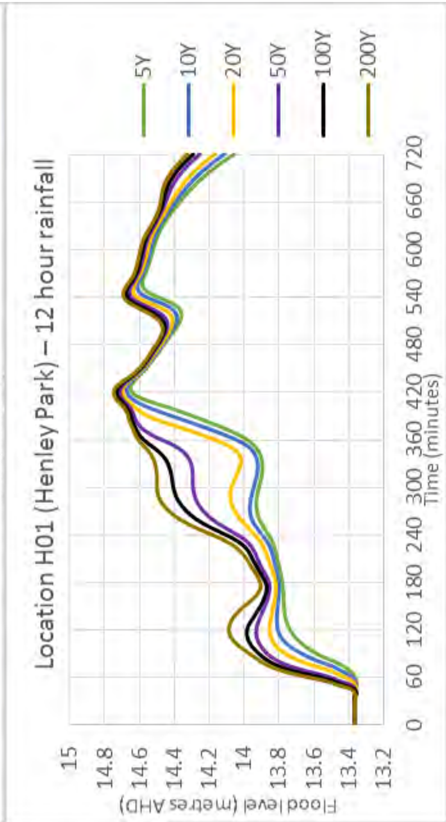

Location H01 (Henley Park) – 2 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF

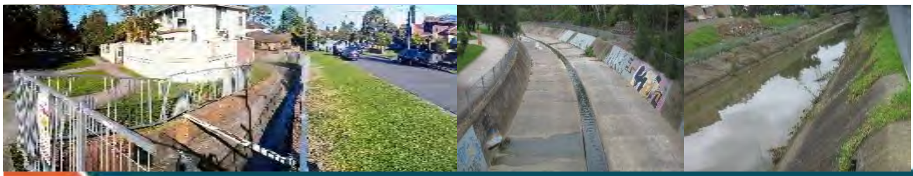

Location H01 (Henley Park) – 6 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF


Location H01 (Henley Park) – 3 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF

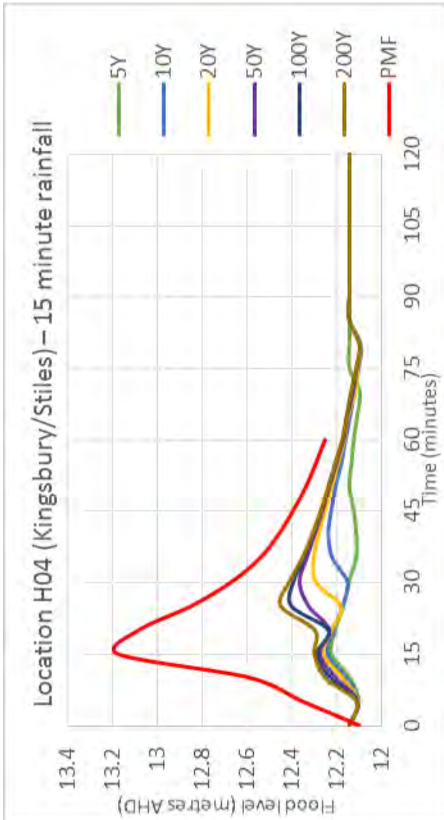

Location H01 (Henley Park) – 9 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y

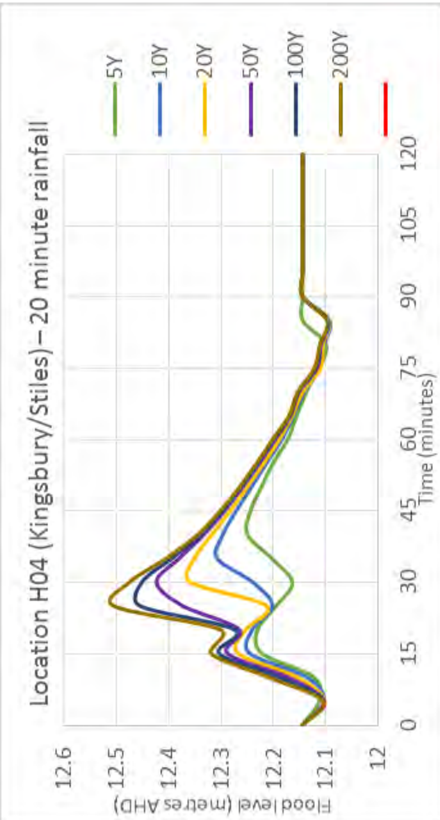

Location H01 (Henley Park) – 4.5 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y

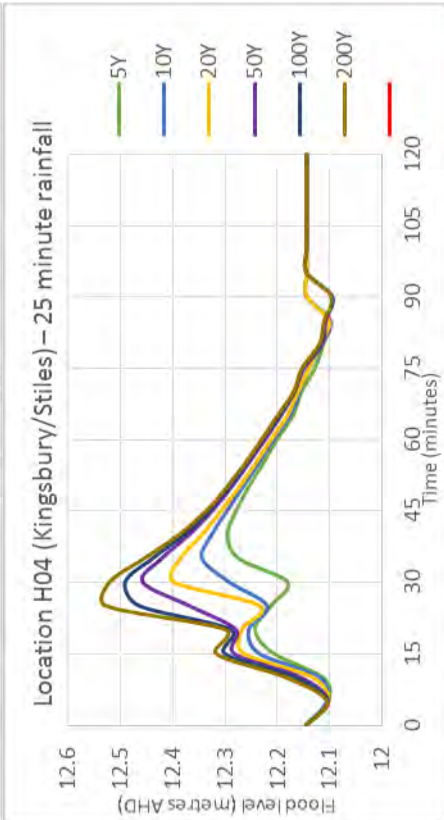

Location H01 (Henley Park) – 12 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y

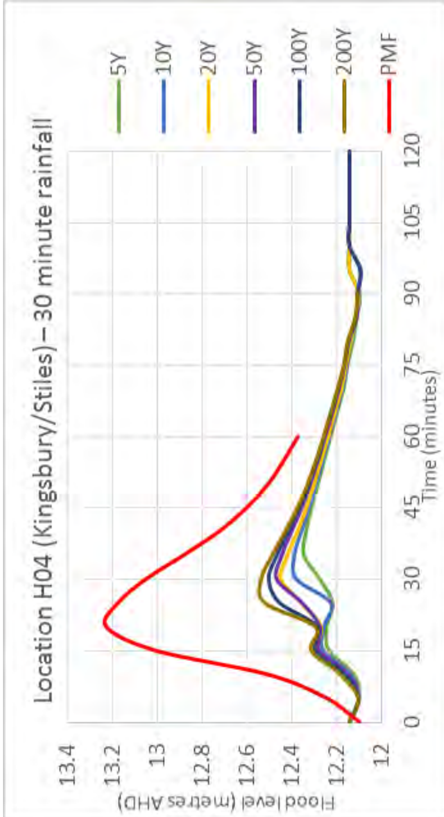


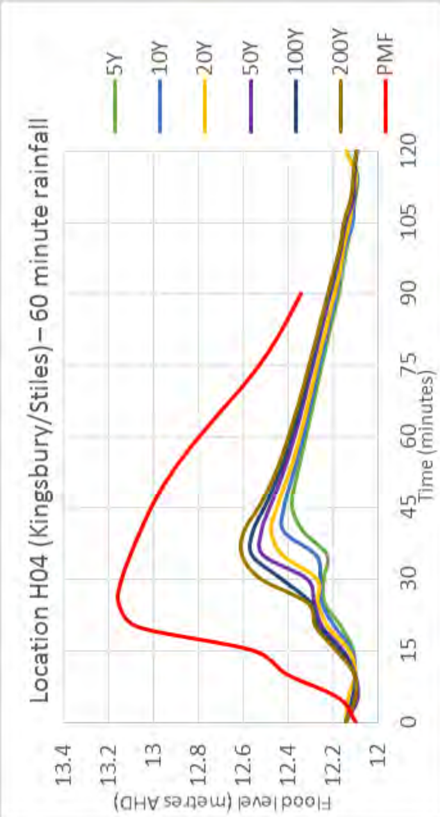
Stage Hydrographs – H04 – Kingsbury Street and Stiles Street

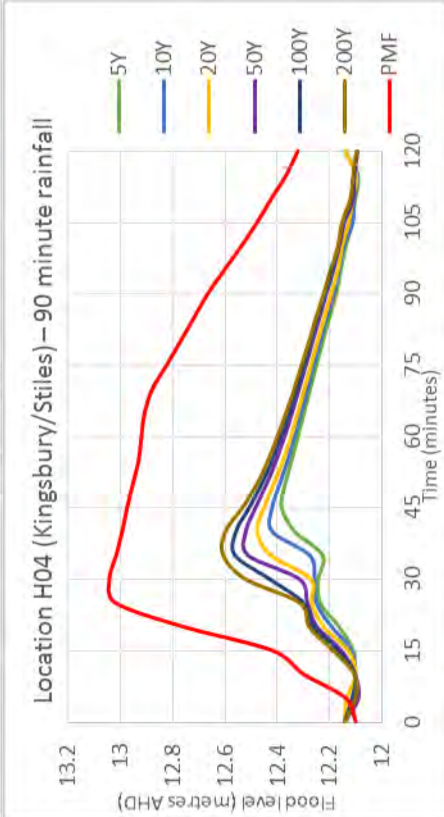


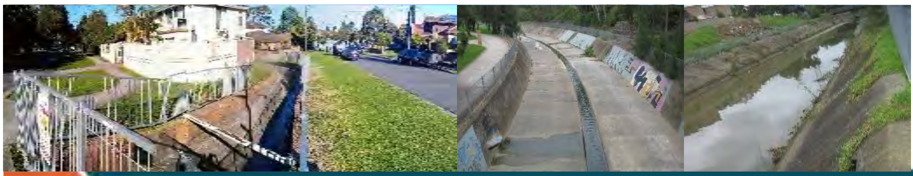


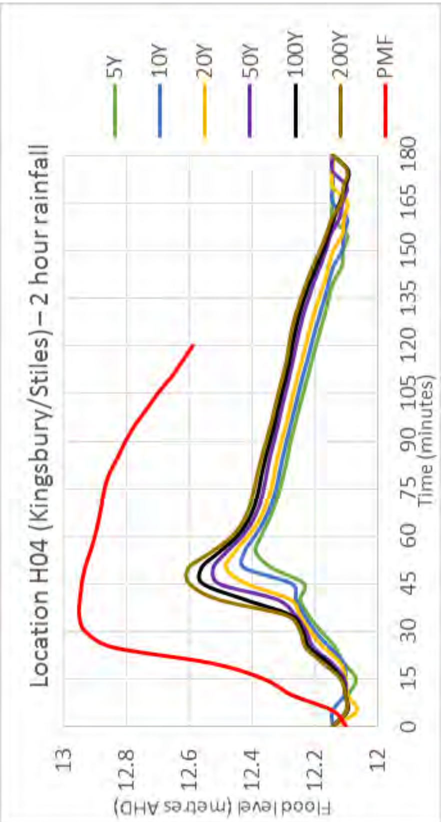


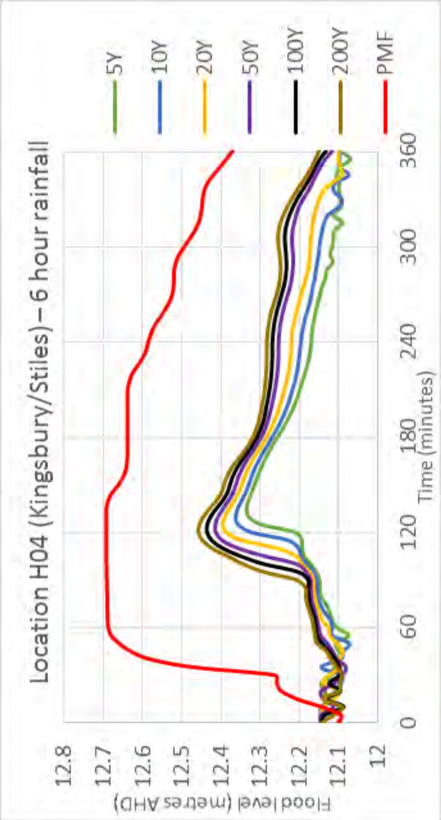


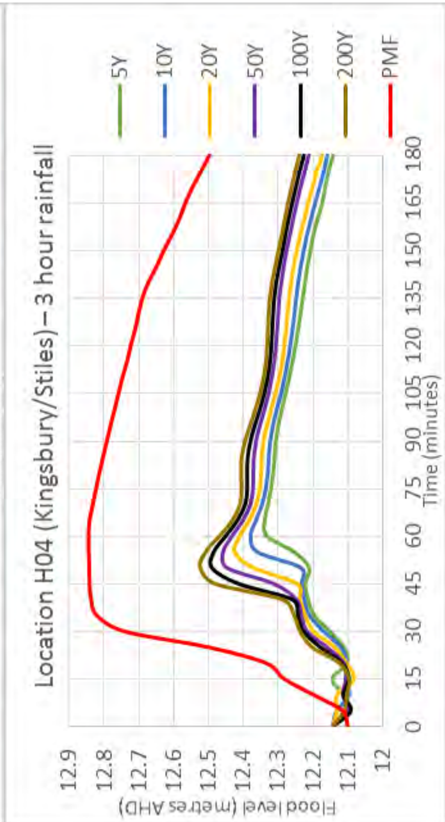


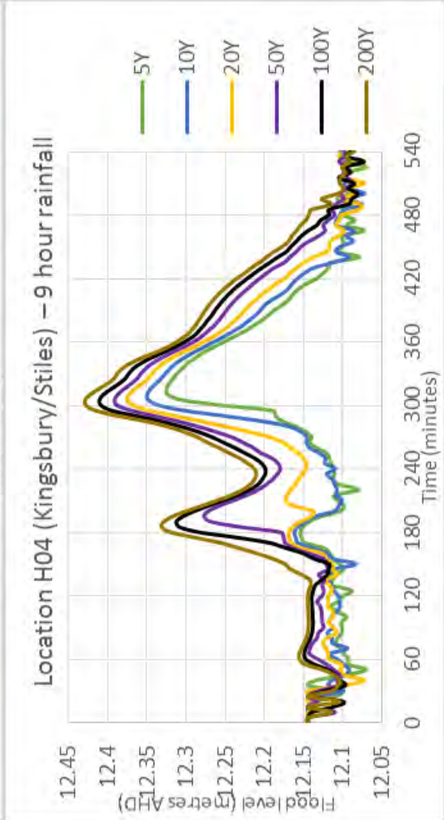


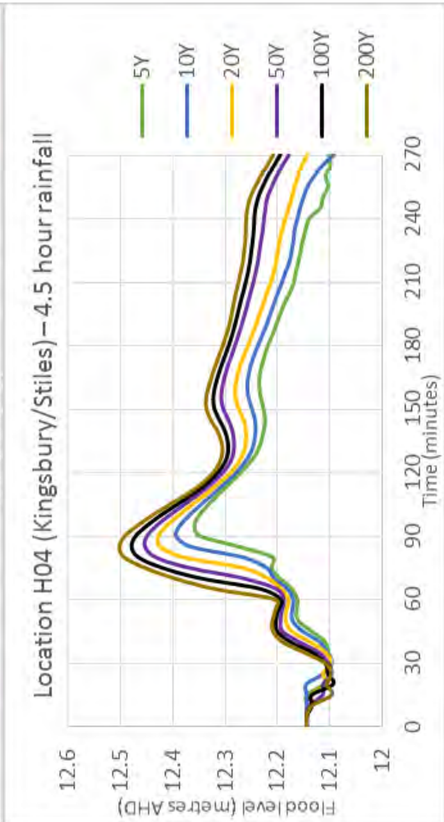


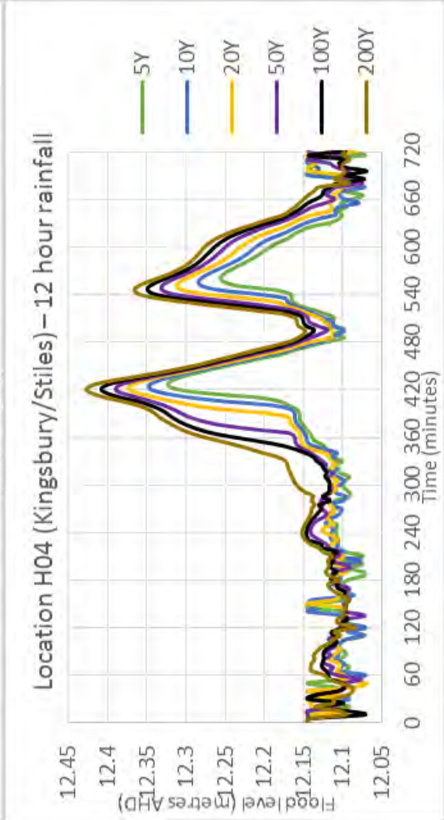

Location H04 (Kingsbury/Stiles) – 2 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF


Location H04 (Kingsbury/Stiles) – 6 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF

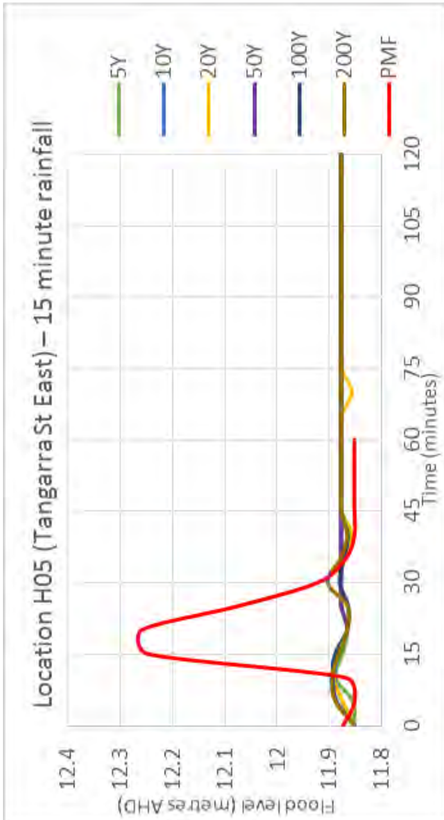

Location H04 (Kingsbury/Stiles) – 3 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF

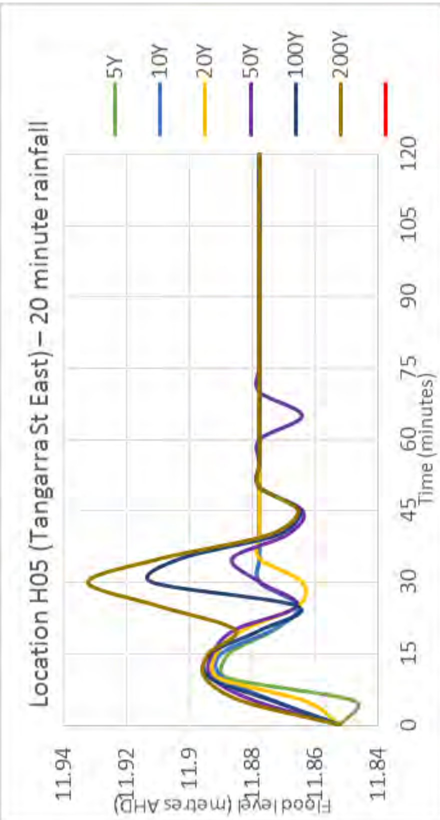

Location H04 (Kingsbury/Stiles) – 9 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y

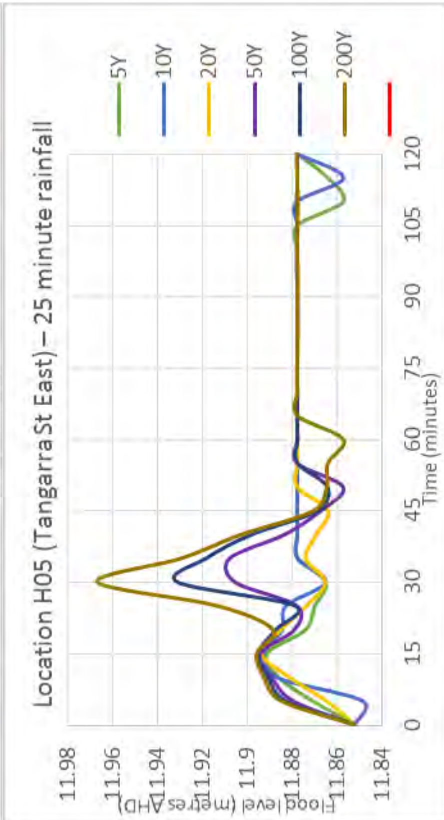

Location H04 (Kingsbury/Stiles) – 4.5 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y

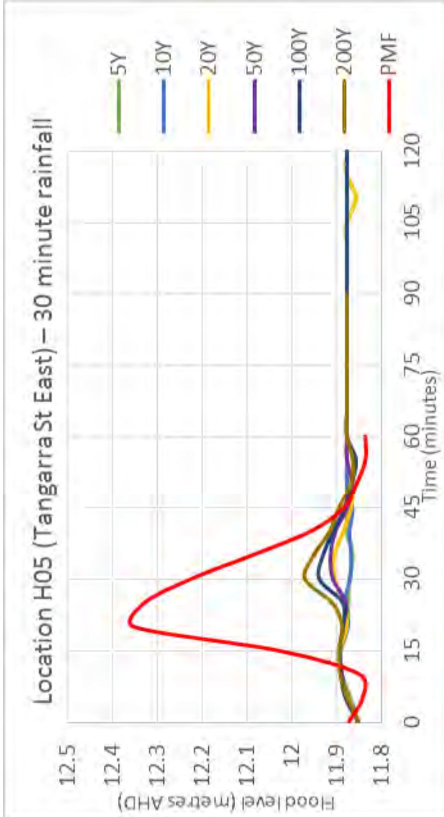

Location H04 (Kingsbury/Stiles) – 12 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y

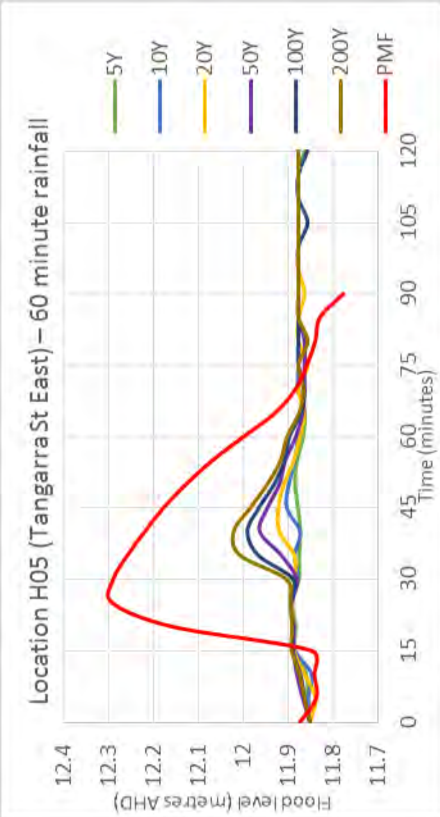
Stage Hydrographs – H05 – Tangarra Street East

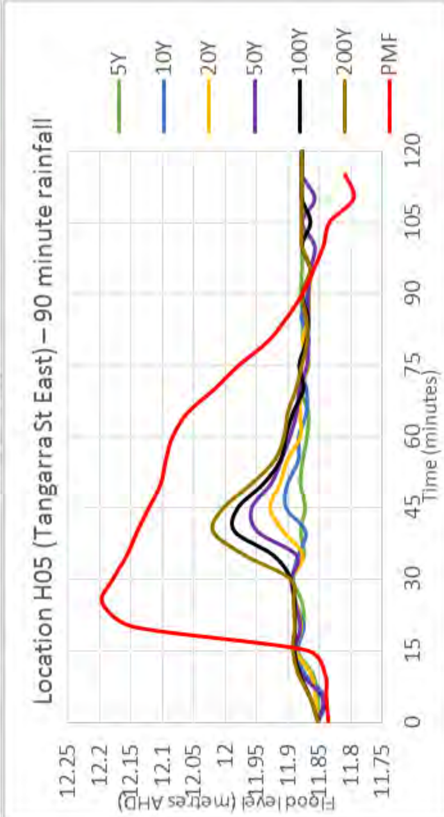


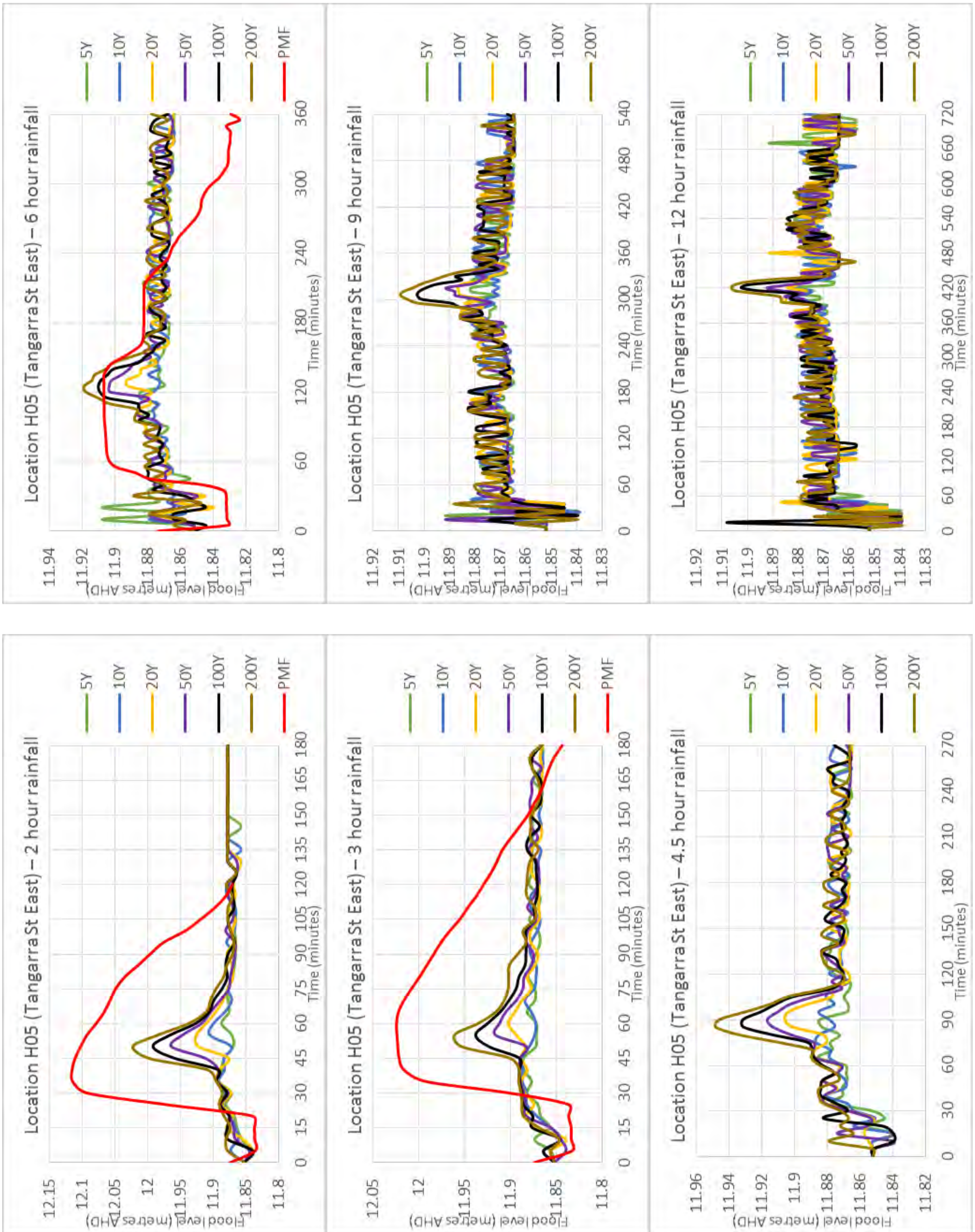




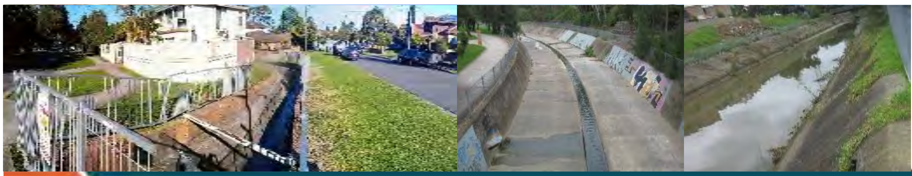








Location H05 (Tangarra St East) – 2 hour rainfall
Location H05 (Tangarra St East) – 3 hour rainfall
Location H05 (Tangarra St East) – 4.5 hour rainfall
Location H05 (Tangarra St East) – 6 hour rainfall
Location H05 (Tangarra St East) – 9 hour rainfall
Location H05 (Tangarra St East) – 12 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF



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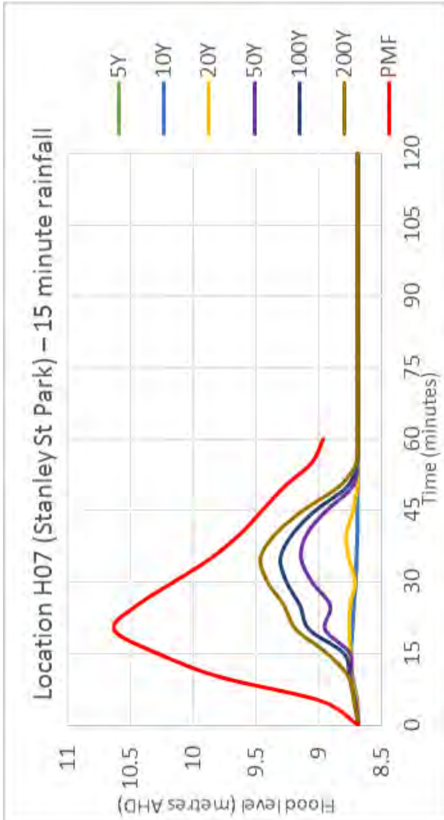
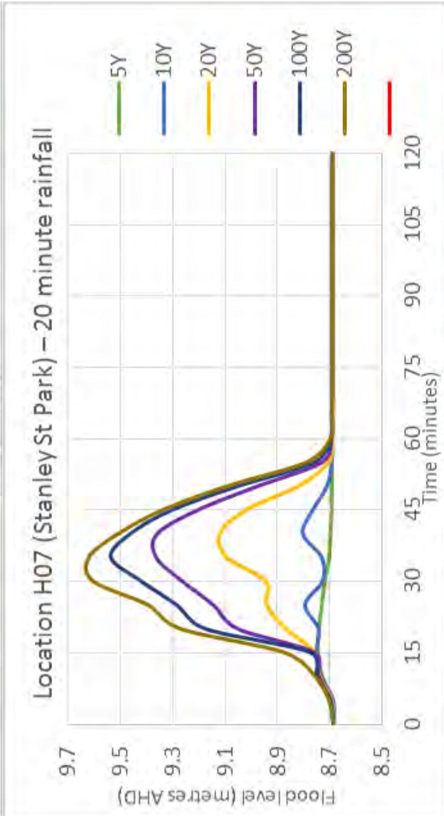
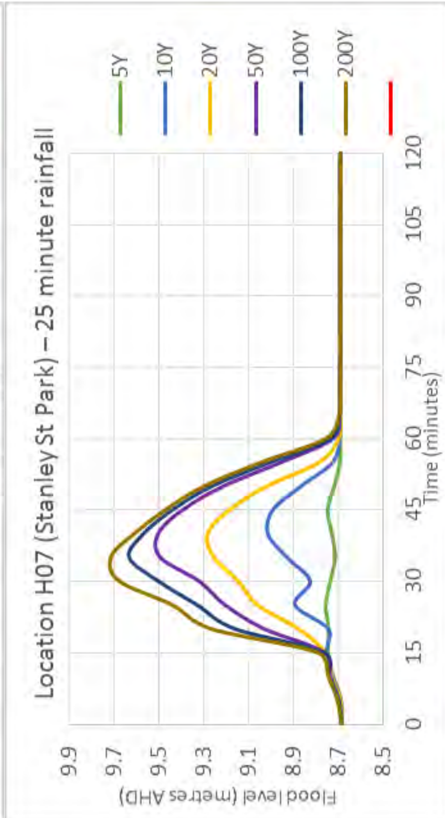
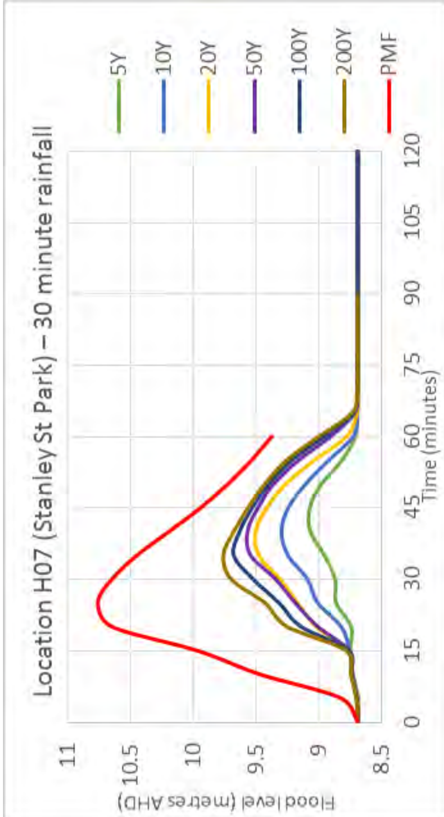
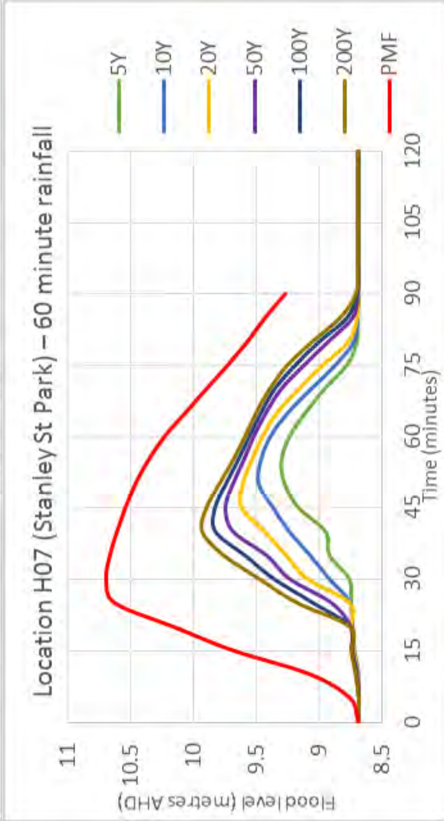
Stage Hydrographs – H07 – Stanley Street Park

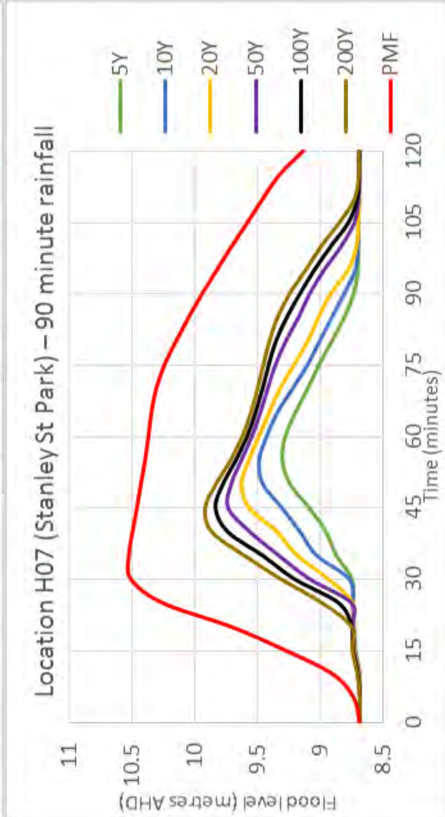


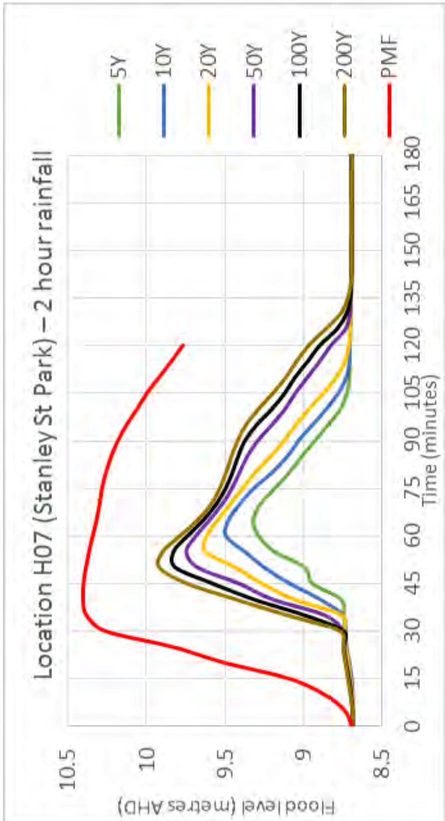




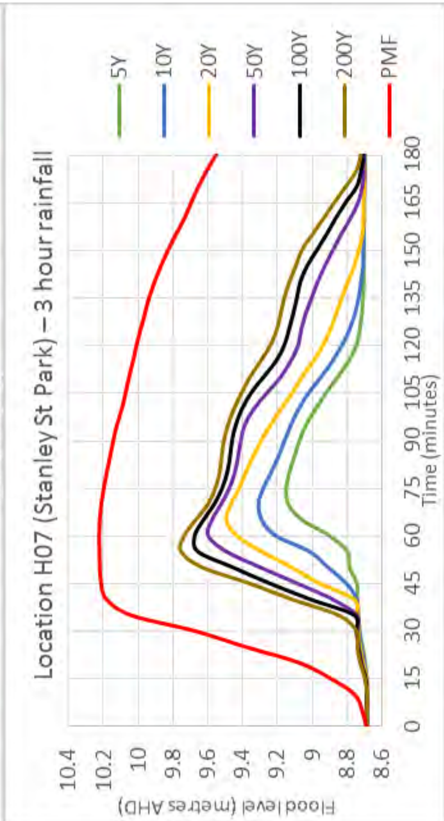




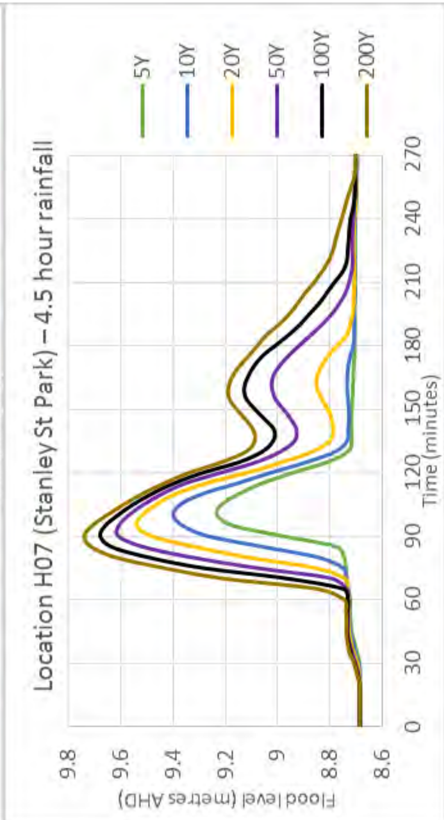




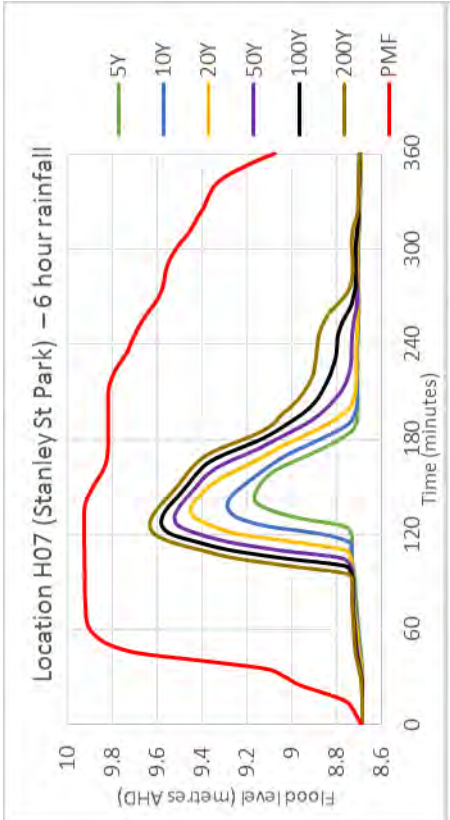
Location H07 (Stanley St Park) – 2 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF



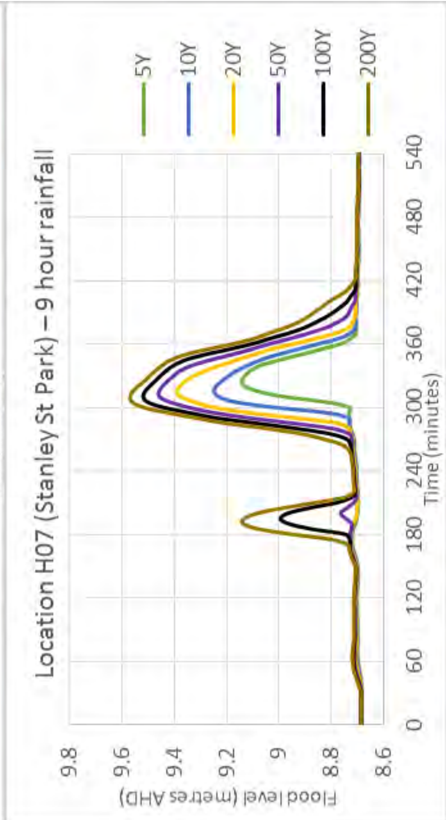
Location H07 (Stanley St Park) – 3 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF



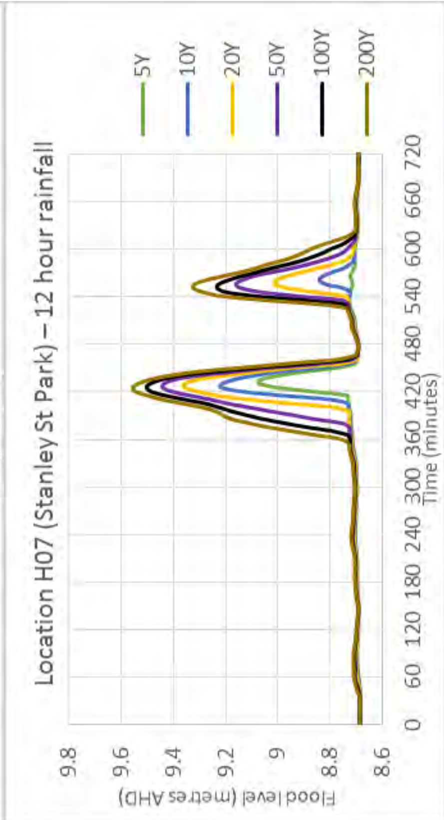
Location H07 (Stanley St Park) – 4.5 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y



Location H07 (Stanley St Park) – 6 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF

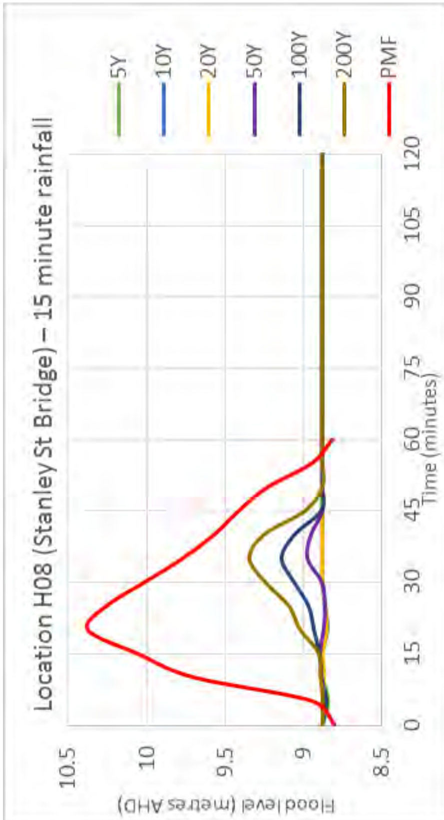


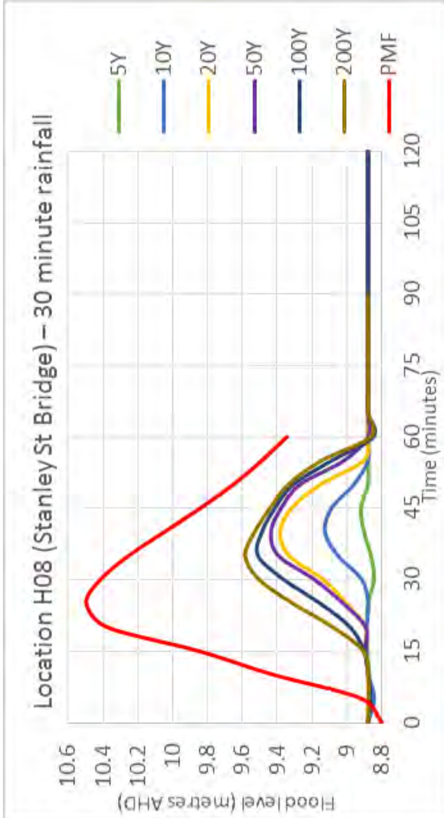
Location H07 (Stanley St Park) – 9 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y

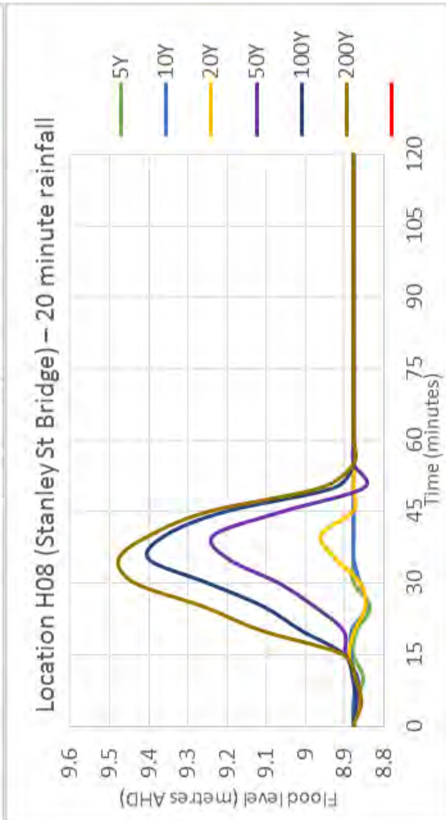


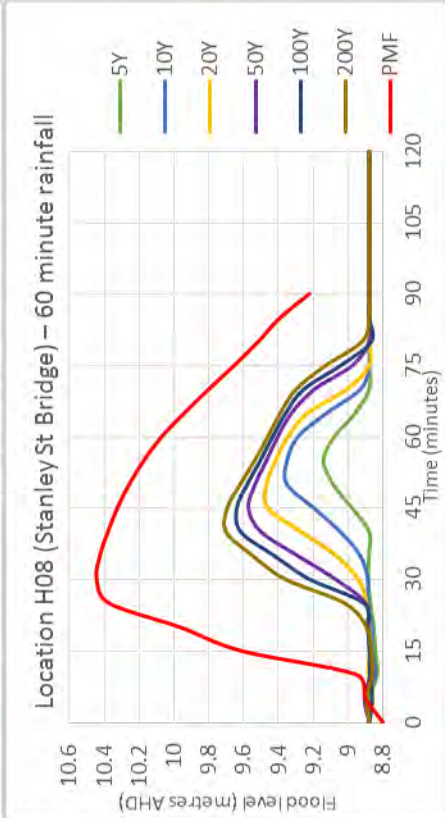
Location H07 (Stanley St Park) – 12 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y

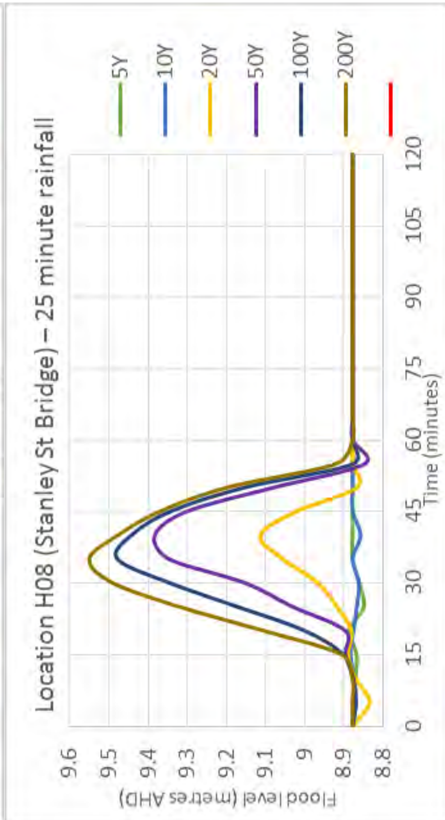
Stage Hydrographs – H08 – Stanley Street Bridge

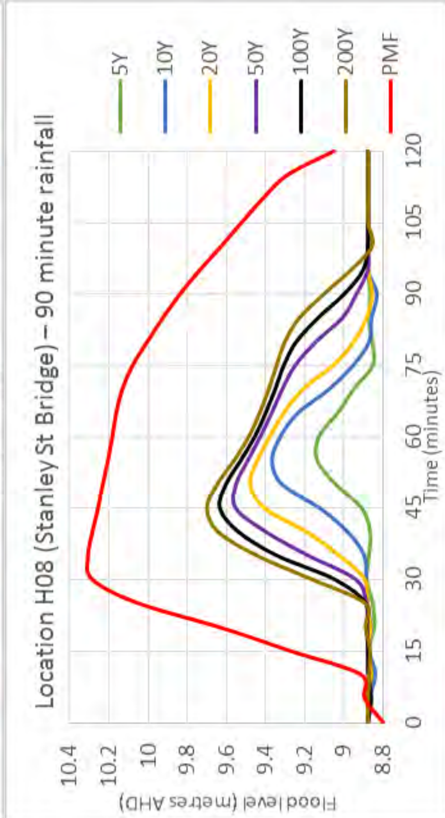


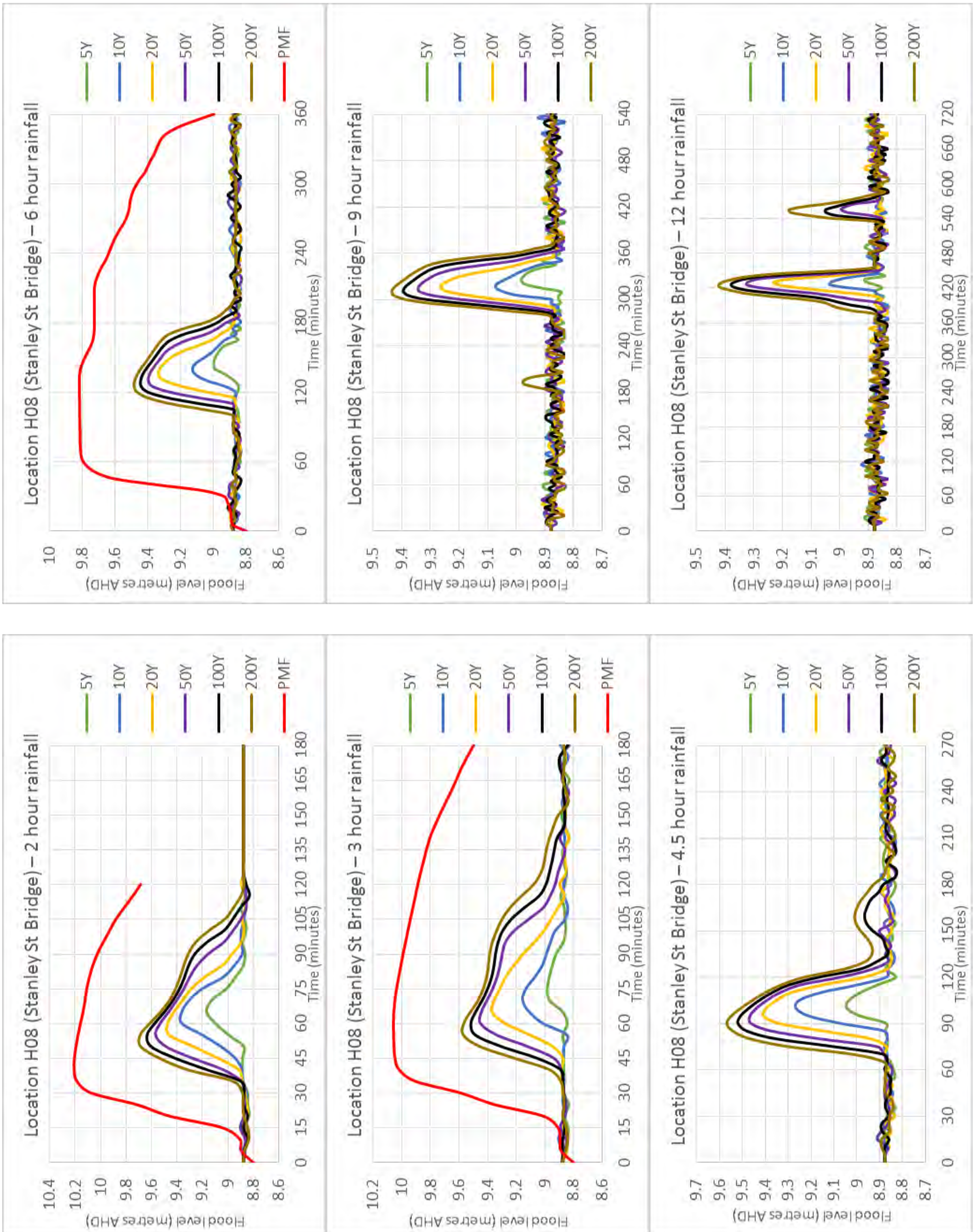






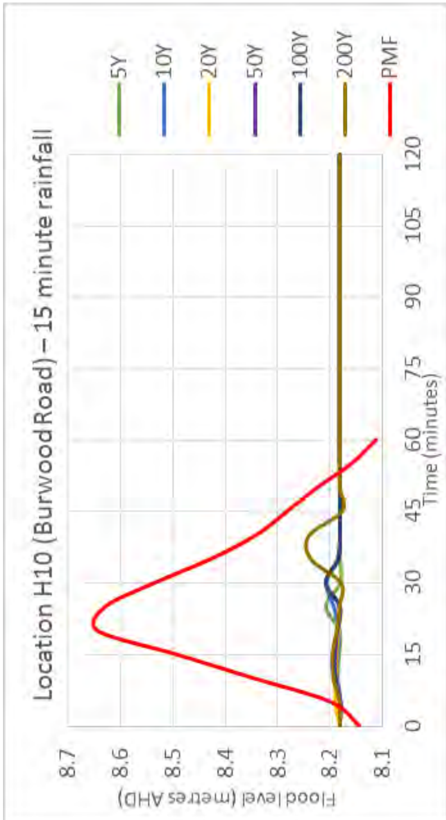


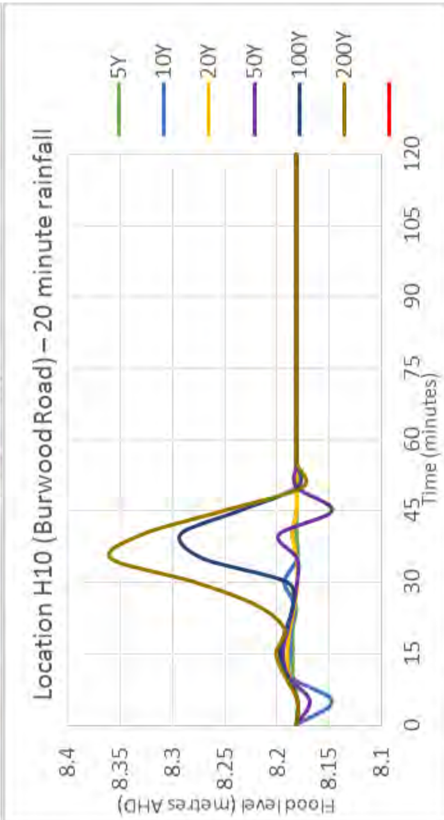


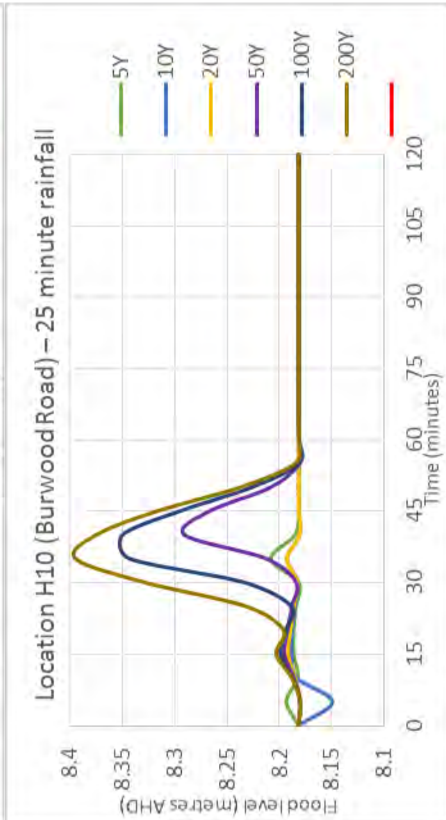


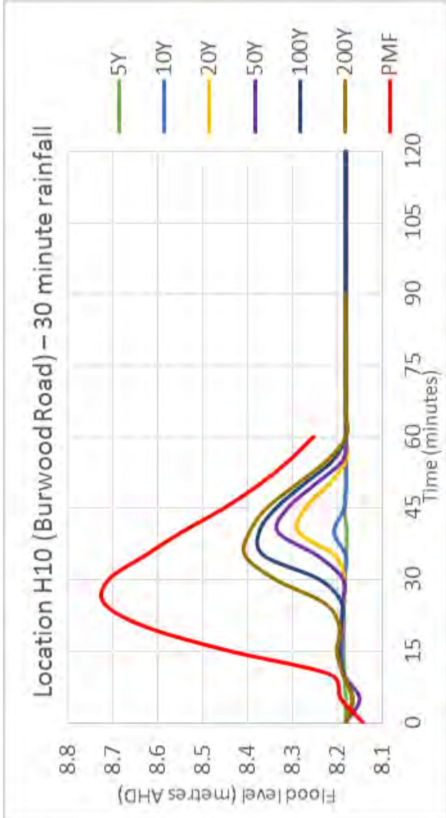
Location H08 (Stanley St Bridge) – 6 hour rainfall
Location H08 (Stanley St Bridge) – 9 hour rainfall
Location H08 (Stanley St Bridge) – 12 hour rainfall
Location H08 (Stanley St Bridge) – 2 hour rainfall
Location H08 (Stanley St Bridge) – 3 hour rainfall
Location H08 (Stanley St Bridge) – 4.5 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF

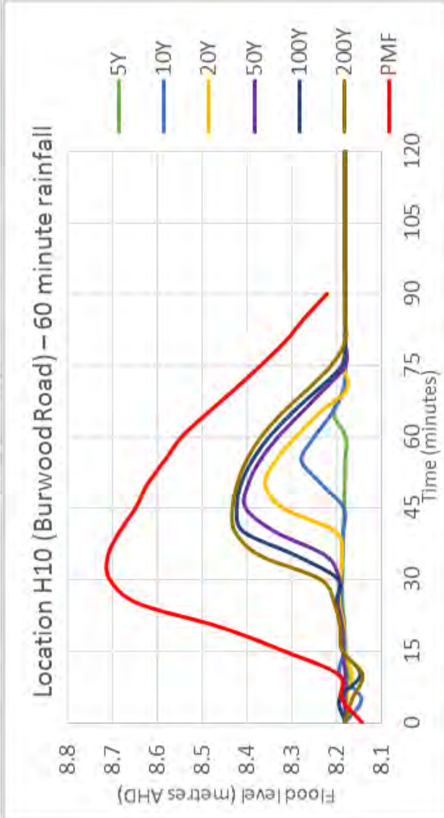
Stage Hydrographs – H10 – Burwood Road

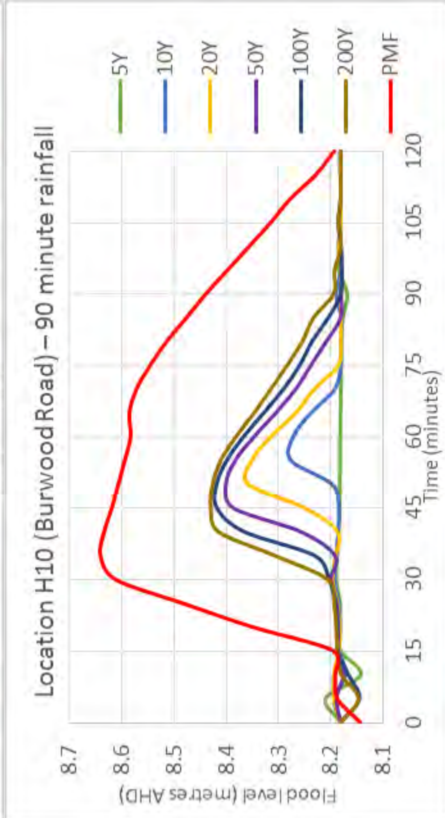


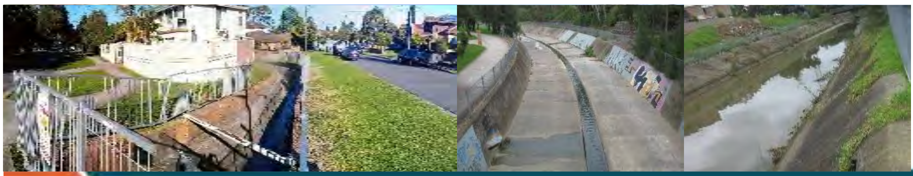


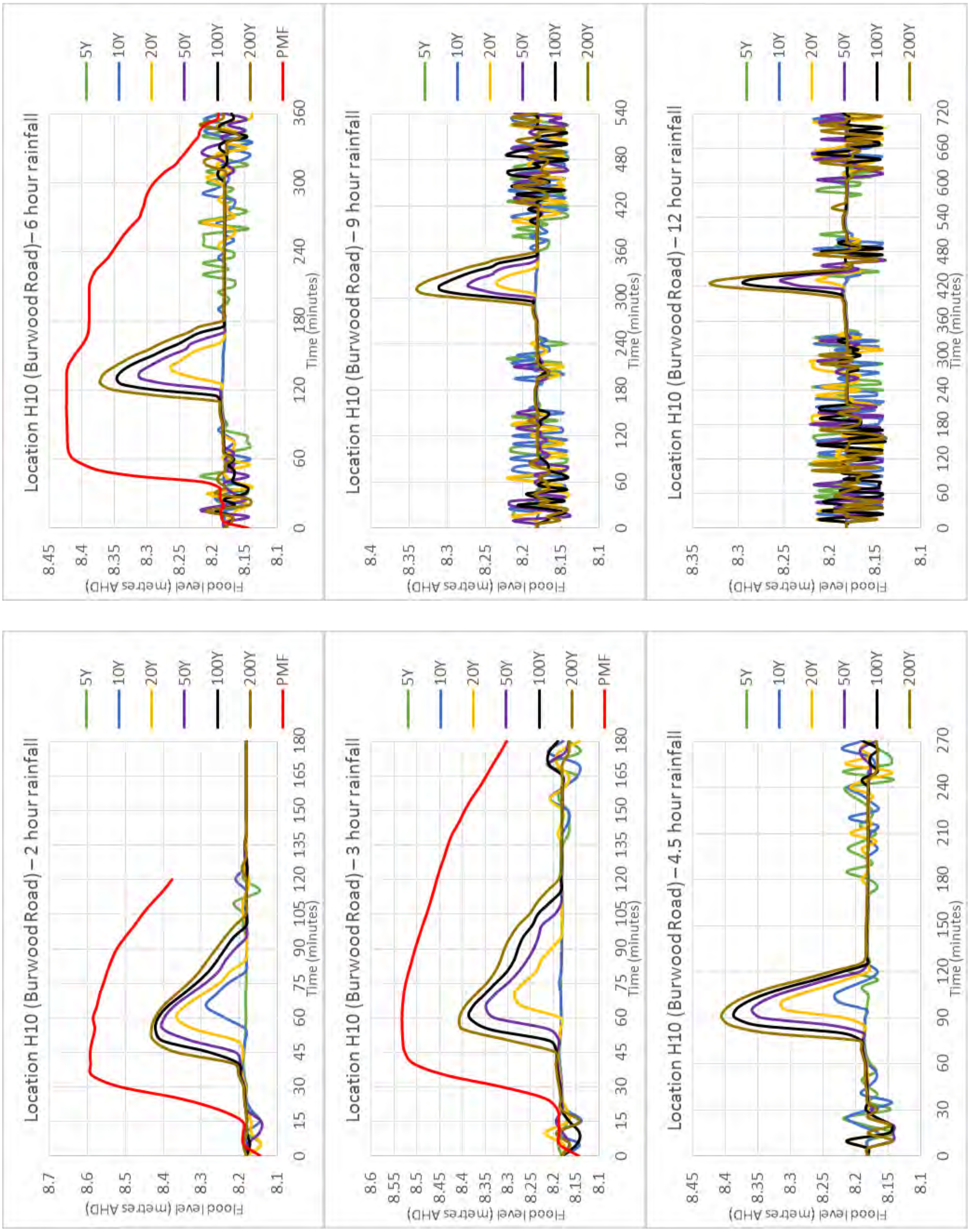




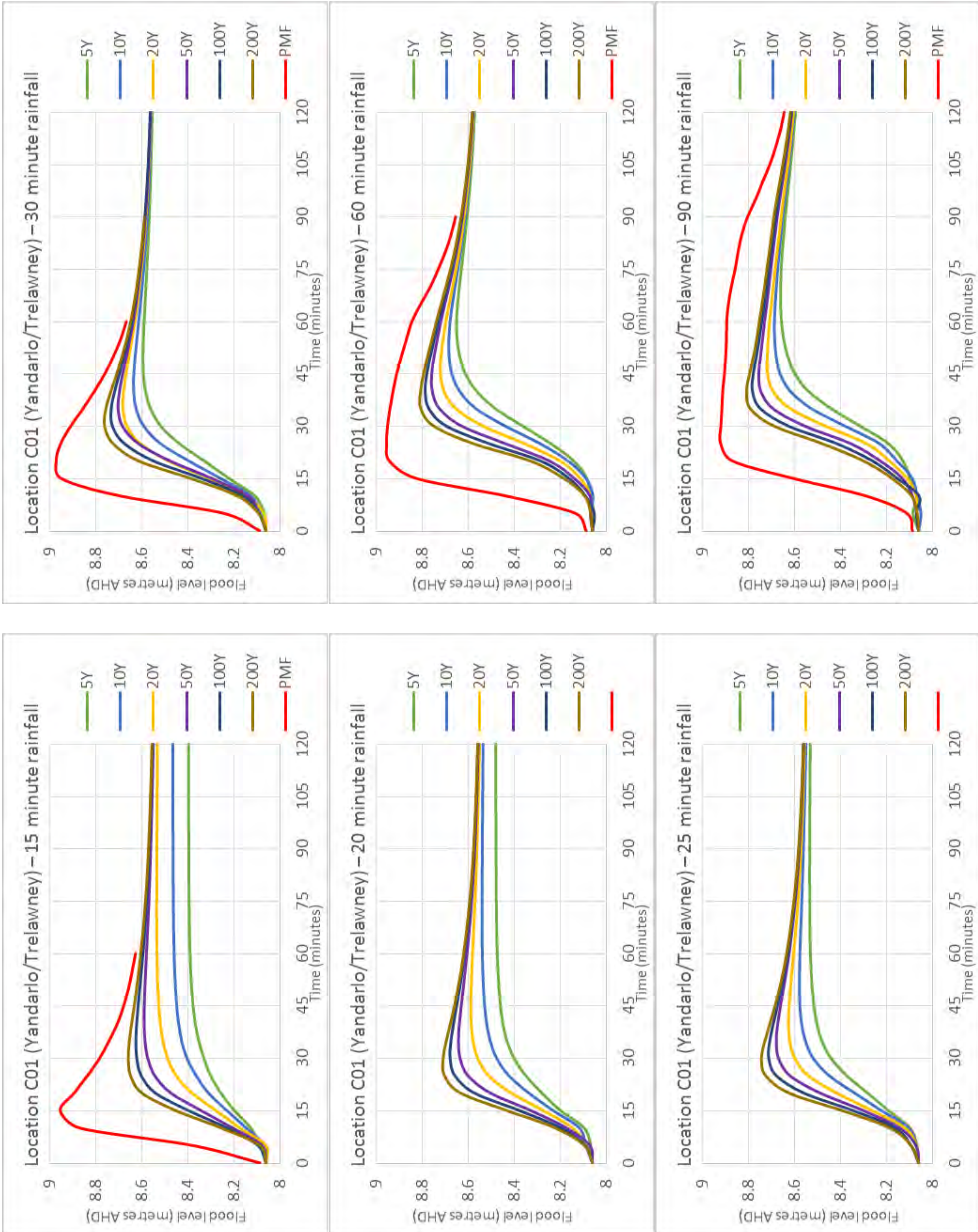


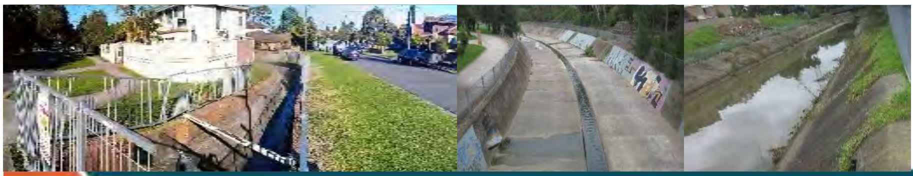





Location H10 (Burwood Road) – 2 hour rainfall
Location H10 (Burwood Road) – 3 hour rainfall
Location H10 (Burwood Road) – 4.5 hour rainfall
Location H10 (Burwood Road) – 6 hour rainfall
Location H10 (Burwood Road) – 9 hour rainfall
Location H10 (Burwood Road) – 12 hour rainfall
Flood level (metres AHD)
Time (minutes)
5Y
10Y
20Y
50Y
100Y
200Y
PMF

Stage Hydrographs – C01 – Yarlando Avenue and Trelawney Avenue





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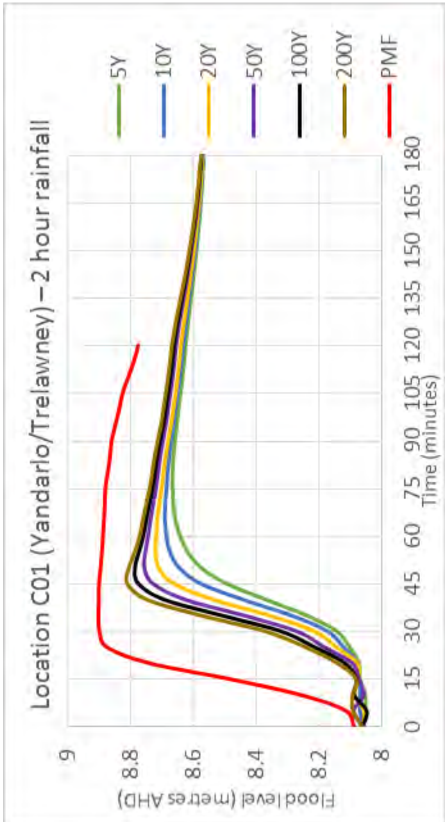
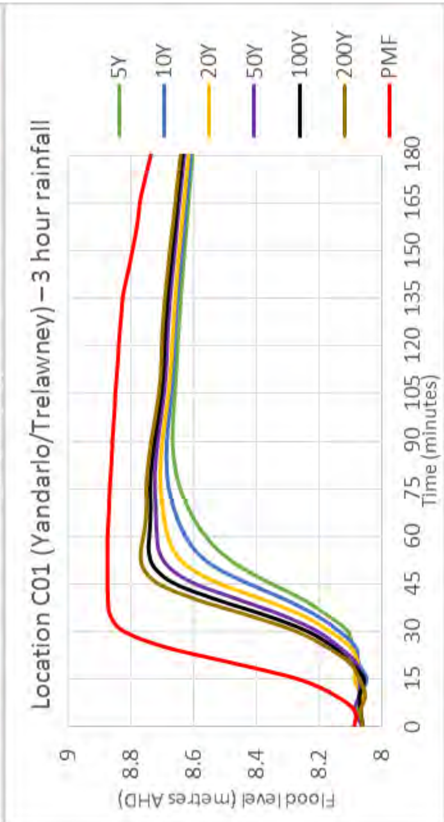
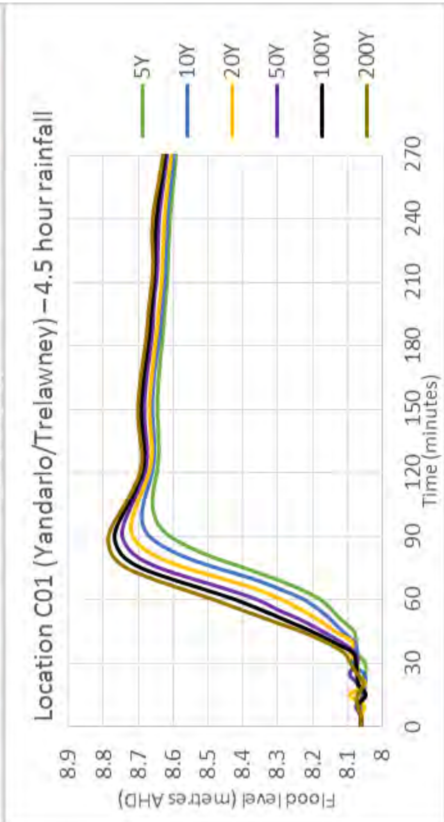
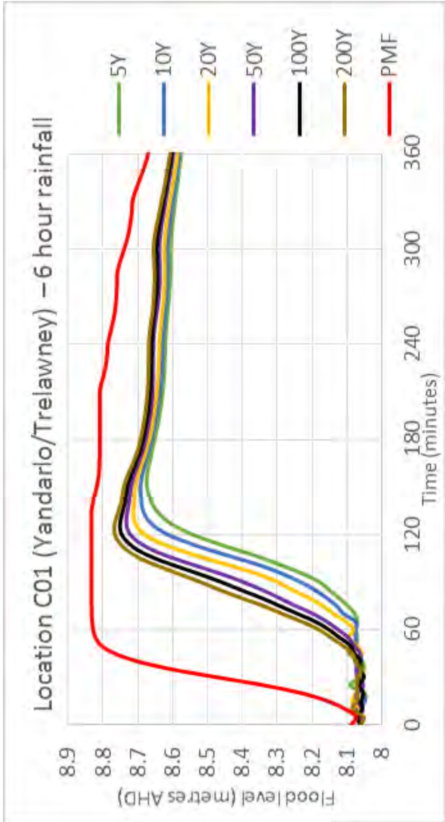
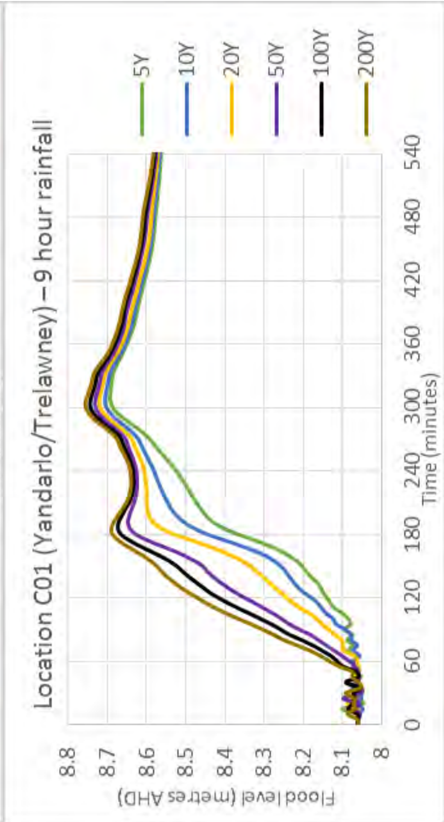
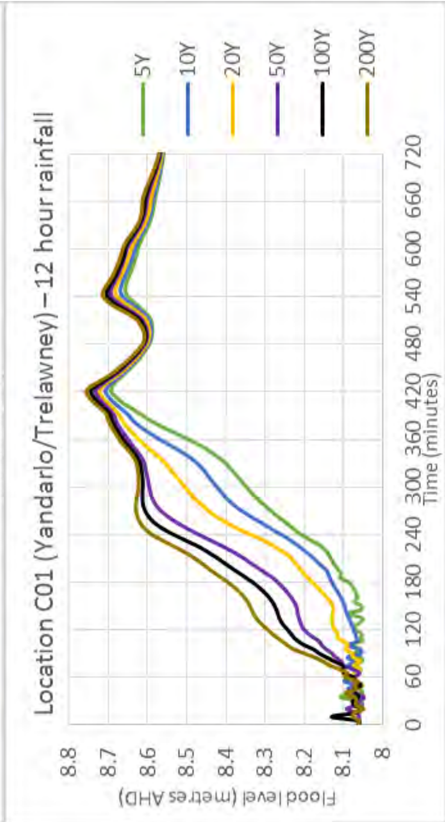


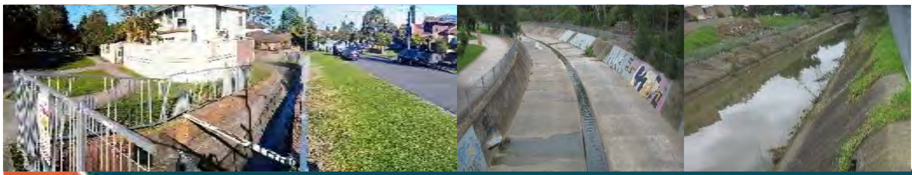












Appendix E Sensitivity Analysis

Appendix E – Sensitivity Analysis

Results of Sensitivity Analysis

The sensitivity scenario results were compared to the 100 year ARI 2 hour rainfall event, provided in volume 3 in *Map S.1*. A summary of peak flood level and peak flow differences at various locations are provided the following tables:

- Table E10 and Table E11 for variations in roughness and slope
- Table E12 and Table E13 for 100 year ARI flood levels in Cooks River
- Table E14 and Table E15 for variations in Ku, Initial and Continued Loss
- Table E16 and Table E17 for variations in blockage.

Comparison of peak flood levels have been highlighted such that yellow highlighting indicates that the magnitude of the change is greater than 0.1 metres, with the text highlighted in orange indicating changes greater than 0.3 metres in magnitude.

Roughness and slope

The results of the sensitivity analysis for Manning's 'n' Roughness and slope are presented in Table E10 and Table E11 and in Volume 3 on *Maps S.2* to *S.5*.

Table E10 – Results of sensitivity analysis for roughness and slope - 100 year ARI flood depths – 20% variation

Location	Depth Location	100 year Flood Depth	Difference in Flood Depth (m)			
			Roughness +20%	Roughness -20%	Slope - 20%	Slope +20%
Detention Basin	H01	1.52	0	0	0	0
Mitchell St	H02	0.17	0.01	0.01	0	0
Kingsbury St - Channel	H03	0.52	0.01	-0.01	0	0
Kingsbury St - Styles St	H04	0.11	0.04	-0.02	0	0
Tangarra St East	H05	0.30	-0.01	0.01	0	0
Rawson St	H06	1.13	-0.01	0	0	0
Park U/S Stanley St	H07	0.72	0.02	-0.05	0	0
Stanley St	H08	0.32	0.02	-0.02	0	0
Georges River Road	H09	0.24	0.01	-0.02	0	0
Burwood Road [D/S limit of LGA]	H10	0.32	0.01	-0.03	0	0
Windsor Ave	H11	2.83	0	0.01	0	0
Balmoral Ave	H12	0.33	0.03	-0.02	0.02	0
Hampton St	H13	2.70	0.04	0.01	0	0
Small Bridge U/S Brighton Ave	H14	0.39	0.08	-0.09	0	0

The result of sensitivity analysis shows the *TUFLOW* model is not sensitive to slope and Manning's 'n' where the resulting difference in analysed flood surface level varied by less than 0.01 metres in the majority of the scenarios tested. The results in Table E10 and Table E11 indicate that the largest variation in flow depth is of the order of 0.04 metres.

Table E11 – Results of sensitivity analysis for roughness and slope - 100 year ARI flows – 20% variation

Location	ID	100 year ARI Flow	Difference in Flow (m^3/s)			
			Roughness +20%	Roughness -20%	Slope +20%	Slope -20%
Shelley St (Into Park)	117 & 74	9.7	-0.3	0.4	0	0
Basin Inflow (U/S) From NE	56 & 116	30.3	-1.1	1.4	0	0
Basin Inflow From West (Portland St)	115	3.3	-0.1	0.1	0	0
Basin Outflow (D/S) (Us Mitchell St)	55	33.1	-1.3	1.8	0	0
D/S Mitchell St	18	9.4	-0.5	0.4	0	0
Stiles St (Inflow)	1	20.0	-1.4	0.9	0	0
Kingsbury Channel O/L Flow	119	9.0	0.5	-0.4	0	0
Stiles St (Cnr Kingsbury) (Outflow)	3	13.3	-1.8	1.7	0	0
Tangarra St East Culvert	120	21.0	-0.1	0.2	0	0
Rawson St	122	14.0	-0.9	1.3	0	0
Stanley St	30	28.9	-1.7	2.1	0	0
Georges River Rd	33	23.0	-2.9	3.9	0	0
Burwood Rd	35	30.4	-3.0	6.9	0	0
Windsor Ave	37	38.7	-2.3	3.2	0	0
Balmoral Ave	40	39.9	-2.0	3.7	0	0
Hampton St	43	44.4	-4.5	0.4	0.2	-0.3

The results in Table E10 and Table E11 indicate that the largest variation in flow depth is of the order of 0.04 metres.

Cooks River Boundary Condition

Flood levels within the main channel of the Cooks River, downstream of where the Cooks River feeder channel leaves Burwood LGA were modelled, with the results provided in Table E12 and *Maps S.6* to *S.8* in Volume 3.

Table E12 – Results of sensitivity analysis for Cooks River boundary condition - 100 year ARI flood depths

location	depth location	100 year ari flood depth	difference in flood depth (m)	
			Cooks River 100 Year Flood BC	Cooks River 100 Year Climate Change Flood BC
Detention Basin	H01	1.52	0	0
Mitchell St	H02	0.17	0	0
Kingsbury St - Channel	H03	0.52	0	0
Kingsbury St - Styles St	H04	0.39	0	0
Tangarra St East	H05	0.11	0	0
Rawson St	H06	0.30	0	0
Park U/S Stanley St	H07	1.13	0	0
Stanley St	H08	0.72	0	0
Georges River Road	H09	0.32	0	0
Burwood Road [D/S limit of LGA]	H10	0.24	0	0
Windsor Ave	H11	0.32	0	0
Balmoral Ave	H12	2.83	0.17	0.43
Hampton St	H13	0.33	0.75	1.36
Small Bridge U/S Brighton Ave	H14	2.70	2.03	2.88

The sensitivity analysis using flood level data from the Cooks River Flood Study (Sydney Water, 2009) showed the backwater effect of the Cooks River whilst extends into the main channel, does not influence flood levels within the Burwood Council LGA, the limit of this study.

Table E13 – Results of sensitivity analysis for Cooks River boundary condition - 100 year ARI flows

Location	ID	100 year ARI Flow	Difference in Flow (m^3/s)	
			Cooks River 100 Year Flood BC	Cooks River 100 Year Climate Change Flood BC
Shelley St (Into Park)	117 & 74	9.7	0.0	0.0
Basin Inflow (U/S) From Neast	56 & 116	30.3	0.0	0.0
Basin Inflow From West (Portland St)	115	3.3	0.0	0.0
Basin Outflow (D/S) (Us Mitchell St)	55	33.1	0.0	0.0
D/S Mitchell St	18	9.4	0.0	0.0
Stiles St (Inflow)	1	20.0	0.0	0.0
Kingsbury Channel O/L Flow To Channel	119	9.0	0.0	0.0
Stiles St (Cnr Kingsbury) (Outflow)	3	13.3	0.0	0.0
Tangarra St East Culvert	120	21.0	0.0	0.0
Rawson St	122	14.0	0.0	0.0
Stanley St	30	28.9	0.0	0.0
Georges River Rd	33	23.0	0.0	0.0
Burwood Rd	35	30.4	0.0	0.0
Windsor Ave	37	38.7	0.0	0.0
Balmoral Ave	40	39.9	0.0	+0.2
Hampton St	43	44.4	-1.6	0.0

Ku, Initial Loss and Continuing Loss

The results of the sensitivity analysis for losses are provided in Table E14 and Table E15 and on *Maps S.9* to *S.14* in Volume 3.

Table E14 – Results of sensitivity analysis for Ku, IL and CL - 100 year ARI flood depths

Location	Depth Location	100 year ARI Flood Depth	Difference in Flood Depth (m)					
			Ku -20%	Ku +20%	IL -10%	IL +10%	CL -10%	CL +10%
Detention Basin	H01	1.52	0	0	0	0	0	0
Mitchell St	H02	0.17	0	0	0	0	0	0
Kingsbury St - Channel	H03	0.52	0	0	0	0	0	0
Kingsbury St - Styles St	H04	0.11	0	0	0	0	0	0
Tangarra St East	H05	0.30	0	0	0	0	0	0
Rawson St	H06	1.13	0	0	0	-0.01	0	-0.01
Park U/S Stanley St	H07	0.72	0	0	0	0	0	0
Stanley St	H08	0.32	0	0	0	0	0	0
Georges River Road	H09	0.24	0	0	0	0	0	0
Burwood Road [D/S limit of LGA]	H10	0.32	0	0	0	0	0	0
Windsor Ave	H11	2.83	0	0	0.01	0	0.01	0
Balmoral Ave	H12	0.33	0	0	0.01	0.02	0	0
Hampton St	H13	2.70	0	0	0	0	0	0
Small Bridge U/S Brighton Ave	H14	0.39	0	0	0	0	0	0

The result of sensitivity analysis shows the *TUFLOW* model is not sensitive to initial loss, continued loss, pit Ku loss parameter and Manning's 'n' where the resulting difference in analysed flood surface level varied by less than 0.01 metres in the majority of the scenarios tested.

Table E15 – Results of sensitivity analysis for Ku, IL and CL - 100 year ARI flows

Location	ID	100 year ARI Flow	Difference in Flow (m^3/s)					
			Ku +20%	Ku -20%	IL +10%	IL -10%	CL +10%	CL -10%
Shelley St (Into Park)	117 & 74	9.7	0.0	-0.1	0.0	0.0	0.0	0.0
Basin Inflow (U/S) From Neast	56 & 116	30.3	-0.1	0.0	0.0	0.0	0.0	0.0
Basin Inflow From West (Portland St)	115	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Basin Outflow (D/S) (Us Mitchell St)	55	33.1	-0.1	0.0	0.0	0.0	-0.1	0.1
D/S Mitchell St	18	9.4	-0.2	0.0	0.0	0.0	0.0	0.0
Stiles St (Inflow)	1	20.0	0.0	-0.1	0.0	0.0	0.0	0.0
Kingsbury Channel O/L Flow To Channel	119	9.0	0.0	0.0	0.0	0.0	0.0	0.0
Stiles St (Cnr Kingsbury) (Outflow)	3	13.3	0.0	0.0	0.0	0.0	0.0	0.0
Tangarra St East Culvert	120	21.0	0.0	0.0	0.0	0.0	0.0	0.0
Rawson St	122	14.0	0.0	0.0	0.0	0.0	0.0	0.0
Stanley St	30	28.9	0.0	0.0	0.0	0.0	0.0	0.0
Georges River Rd	33	23.0	0.0	0.0	0.0	0.0	-0.1	0.1
Burwood Rd	35	30.4	0.0	0.0	0.0	0.0	-0.1	0.1
Windsor Ave	37	38.7	0.0	0.0	0.0	0.0	-0.1	0.1
Balmoral Ave	40	39.9	0.0	0.0	0.0	0.0	-0.1	0.1
Hampton St	43	44.4	0.0	0.3	0.2	-0.3	0.2	0.2

Blockage Variations

The effect of blockage of hydraulic structures has been investigated in accordance with the recommendations on Engineers Australia, (2013) *Australian Rainfall and Runoff: Revision Projects Project 11: Blockage of Hydraulic Structures (Stage 2)*. The results of the sensitivity analysis for blockage are provided in Table E16 and Table E17 and on *Maps S.15* to *S.17* in Volume 3.

Table E16 – Results of sensitivity analysis for blockage variations - 100 year ARI flood depths

Location	Depth Location	100 year ARI Flood Depth	Difference in Flood Depth (m)		
			20% Blockage Pits 0% Blockage Culverts	100% Blockage Pits 50% Blockage Culverts	100% Blockage Pits 100% Blockage Culverts
Detention Basin	H01	1.52	-0.01	0.05	0.05
Mitchell St	H02	0.17	0	0.05	0.05
Kingsbury St - Channel	H03	0.52	0	0.1	0.18
Kingsbury St - Styles St	H04	0.11	0	0.07	0.1
Tangarra St East	H05	0.30	0	0.06	0.11
Rawson St	H06	1.13	-0.01	0.11	0.19
Park U/S Stanley St	H07	0.72	-0.01	0.12	0.22
Stanley St	H08	0.32	0	0.09	0.14
Georges River Road	H09	0.24	-0.01	0.01	0.06
Burwood Road [D/S limit of LGA]	H10	0.32	-0.01	0.11	0.18
Windsor Ave	H11	2.83	-0.01	0.16	0.29
Balmoral Ave	H12	0.33	-0.01	0.3	0.54
Hampton St	H13	2.70	0	0.32	0.84
Small Bridge U/S Brighton Ave	H14	0.39	-0.01	0.07	0.14

Flood levels adjacent to the main central channel are sensitive to blockage of culvert crossings, particularly upstream of culverts. Flood levels increase by as much as 0.2 metres for 50% blockage and 0.3 metres for 100% blockage. This is attributable to a large component of the 100 year event conveyance being contained within the channel. As such, a blockage factor has been applied to all design runs in determining Flood Planning Levels and Flood Planning Area such that any incidence of total blockage is appropriately contained within any freeboard provision for properties which may be affected by a blockage scenario is appropriately identified in the analysed flood extents.

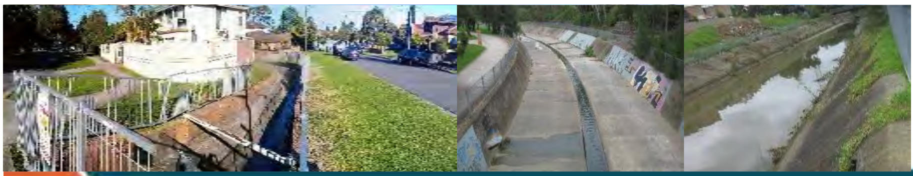


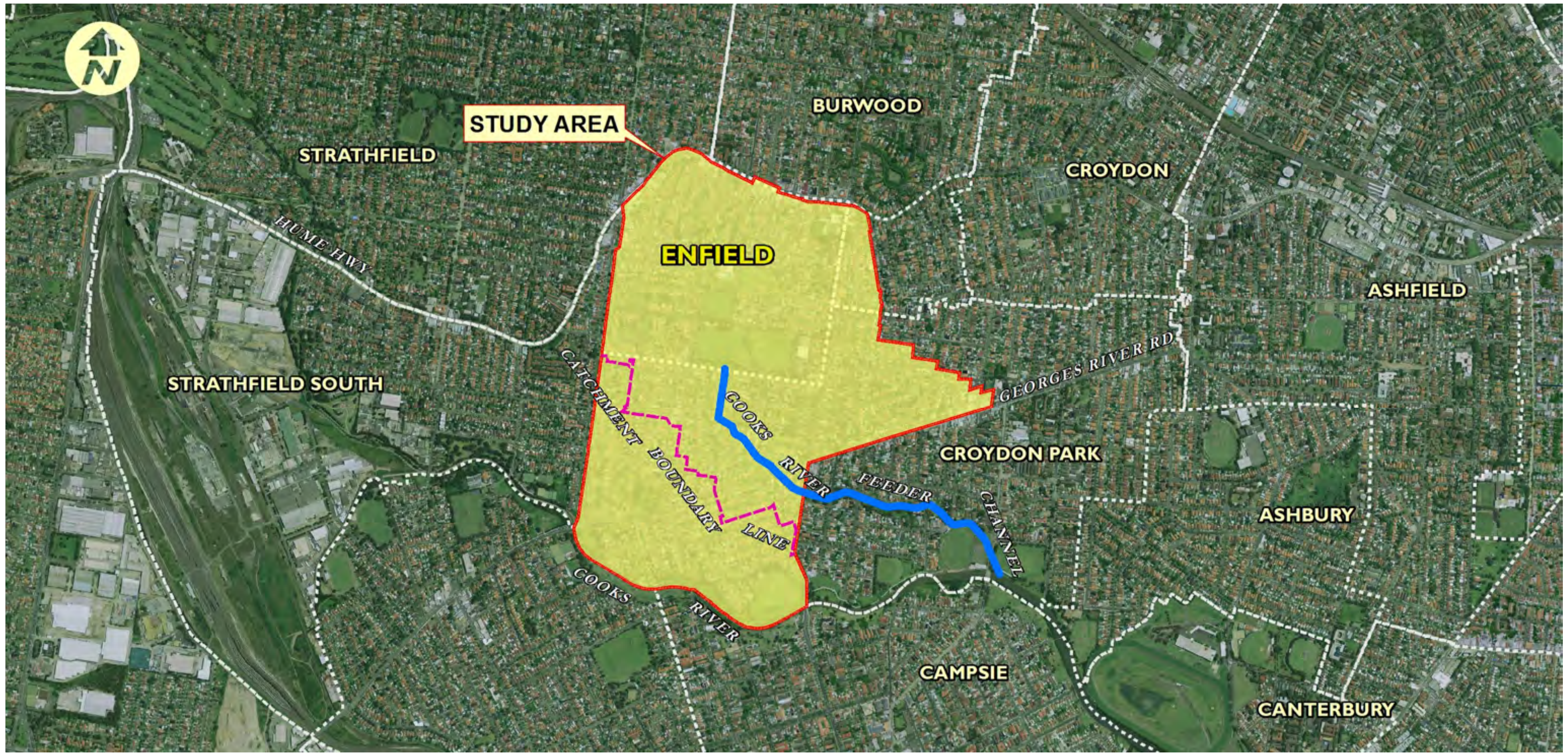
Table E17 – Results of sensitivity analysis for blockage variations - 100 year ARI flows

Location	ID	100 year ARI Flow	Difference in Flow (m^3/s)		
			20% Blockage Pits 0% Blockage Culverts	100% Blockage Pits 50% Blockage Culverts	100% Blockage Pits 100% Blockage Culverts
Shelley St (Into Park)	117 & 74	9.7	-0.1	1.7	1.7
Basin Inflow (U/S) From Neast	56 & 116	30.3	-0.3	1.5	1.5
Basin Inflow From West (Portland St)	115	3.3	-0.1	0.6	0.6
Basin Outflow (D/S) (Us Mitchell St)	55	33.1	-0.4	1.9	1.9
D/S Mitchell St	18	9.4	0.8	-9.7	-9.7
Stiles St (Inflow)	1	20.0	-0.9	4.1	4.1
Kingsbury Channel O/L Flow To Channel	119	9.0	-0.3	0.3	-1.1
Stiles St (Cnr Kingsbury) (Outflow)	3	13.3	-0.7	4.2	5.2
Tangarra St East Culvert	120	21.0	-0.1	-4.0	-9.0
Rawson St	122	14.0	-0.4	5.0	8.5
Stanley St	30	28.9	-0.3	-17.2	-16.4
Georges River Rd	33	23.0	-0.4	-11.9	-7.3
Burwood Rd	35	30.4	-0.5	-7.6	0.9
Windsor Ave	37	38.7	-0.5	2.7	2.9
Balmoral Ave	40	39.9	-0.6	2.8	4.4
Hampton St	43	44.4	-0.1	1.0	1.7

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY

BROWN Smart Consulting

FOR BURWOOD COUNCIL
VOLUME 2: FLOOD MAPPING



LOCALITY PLAN
N.T.S.

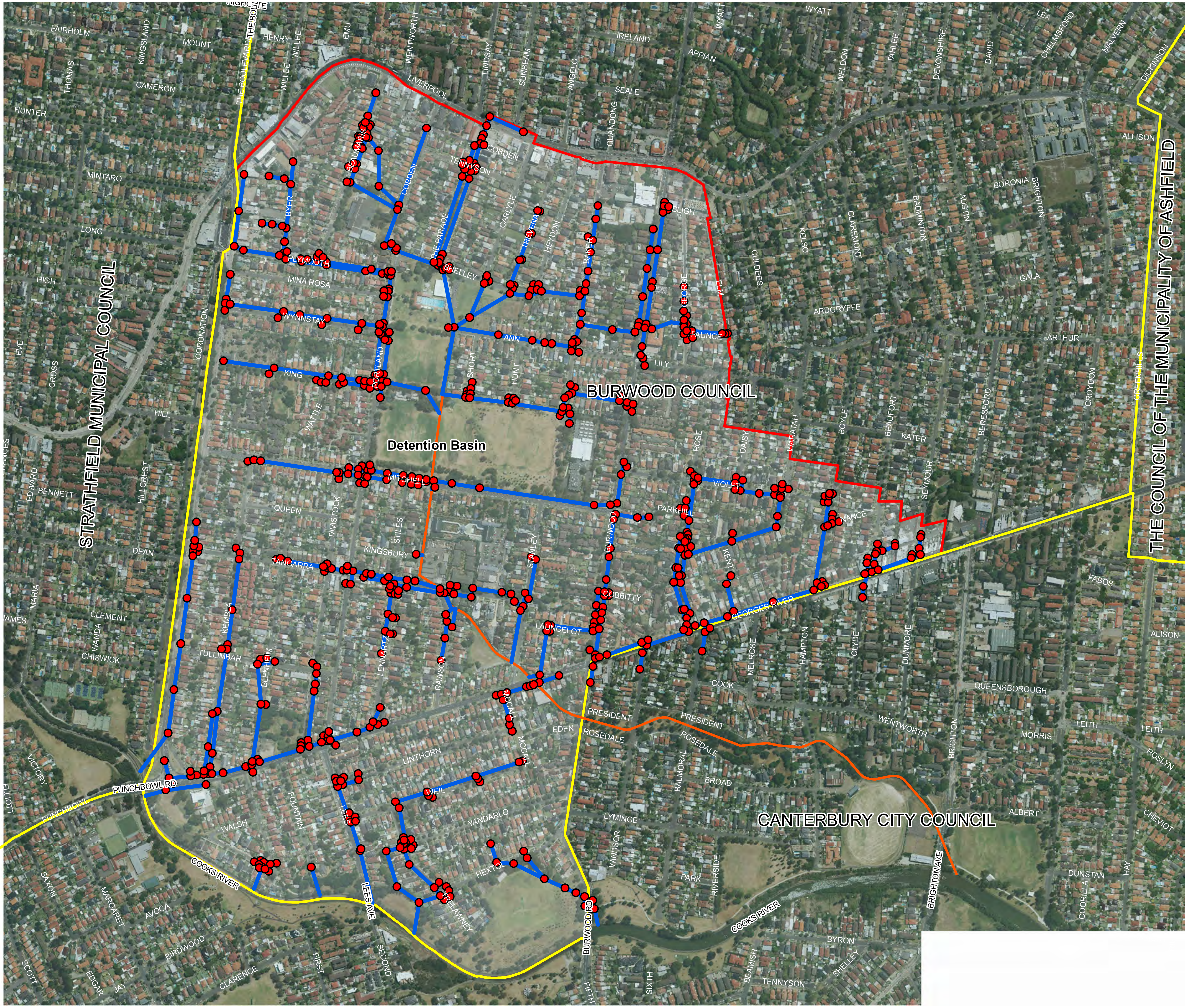
SHEET LIST TABLE

MAP No.	DRAWING ID	DRAWING TITLE
GENERAL		
1	StudyArea	STUDY AREA
2	Catchments	INDIVIDUAL URBAN CATCHMENT DELINEATION
3	Rough_Area	SPATIAL DISTRIBUTION OF ROUGHNESS VALUES
4	STAT.LOC	STATIONS AND HOTSPOT LOCATIONS
5	Comm_cons	COMMUNITY CONSULTATION RESULTS
6	5y.D	5 YEAR ARI PEAK FLOOD DEPTH
7	10y.D	10 YEAR ARI PEAK FLOOD DEPTH
8	20y.D	20 YEAR ARI PEAK FLOOD DEPTH
9	50y.D	50 YEAR ARI PEAK FLOOD DEPTH
10	100y.D	100y YEAR ARI PEAK FLOOD DEPTH
11	200y.D	200y YEAR ARI PEAK FLOOD DEPTH
12	PMF.D	PMF PEAK FLOOD DEPTH
13	5y.V	5 YEAR ARI PEAK FLOOD VELOCITY
14	10y.V	10 YEAR ARI PEAK FLOOD VELOCITY
15	20y.V	20 YEAR ARI PEAK FLOOD VELOCITY
16	50y.V	50 YEAR ARI PEAK FLOOD VELOCITY
17	100y.V	100 YEAR ARI PEAK FLOOD VELOCITY
18	200y.V	200 YEAR ARI PEAK FLOOD VELOCITY
19	PMF.V	PMF PEAK FLOOD VELOCITY
20	5y.PFHC	5 YEAR ARI PROVISIONAL FLOOD HAZARD CATEGORISATION
21	10y.PFHC	10 YEAR ARI PROVISIONAL FLOOD HAZARD CATEGORISATION
22	20y.PFHC	20 YEAR ARI PROVISIONAL FLOOD HAZARD CATEGORISATION
23	50y.PFHC	50 YEAR ARI PROVISIONAL FLOOD HAZARD CATEGORISATION
24	100y.PFHC	100 YEAR ARI PROVISIONAL FLOOD HAZARD CATEGORISATION
25	200y.PFHC	200 YEAR ARI PROVISIONAL FLOOD HAZARD CATEGORISATION
26	PMF.PFHC	PMF PROVISIONAL FLOOD HAZARD CATEGORISATION
27	5y.HC	5 YEAR ARI HYDRAULIC CATEGORISATION
28	10y.HC	10 YEAR ARI HYDRAULIC CATEGORISATION
29	20y.HC	20 YEAR ARI HYDRAULIC CATEGORISATION
30	50y.HC	50 YEAR ARI HYDRAULIC CATEGORISATION
31	100y.HC	100 YEAR ARI HYDRAULIC CATEGORISATION
32	200y.HC	200 YEAR ARI HYDRAULIC CATEGORISATION
33	PMF.HC	PMF HYDRAULIC CATEGORISATION
34	5y.BCHC	5 YEAR ARI BC PROVISIONAL HYDRAULIC CATEGORISATION
35	10y.BCHC	10 YEAR ARI BC PROVISIONAL HYDRAULIC CATEGORISATION
36	20y.BCHC	20 YEAR ARI BC PROVISIONAL HYDRAULIC CATEGORISATION
37	50y.BCHC	50 YEAR ARI BC PROVISIONAL HYDRAULIC CATEGORISATION
38	100y.BCHC	100 YEAR ARI BC PROVISIONAL HYDRAULIC CATEGORISATION
39	200y.BCHC	200 YEAR ARI BC PROVISIONAL HYDRAULIC CATEGORISATION
40	PMF.BCHC	PMF BC PROVISIONAL HYDRAULIC CATEGORISATION
41	100y. FERP	100 YEAR ARI PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION
42	PMF. FERP	PMF PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION
43	OF.TAG	OVERLAND FLOODING PROPERTY TAGGING FOR 100 YEAR ARI
44	MF.TAG	MAINSTREAM FLOODING PROPERTY TAGGING FOR 100 YEAR ARI + 0.5M
45	CR.TAG	PROPERTY TAGGING FOR COOKS RIVER 100 YEAR ARI + 0.5M
46	LOT.TAG	AMALGAMATED PROPERTY TAGGING

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY

CONSULT AUSTRALIA Member Firm

Project No.:	Stage:	Revision:
X12342	SUBMISSION	D



BROWN Smart Water

Legend

- Pits
- Pipes
- Cooks River Feeder Channel
- LGA Boundary
- Study Area

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

STUDY AREA

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	StudyArea

Map No. **1**

BROWN
Smart Water

Legend

- Cooks River Feeder Channel
- Pipes
- Internal Catchment Boundary
- Catchments
- Cadastre

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

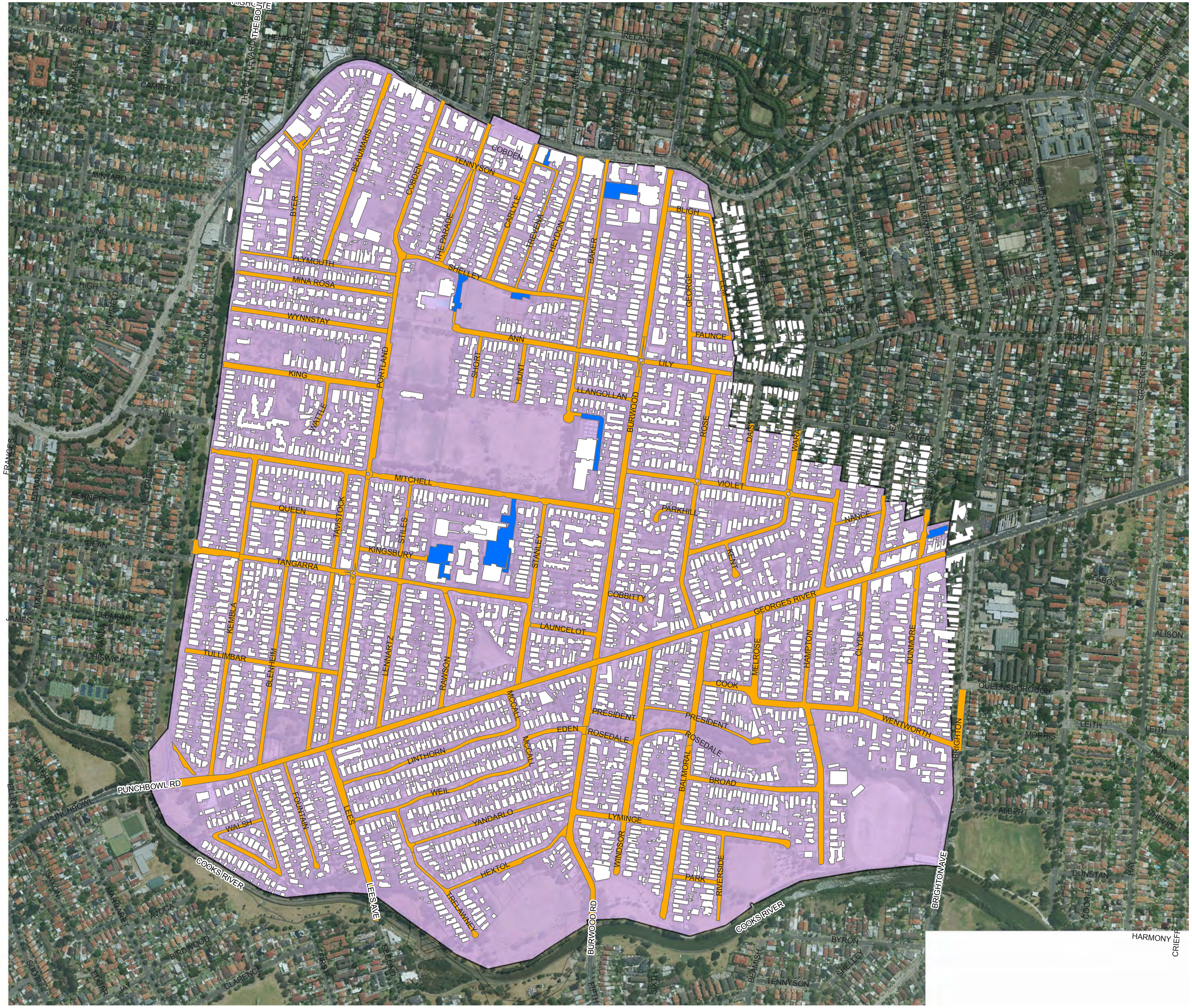
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

INDIVIDUAL URBAN CATCHMENT DELINEATION

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	Catchments

Map No. **2**



BROWN
Smart Water

Legend

Cadastre

Roughness

- Bitumen Road
- Car Parks
- Buildings
- Pervious Areas

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SPATIAL DISTRIBUTION OF ROUGHNESS VALUES

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	Rough_Area

Map No. **3**

BROWN
Smart Water

Legend

- Depth Location
- Flow Stations
- Cooks River Feeder Channel
- Study Area
- Cadastre

N

0 50 100 200 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

HISTORY STATIONS AND HOTSPOT LOCATIONS

Scale	
Drawn	1:6,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	STAT.LOC

Map No. 4

BROWN
Smart Water

Legend

- Community Consultation Sought
- Community Consultation Replies
- Cooks River Feeder Channel
- Cadastre

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

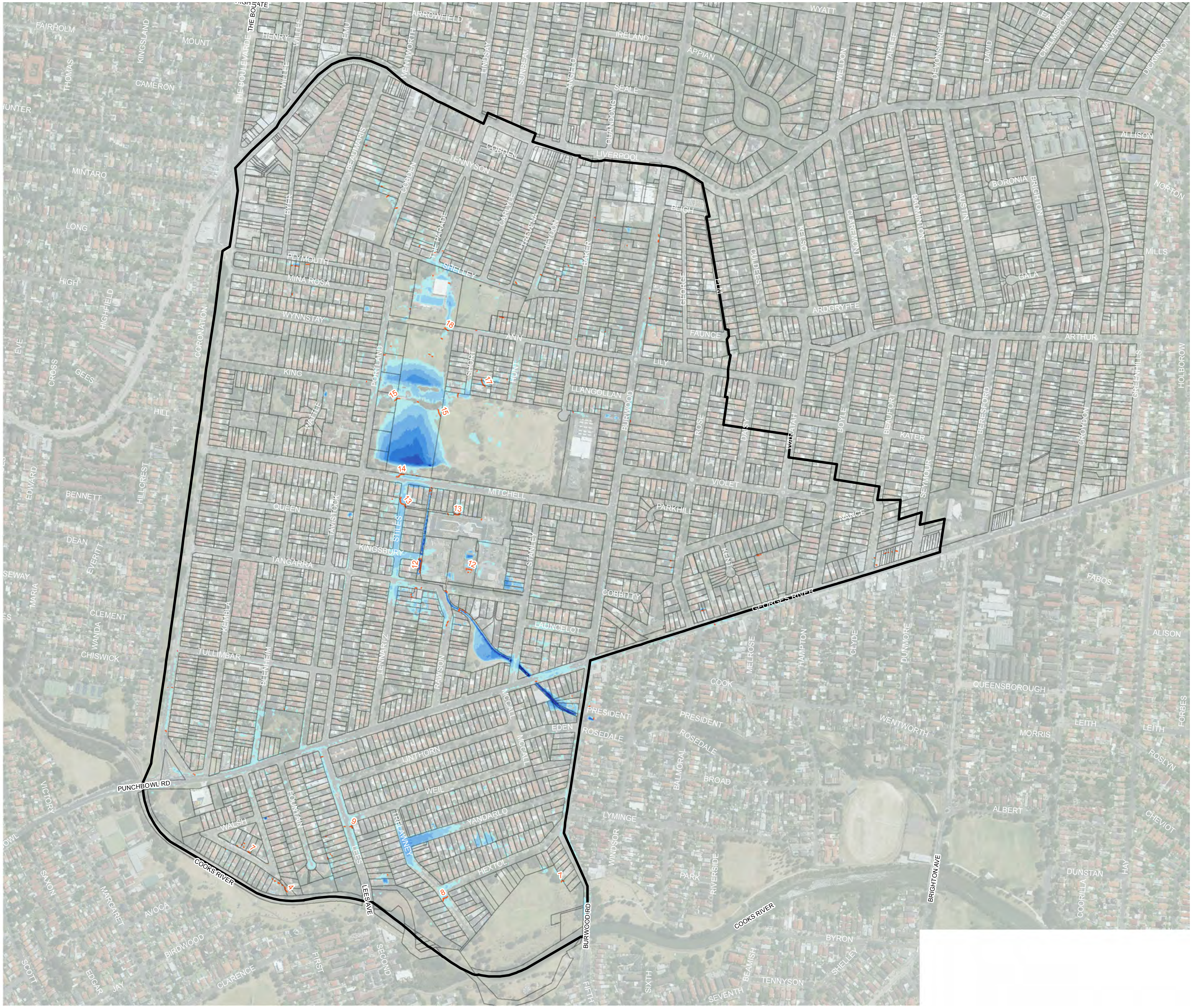
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

COMMUNITY CONSULTATION RESULTS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	Comm_cons

Map No. **5**



BROWN
Smart Water

Legend

- Study Area
- Cadastre
- Contours (m AHD)

Depth (m)

- 0.15 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

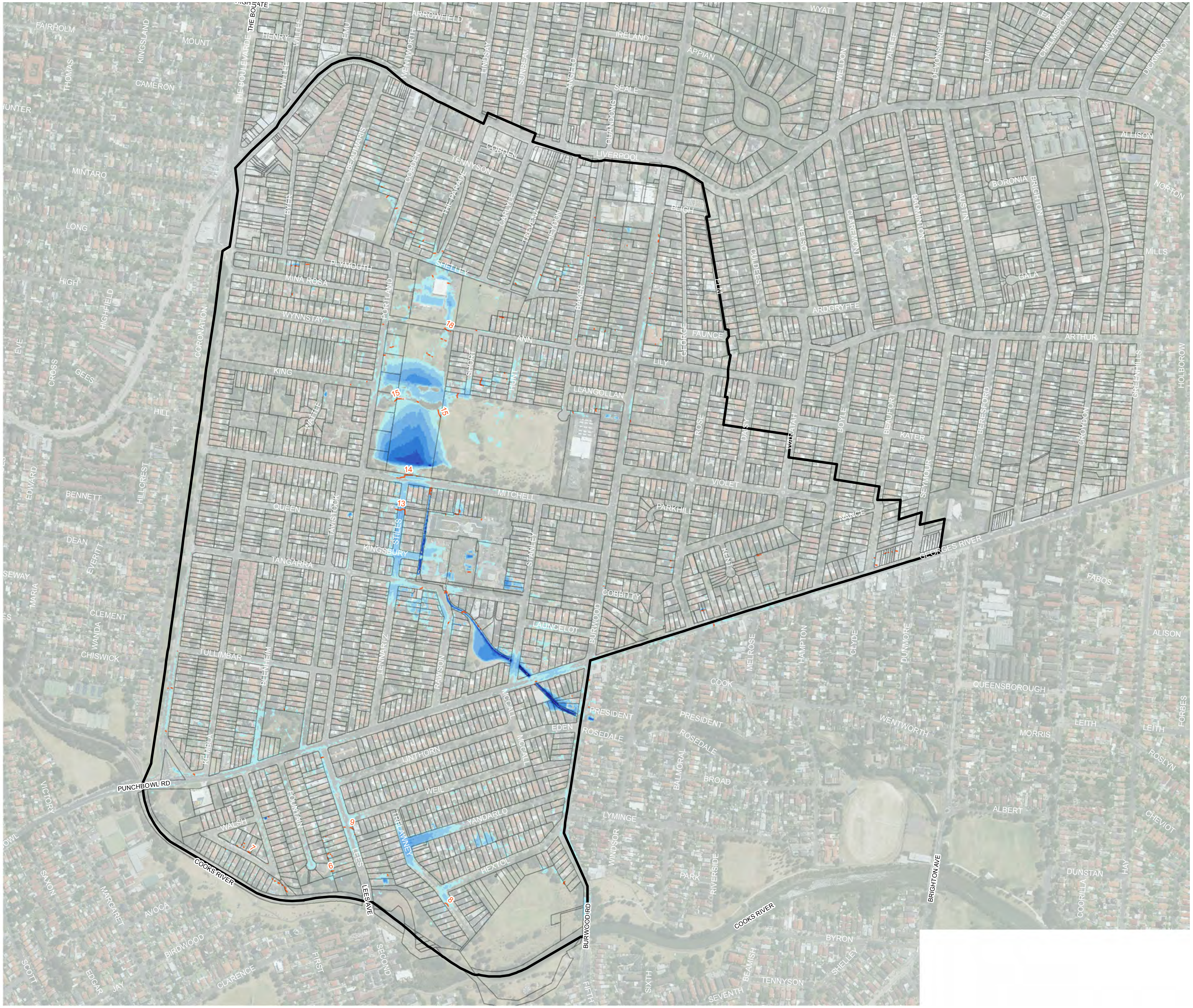
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD DEPTH FOR 5 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	5y.D

Map No. **6**



BROWN
Smart Water

Legend

- Study Area
- Cadastre
- Contours (m AHD)

Depth (m)

- 0.15 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

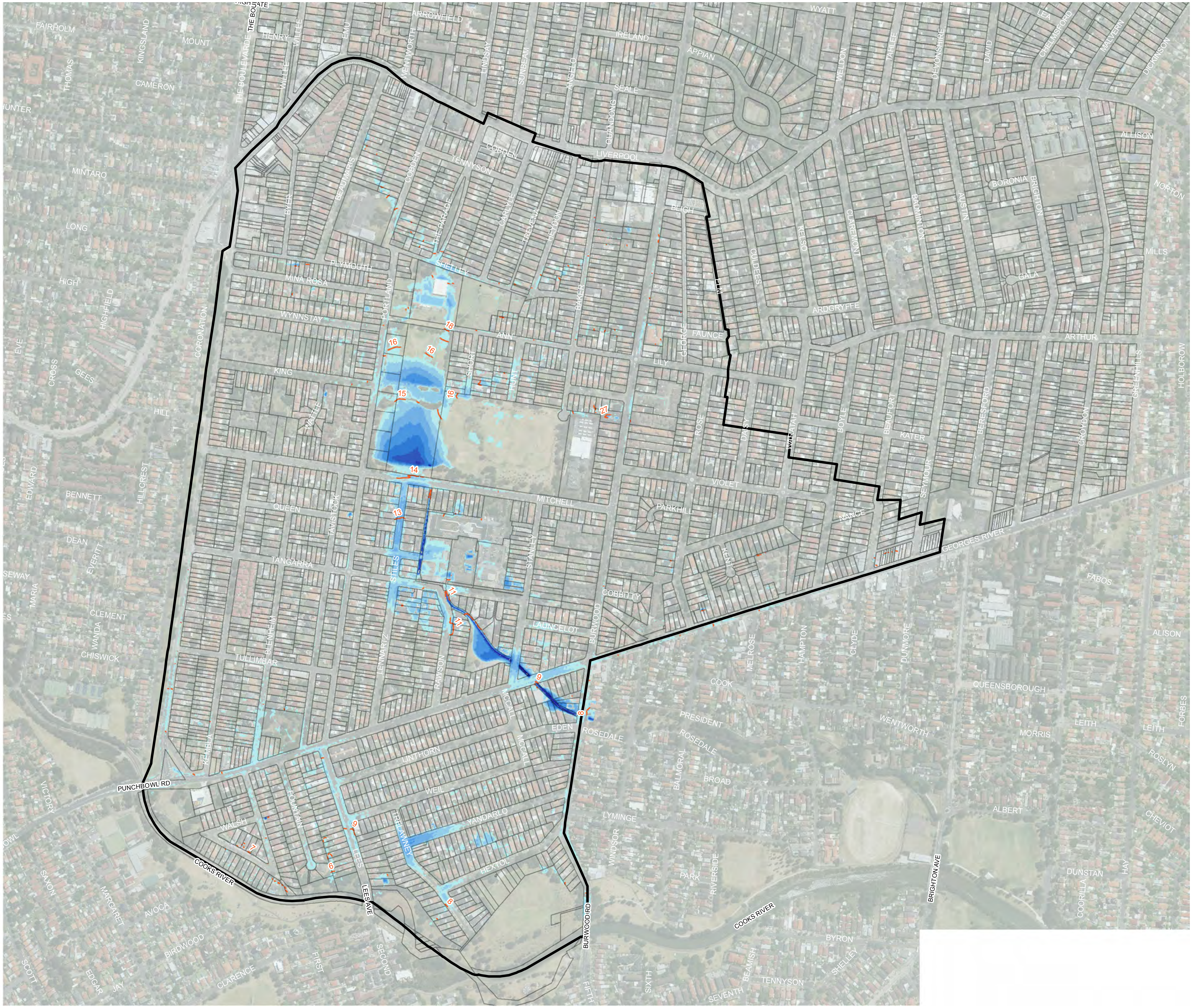
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD DEPTH FOR 10 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	10y.D

Map No. 7



Legend

Study Area
Cadastre
Contours (m AHD)

Depth (m)

- 0.15 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2

N

0 50 100 200 300 Metres

BROWN *Smart Water*

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

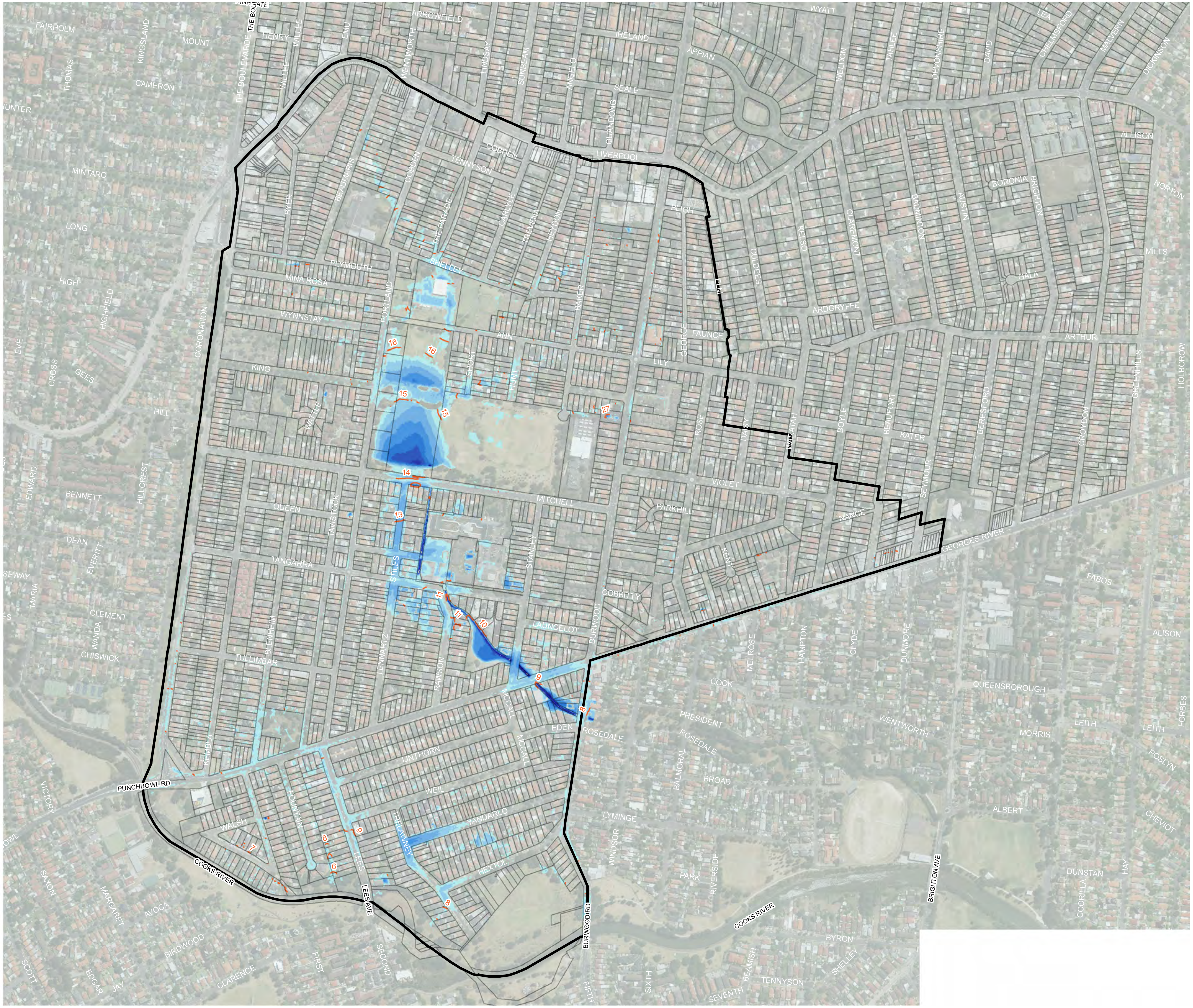
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD DEPTH FOR 20 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	20y.D

Map No. 8



BROWN *Smart Water*

Legend

- Study Area
- Cadastre
- Contours (m AHD)

Depth (m)

- 0.15 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

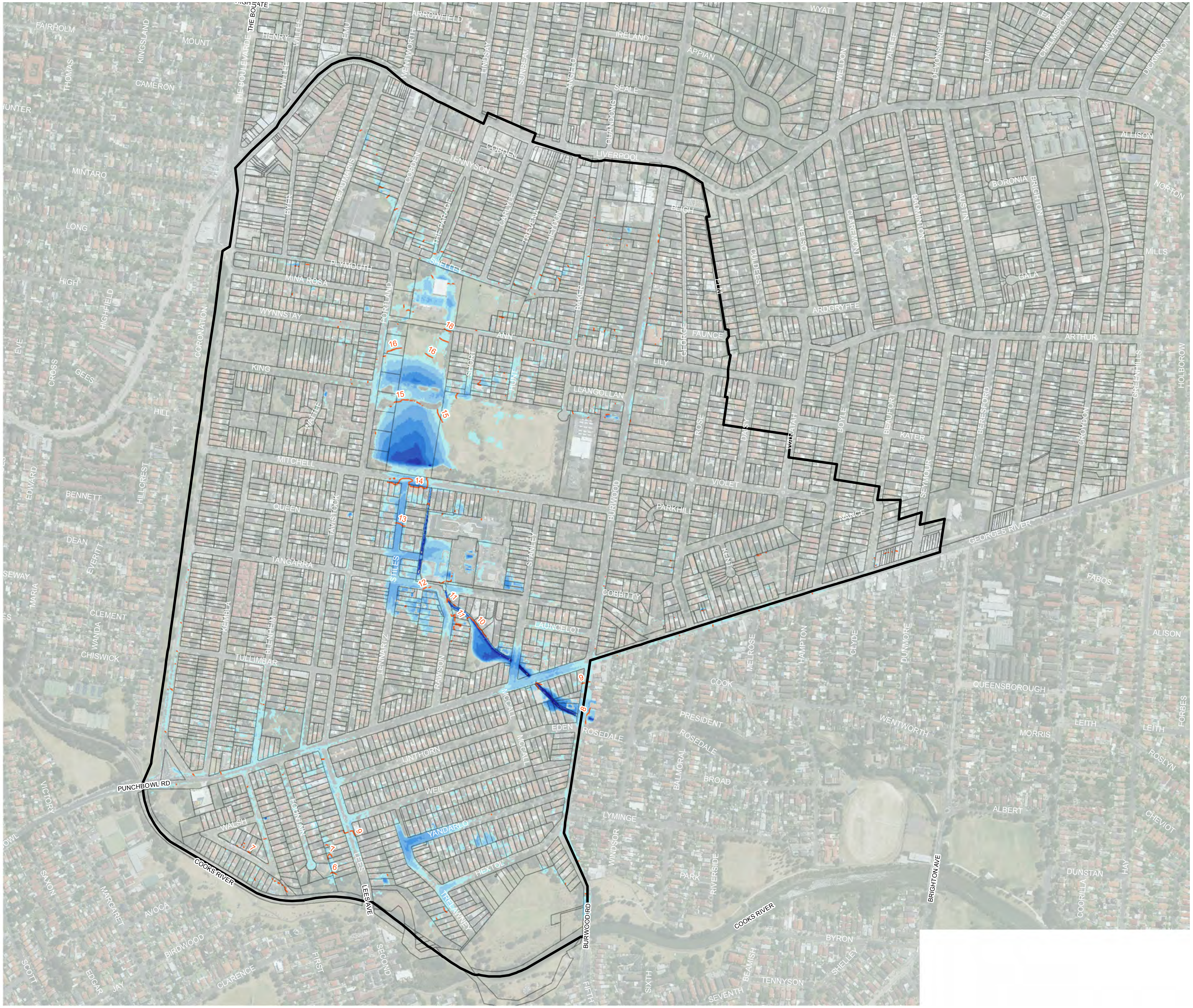
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD DEPTH FOR 50 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	50y.D

Map No. **9**



Legend

Study Area

Cadastre

Contours (m AHD)

Depth (m)

0.15 - 0.3

0.3 - 0.5

0.5 - 0.75

0.75 - 1

1 - 1.25

1.25 - 1.5

1.5 - 2

> 2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

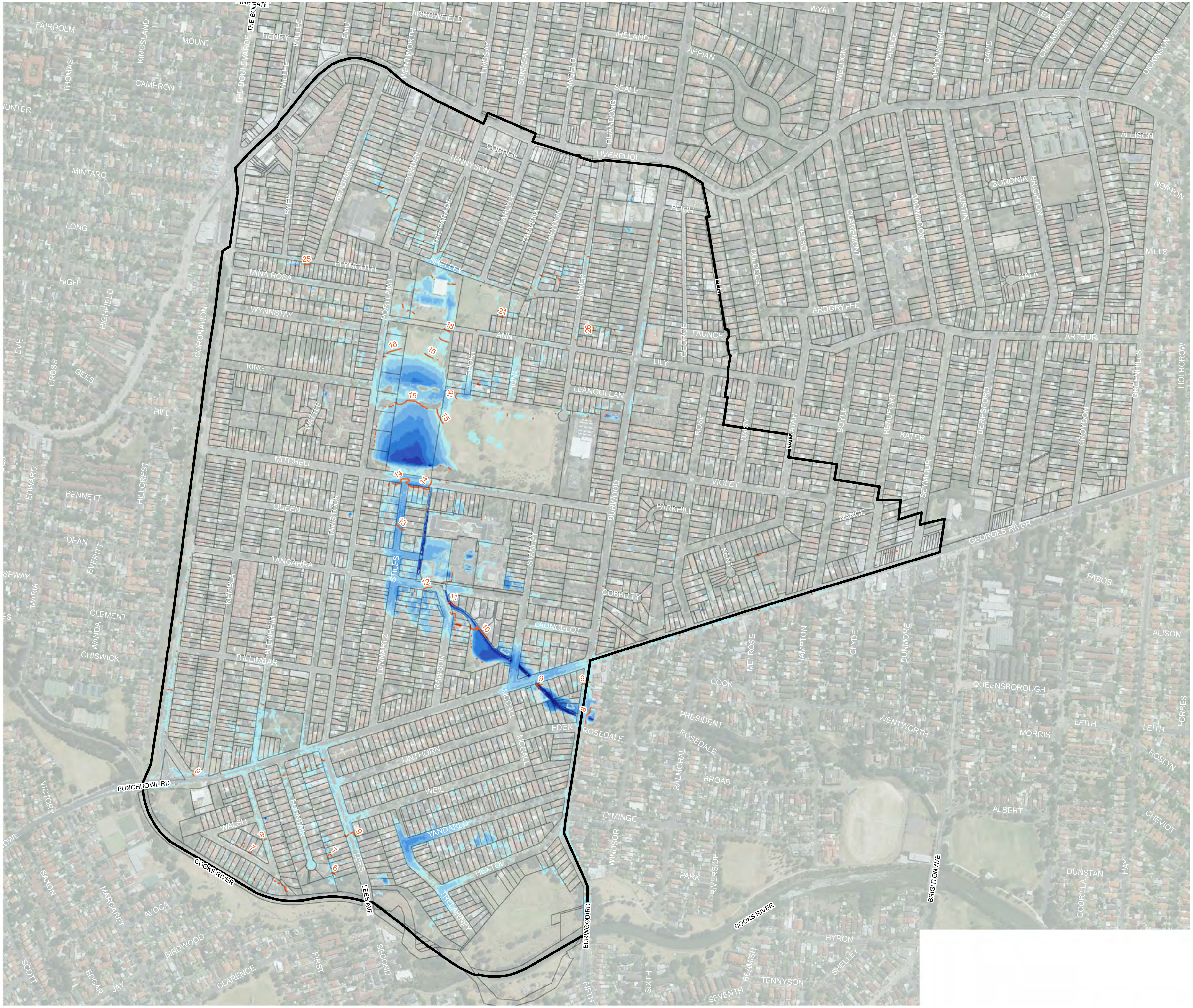
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD DEPTH FOR 100 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	100y.D

Map No. **10**



BROWN *Smart Water*

Legend

- Study Area
- Cadastre
- Contours (m AHD)

Depth (m)

- 0.15 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

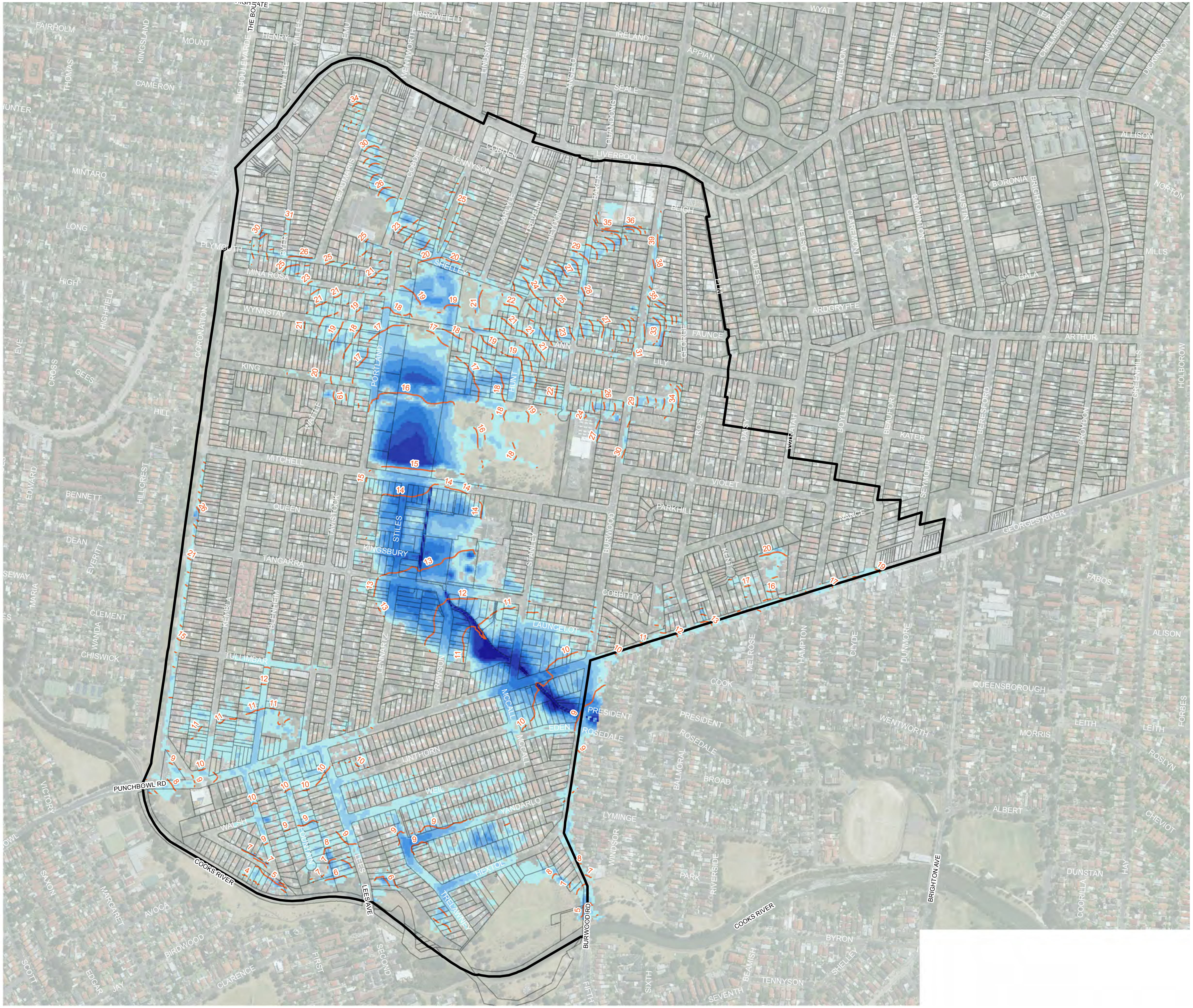
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD DEPTH FOR 200 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	200y.D

Map No. **11**



BROWN
Smart Water

Legend

- Study Area
- Cadastre
- Contours (m AHD)

Depth (m)

- 0.15 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

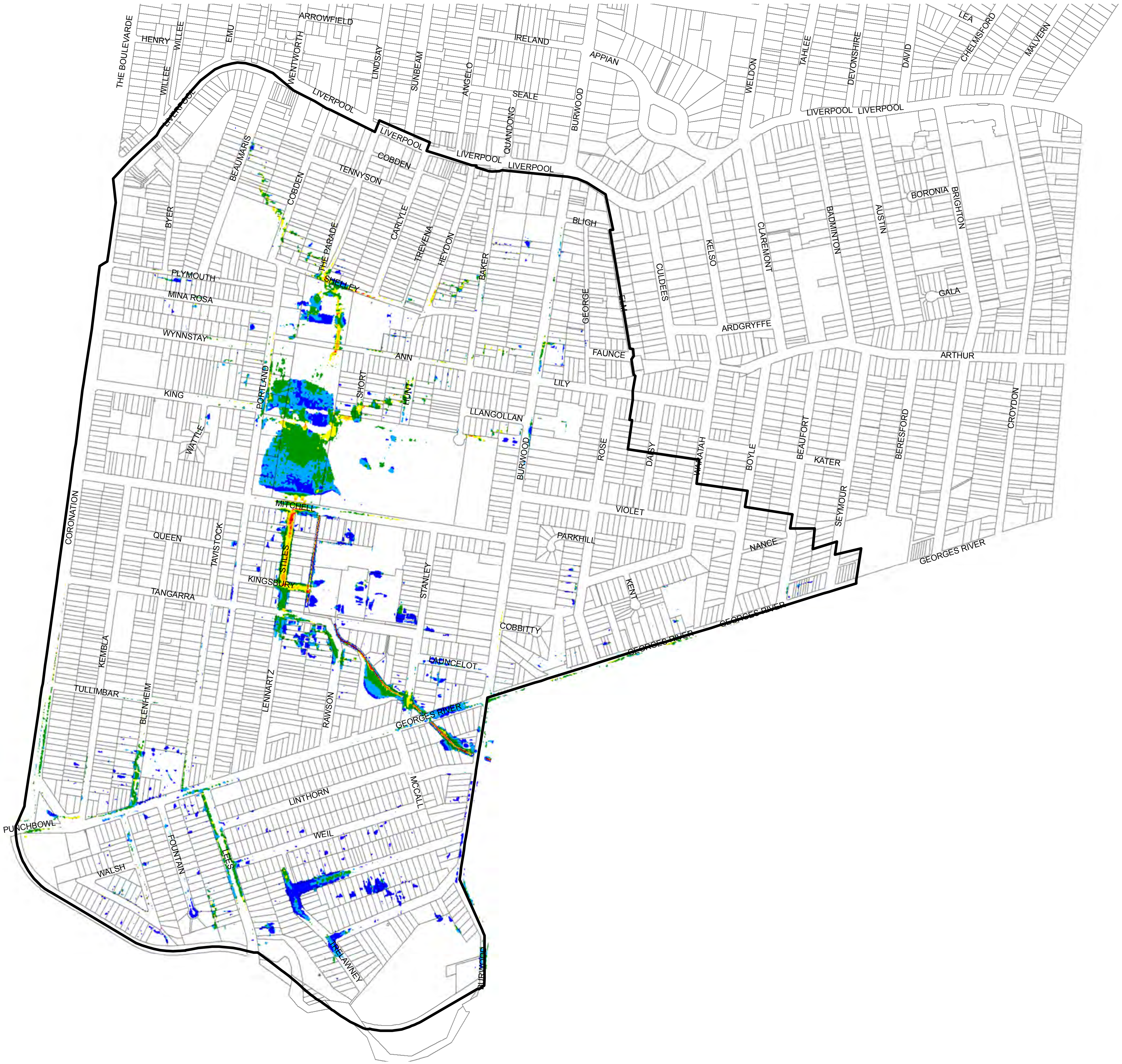
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD DEPTH FOR PROBABLE MAXIMUM FLOOD

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	PMF.D

Map No. **12**



BROWN
Smart Water

Legend

Study Area
Cadastre

Peak Flood Velocity (m/s)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 3
- > 3.0

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

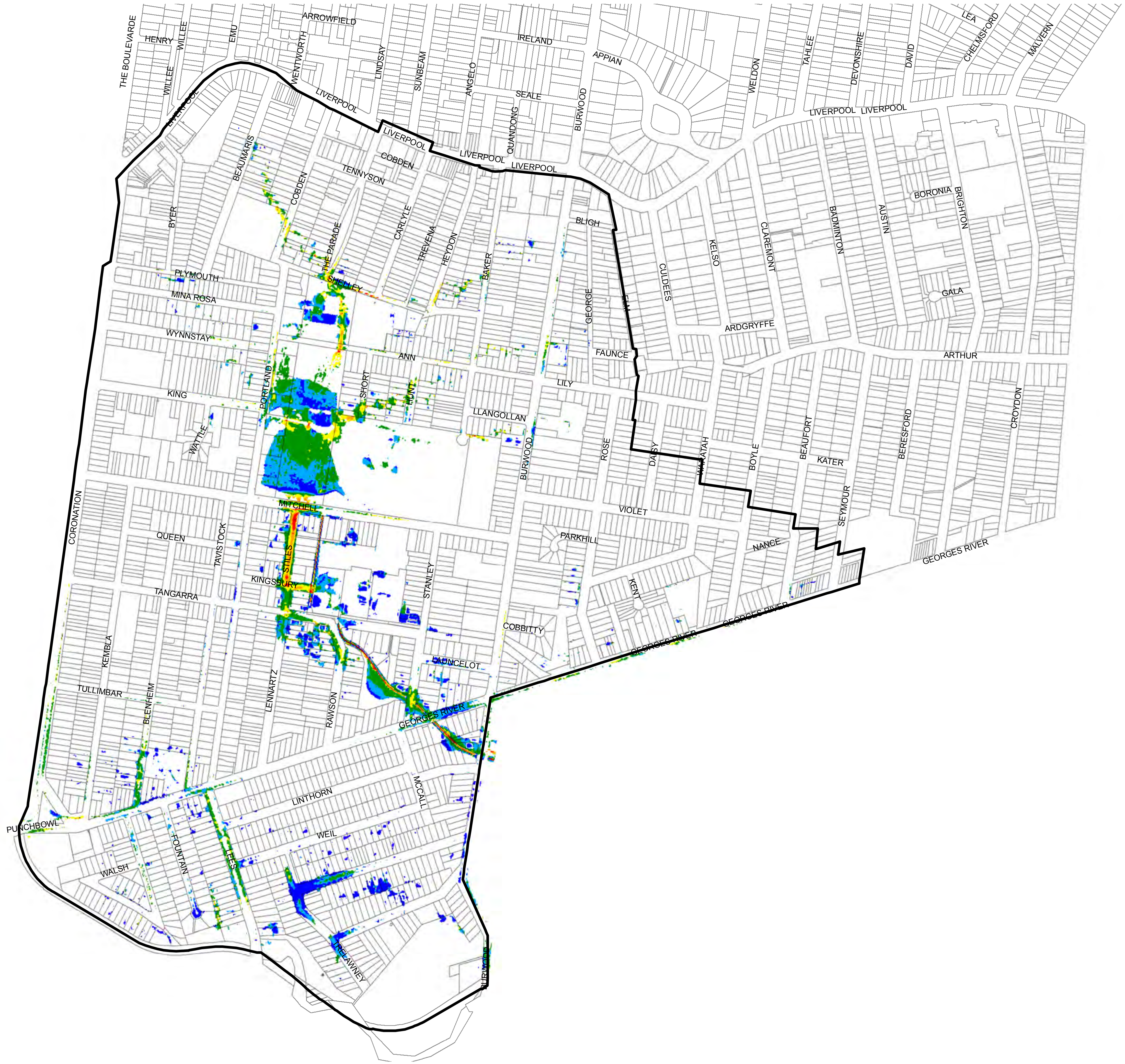
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD VELOCITY FOR 5 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	5y.V

Map No. **13**



BROWN
Smart Water

Legend

Study Area
Cadastre

Peak Flood Velocity (m/s)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 3
- > 3.0

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

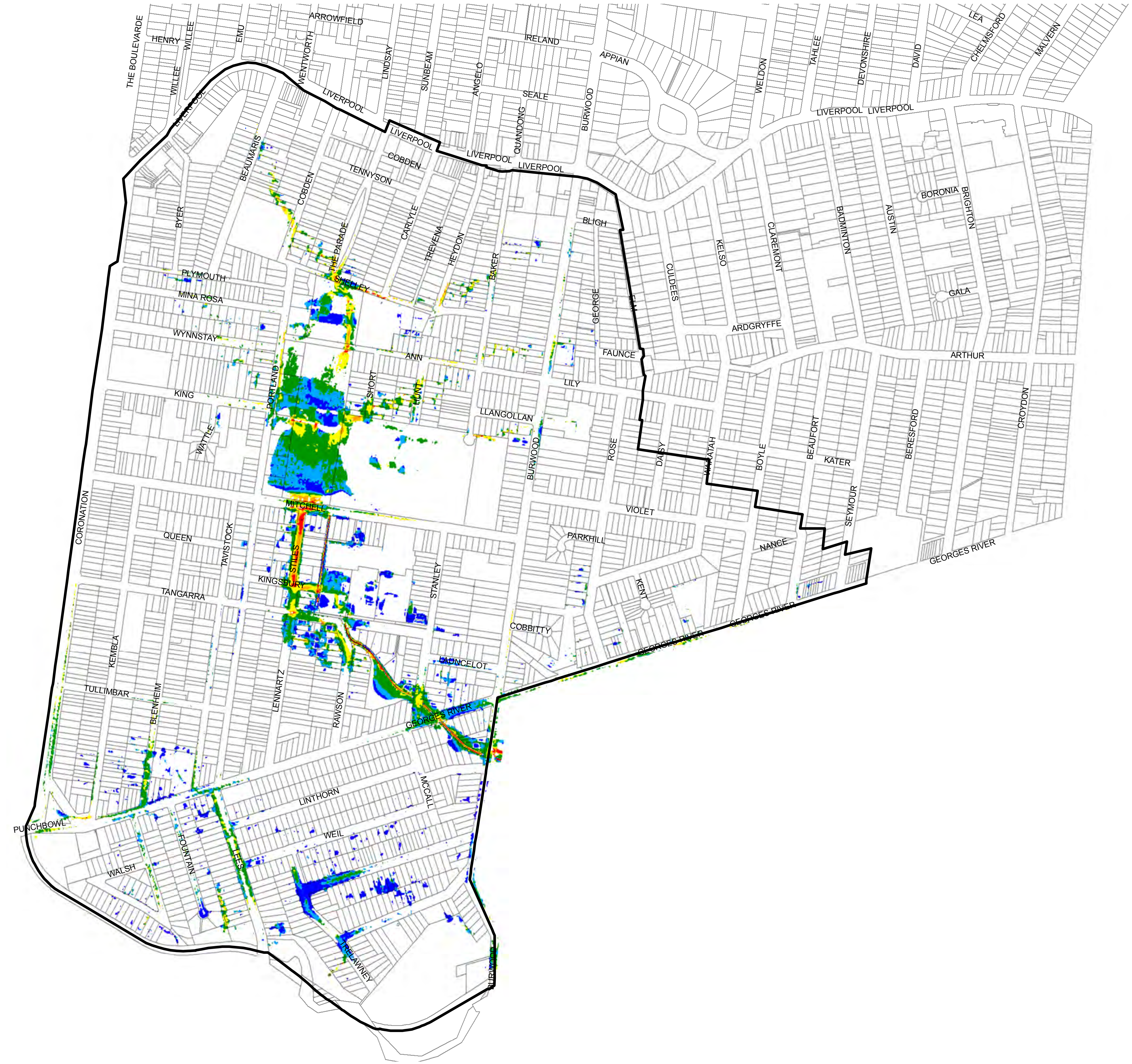
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD VELOCITY FOR 10 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	10y.V

Map No. **14**



BROWN Smart Water

Legend

- Study Area
- Cadastre

Peak Flood Velocity (m/s)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 3
- > 3.0

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

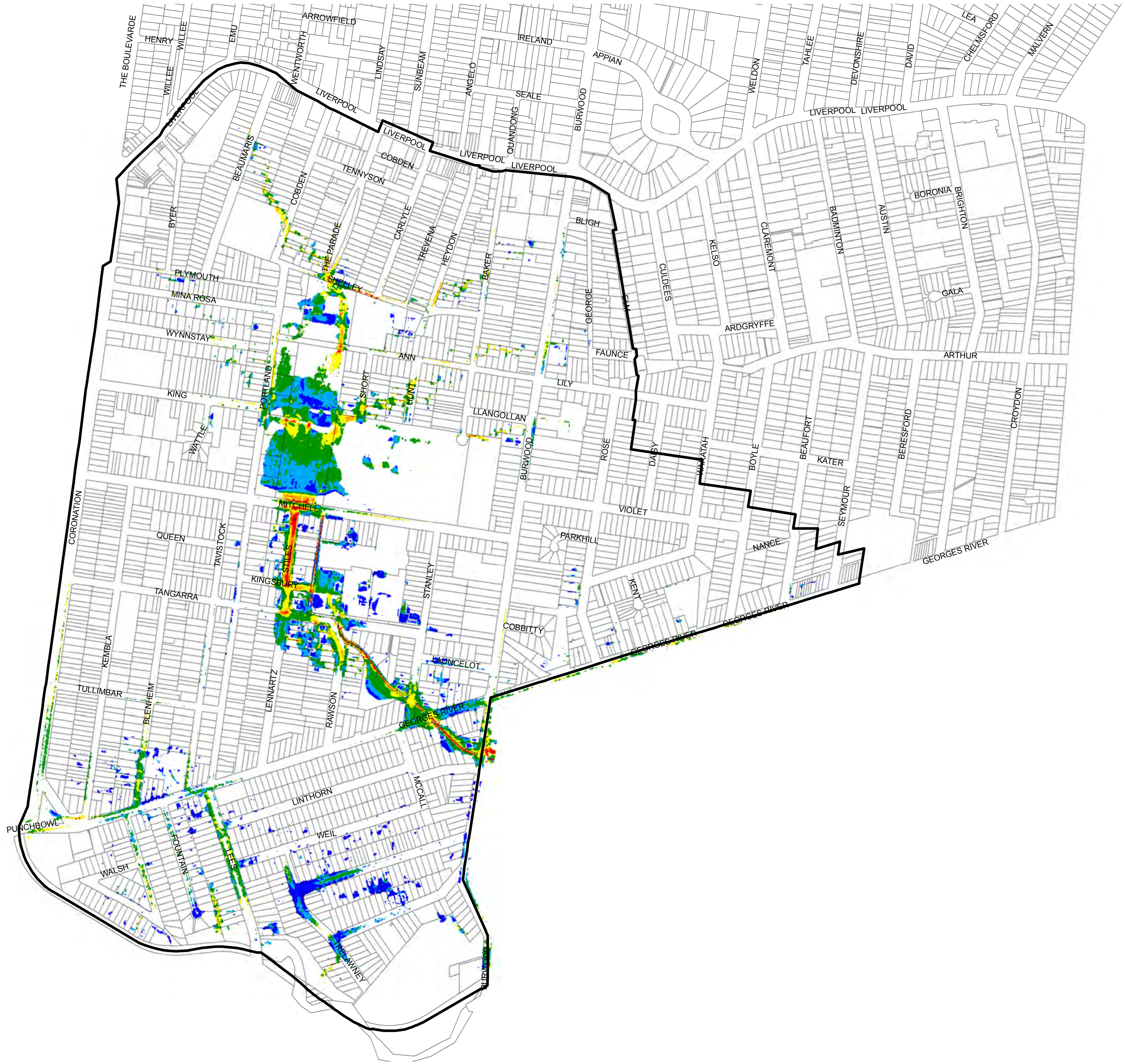
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD VELOCITY FOR 20 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	20y.V

Map No. **15**



BROWN *Smart Water*

Legend

- Study Area
- Cadastre

Peak Flood Velocity (m/s)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 3
- > 3.0

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

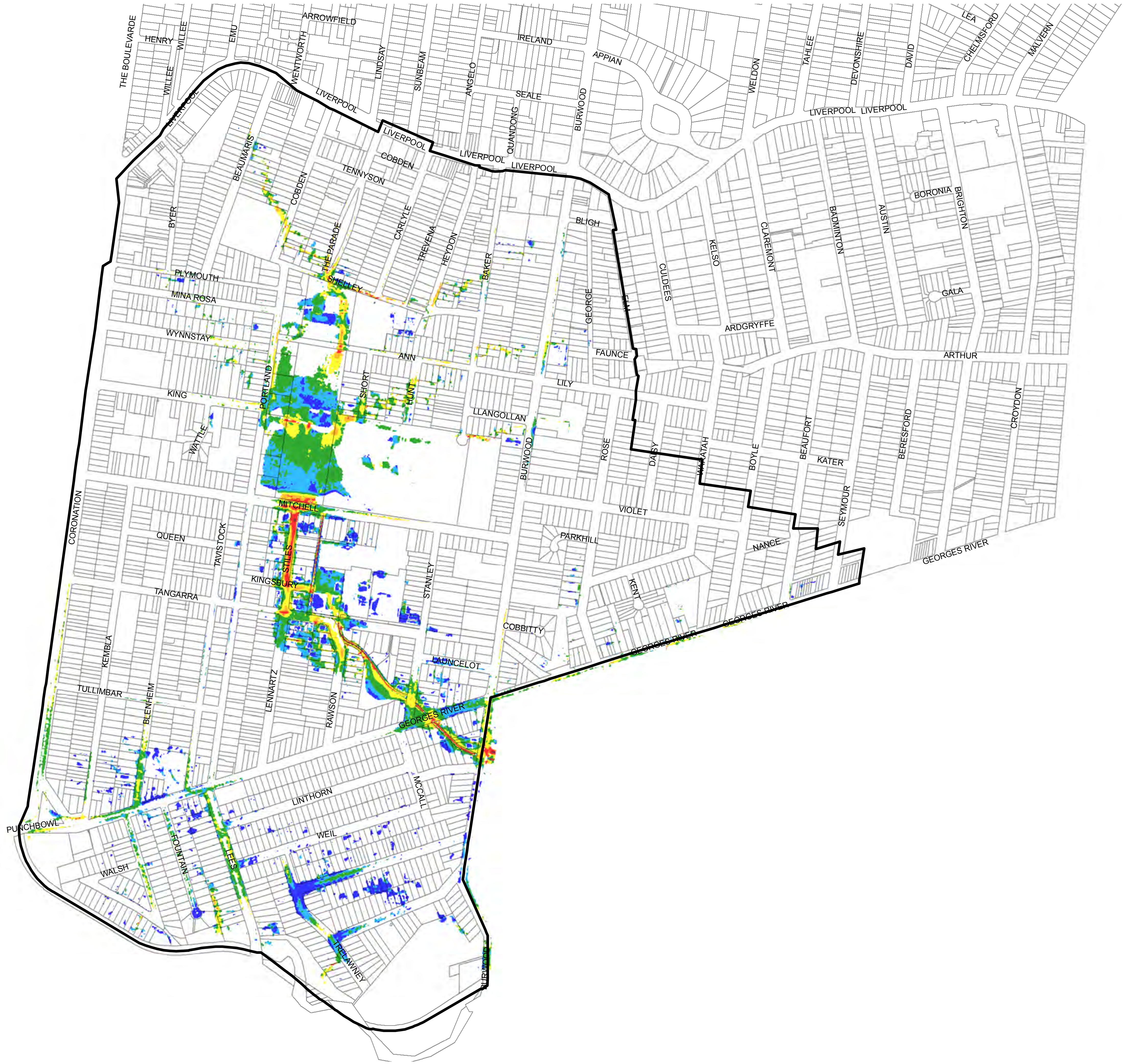
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD VELOCITY FOR 50 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	50y.V

Map No. **16**



BROWN *Smart Water*

Legend

- Study Area
- Cadastre

Peak Flood Velocity (m/s)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 3
- > 3.0

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

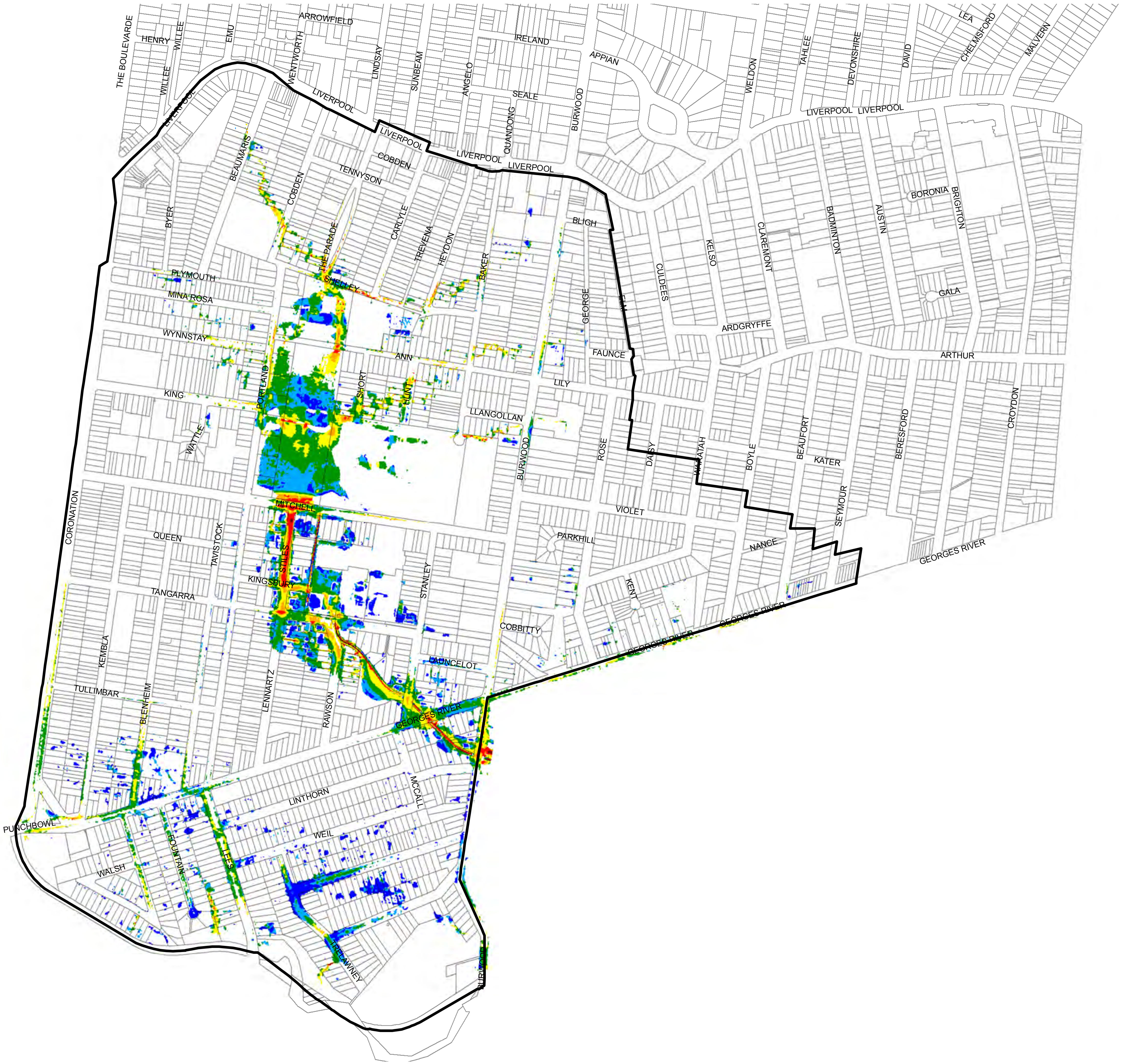
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD VELOCITY FOR 100 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	100y.V

Map No. **17**



BROWN
Smart Water

Legend

Study Area
Cadastre

Peak Flood Velocity (m/s)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 3
- > 3.0

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

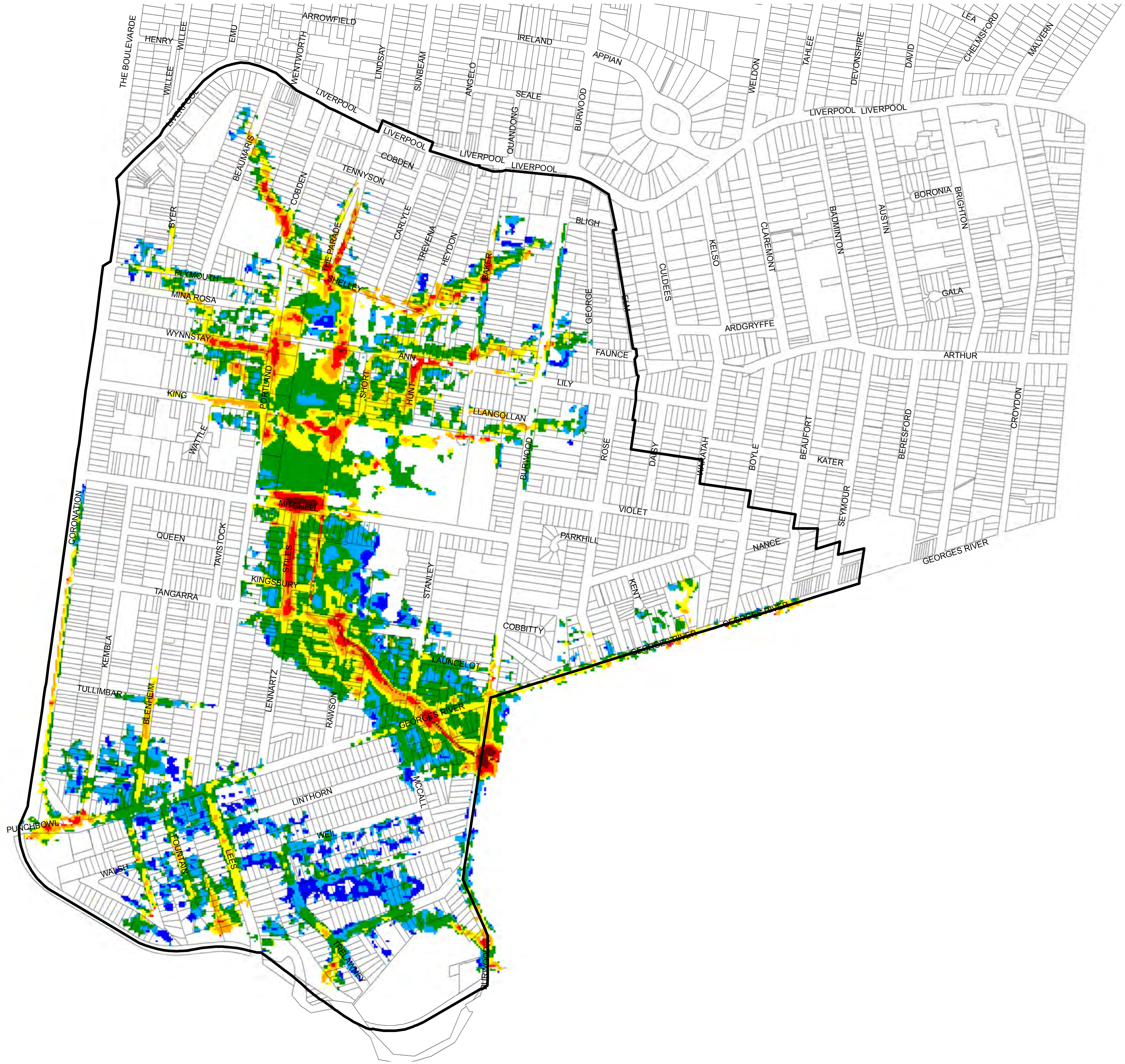
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD VELOCITY FOR 200 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	200y.V

Map No. **18**



Legend

- Study Area
- Cadastre

Peak Flood Velocity (m/s)

- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 3
- > 3.0

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD VELOCITY FOR PROBABLE MAXIMUM FLOOD

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	PMF.V

Map No. **19**

BROWN *Smart Water*

Legend

Study Area
Cadastre

Provisional Flood Hazard

Low Hazard
High Hazard

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROVISIONAL FLOOD HAZARD CATEGORISATION FOR 5 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	5y.PHFC

Map No. **20**

BROWN *Smart Water*

Legend

- Study Area
- Cadastre

Provisional Flood Hazard

- Low Hazard
- High Hazard

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

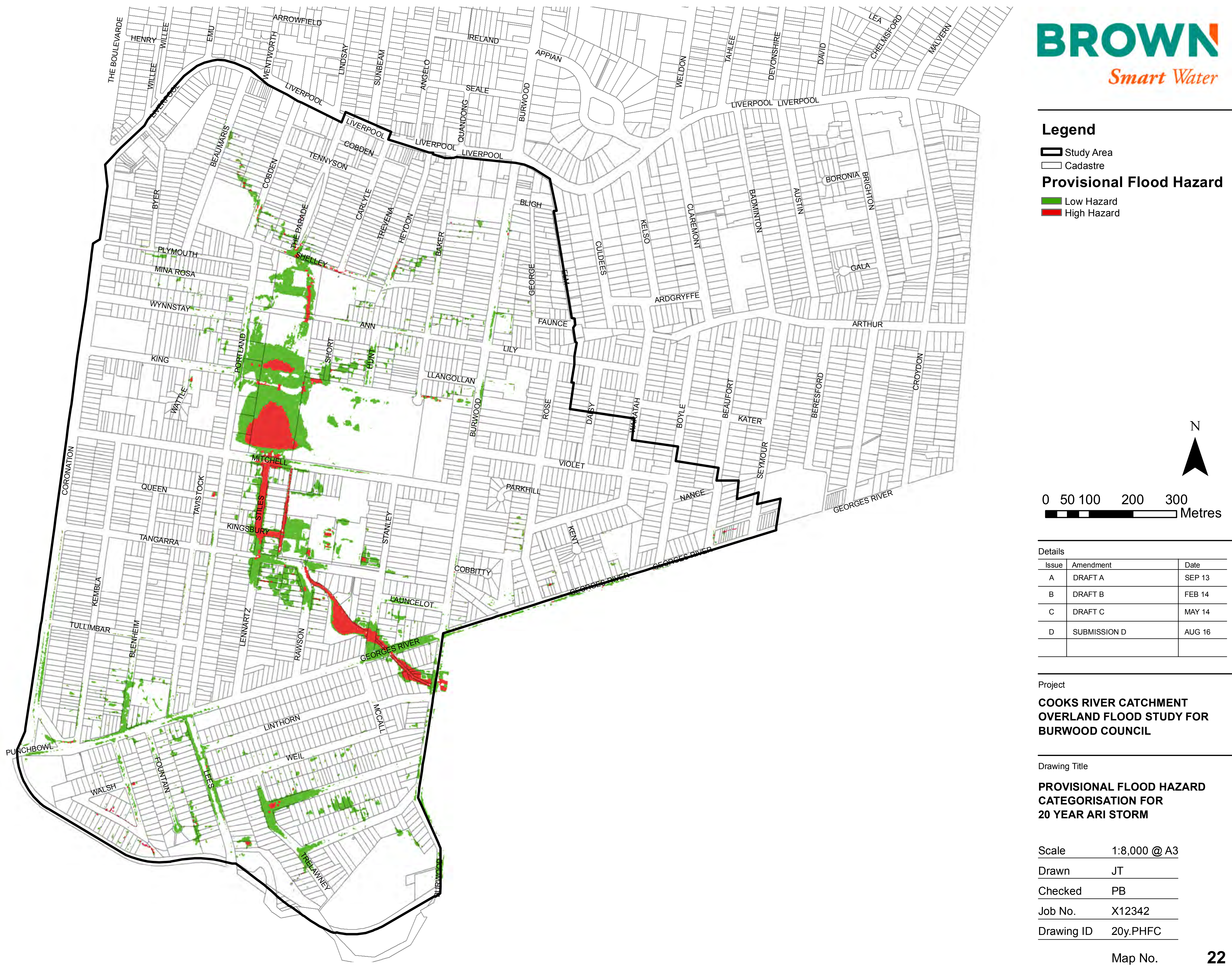
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROVISIONAL FLOOD HAZARD CATEGORISATION FOR 10 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	10y.PHFC

Map No. **21**



BROWN *Smart Water*

Legend

- Study Area
- Cadastre

Provisional Flood Hazard

- Low Hazard
- High Hazard

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROVISIONAL FLOOD HAZARD CATEGORISATION FOR 20 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	20y.PHFC

Map No. **22**

BROWN
Smart Water

Legend

Study Area
Cadastre

Provisional Flood Hazard

Low Hazard
High Hazard

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROVISIONAL FLOOD HAZARD CATEGORISATION FOR 50 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	50y.PHFC

Map No. **23**

BROWN Smart Water

Legend

Study Area
Cadastre

Provisional Flood Hazard

Low Hazard
High Hazard

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROVISIONAL FLOOD HAZARD CATEGORISATION FOR 100 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	100y.PHFC

Map No. **24**

BROWN
Smart Water

Legend

Study Area
Cadastre

Provisional Flood Hazard

Low Hazard
High Hazard

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROVISIONAL FLOOD HAZARD CATEGORISATION FOR 200 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	200y.PHFC

Map No. **25**

BROWN
Smart Water

Legend

Study Area
Cadastre

Provisional Flood Hazard

Low Hazard
High Hazard

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROVISIONAL FLOOD HAZARD CATEGORISATION FOR PROBABLE MAXIMUM FLOOD

Scale

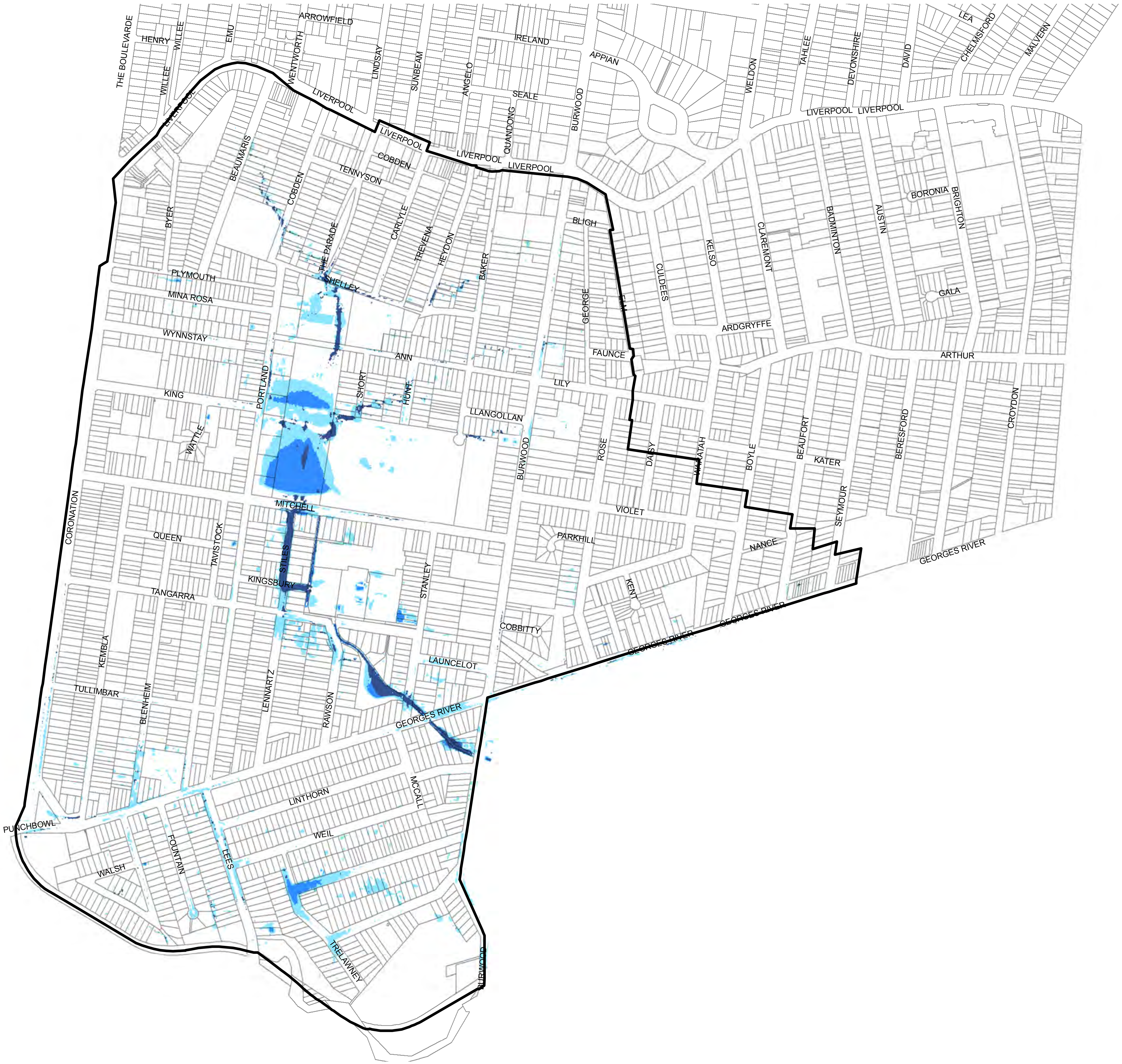
Drawn 1:8,000 @ A3

Checked JT

Job No. PB

Drawing ID PMF.PHFC

Map No. **26**



BROWN
Smart Water

Legend

Study Area
Cadastre

Flood Categorisation

Flood Fringe
Flood Storage
Floodway

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

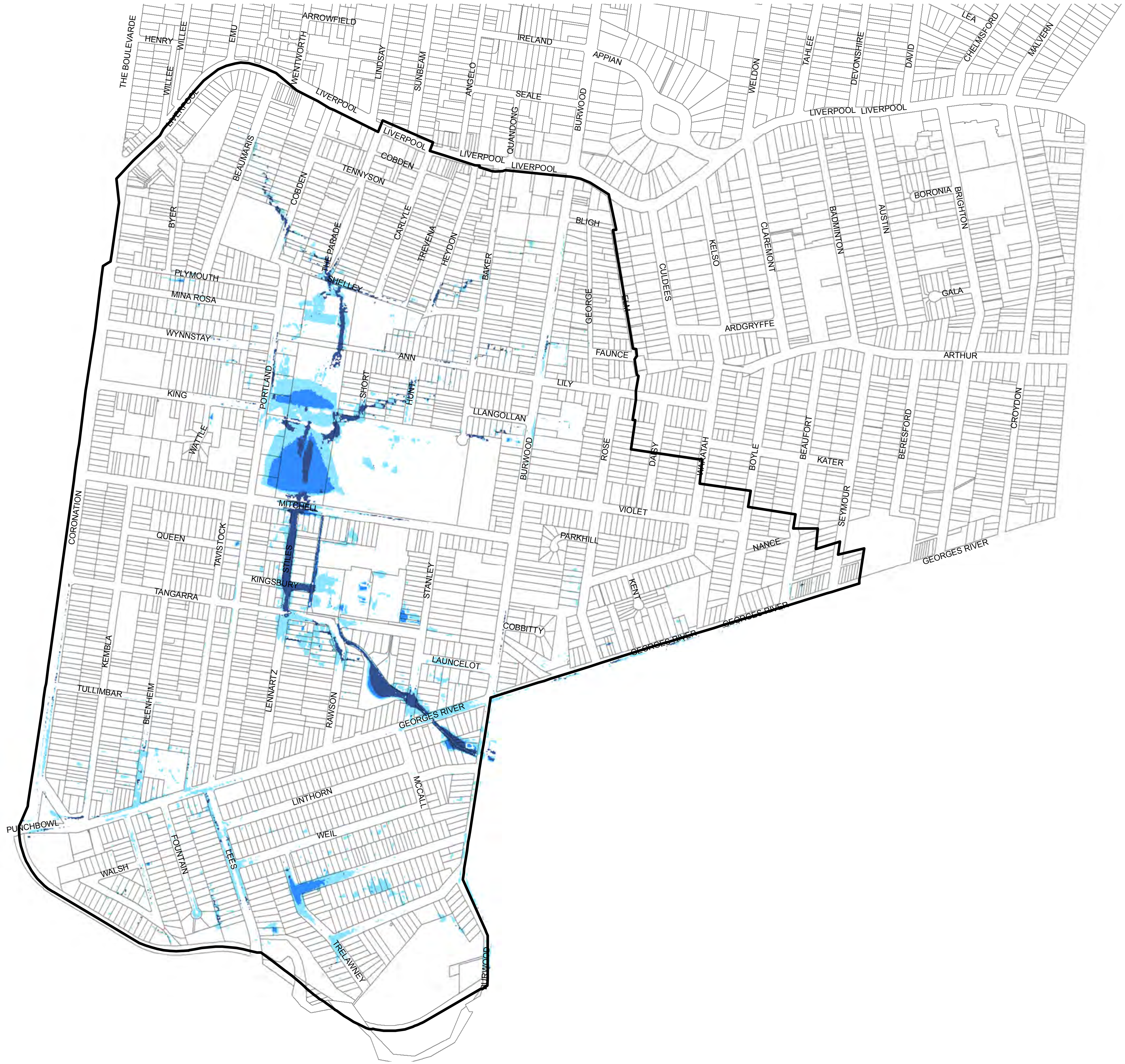
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

5 YEAR ARI HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	5y.HC

Map No. **27**



BROWN
Smart Water

Legend

Study Area
Cadastre

Flood Categorisation

Flood Fringe
Flood Storage
Floodway

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

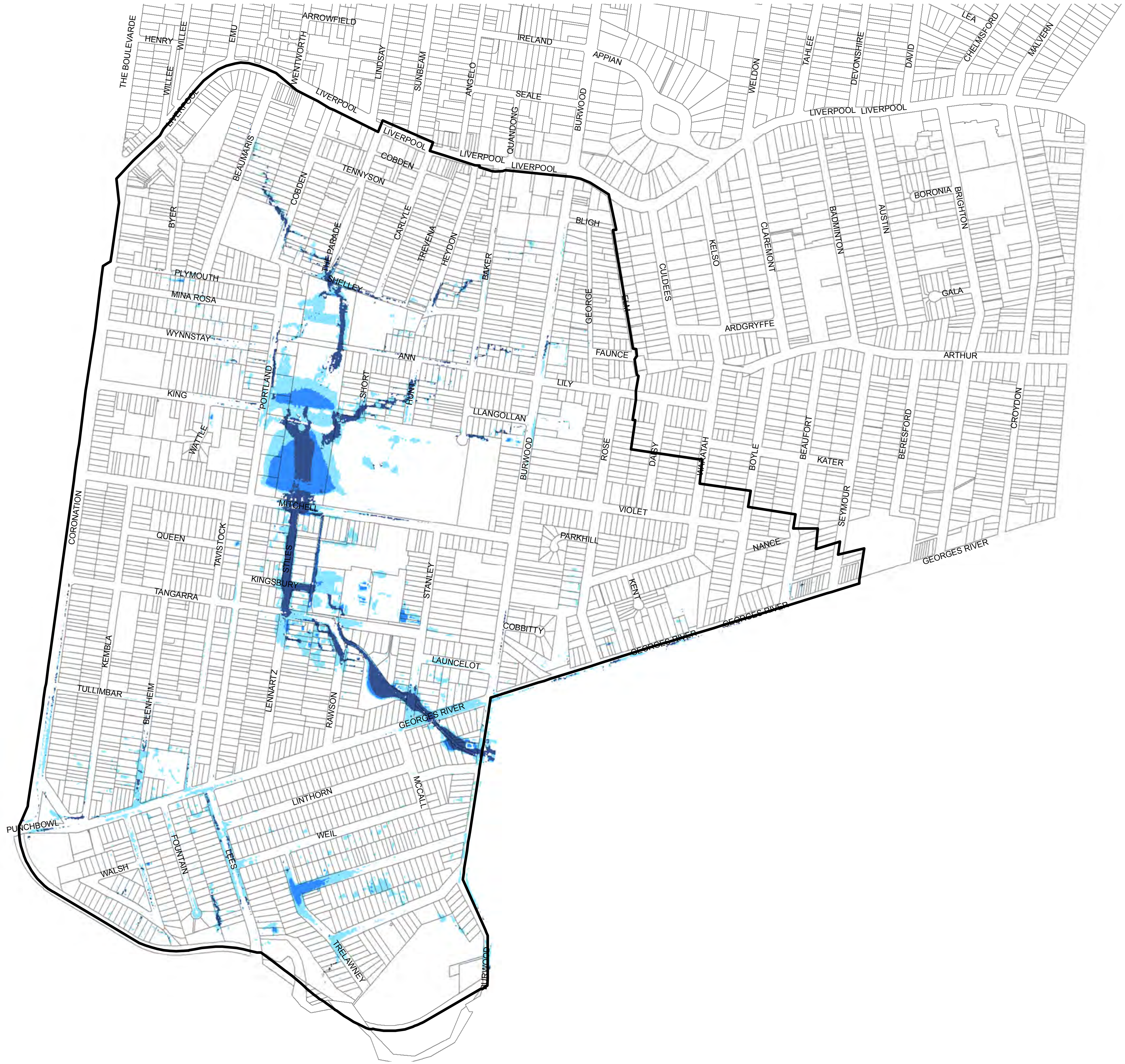
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

10 YEAR ARI HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	10y.HC

Map No. **28**



BROWN *Smart Water*

Legend

Study Area
Cadastre

Flood Categorisation

Flood Fringe
Flood Storage
Floodway

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

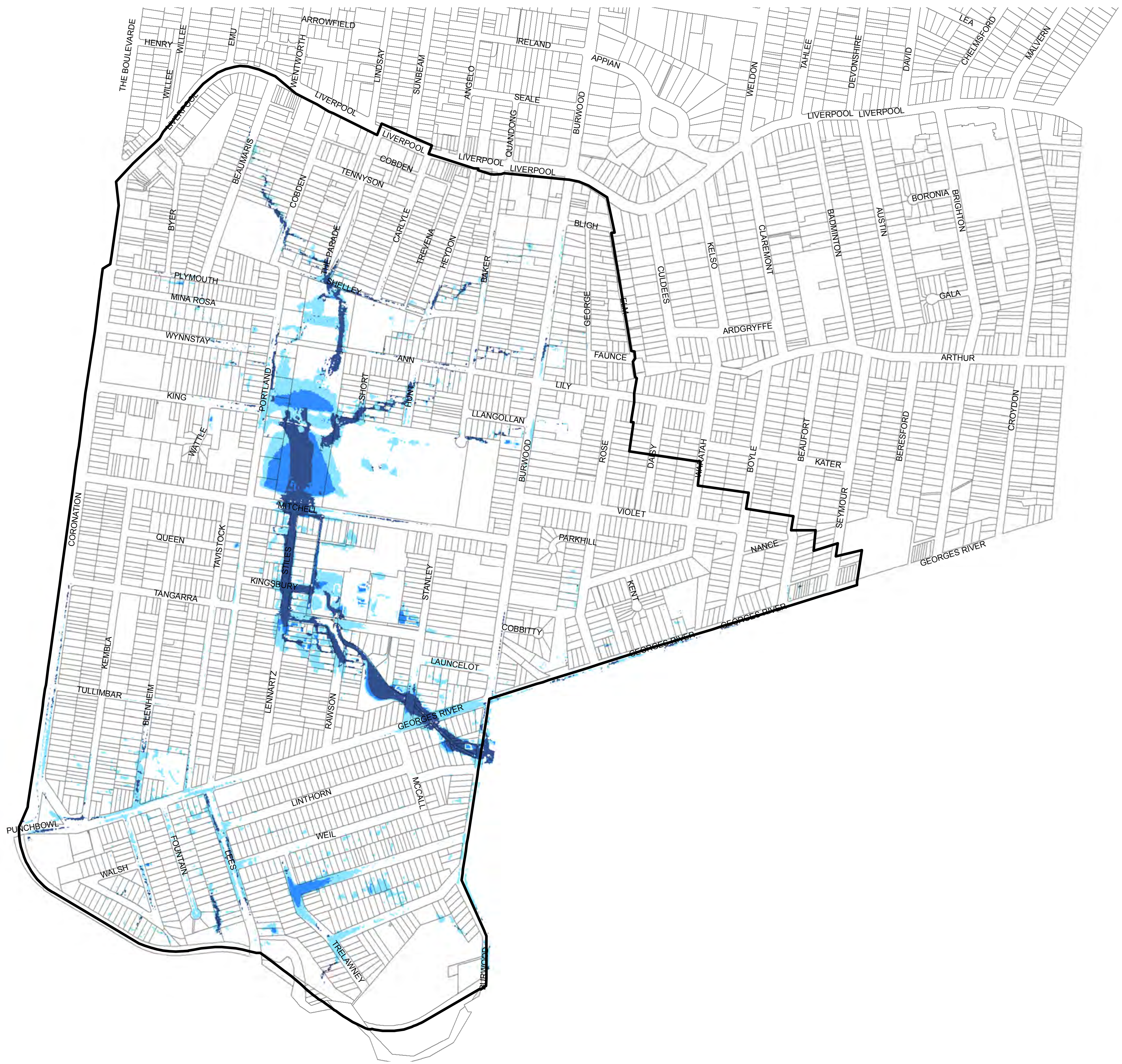
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

20 YEAR ARI HYDRAULIC CATEGORISATION

Scale
Drawn 1:8,000 @ A3
Checked JT
Job No. PB
Drawing ID 20y.HC

Map No. **29**



BROWN Smart Water

Legend

- Study Area
- Cadastre

Flood Categorisation

- Flood Fringe
- Flood Storage
- Floodway

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

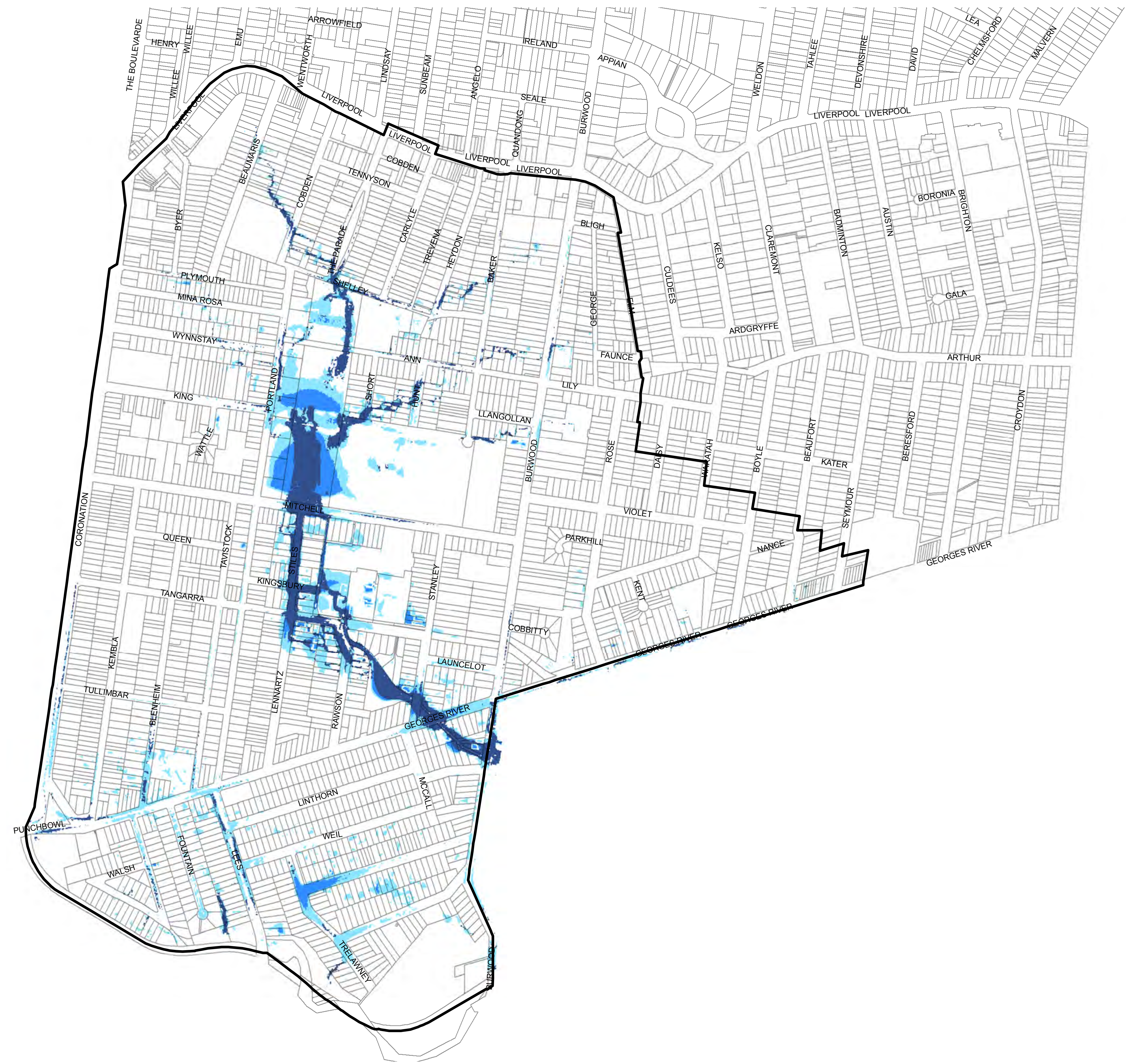
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

50 YEAR ARI HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	50y.HC

Map No. **30**



BROWN
Smart Water

Legend

- Study Area
- Cadastre

Flood Categorisation

- Flood Fringe
- Flood Storage
- Floodway

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

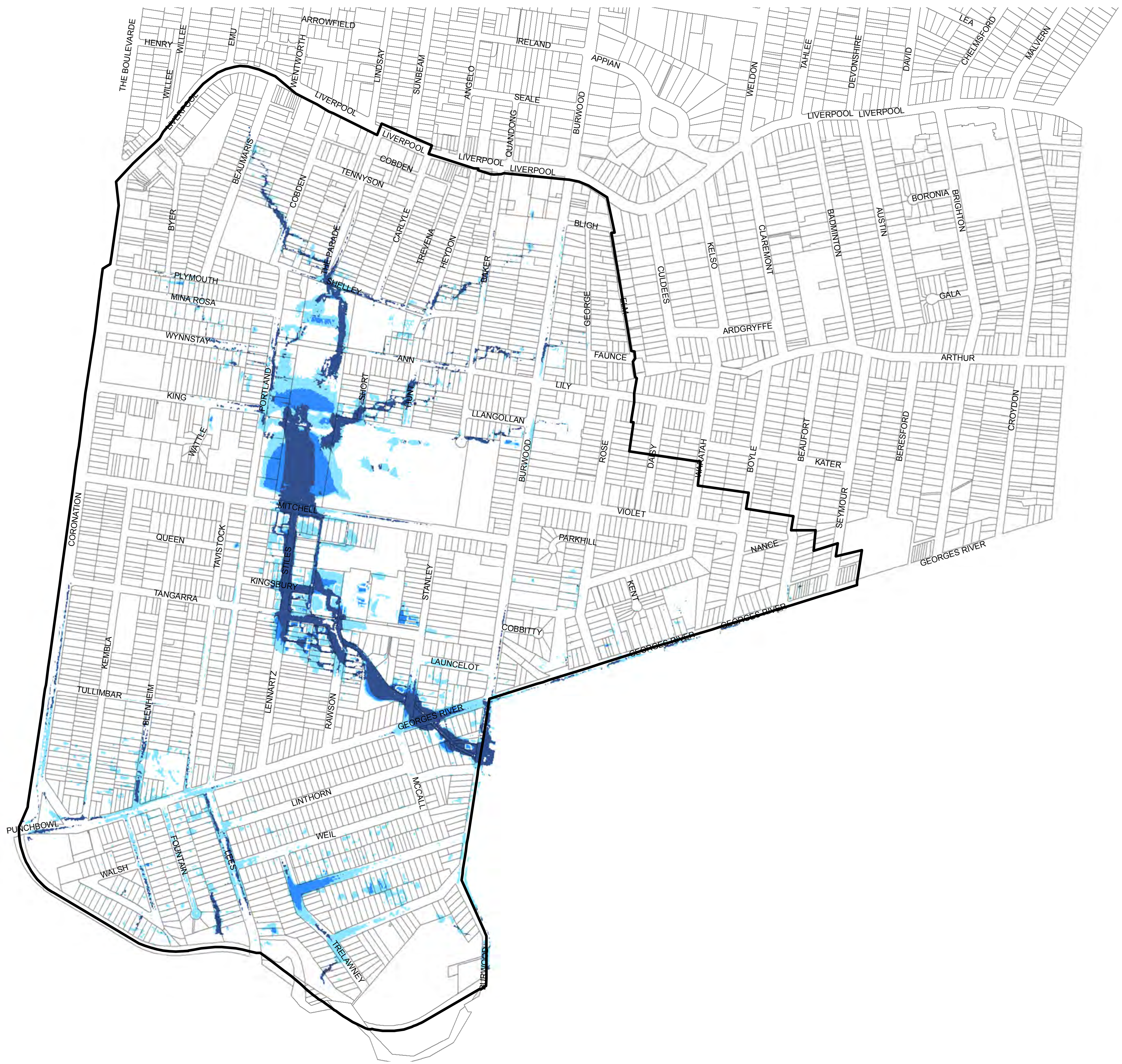
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

100 YEAR ARI HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	100y.HC

Map No. **31**



BROWN *Smart Water*

Legend

Study Area
Cadastre

Flood Categorisation

Flood Fringe
Flood Storage
Floodway

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

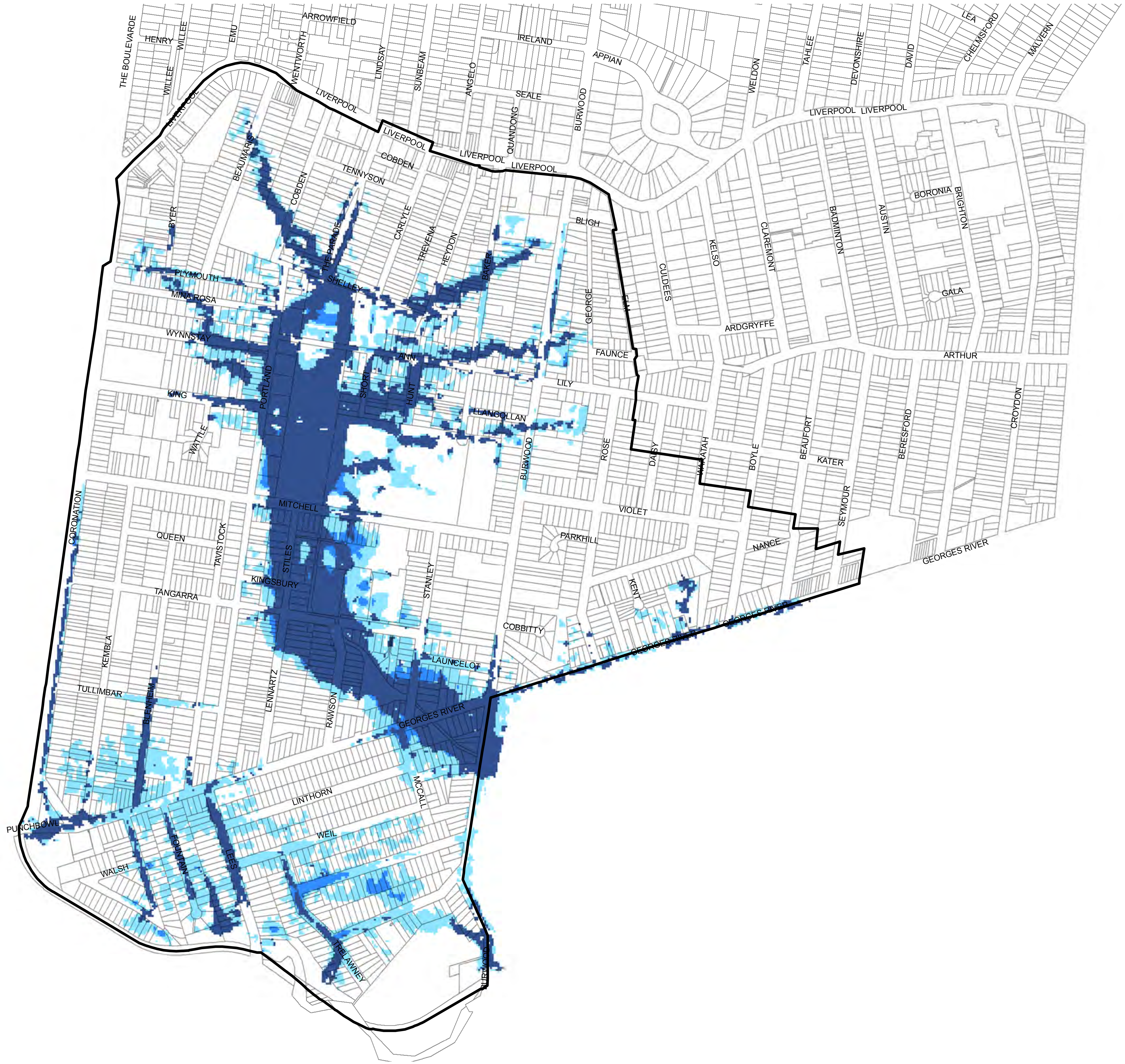
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

200 YEAR ARI HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	200y.HC

Map No. **32**



BROWN
Smart Water

Legend

Study Area
Cadastre

Flood Categorisation

Flood Fringe
Flood Storage
Floodway

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

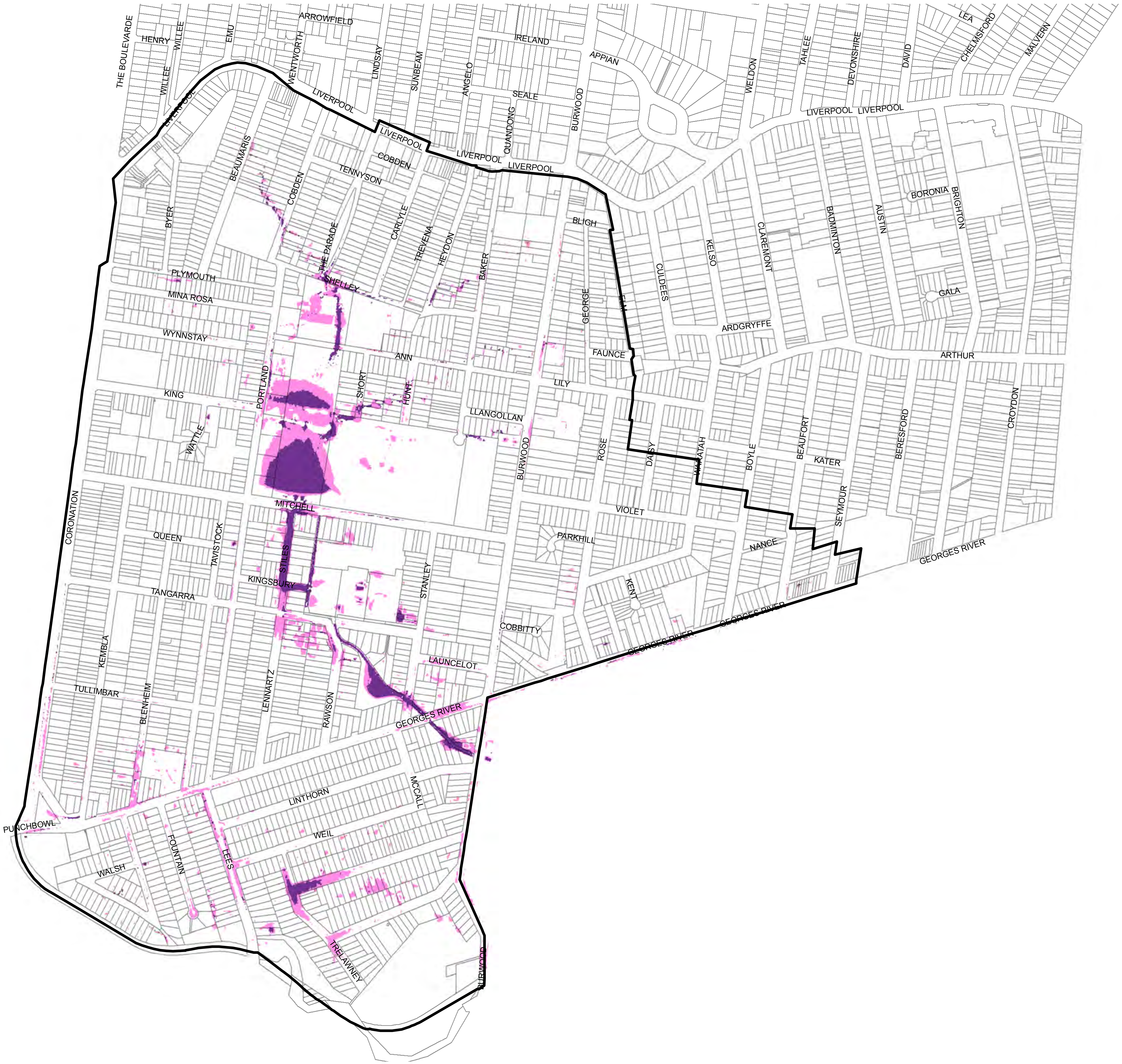
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROBABLE MAXIMUM FLOOD HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	PMF.HC

Map No. **33**



BROWN
Smart Water

Legend

Study Area
Cadastre

Flood Categorisation

Low Risk
High Risk

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

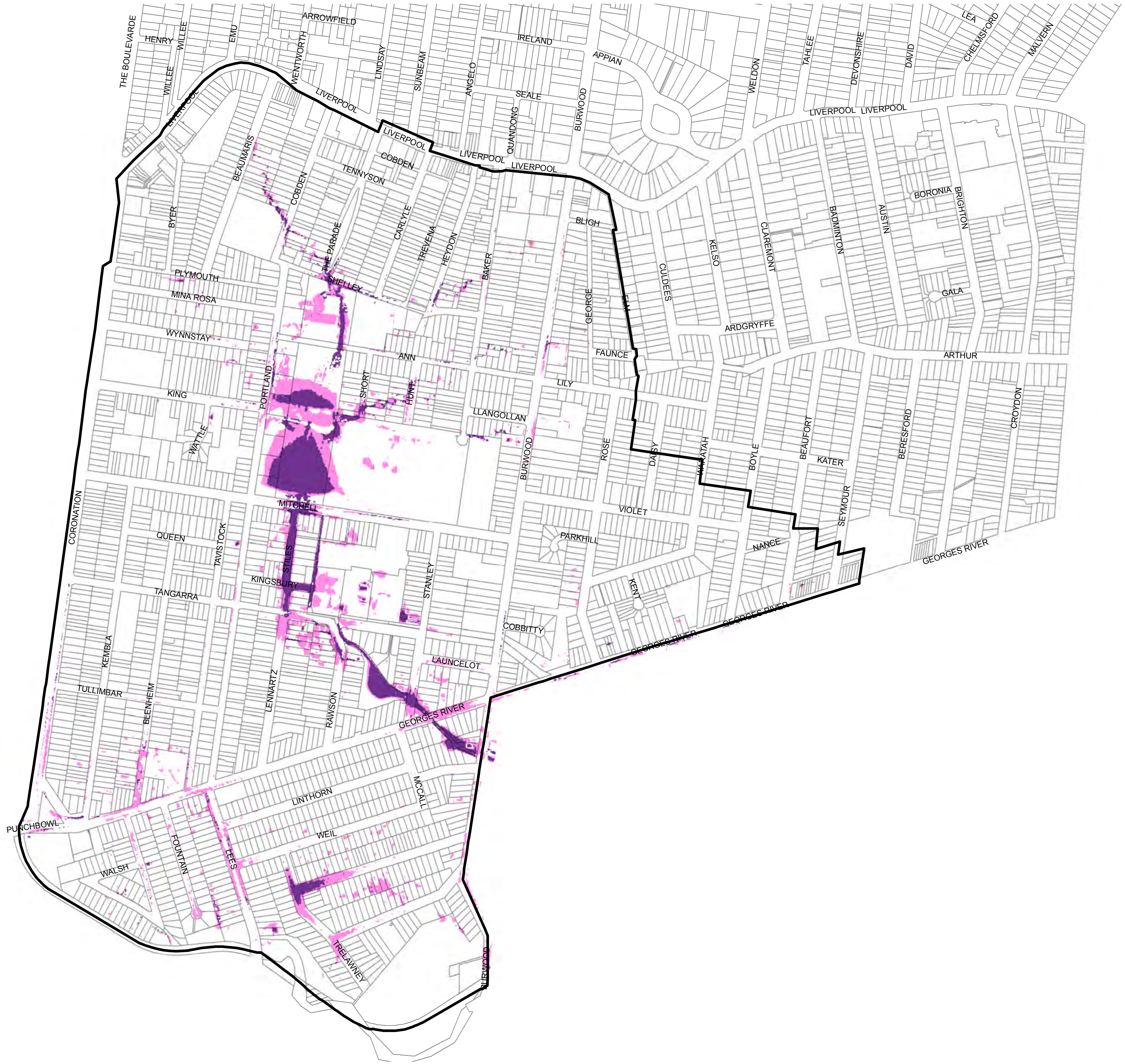
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

5 YEAR ARI BURWOOD COUCIL PROVISIONAL HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	5y.BCHC

Map No. **34**



BROWN
Smart Water

Legend

Study Area
Cadastre

Flood Categorisation

Low Risk
High Risk

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

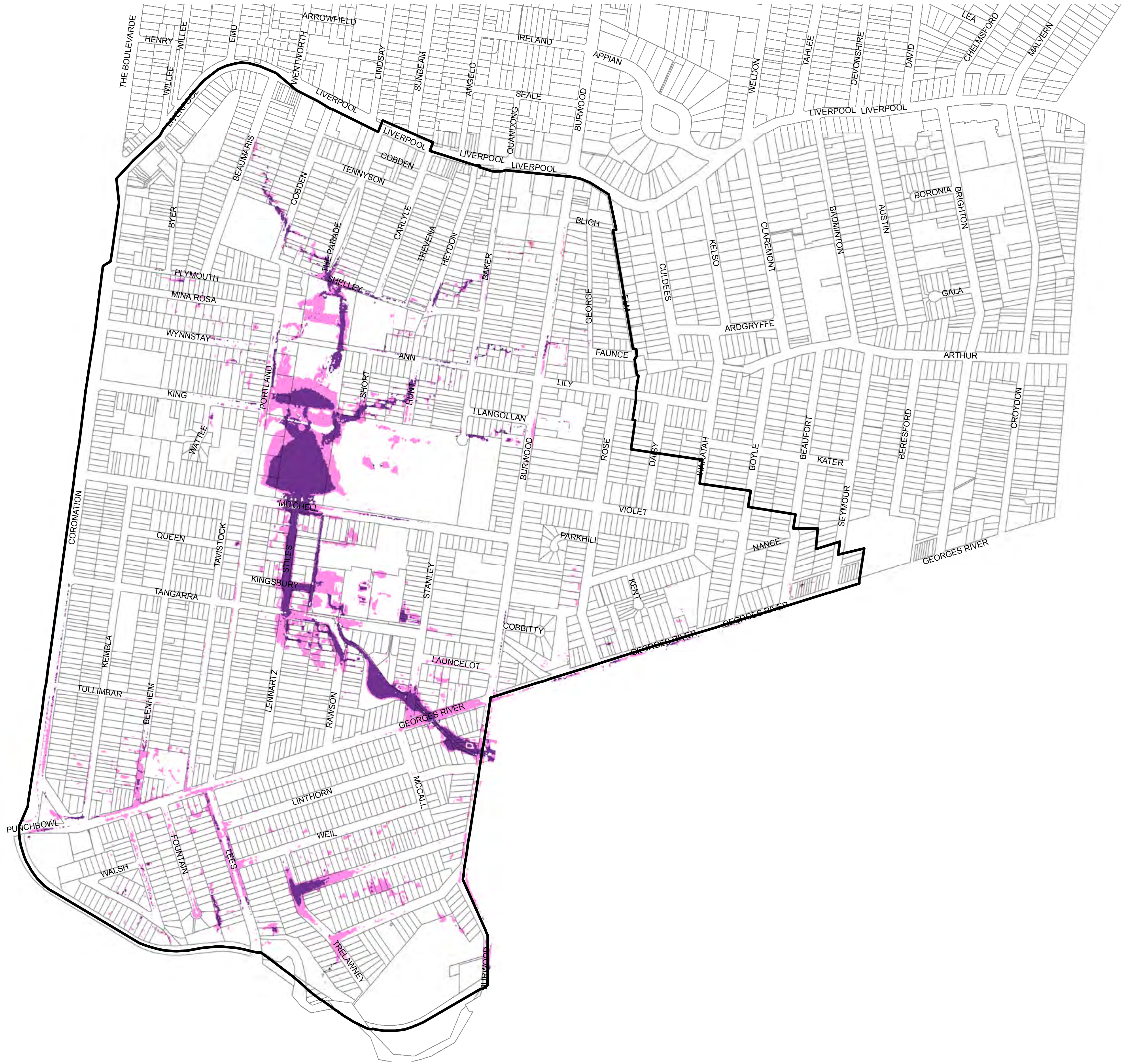
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

10 YEAR ARI BURWOOD COUCIL PROVISIONAL HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	10y.BCHC

Map No. **35**



BROWN
Smart Water

Legend

Study Area
Cadastre

Flood Categorisation

Low Risk
High Risk

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

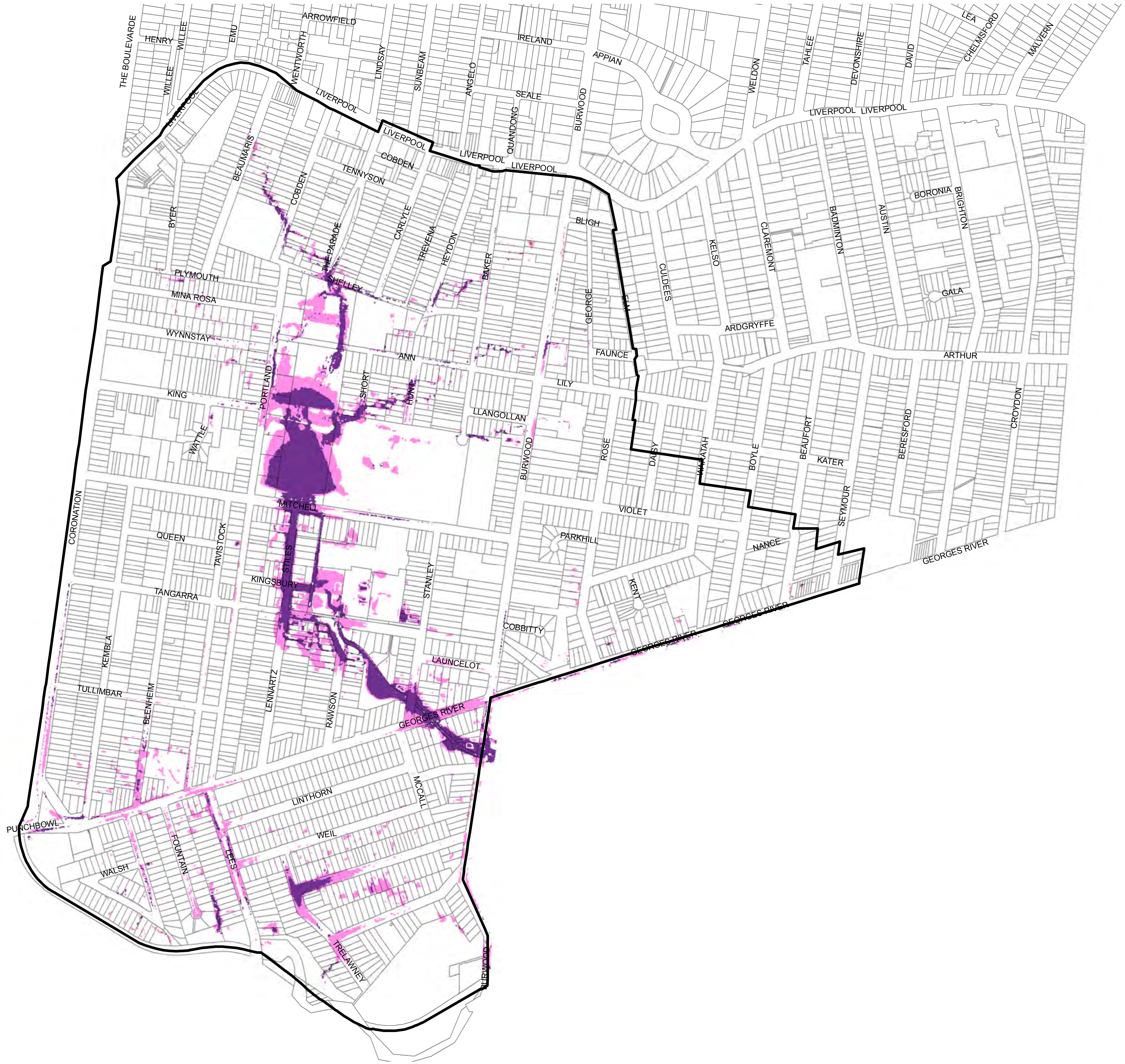
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

20 YEAR ARI BURWOOD COUCIL PROVISIONAL HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	20y.BCHC

Map No. **36**



BROWN
Smart Water

Legend

- Study Area
- Cadastre

Flood Categorisation

- Low Risk
- High Risk

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

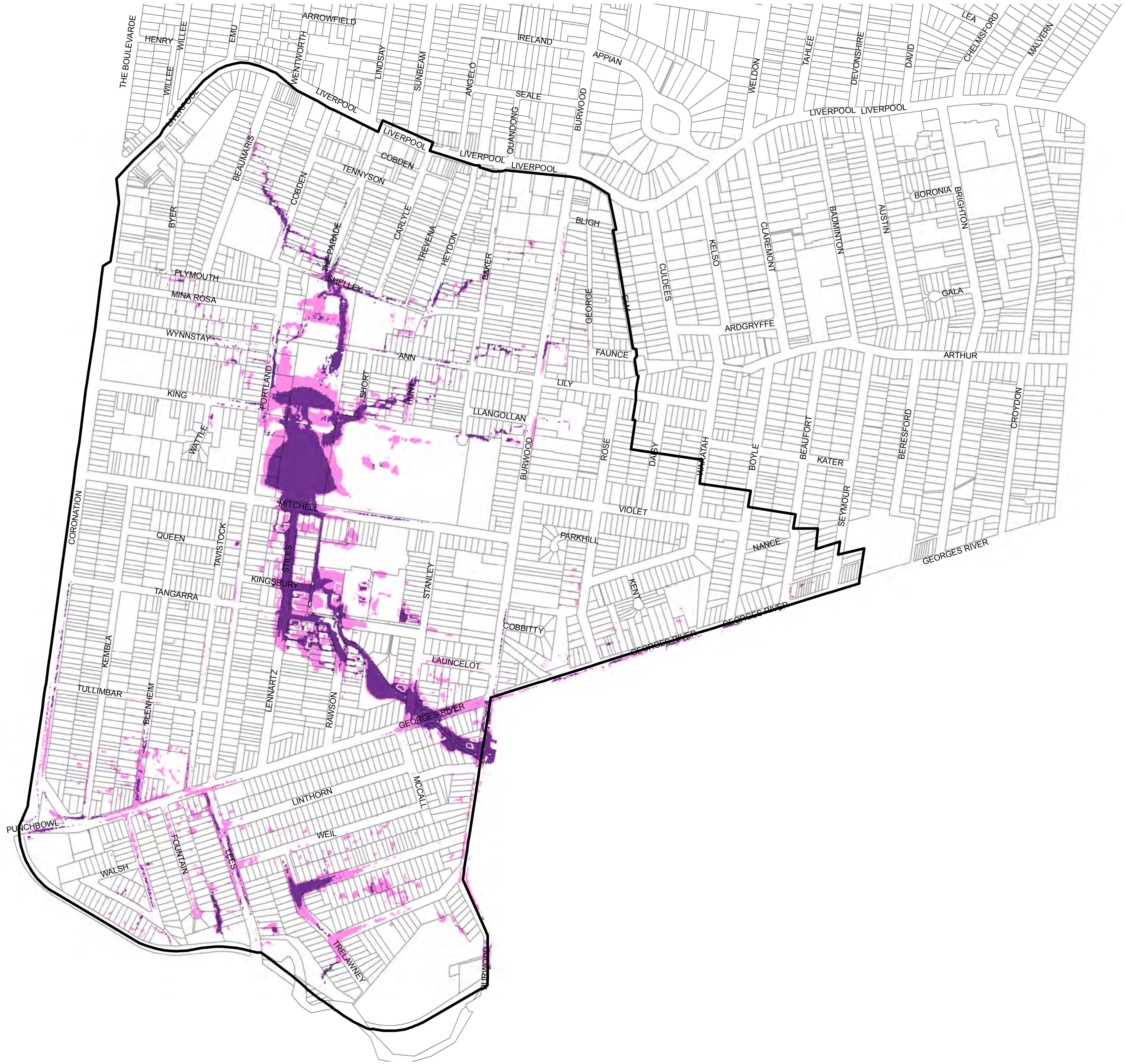
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

50 YEAR ARI BURWOOD COUCIL PROVISIONAL HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	50y.BCHC

Map No. **37**



BROWN *Smart Water*

Legend

- Study Area
- Cadastre

Flood Categorisation

- Low Risk
- High Risk

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

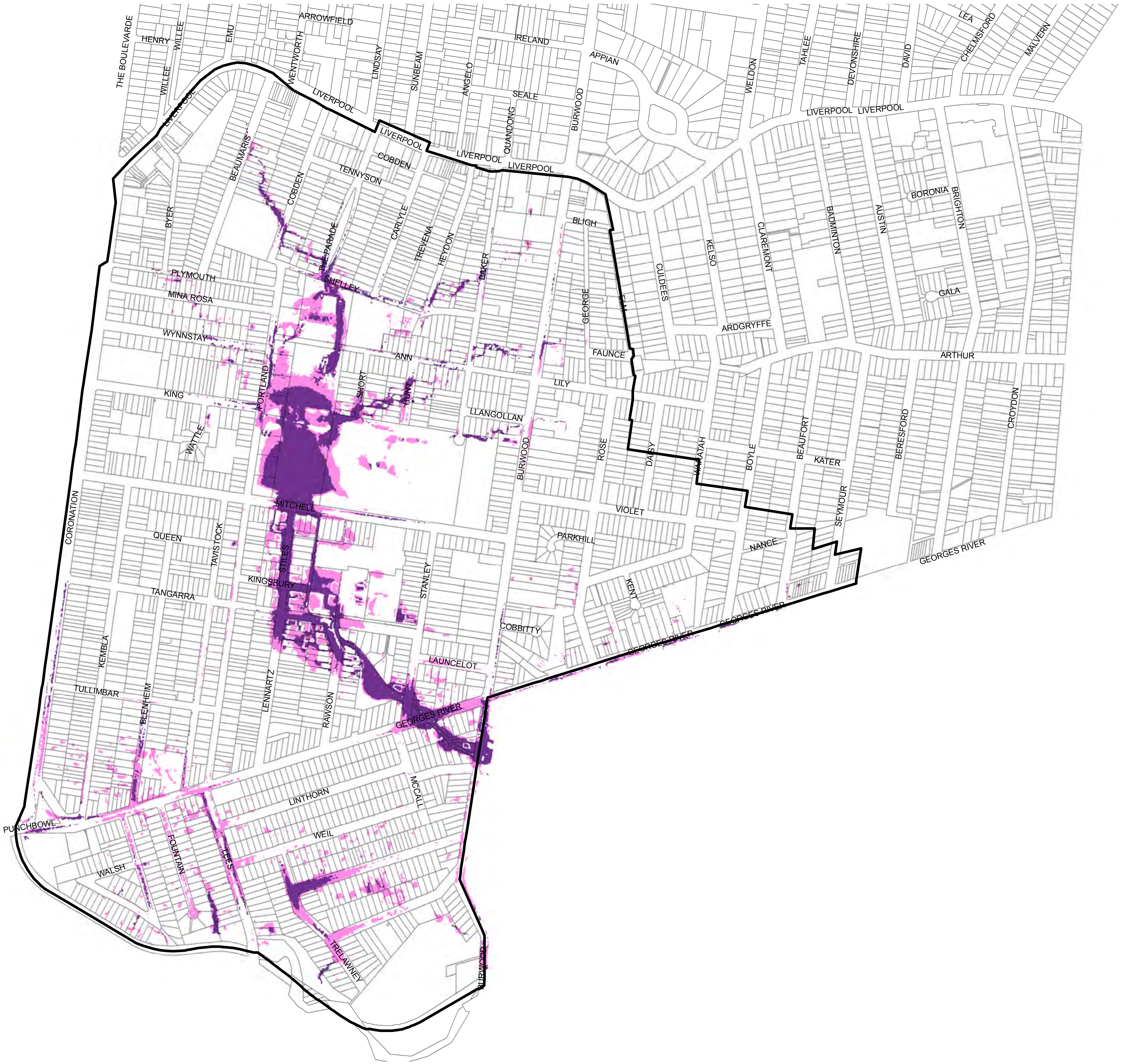
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

100 YEAR ARI BURWOOD COUCIL PROVISIONAL HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	100y.BCHC

Map No. **38**



BROWN *Smart Water*

Legend

Study Area
Cadastre

Flood Categorisation

Low Risk
High Risk

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

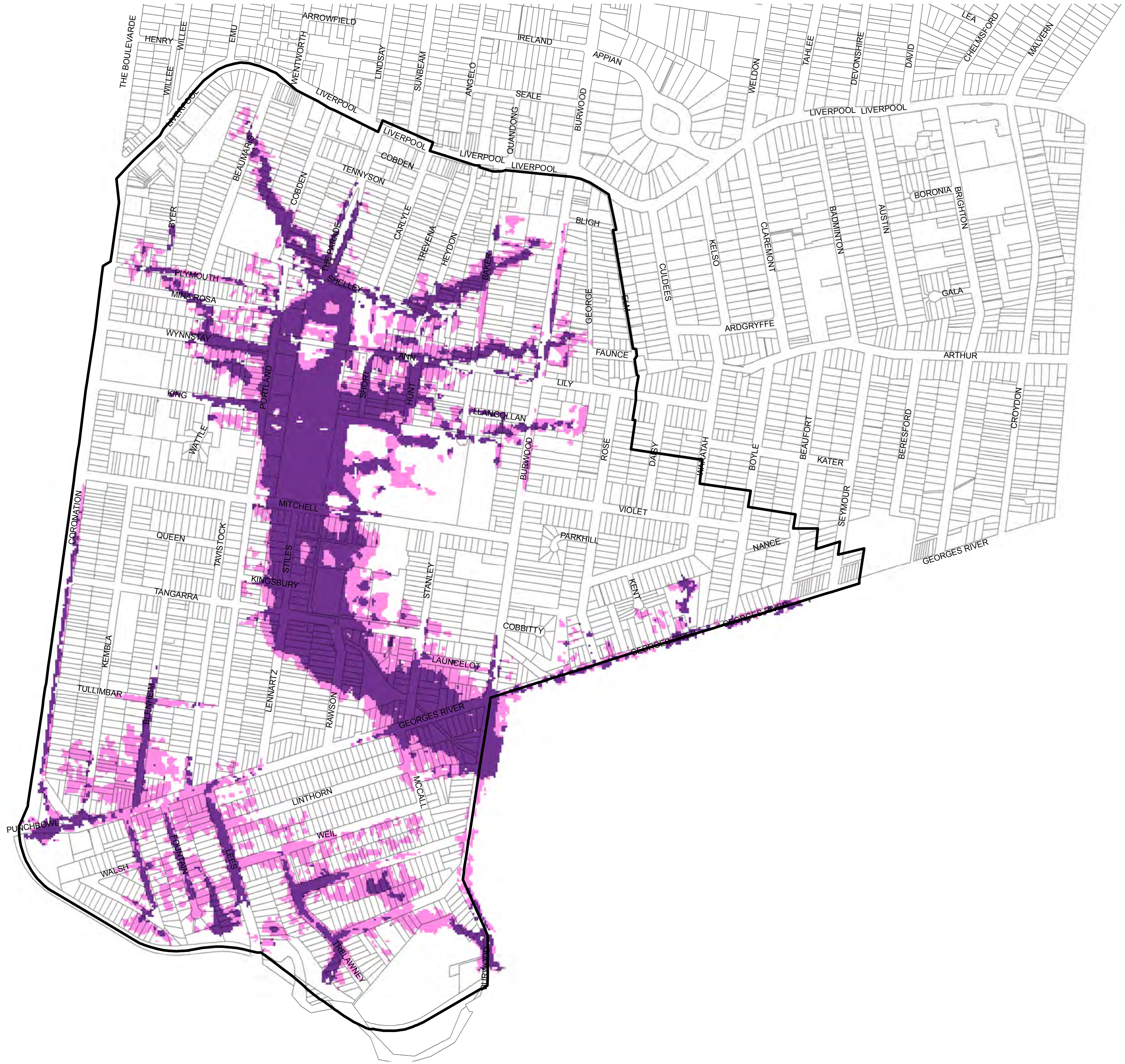
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

200 YEAR ARI BURWOOD COUCIL PROVISIONAL HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	200y.BCHC

Map No. **39**



BROWN
Smart Water

Legend

Study Area
Cadastre

Flood Categorisation

Low Risk
High Risk

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

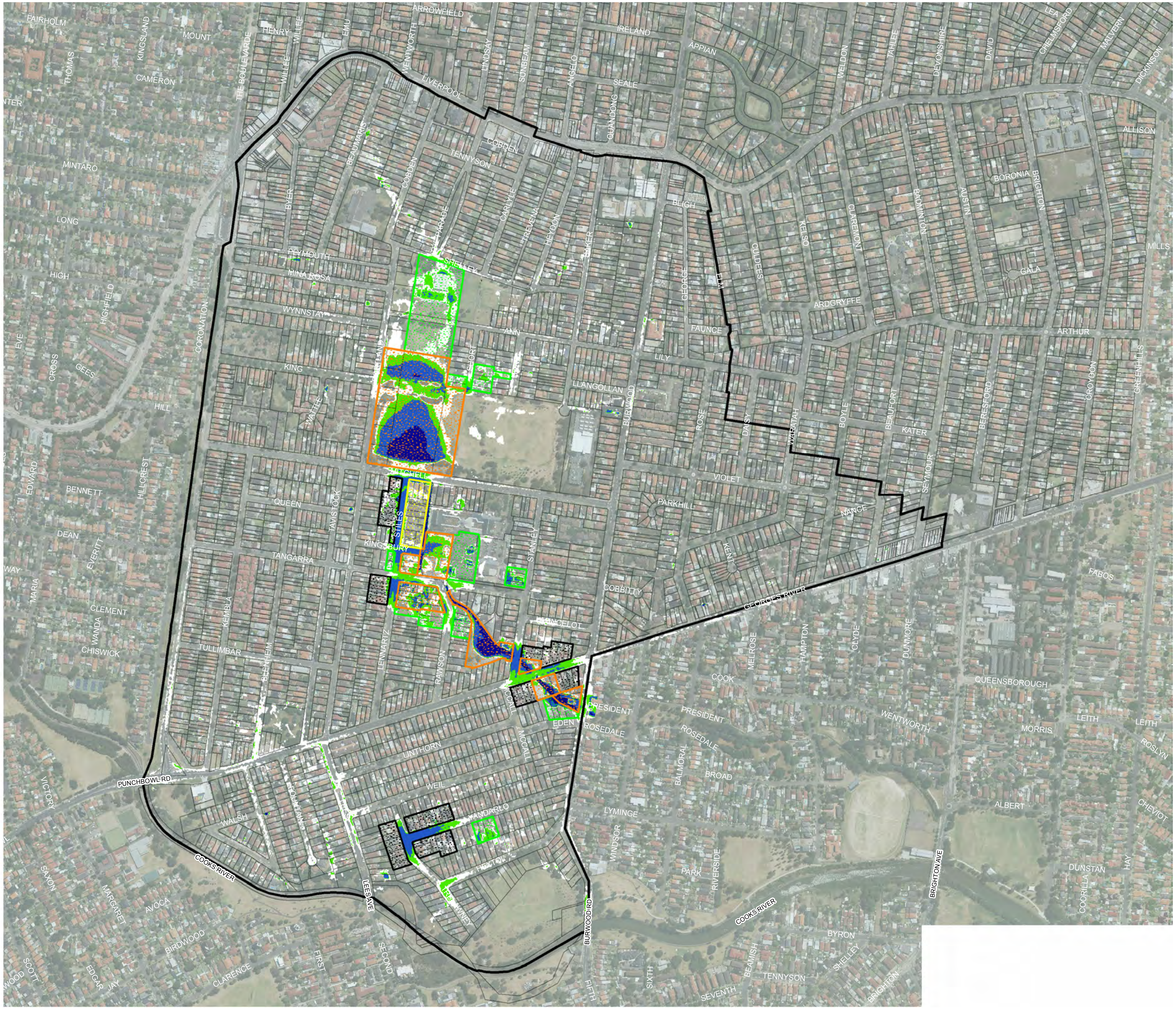
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROBABLE MAXIMUM FLOOD BURWOOD COUCIL PROVISIONAL HYDRAULIC CATEGORISATION

Scale	
Drawn	1:8,000 @ A3
Checked	JT
Job No.	PB
Drawing ID	PMF.BCHC

Map No. **40**



BROWN
Smart Water

Legend

- Study Area
- Cadastre

ERP Classification

- Rising Road Access
- Low Trapped Perimeter Area
- Low Flood Island
- High Flood Island

Peak Flood Depth (m AHD)

- 0.0 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- > 1.0

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

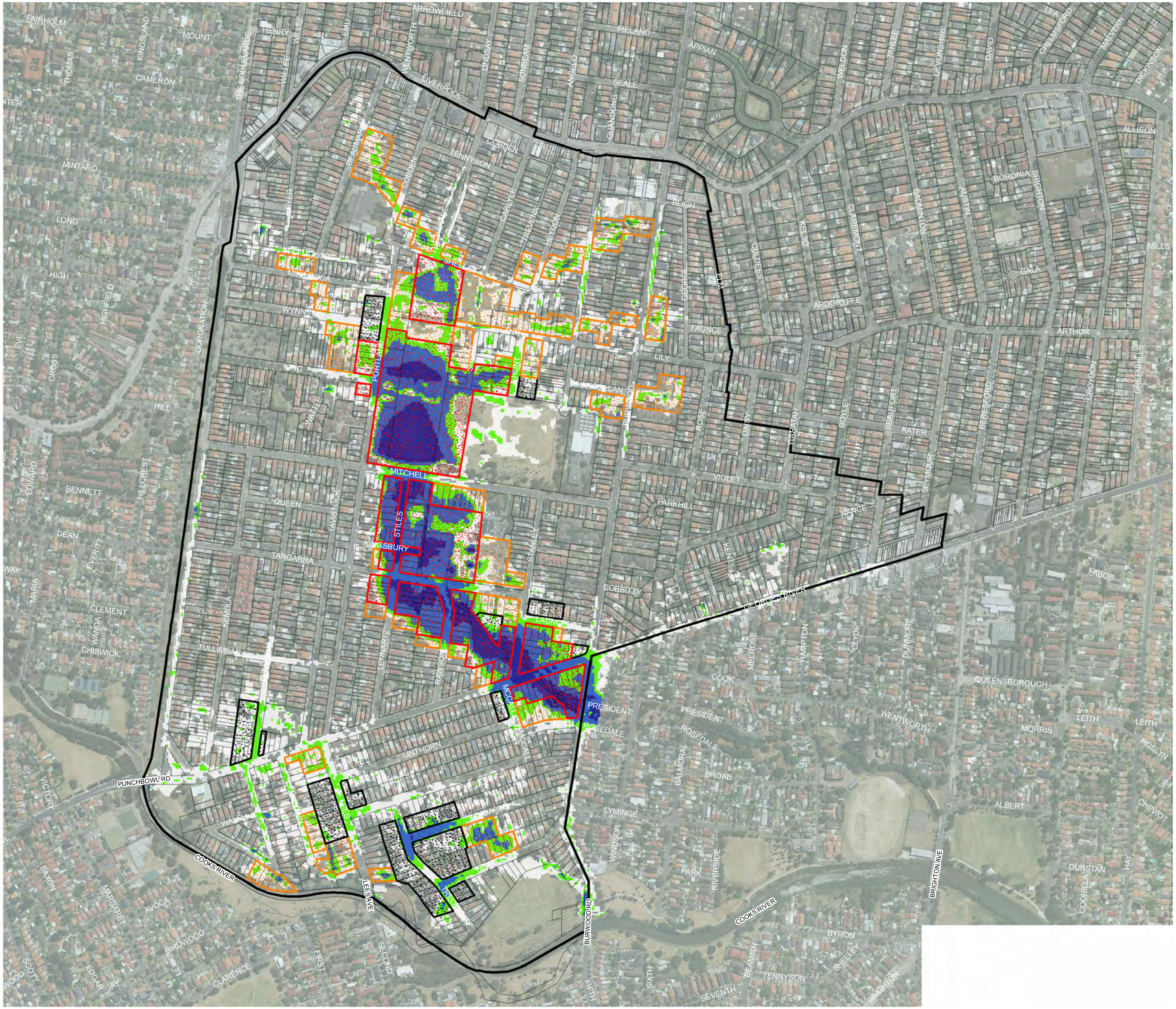
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION FOR 100 YEAR ARI STORM

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	100y.FERP

Map No. 41



BROWN
Smart Water

Legend

- Study Area
- Cadastre

ERP Classification

- Rising Road Access
- Low Trapped Perimeter Area
- Low Flood Island

Peak Flood Depth (m AHD)

- 0.0 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- > 1.0

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	SEP 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

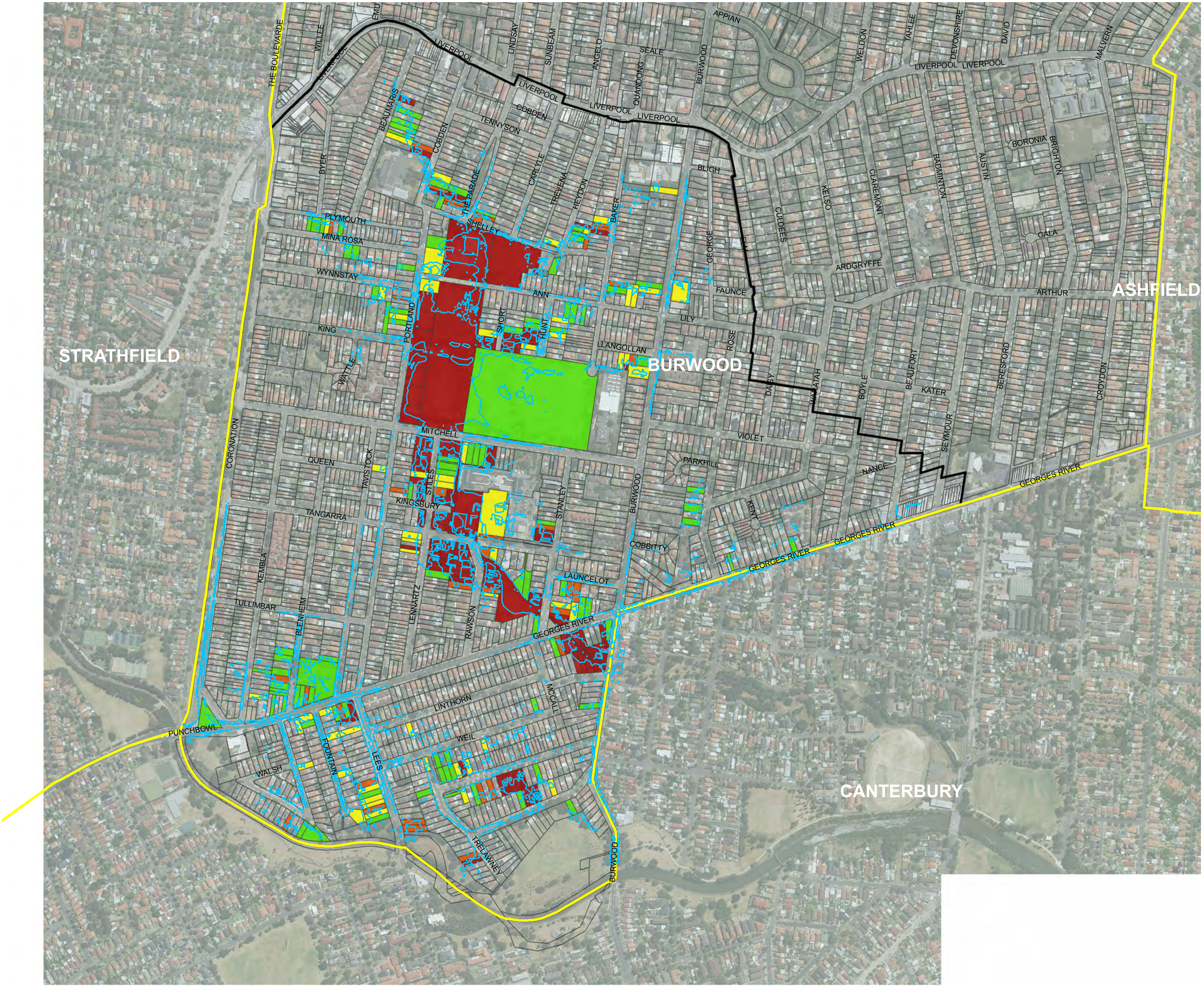
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION FOR PROBABLE MAXIMUM FLOOD

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	PMF.FERP

Map No. 42



![BROWN Smart Water]

Legend

- 100 Year Extents
- LGA Boundaries
- Study Area

Percent of Area Flooded

- < 10
- 11 - 20
- 21 - 30
- 31 - 40
- > 40

Details

Issue	Amendment	Date
A	DRAFT A	OCT 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

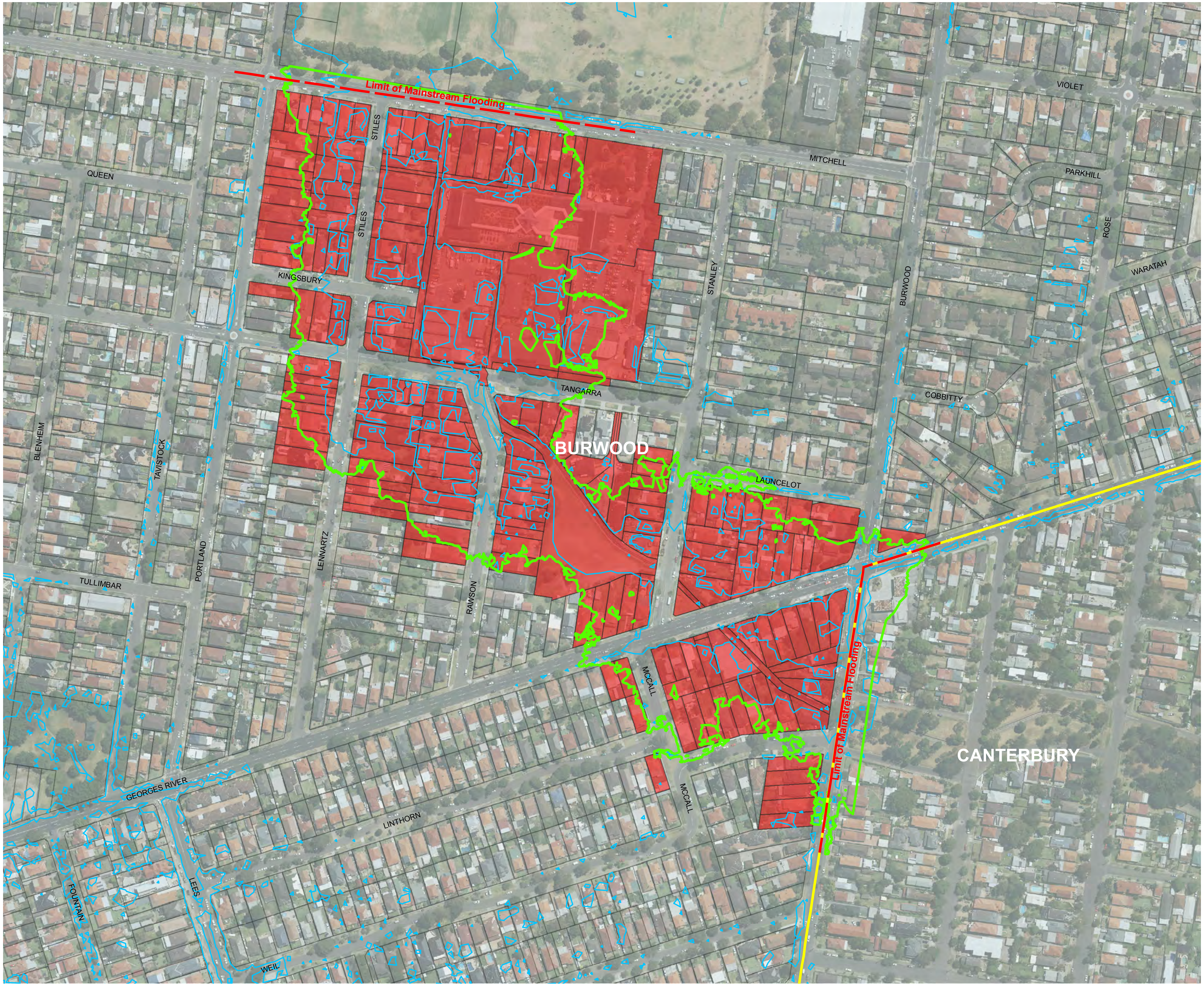
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

OVERLAND FLOODING PROPERTY TAGGING FOR 100 YEAR ARI

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	OF.TAG

Map No. **43**



BROWN
Smart Water

Legend

- LGA Boundaries
- 100 Year + 0.5m Extents
- 100 Year Extents
- Tagged Properties
- Cadastre

N

0 25 50 100
Metres

Details

Issue	Amendment	Date
A	DRAFT A	OCT 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

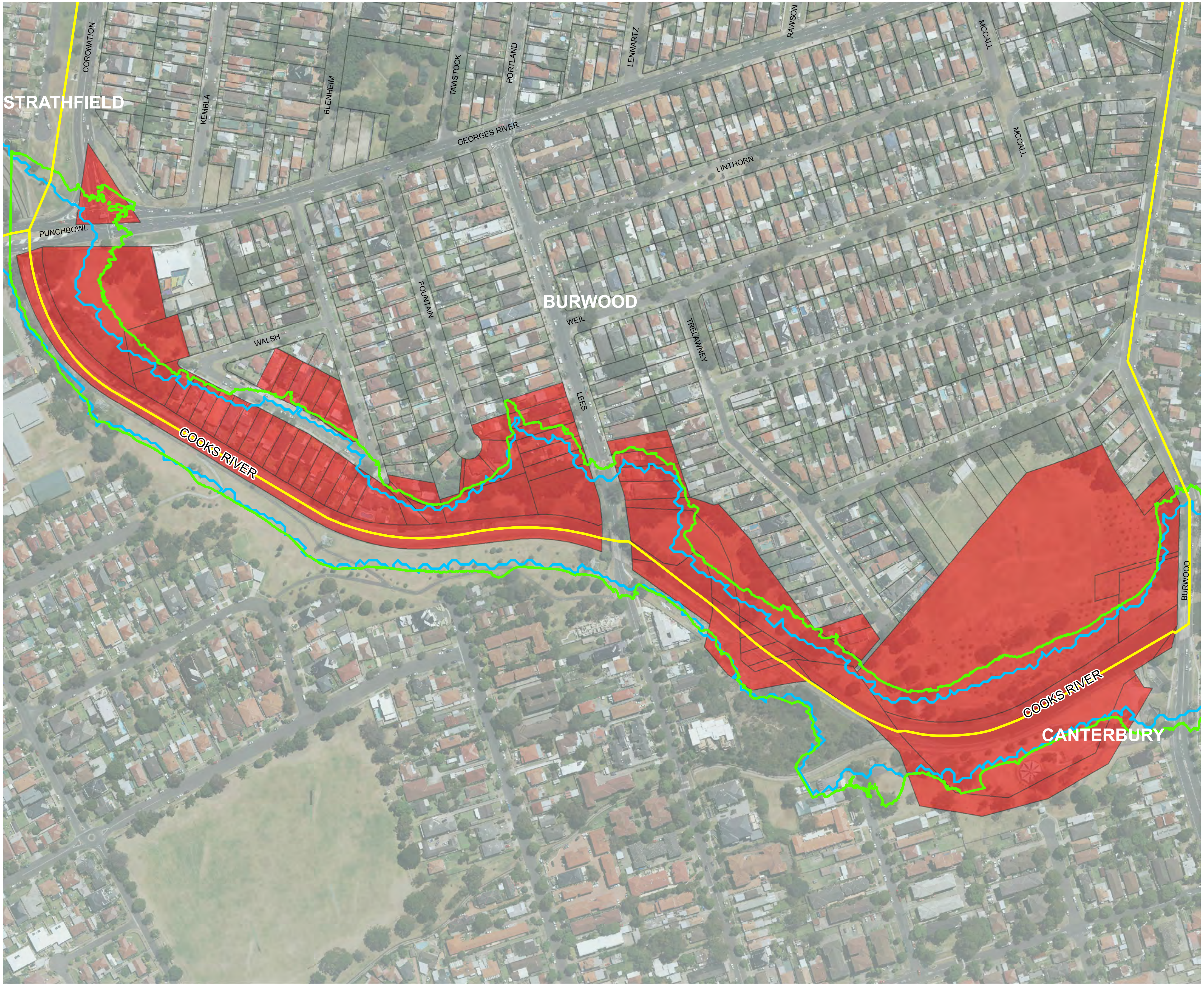
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

MAINSTREAM FLOODING PROPERTY TAGGING FOR 100 YEAR ARI RAISED BY 0.5 M

Scale	1:3,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	MF.TAG

Map No. **44**



BROWN Smart Water

Legend

- LGA Boundaries
- 100 Year ARI +0.5m Extents
- 100 Year ARI Extents
- Tagged Properties
- Cadastre

NOTE: THE FLOOD DATA USED IN THIS MAP WAS BASED ON COOKS RIVER FLOOD STUDY FINAL REPORT REV. 1 BY MWHPB (FEB 2009)

N

0 25 50 100 Metres

Details

Issue	Amendment	Date
A	DRAFT A	OCT 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

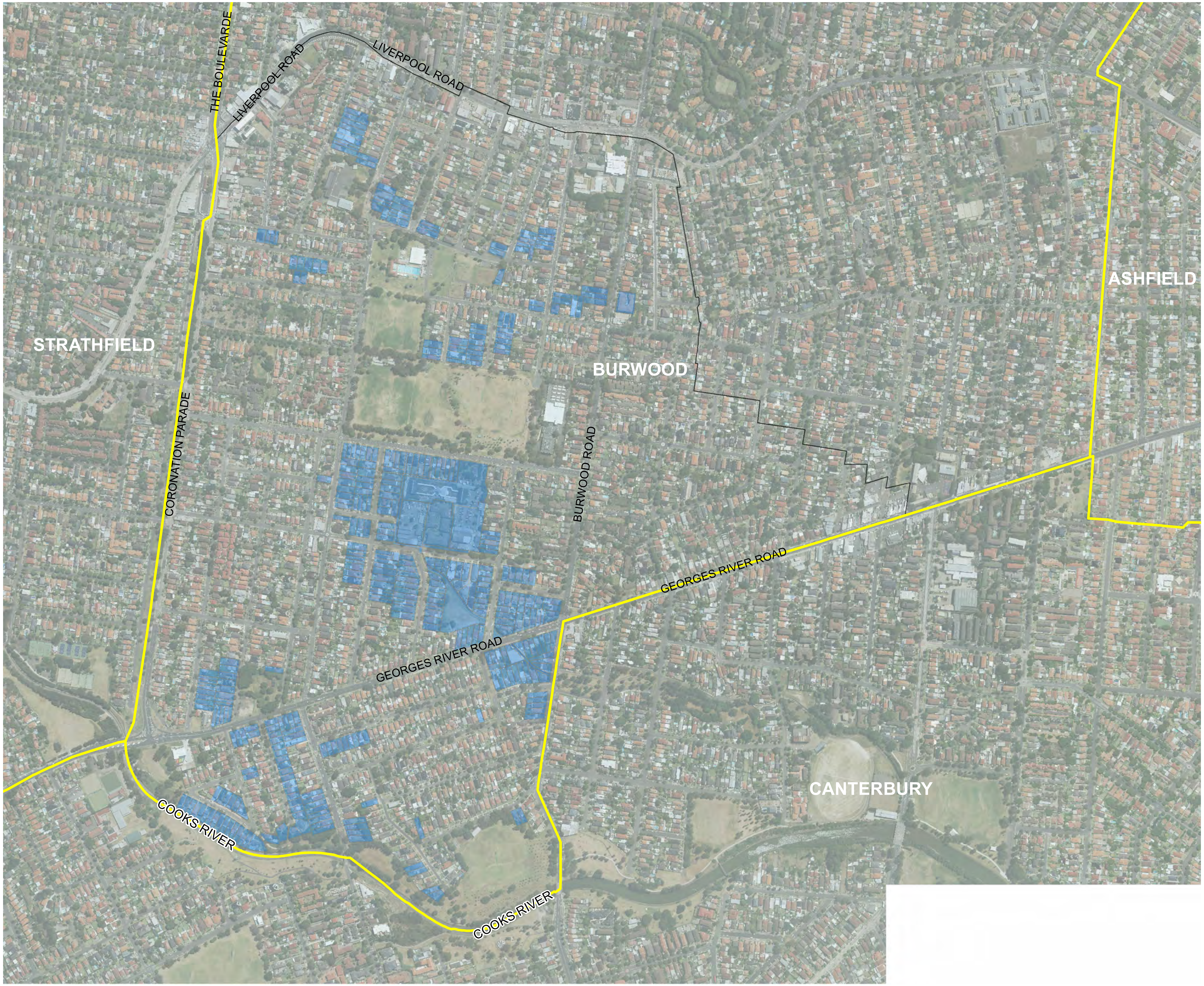
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PROPERTY TAGGING FOR COOKS RIVER 100 YEAR ARI RAISED BY 0.5 M

Scale	1:3,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	CR.TAG

Map No. **45**



BROWN
Smart Water

Legend

- LGA Boundaries
- 160616SIteWalkv2
- Study Area

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	OCT 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16
E	SUBMISSION E	SEPT 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

AMALGAMATED PROPERTY TAGGING (GROUND TRUTHED)

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	LOT.TAG

Map No. **46**

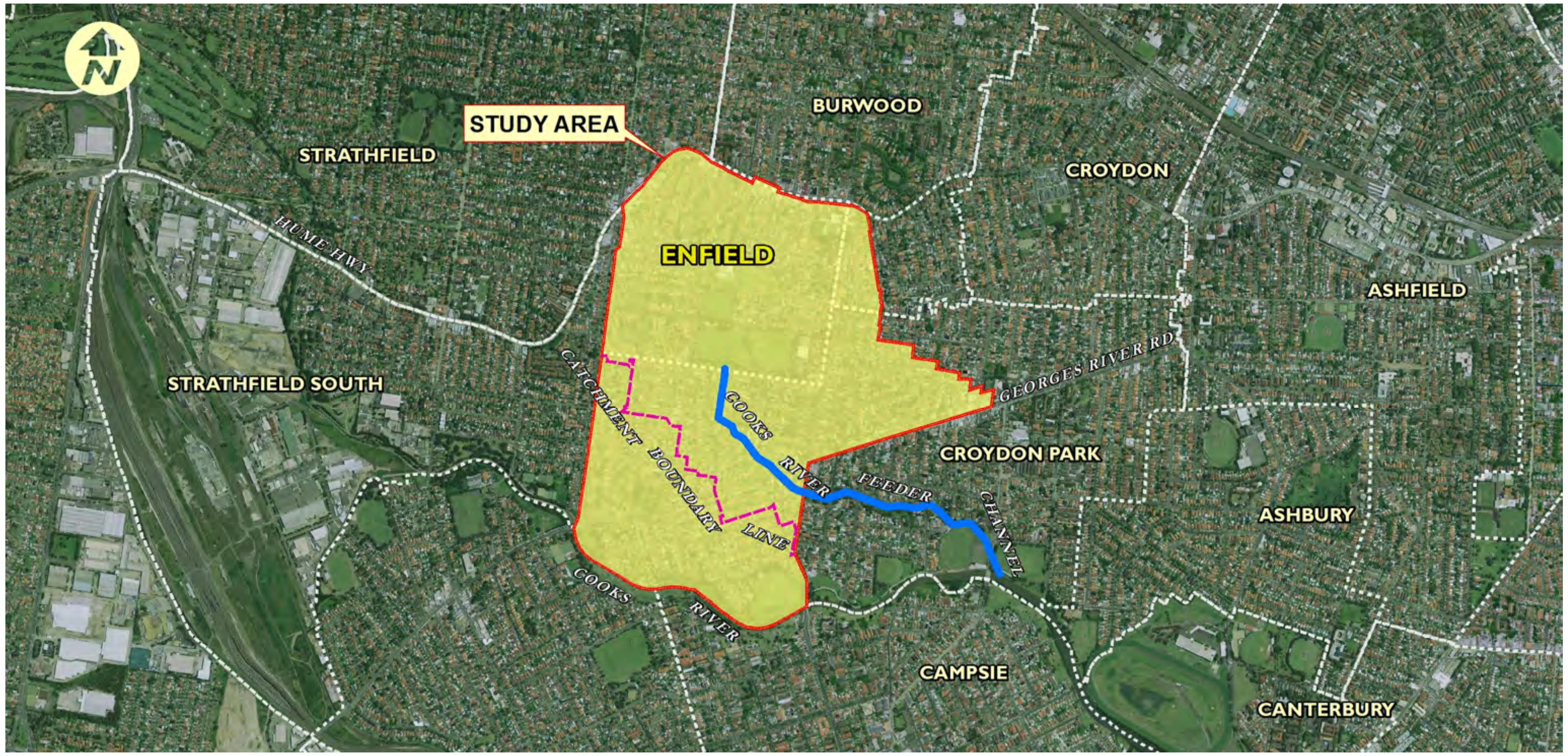
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY

FOR BURWOOD COUNCIL
VOLUME 3: SENSITIVITY MAPPING

BROWN Smart Consulting

SHEET LIST TABLE

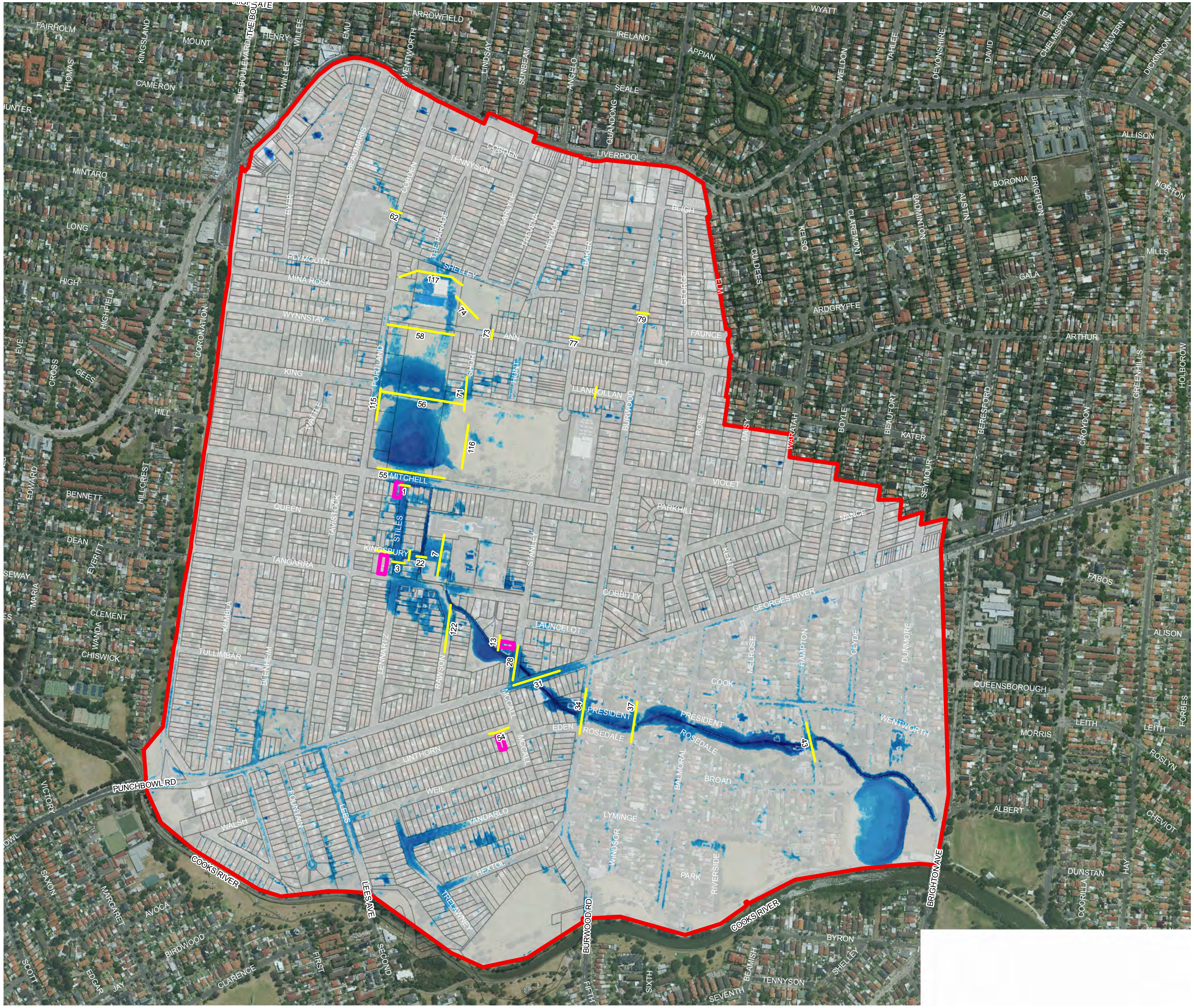
MAP No.	DRAWING ID	DRAWING TITLE
GENERAL		
S1	100y2h_BaseCase	PEAK FLOOD DEPTH FOR 100 YEAR ARI 2 HOUR STORM (BASE CASE)
S2	MAN.01	SENSITIVITY DIFFERENCE ANALYSIS FOR +20% MANNING N
S3	MAN.02	SENSITIVITY DIFFERENCE ANALYSIS FOR -20% MANNING N
S4	SLOPE.01	SENSITIVITY DIFFERENCE ANALYSIS FOR +20% SLOPE AT BOUNDARY CONDITION
S5	SLOPE.02	SENSITIVITY DIFFERENCE ANALYSIS FOR -20% SLOPE AT BOUNDARY CONDITION
S6	COOKSBC.01	SENSITIVITY DIFFERENCE ANALYSIS FOR 20 YEAR COOKS RIVER BOUNDARY CONDITIONS
S7	COOKSBC.02	SENSITIVITY DIFFERENCE ANALYSIS FOR 100 YEAR COOKS RIVER BOUNDARY CONDITIONS
S8	COOKSBC.03	SENSITIVITY DIFFERENCE ANALYSIS FOR COOKS RIVER SEA LEVEL RISE BOUNDARY CONDITIONS
S9	KU.01	SENSITIVITY DIFFERENCE ANALYSIS FOR +20% KU PIPE LOSS
S10	KU.02	SENSITIVITY DIFFERENCE ANALYSIS FOR -20% KU PIPE LOSS
S11	IL.01	SENSITIVITY DIFFERENCE ANALYSIS FOR +10% INITIAL LOSS
S12	IL.02	SENSITIVITY DIFFERENCE ANALYSIS FOR -10% INITIAL LOSS
S13	CL.01	SENSITIVITY DIFFERENCE ANALYSIS FOR +10% CONTINUOUS LOSS
S14	CL.02	SENSITIVITY DIFFERENCE ANALYSIS FOR -10% CONTINUOUS LOSS
S15	BLOCK.01	SENSITIVITY DIFFERENCE ANALYSIS FOR 20% BLOCKAGE IN PITS
S16	BLOCK.02	SENSITIVITY DIFFERENCE ANALYSIS FOR 100% BLOCKAGE IN PITS 50% BLOCKAGE IN CULVERTS
S17	BLOCK.03	SENSITIVITY DIFFERENCE ANALYSIS FOR 100% BLOCKAGE IN PITS 100% BLOCKAGE IN CULVERTS
S18	CC.01	SENSITIVITY DIFFERENCE ANALYSIS FOR +10% RAINFALL CLIMATE CHANGE
S19	CC.02	SENSITIVITY DIFFERENCE ANALYSIS FOR +20% RAINFALL CLIMATE CHANGE
S20	CC.03	SENSITIVITY DIFFERENCE ANALYSIS FOR +30% RAINFALL CLIMATE CHANGE



LOCALITY PLAN
N.T.S.

COOKS RIVER CATCHMENT
OVERLAND FLOOD STUDY

Project No.:	Stage:	Revision:
X12342	SUBMISSION	D



BROWN
Smart Water

Legend

- Measuring Stations
- Study Area
- Community Consultation
- Cadastre

Depth (m)

- < 0.15
- 0.15 - 0.2
- 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1.0 - 1.5
- 1.5 - 2
- > 2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

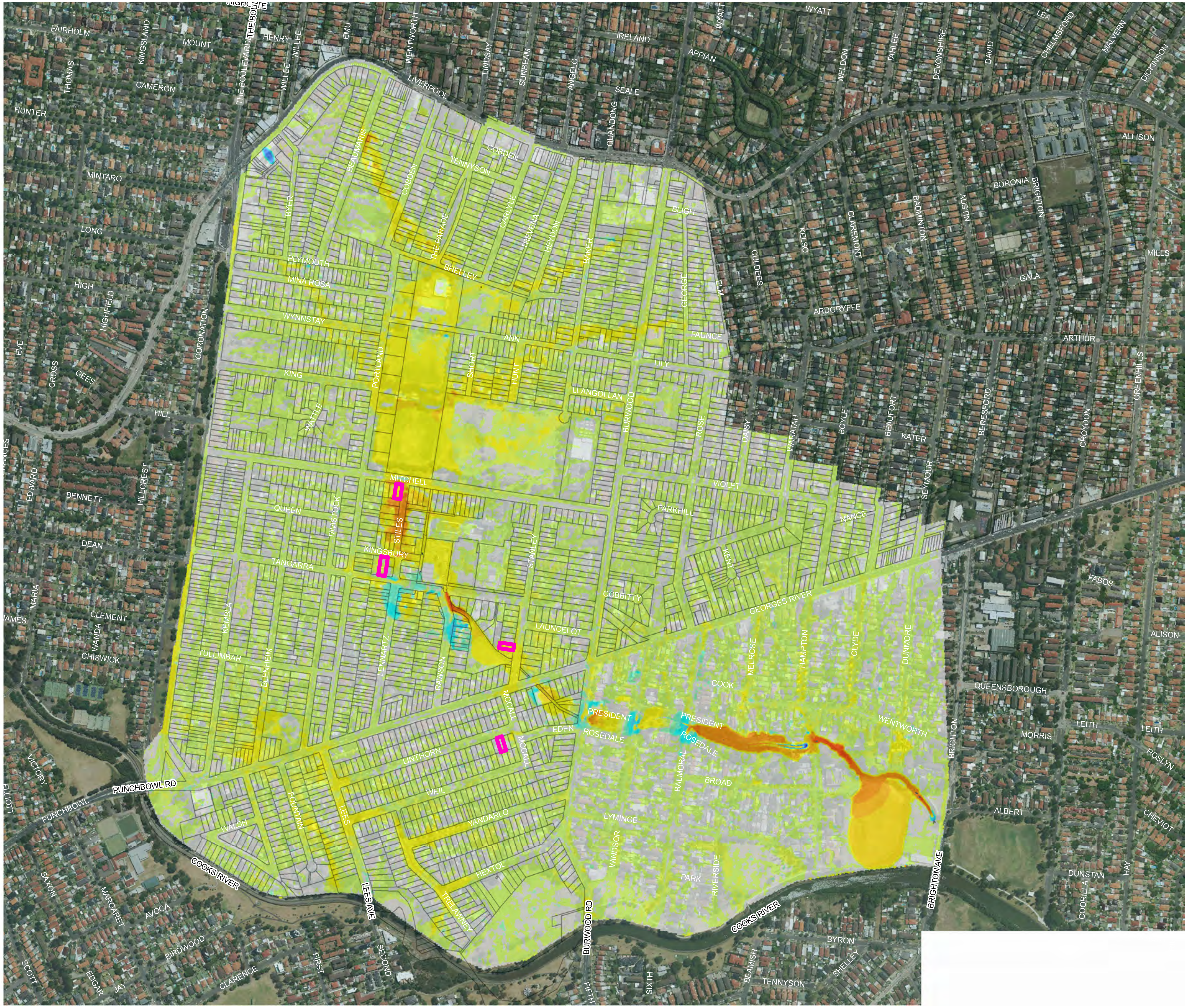
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

PEAK FLOOD DEPTH FOR 100 YEAR ARI 120 MINUTE DURATION STORM (BASE CASE)

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	100y2h_Base

Map No. **S1**



BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

- < -0.1
- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
- -0.005 - -0.001
- -0.001 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

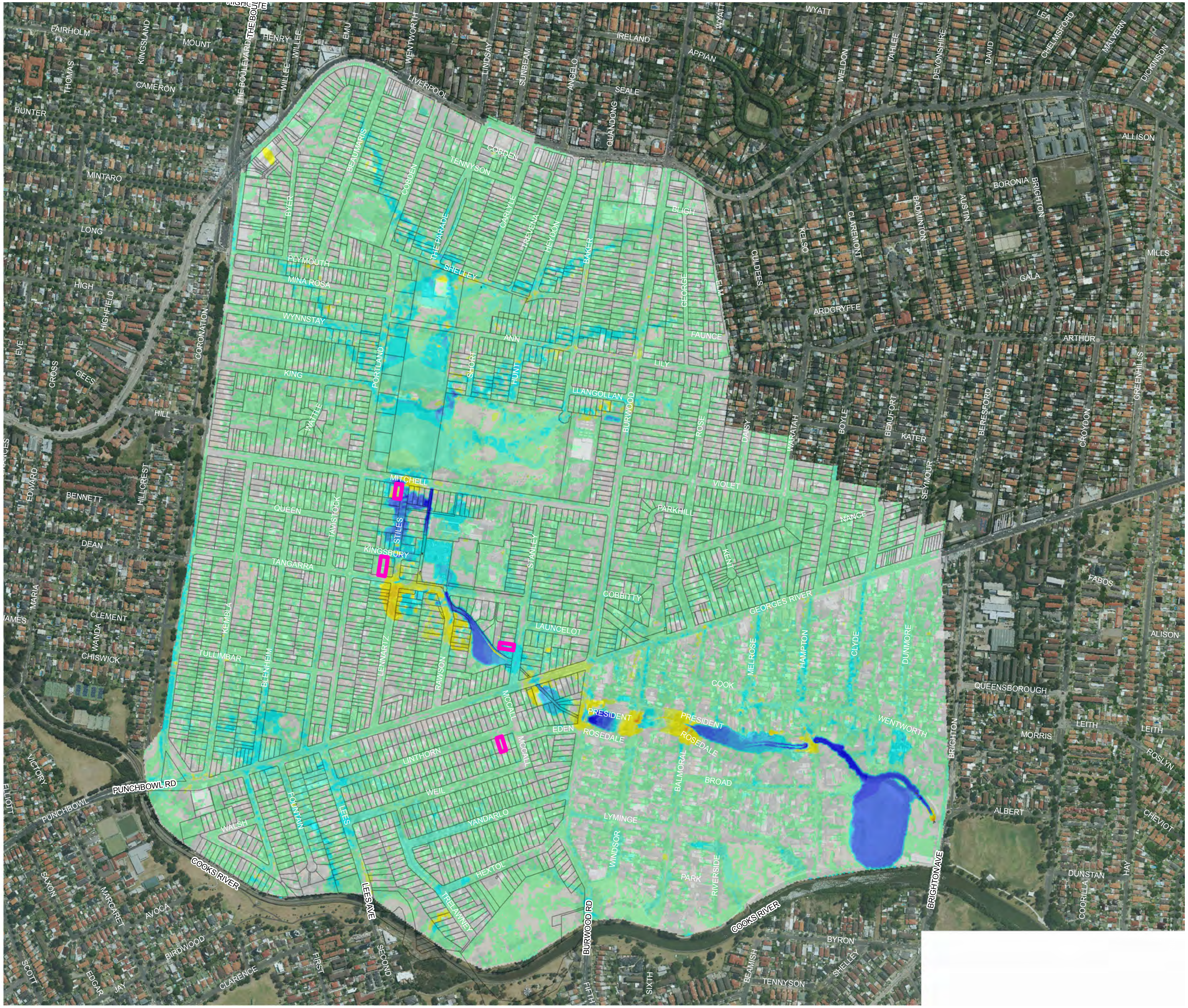
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR + 20% MANNING N

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	MAN.01

Map No. **S2**



![BROWN Smart Water]

Legend

- Community Consultation
- Cadastre

Difference (m)

- < -0.1
- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
- -0.005 - -0.001
- -0.001 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

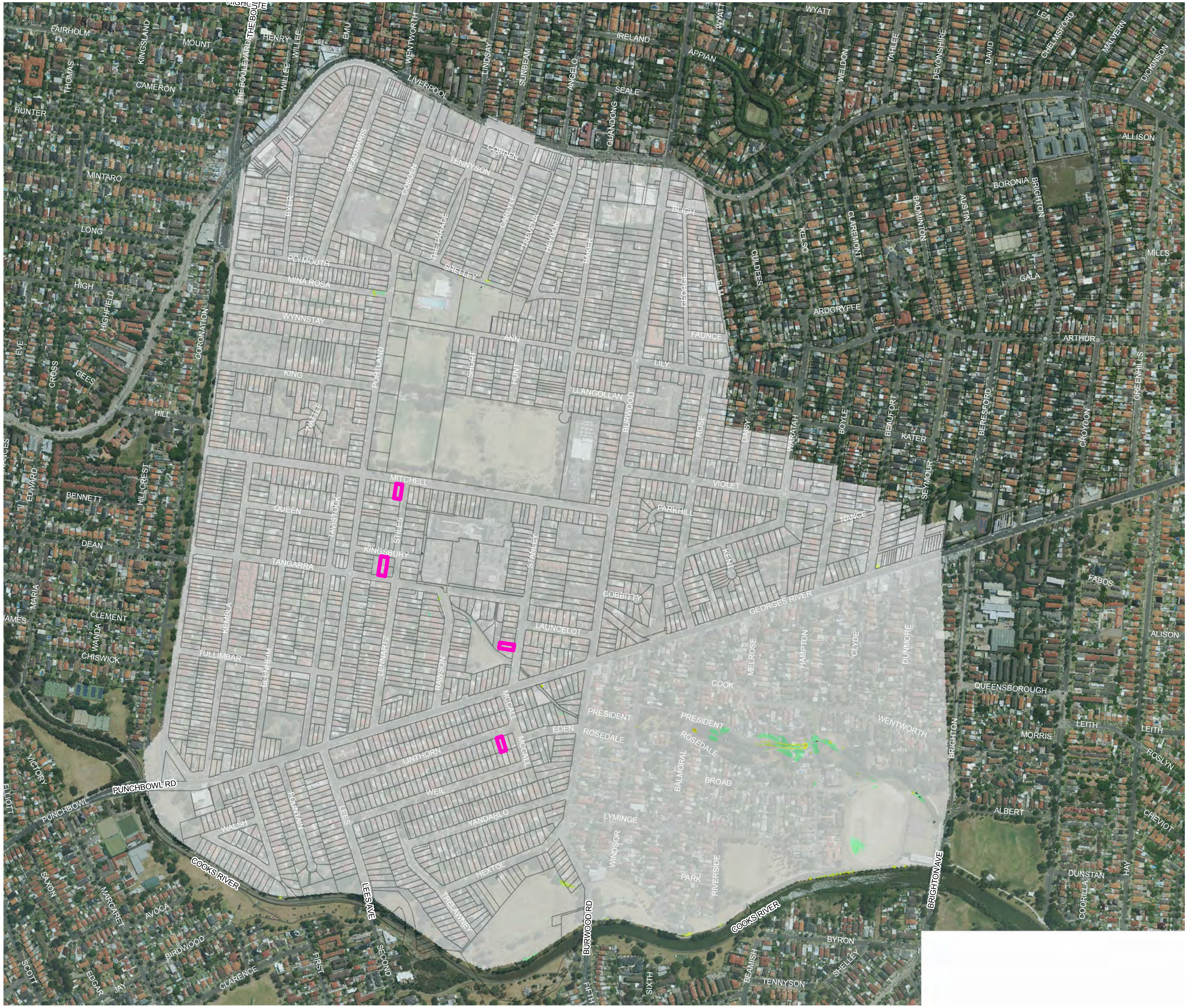
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR - 20% MANNING N

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	MAN.02

Map No. **S3**



BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

- < -0.1
- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
- -0.005 - -0.001
- -0.001 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

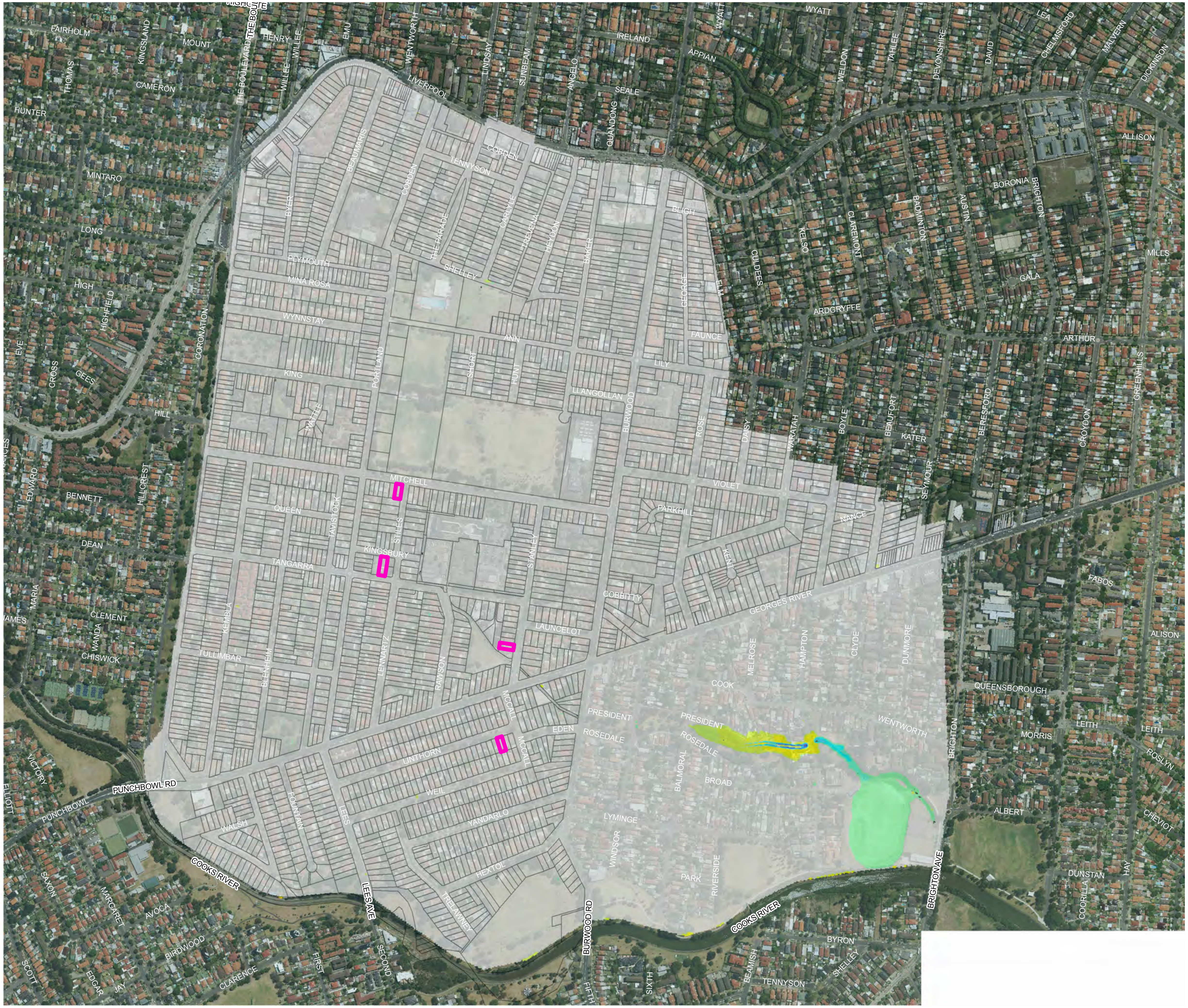
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR +20% SLOPE AT BOUNDARY CONDITION

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	SLOPE.01

Map No. **S4**



BROWN *Smart Water*

Legend

- Community Consultation
- Cadastre

Difference (m)

- < -0.1
- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
- -0.005 - -0.001
- -0.001 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

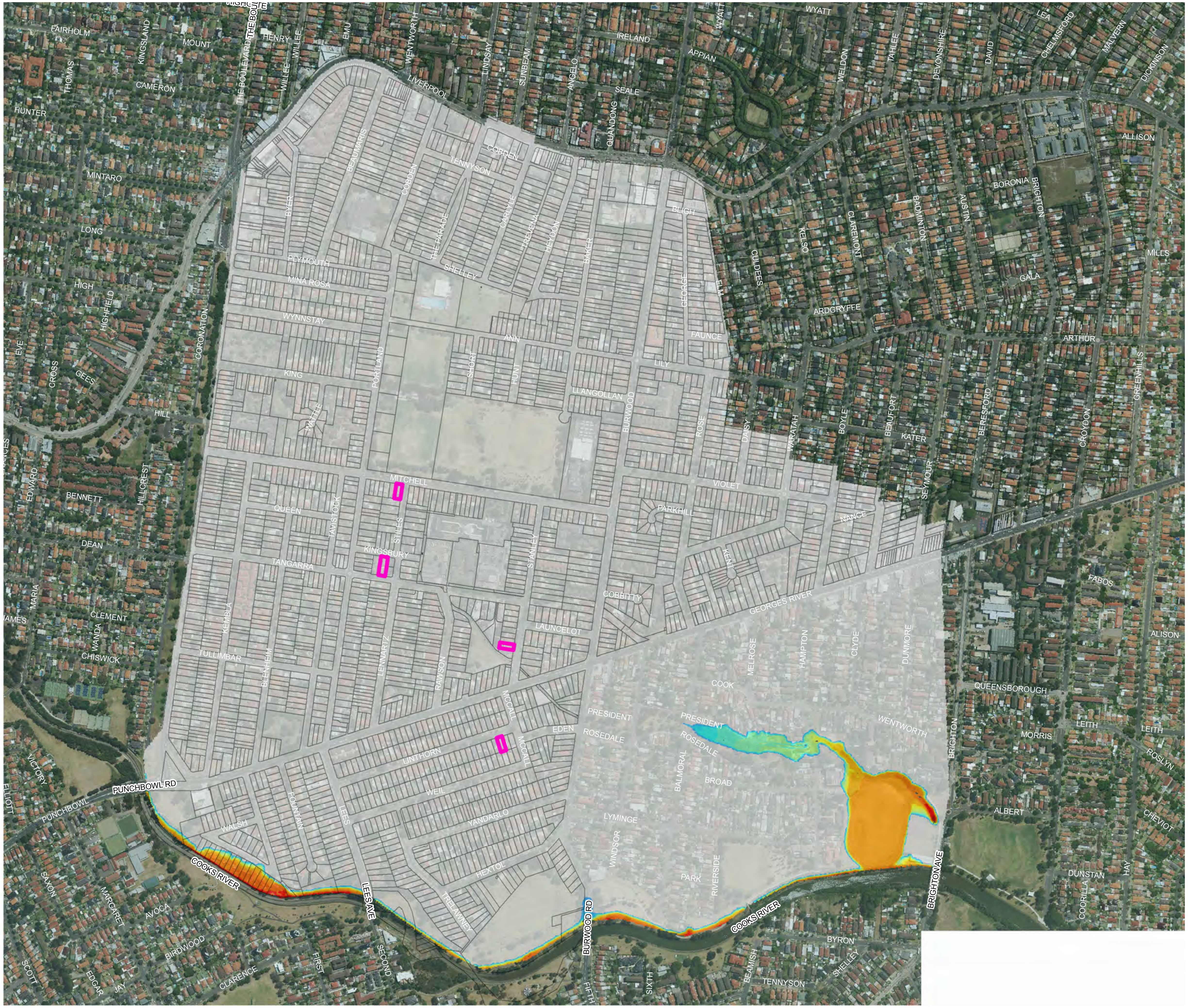
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR -20% SLOPE AT BOUNDARY CONDITION

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	SLOPE.02

Map No. **S5**



BROWN
Smart Water

Legend

Community Consultation
Cadastre
Difference (m)

- < -0.2
- -0.2 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - 0.01
- 0.01 - 0.025
- 0.025 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.125
- 0.125 - 0.15
- 0.15 - 0.2
- 0.2 - 0.25
- 0.25 - 0.3
- 0.3 - 0.35
- 0.35 - 0.4
- 0.4 - 0.45
- 0.45 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2.0

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

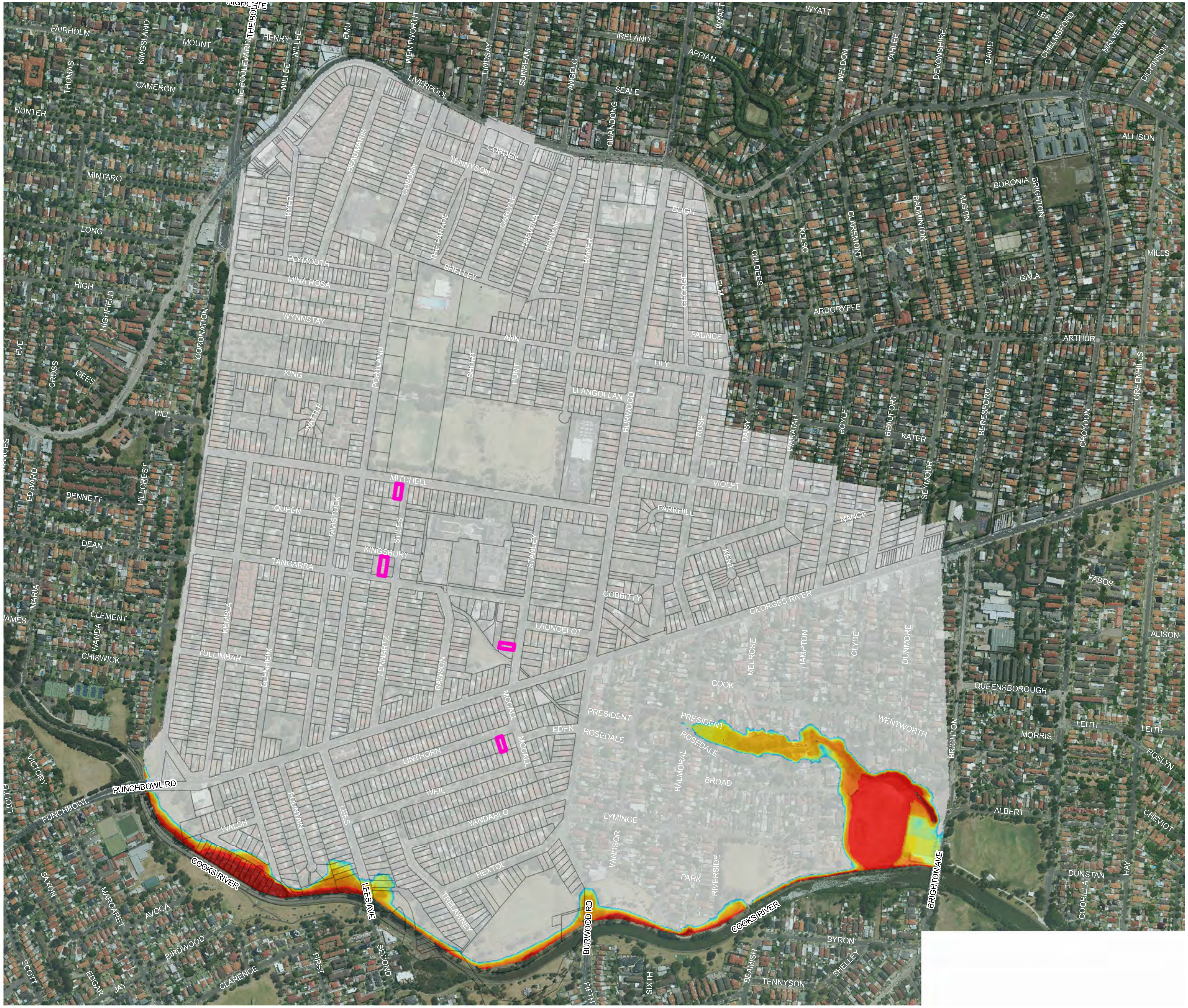
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR 20 YEAR COOKS RIVER BOUNDARY CONDITIONS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	COOKSBC.01

Map No. **S6**



BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

- < -0.2
- -0.2 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - 0.01
- 0.01 - 0.025
- 0.025 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.125
- 0.125 - 0.15
- 0.15 - 0.2
- 0.2 - 0.25
- 0.25 - 0.3
- 0.3 - 0.35
- 0.35 - 0.4
- 0.4 - 0.45
- 0.45 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2.0

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

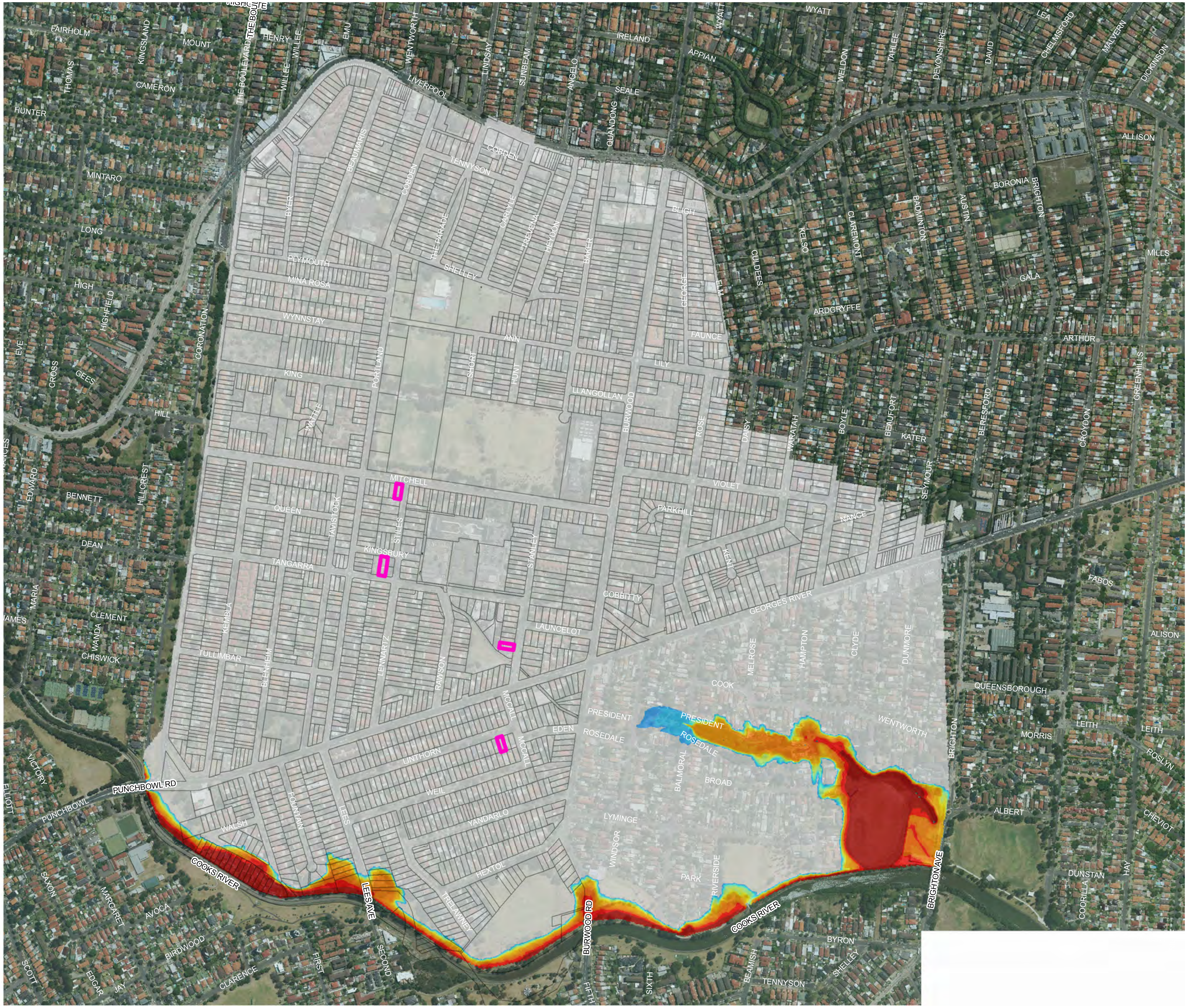
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR 100 YEAR COOKS RIVER BOUNDARY CONDITIONS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	COOKSBC.02

Map No. **S7**



BROWN
Smart Water

Legend

Community Consultation
Cadastre
Difference (m)

- < -0.2
- -0.2 - -0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - 0.01
- 0.01 - 0.025
- 0.025 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.125
- 0.125 - 0.15
- 0.15 - 0.2
- 0.2 - 0.25
- 0.25 - 0.3
- 0.3 - 0.35
- 0.35 - 0.4
- 0.4 - 0.45
- 0.45 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1.0 - 1.25
- 1.25 - 1.5
- 1.5 - 2
- > 2.0

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

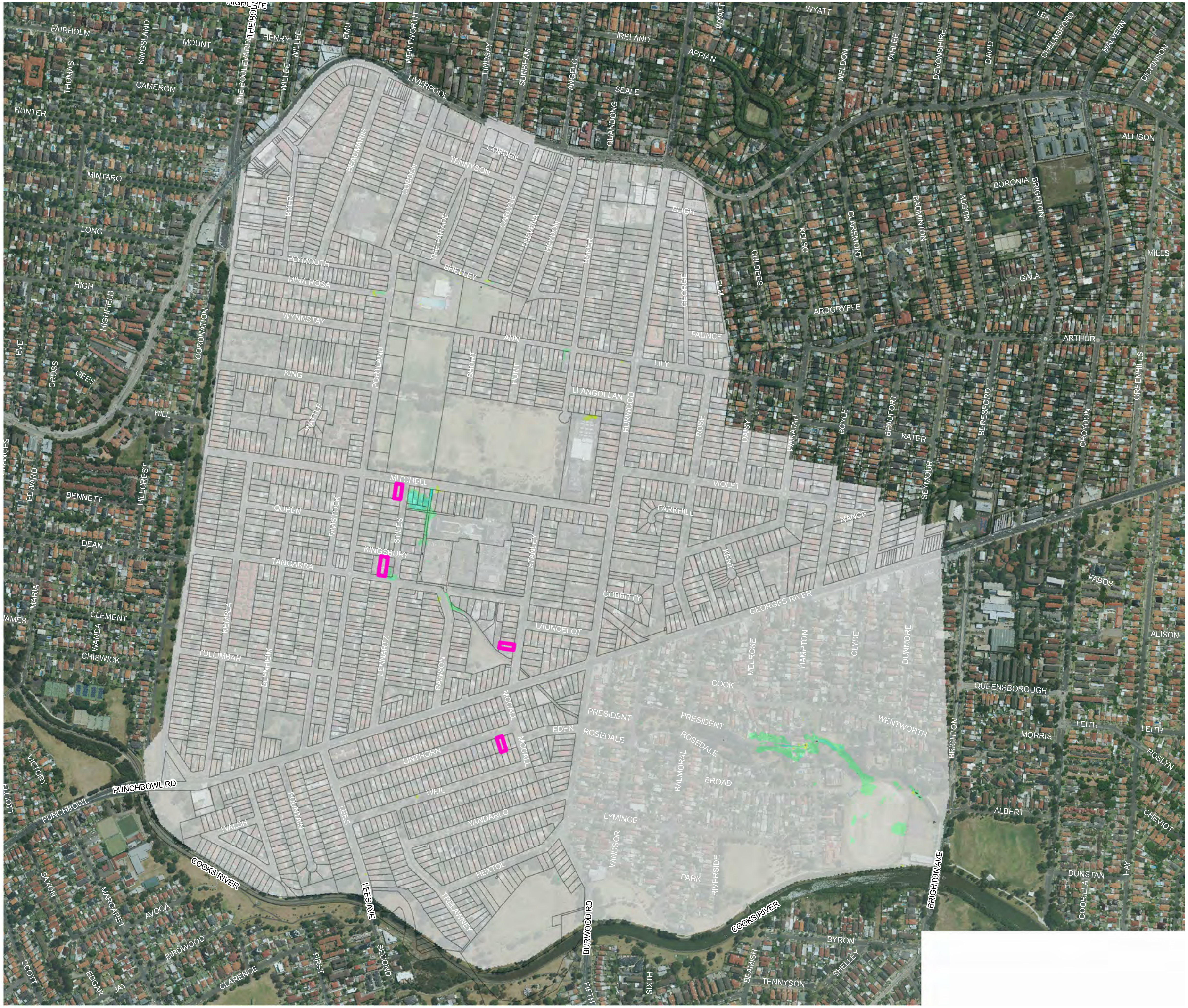
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR COOKS RIVER SEA LEVEL RISE BOUNDARY CONDITIONS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	COOKSBC.03

Map No. **S8**



BROWN
Smart Water

Legend

Community Consultation
Cadastre
Difference (m)

- < -0.1
- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
- -0.005 - -0.001
- -0.001 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

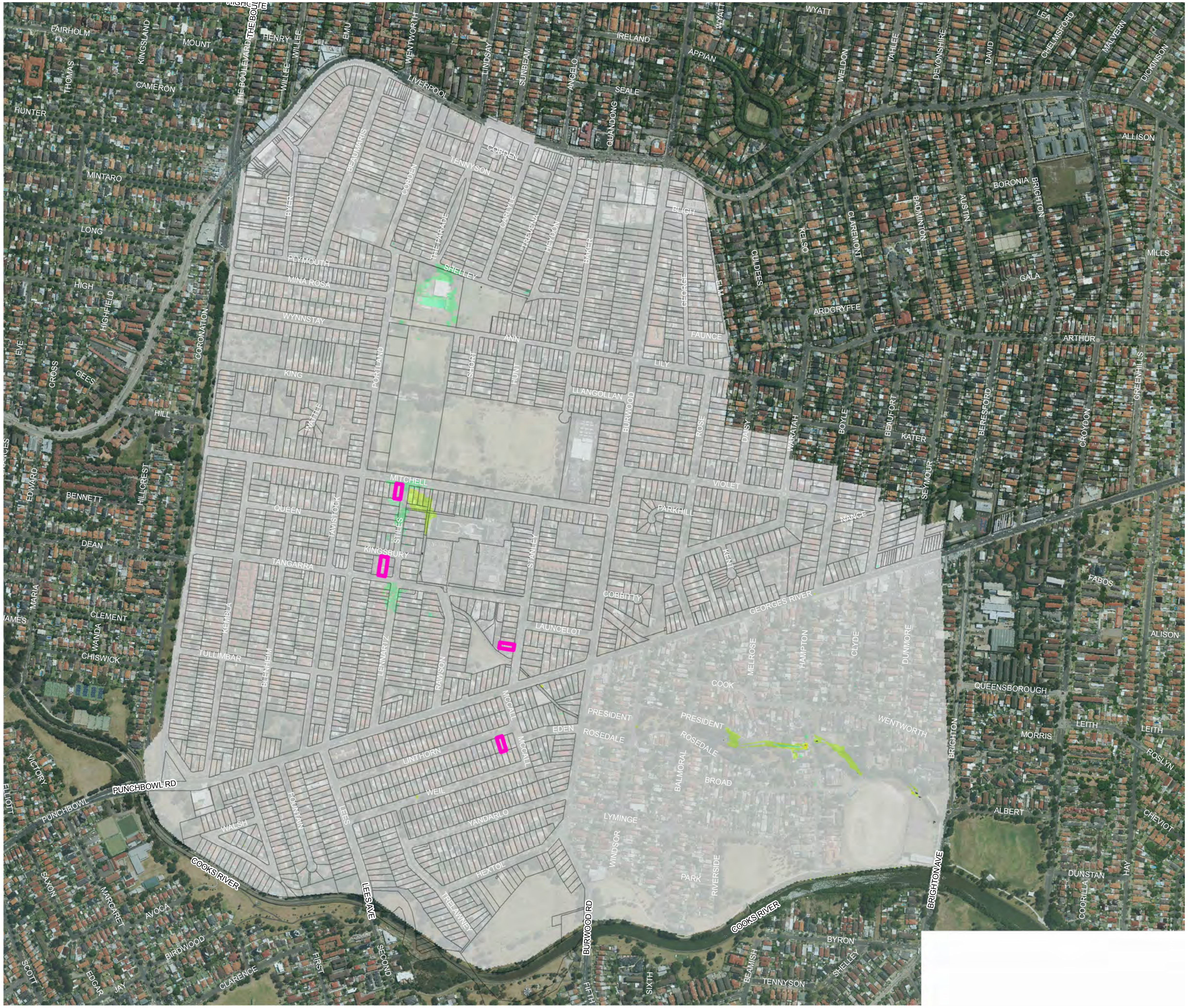
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR +20% KU PIPE LOSS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	KU.01

Map No. **S9**



BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

- < -0.1
- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
- -0.005 - -0.001
- -0.001 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

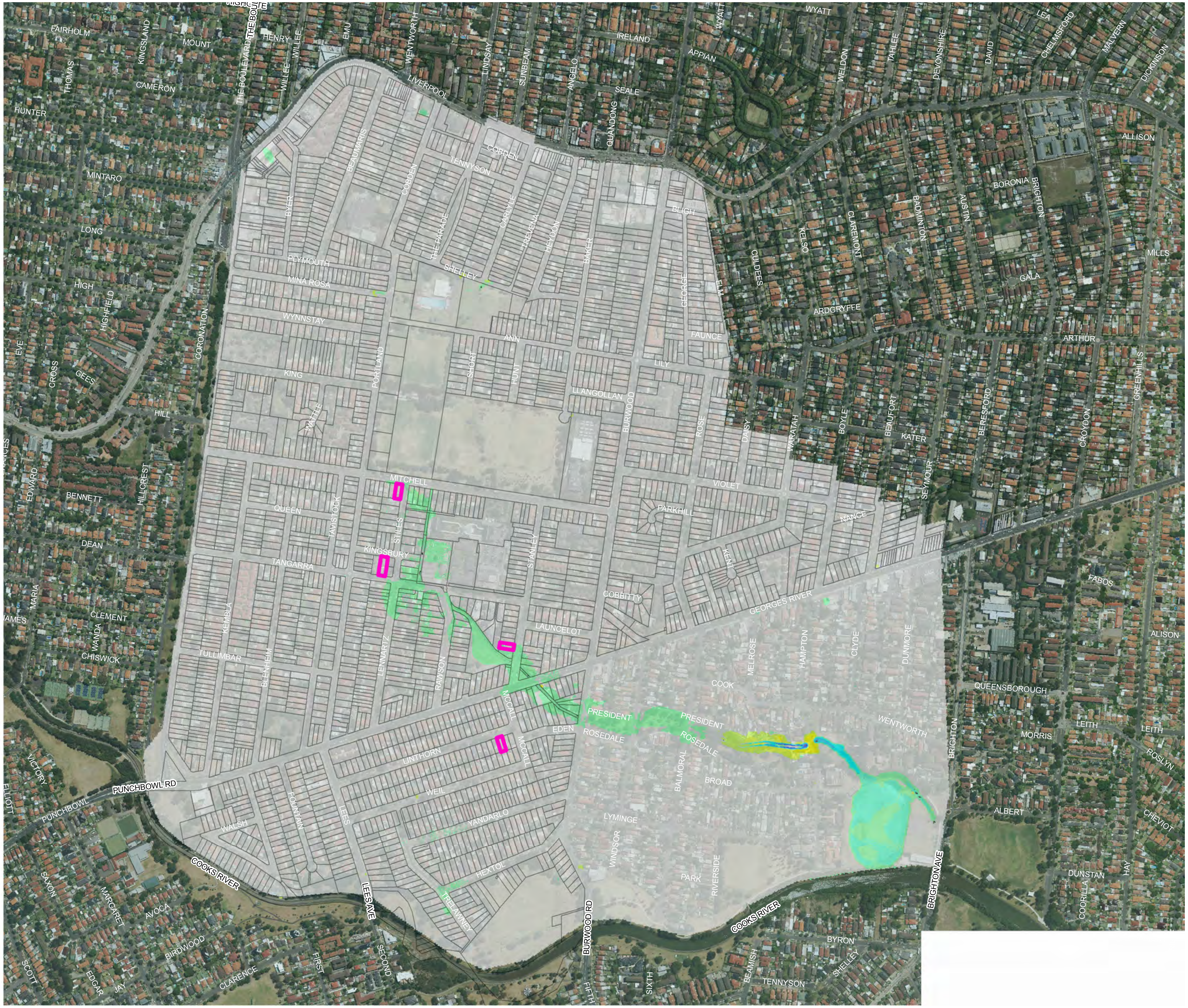
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR -20% KU PIPE LOSS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	KU.02

Map No. **S10**



BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

- < -0.1
- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
- -0.005 - -0.001
- -0.001 - 0.001
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- 0.01 - 0.03
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- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR +10% INITIAL LOSS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	IL.01

Map No. **S11**

BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

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- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
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- -0.03 - -0.02
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- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR -10% INITIAL LOSS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	IL.02

Map No. **S12**

BROWN *Smart Water*

Legend

- Community Consultation
- Cadastre

Difference (m)

- < -0.1
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- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
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- -0.001 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.03
- 0.03 - 0.04
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- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR +10% CONTINUOUS LOSS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	CL.01

Map No. **S13**

BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

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- 0.01 - 0.03
- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR -10% CONTINUOUS LOSS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	CL.02

Map No. **S14**

BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

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- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

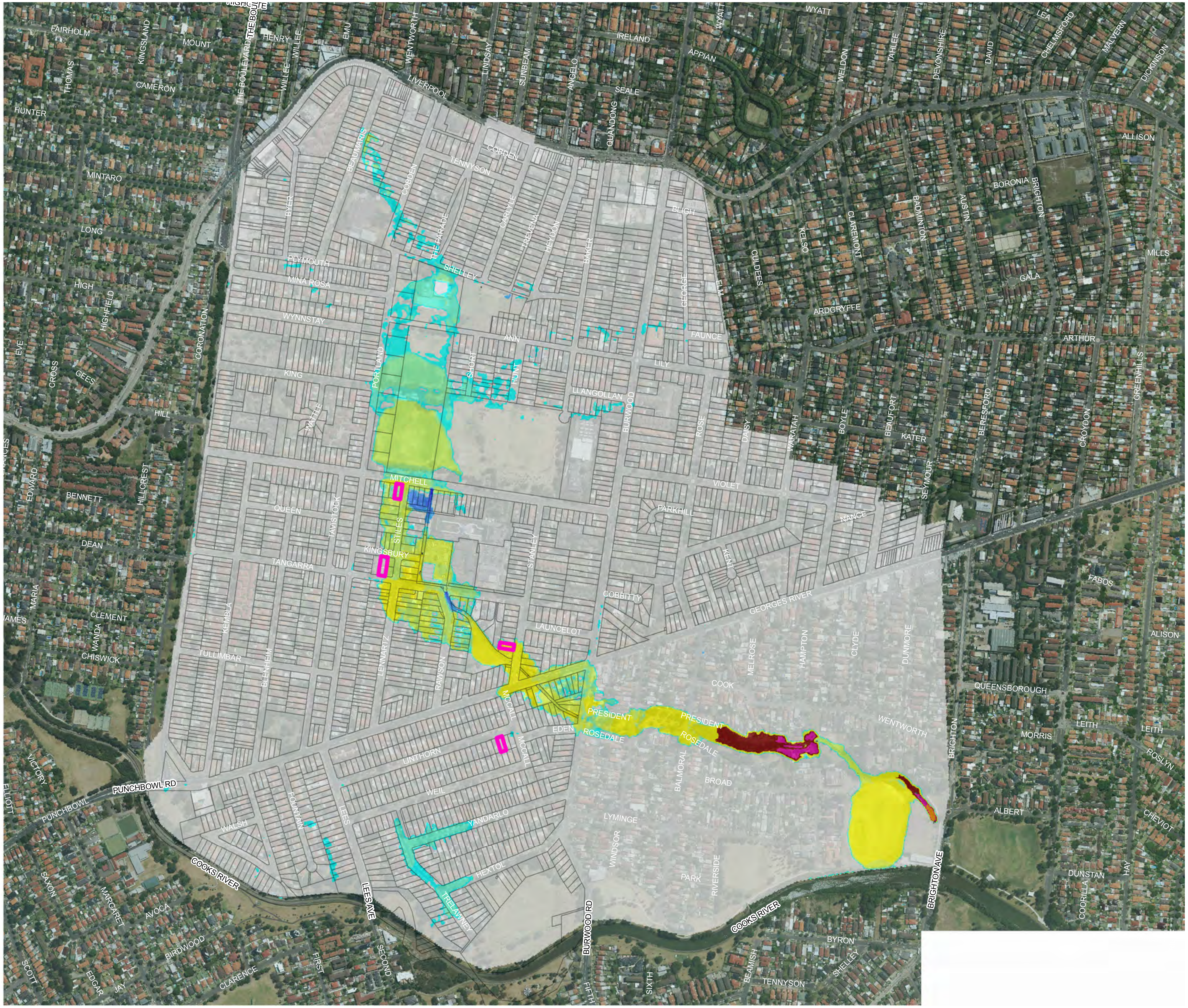
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR 20% BLOCKAGE IN PITS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	BLOCK.01

Map No. **S15**



BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

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- > 2

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

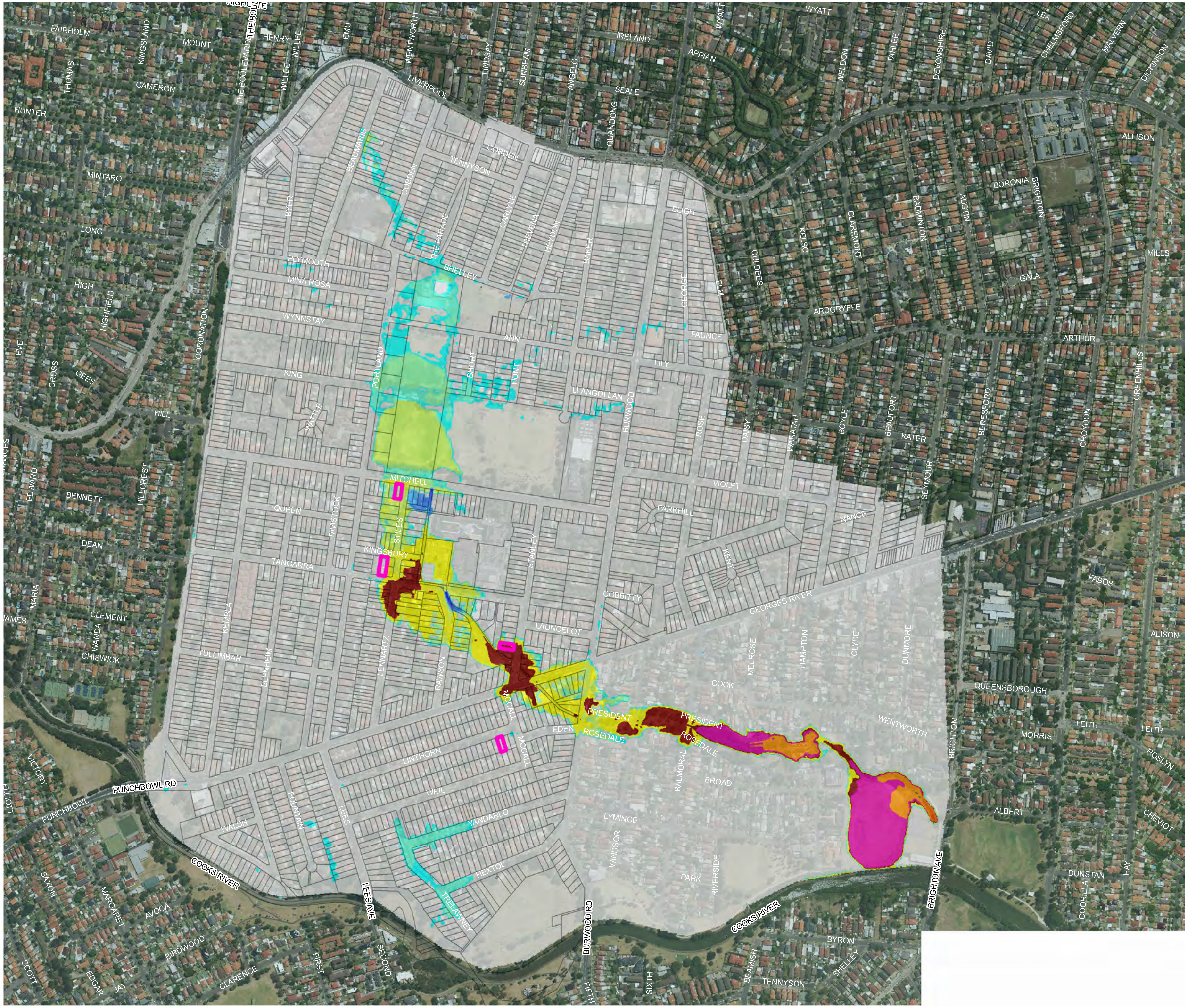
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR 100% BLOCKAGE IN PITS 50% BLOCKAGE IN CULVERTS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	BLOCK.02

Map No. **S16**



BROWN *Smart Water*

Legend

- Community Consultation
- Cadastre

Difference (m)

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- -0.1 - -0.05
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- 1 - 1.5
- 1.5 - 2
- > 2

N

0 50 100 200 300 Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

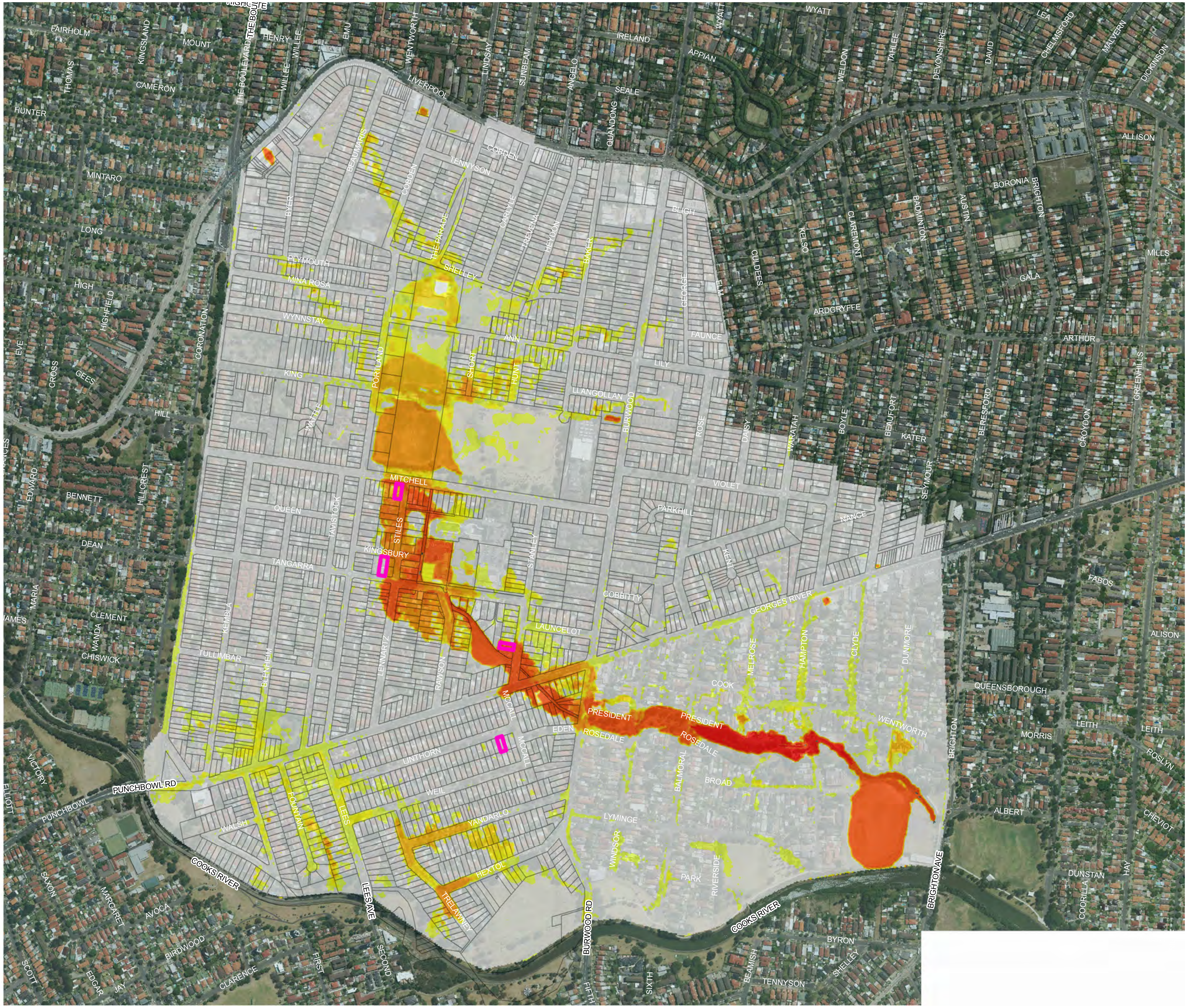
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR 100% BLOCKAGE IN PITS 100% BLOCKAGE IN CULVERTS

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	BLOCK.03

Map No. **S17**



BROWN
Smart Water

Legend

Community Consultation
Cadastre
Difference (m)
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- -0.2 - -0.15
- -0.15 - -0.1
- -0.1 - -0.075
- -0.075 - -0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
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- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

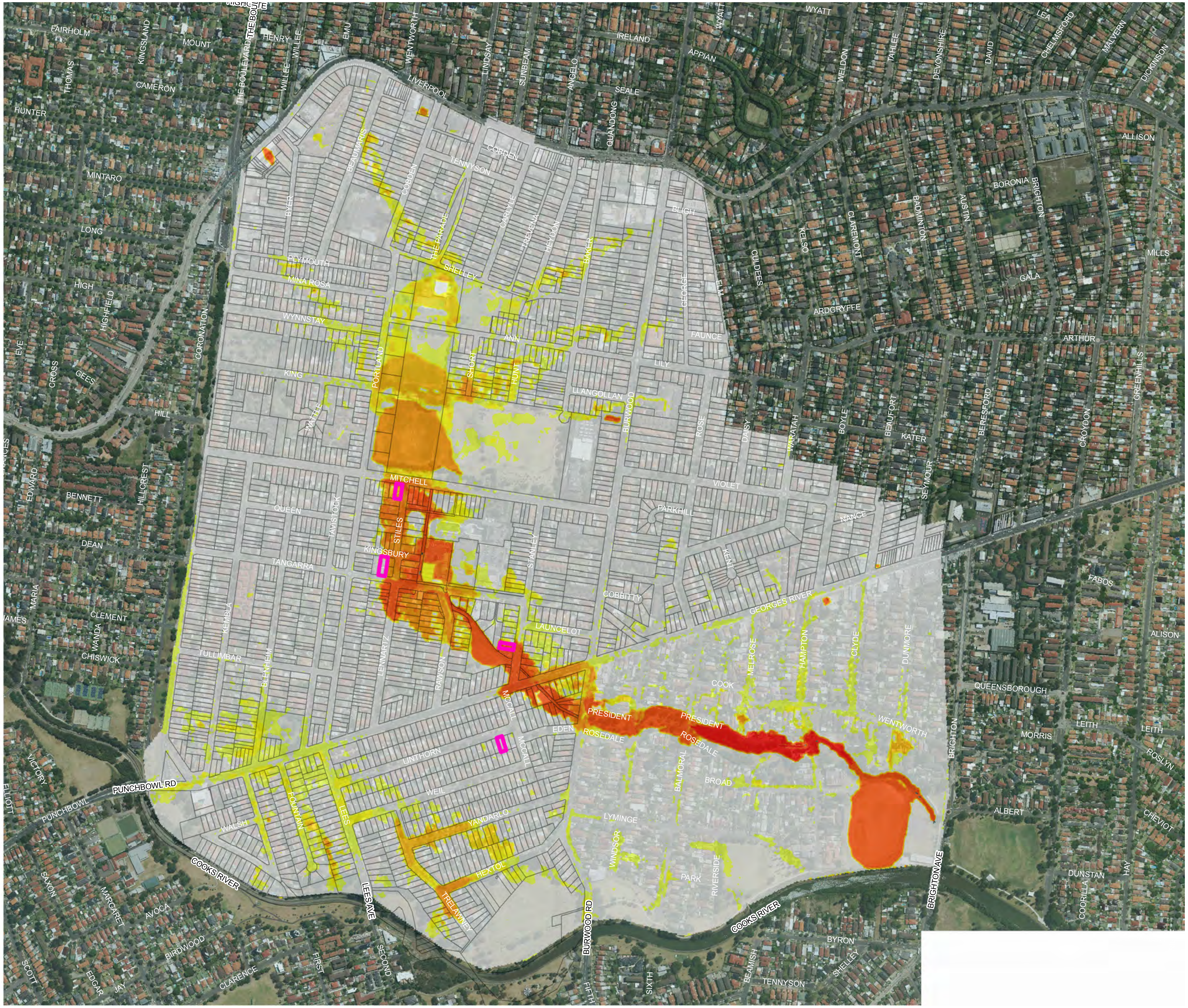
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR +20% RAINFALL CLIMATE CHANGE

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	CC.02

Map No. **S18**



BROWN
Smart Water

Legend

Community Consultation
Cadastre

Difference (m)

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- -0.03 - -0.02
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- -0.1 - 0.01
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- 0.03 - 0.04
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- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- > 0.2

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

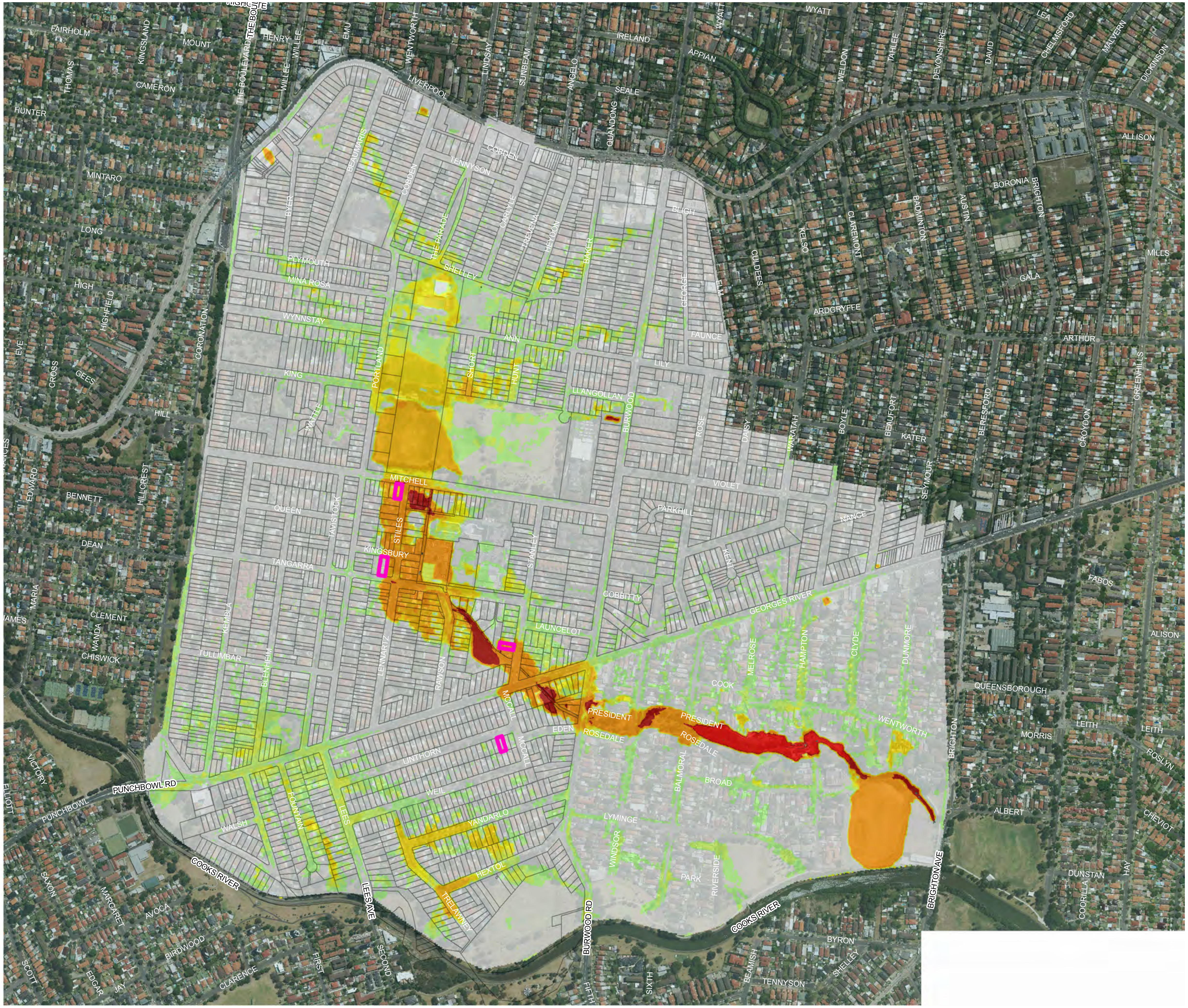
COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR +20% RAINFALL CLIMATE CHANGE

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	CC.02

Map No. **S19**



BROWN
Smart Water

Legend

- Community Consultation
- Cadastre

Difference (m)

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- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - 0.01
- 0.01 - 0.02
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- 0.03 - 0.04
- 0.04 - 0.05
- 0.05 - 0.075
- 0.075 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.5

N

0 50 100 200 300
Metres

Details

Issue	Amendment	Date
A	DRAFT A	JUNE 13
B	DRAFT B	FEB 14
C	DRAFT C	MAY 14
D	SUBMISSION D	AUG 16

Project

COOKS RIVER CATCHMENT OVERLAND FLOOD STUDY FOR BURWOOD COUNCIL

Drawing Title

SENSITIVITY DIFFERENCE ANALYSIS FOR +30% RAINFALL CLIMATE CHANGE

Scale	1:8,000 @ A3
Drawn	JT
Checked	PB
Job No.	X12342
Drawing ID	CC.03

Map No. **S20**

Burwood Council
heritage ▪ progress ▪ pride

POWELLS CREEK AND SALEYARDS CREEK DRAFT FLOOD STUDY

wma water

MARCH 2017

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: 9299 2855
Fax: 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

POWELLS CREEK FLOOD STUDY

MARCH, 2017

Project Powells Creek Flood Study	**Project Number** 115010
Client Burwood Council	**Client's Representative** Kundan Pokharel
Authors Richard Dewar Felix Taaffe Erika Taylor	**Prepared by** TO BE SIGNED FOR FINAL REPORT
Date 1 March 2017	**Verified by** TO BE SIGNED FOR FINAL REPORT

Revision	Description	Date
1	Draft Report	March 2016
2	Draft Report	June 2016
3	Draft Report	March 2017

POWELLS CREEK AND SALEYARDS CREEK FLOOD STUDY

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
ALS	Airborne Laser Scanning sometimes known as LiDAR
BoM	Bureau of Meteorology
CBD	Central Business District
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CFERP	Community Flood Emergency Response Plan
DEM	Digital Elevation Model
DRAINS	Hydrologic computer model developed from ILSAX
EPR	Entire Period of Record of gauge data at Elva Street gauge)
EY	Exceedances per Year
FFA	Flood Frequency Analysis
GEV	Generalised Extreme Value probability distribution
GIS	Geographic Information System
GSDM	Generalised Short Duration Method
HEC-RAS	1D hydraulic computer model
HGL	Hydraulic Grade Line
ILSAX	Hydrologic model - a precursor to DRAINS
IFD	Intensity, Frequency and Duration of Rainfall
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
LiDAR	Light Detection and Radar
LP3	Log Pearson III probability distribution
m	metre
MHL	Manly Hydraulics Laboratory
m^3/s	cubic metres per second (flow measurement)
m/s	metres per second (velocity measurement)
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SEPP	State Environmental Planning Policy
SMC	Strathfield Municipal Council
SWC	Sydney Water Corporation
TIN	Triangular Irregular Network
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
UNSW	University of New South Wales
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

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

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

1. Flood Study
- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management Study
- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan
- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan
- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Powells Creek Flood Study constitutes the first stage of the management process and is based on the recent study for the wider catchment undertaken by Sydney Water Corporation.

EXECUTIVE SUMMARY

BACKGROUND

Powells Creek is a small southern tributary of the Parramatta River and Saleyards Creek is the major tributary of Powells Creek (Figure 1). The total catchment area of Powells Creek to Homebush Bay Drive is 8.1 km^2 and Saleyards Creek to the confluence with Powells Creek is 3.2 km^2.

The Powells Creek catchment is located in Sydney's Inner West region, approximately 12 kilometres west of the CBD. The catchment includes the suburbs (or parts) of Burwood, Concord West, Homebush, Homebush West, North Strathfield, Strathfield and Rookwood (cemetery). Approximately 77% of the catchment is within the Strathfield Municipal Council (SMC) local government area (LGA), 15% is within City of Canada Bay Council, 5% is within Burwood Council LGA and 3% (Rookwood cemetery) within Auburn LGA. Saleyards Creek is predominantly within the SMC LGA apart from Rookwood cemetery.

The Powells Creek catchment drains to Homebush Bay on the Parramatta River via an open channel and a series of inlet pits and pipes. Sydney Water Corporation (SWC) owns the larger "trunk" drainage assets including the open channel and the smaller pipe and pit networks are owned by the various councils.

The current study concerns the part of the Burwood LGA in the Powells Creek catchment.

OBJECTIVES

The purpose of this Flood Study is to identify mainstream and overland flow flooding (where there is no defined channel) in order to define the existing flood liability within the catchment. This objective is achieved through the development of a suitable hydrologic and hydraulic modelling platform that can subsequently be used as the basis for a future Floodplain Risk Management Study and Plan for the study area, and to assist Council when undertaking flood-related planning decisions for existing and future developments.

The primary objectives of the study are to:

- prepare suitable models of the catchment and floodplain for use in subsequent detailed overland flow studies and a Floodplain Risk Management Study;
- provide results for flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area;
- prepare maps of provisional hydraulic categories and provisional hazard categories; and
- assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.

FLOODING HISTORY

In examining the flooding history it must be noted that the drainage characteristics of this catchment have been significantly altered as a result of urbanisation and as such older flood extents and depths for a given storm may not apply to present day conditions. There have been many instances of flooding in the past with November 1961, March 1975 and March 1983 having the greatest number of records. Archival records also mention several prior large floods including a particularly severe event in 1860. More recently, reports of minor property inundation from overland flow in 2015 and 2016 in the Burwood LGA have been received.

A water level gauge at Elva Street was operated from 1958 to approximately 2010 by the University of New South Wales (UNSW). The records have been digitised up to 1997 and were used for calibration of the modelling system as well as flood frequency analysis.

PAST STUDIES

Initially a review of the available reports and data was undertaken. The previous Powells Creek Flood Study undertaken for SMC in 1998 is the only study covering the entire catchment and providing detailed flood levels. All relevant data from the 1998 Powells Creek Flood Study was obtained and used in the present study and the results compared. The other prior studies used hydrologic models (ILSAX) to determine pipe flows and assess mitigation measures and are of less relevance for the present study.

RAINFALL AND FLOOD HEIGHT DATA

There is a limited amount of rainfall data covering the catchment, particularly pluviometer data which is needed to describe the temporal pattern of historical events. A reasonable amount of historical flood height data is available from SWC records as well as the 1998 Powells Creek Flood Study. As no significant floods have occurred since the completion of the 1998 Flood Study, no further attempt of obtaining historical flood data from the residents was made as part of the present study.

HYDROLOGIC AND HYDRAULIC MODELLING PROCESS

The hydrologic modelling was undertaken using DRAINS and the hydraulic model was undertaken using TUFLOW. These models were verified by comparison to six historical events (3rd, 7th, 10th and 17th February 1990, 18th March 1990 and 2nd January 1996).

The design rainfall events modelled were the 0.5EY, 0.2EY, 10%, 5%, 1% AEP, 0.5% and 0.2% design events and the Probable Maximum Flood (PMF). The temporal patterns for the design events were sourced from Australian Rainfall and Runoff (1987) and the rainfall data was obtained from the Bureau of Meteorology's (BoM) internet-based tool. The PMP estimates were derived according to the BoM guidelines.

FLOOD FREQUENCY ANALYSIS

An extensive flood frequency analysis (FFA) was carried out which examined different rating curves and the use of different data sets. When compared to FFA design flow estimates, those from TUFLOW appear to overestimate flows for more frequent events and underestimate flow in the 2% AEP event or greater.

SENSITIVITY ANALYSIS, BLOCKAGE AND CLIMATE CHANGE

Sensitivity analysis and blockage assessments were undertaken to assess the effects of varying key model parameters. In addition, assessments of the effects of a sea level rise elevating the adopted design water levels in the Parramatta River and an increase in design rainfall intensities were undertaken. Sea level rise made little difference in the upstream developed areas; however, rainfall increases will produce a significant increase in flood levels.

OUTCOMES

The results from this study provide design flood data (levels, depths, velocity, hazard, hydraulic classification) which supersede those derived in the 1998 Powells Creek Flood Study.

Immediately following the next large flood event (10% AEP or greater) water level and rainfall data should be collected and used to verify the hydrologic and hydraulic model calibration.

1. INTRODUCTION

1.1. Background

The Powells Creek catchment (Figure 1) is located on the southern bank of the Parramatta River at Homebush Bay, approximately 12 kilometres west of the Sydney CBD. The main tributary of Powells Creek is Saleyards Creek which enters immediately upstream of Homebush Bay Drive. Downstream of Homebush Bay Drive, Powells Creek is a natural channel surrounded by dense mangrove vegetation on both sides. Upstream Powells and Saleyards Creeks are concrete lined channels with Powells Creek bounded on the east by the City of Canada Bay LGA; largely comprising of residential development with residential, light industry and open space on the western SMC side. Saleyards Creek is bounded on both sides by open space until reaching Underwood Road where it is largely bordered by commercial developments.

The total catchment area of Powells Creek to Homebush Bay Drive is 8.1 km^2 and Saleyards Creek to the confluence with Powells Creek is 3.2 km^2.

The catchment includes the suburbs (or parts) of Burwood, Concord West, Homebush, Homebush West, North Strathfield, Strathfield and Rookwood (cemetery). Approximately 77% of the catchment is within the SMC LGA, 15% is within City of Canada Bay Council, 5% is within Burwood Council LGA and 3% (Rookwood cemetery) within Auburn LGA (herein termed the Councils). Saleyards Creek is predominantly within the SMC LGA apart from Rookwood cemetery.

Drainage elements in the catchment include kerbs and gutters, pits and pipes, and a network of trunk drainage elements including culverts and open channels. Ownership of the assets is split between SWC and the Councils, with SWC owning the larger "trunk" elements. Amongst the drainage assets is a length of brickwork drain that was one of the first purpose-built stormwater drains in Sydney and constructed in the 1890's. Open channel sections extend from Powells Creek under the railway lines to Elva Street, to just beyond Ismay Avenue on the small tributary, and up Saleyards Creek under Flemington markets to upstream of the railway line.

The present study has been commissioned by Burwood Council to extend upon the previous study commissioned by SWC, to define mainstream and overland flood behaviour in the catchment. This report covers the part of the catchment lying in the Burwood LGA, and results and analysis are virtually the same as those presented in the SWC-commissioned study. Mainstream is generally defined as flooding occurring from open channels, either lined or natural, whereas overland is mainly flooding where there is no defined open channel and drainage is via the pit and pipe system or overland through private and public properties. However, there are exceptions to these definitions. The study area does not include any sections of open channel or mainstream flooding (they are located in the Strathfield LGA), however, results from these downstream areas have been presented for completeness.

1.2. Description of Catchment

The study area's catchment is fully urbanised. Within the Strathfield LGA approximately 79% of the catchment is zoned for residential development, 9% for special purpose, 6% for open space areas (parks and recreation areas) and the remaining 7% for business/commercial and industrial areas. Within the Burwood LGA, approximately 90% is zoned for residential development (mix of Low Density and General) with remaining areas containing mixed use, public recreation and infrastructure.

A land use zone map is provided as Figure 2. Upstream of the Parramatta railway Line both catchments are predominantly occupied by residential development with areas of open space, schools and active recreation. The residential developments are largely detached dwellings constructed prior to 1960 but there are also a number of recent higher density developments. Significant commercial development is located near Strathfield railway station at Strathfield Plaza.

Downstream of the railway line the catchments of both creeks are a mixture of residential, commercial (Flemington Markets) and light industrial developments. There are also significant areas of open space surrounding the lower parts of both creeks. The transport routes, M4 Motorway, Parramatta Road, Homebush Bay Drive and the railway lines have influenced the flow paths in the lower reaches.

Very little information is available in Council's records regarding the existing site drainage for the catchment in general (i.e. are there rubble pits? If so what size? Is the existing roof drainage connected directly to the street drainage?). On-site detention has been introduced by the Councils since the mid-1990s.

Diagram 1 indicates the significant change in alignment of Powells Creek with construction of the concrete lined SWC channel.

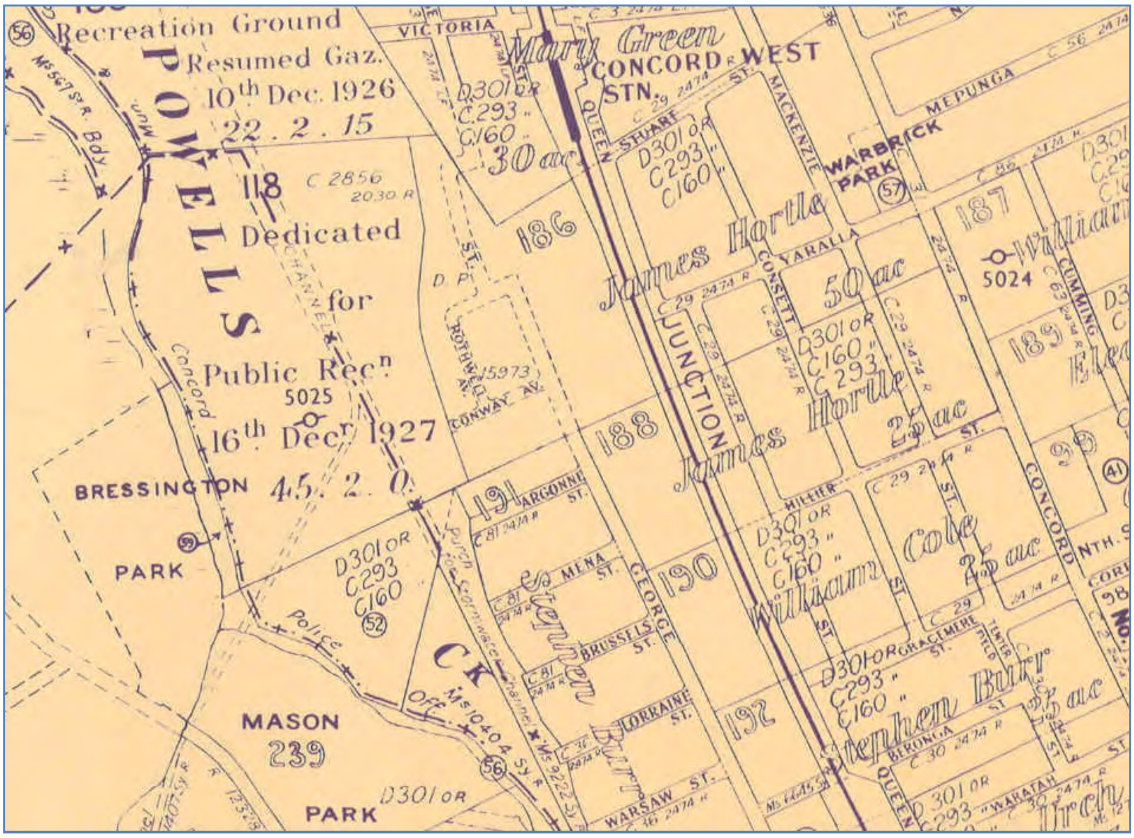


Diagram 1: Cadastral Plan near the time of Construction of the SWC Concrete Channel

Elevations in the upper part of the catchment (Figure 3) reach approximately 55 m AHD near Arthur Street and some reaches are relative steep with 2% to 4% grades. However, the overall catchment slope averages 0.8% along the main flow-path from headwaters to outlet. The main channel is tidal to upstream of Parramatta Road and the lined channel width varies from approximately 2 m in the upper areas to 22 m at Homebush Bay Drive.

Construction of buildings and structures over the open lined channel as shown on Figure 4 has significantly reduced the capacity of the natural waterways. As a result flooding has occurred in the past (Figure 5) causing significant tangible and intangible damages.

1.3. Objectives

The primary objective of the Flood Study was to develop a suitably robust hydrologic and hydraulic modelling system to be used to define flood behaviour, peak flood levels and inundation extents within the study area. This system may subsequently be used within a Floodplain Risk Management Study to assess the effectiveness and suitability of flood mitigation works.

The key stages in the flood study process are:

- undertake a comprehensive review of the available flood related data including previous studies, available survey data, historical rainfall and flood level data;
- establish a hydrologic model for the entire Powells Creek catchment to Homebush Bay Drive;

- develop a suitable hydraulic model of Powells Creek and major tributaries within the study area;
- calibration of the hydrologic and hydraulic models to historic flood data;
- define the flood behaviour and produce information on flood levels, velocities and flows for a full range of design flood events under existing conditions;
- assess the sensitivity of blockage and other assumptions on peak flood flows and levels;
- assess the impacts of sea level rise and increase in rainfall and runoff intensities due to climate change; and,
- prepare hydraulic hazard and category mapping.

This report details the results and findings of the above investigations.

1.4. Floodplain Risk Management Process

As described in the 2005 NSW Government's Floodplain Development Manual (Reference 1), the Floodplain Risk Management Process entails four sequential stages:

Stage 1: *Flood Study*
Stage 2: *Floodplain Risk Management Study*
Stage 3: *Floodplain Risk Management Plan*
Stage 4: *Implementation of the Plan*

The above first three stages were completed with publication of Powells Creek Flood Study (Reference 2) and the Powells Creek Floodplain Risk Management Study and Plan (Reference 3). Several other flood studies have also been undertaken for private developers and these are reviewed in Section 2.2.

This present document provides a review of the past flood studies and updates the design flood analysis to current best practice. A Flood Study is a technical document and is not always easily understood by the general public. A glossary of flood related terms is provided in Appendix A to assist. If more explanation of terms or a better understanding of the approach is required, type "*NSW Government Floodplain Development Manual*" into an internet search engine and you will be directed to the NSW Government web site which provides a copy of this manual (Reference 1) and further explanation.

Australian Rainfall and Runoff (AR&R) have produced a set of draft guidelines for appropriate terminology when referring to the probability of floods. In the past, Annual Exceedance Probability (AEP) has generally been used for those events with greater than 10% probability of occurring in any one year, and Average Recurrence Interval (ARI) used for events more frequent than this. However, the ARI terminology is to be replaced with a new term, EY.

AEP is expressed using percentage probability. It expresses the probability that an event of a certain size or larger will occur in any one year, thus a 1% AEP event has a 1% chance of being equalled or exceeded in any one year. For events smaller than the 10% AEP event however, an annualised exceedance probability can be misleading, especially where strong seasonality is experienced. Consequently, events more frequent than the 10% AEP event are expressed as

Exceedances per Year (EY). Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6 month average recurrence interval where there is no seasonality, or an event that is likely to occur twice in one year.

While AEP has long been used for larger events, the use of EY is to replace the use of ARI, which has previously been used in smaller magnitude events. The use of ARI, the Average Recurrence Interval, which indicates the long term average number of years between events, is now discouraged. It can incorrectly lead people to believe that because a 100-year ARI (1% AEP) event occurred last year it will not happen for another 99 years. For example there are several instances of 1% AEP events occurring within a short period, for example the 1949 and 1950 events at Kempsey.

The Probable Maximum Flood (PMF) is a term used in describing the largest possible flood and is related to the PMP, the Probable Maximum Precipitation.

This report has adopted the approach of the AR&R draft terminology guidelines and uses % AEP for all events greater than the 10% AEP and EY for all events smaller and more frequent than this.

All levels in this report are in metres to Australian Height Datum (AHD). Mean sea level is approximately 0 mAHD and an approximate tidal range in Homebush Bay is +0.6 mAHD to -0.4 mAHD.

1.5. Accuracy of Model Results

The accuracy of all model results provided in this report is dependent on the input data sets and the ability of the modelling approach to replicate recorded historical flood data. As modelling approaches improve over time and additional flood data becomes available from future flood events the accuracy of the results will improve.

A key input data set is the topographic information provided by SWC and the Councils for use in this study. The topographic information was derived from Airborne Laser Scanning (ALS) with an estimated accuracy of ± 0.15m in cleared areas, such as car parks or on roads. In locations with more complex terrain, such as vegetated areas, the accuracy is likely to be much lower and could vary significantly, by up to ± 1m. It is cost prohibitive to obtain detailed field survey throughout the entire study area and the ALS is assumed to be correct. However due to these potential accuracy limitations, some of the floodway extents, depth estimates and design flood levels may change if more accurate field survey is obtained. It is estimated that an order of accuracy of the design flood levels is ± 0.3 m where quality historical calibration data are available nearby and up to ± 0.5 m where no such data are available.

The results from the present study incorporate best practice in design flood estimation at this time but it is acknowledged that changes in approach in the future will cause changes to design flood levels. A good example of this is the collection of rainfall data which forms the basis of design flood estimation. As more rainfall data are collected and analysed (and particularly from continuously read gauges termed pluviometers) the BoM will provide new estimates of design rainfalls and design temporal patterns over NSW. An updated version of the 1987 edition of AR&R - Reference 4 will also introduce new approaches and guidelines which may change design flood levels.

2. AVAILABLE DATA

2.1. Overview

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On large river systems such as the Hawkesbury or Parramatta Rivers there are generally stream height and historical records dating back to the early 1900's, or in some cases even further. However, in most small urban catchments there are no stream gauges or official historical records available.

The Powells Creek catchment is unique in Sydney because a stream gauge has been operated by the UNSW at Elva Street for a long period (50 years). The records from this gauge have been used for many technical papers and university undergraduate and graduate theses.

An overview of historical of flooding is also available from an examination of the Councils and SMC records, previous reports, internet search of newspapers, rainfall records and local knowledge.

2.2. Previous Studies

A number of previous studies (Table 1) have been undertaken as described in Reference 2. Numbers 1 to 6 used ILSAX hydrologic models to assess solutions to drainage problems with the majority distributing a questionnaire to the residents in order to obtain information about the drainage problems. Only numbers 7 to 11 determined design flood levels. No. 1 provides a summary of the more recent studies. No studies have been undertaken specifically on the study area (Burwood LGA in Powells Creek catchment).

Table 1: Previous Studies Listed in Reference 2

Title	Consultant	Branches	Date	Comment	No.
Strathfield Local Flooding Issues	Kinhill Engineers	Wentworth Rd, Strathfield Ck, Albyn Rd	March 1997	Expanded upon References 2 and 3. Undertook HGL.	1
Redmyre Road/Florence Street Catchment Study	Giammarco	Albyn Rd	November 1993	Undertook HGL.	2
Rochester Street Catchment Drainage Investigation	Bewsher Consulting	Strathfield Ck	December 1990	Undertook HGL.	3
Stormwater Drainage Upgrading Programme - Rochester Street Catchment - Feasibility Study and Design Report	Taylor, Thomson, Whitting	Strathfield Ck	1992	Expanded on Ref. 3. Undertook HGL.	4
Rochester Street Drainage Investigation Report	Rankine and Hill	Strathfield Ck	May 1985	Examined upgrading of pipe system.	5
Arthur Street Catchment Study	Bewsher Consulting	Saleyards Ck	July 1996	Only upstream of the railway line.	6
Saleyards Creek at Park Road, Flemington	Bewsher Consulting	Saleyards Ck	October 1996	Determined design flood levels.	7
12-14 Wentworth Road, Homebush	Bewsher Consulting	Saleyards Ck	February 1995	Determined design flood levels.	8

Title	Consultant	Branches	Date	Comment	No.
32-36 Burlington Road, Homebush	B Lysenko	Strathfield Ck	February 1994	Determined design flood levels.	9
Lower Parramatta River Flood Study	Willing & Partners	Powells Ck to approx.Pomeroy St	February 1986	Determined design flood levels.	10
Powells Creek at Underwood Street Site Flood Study	Tierney & Partners	Powells Ck at Pomeroy St	November 1993	Determined design flood levels.	11

However, the references listed in Table 1 are of little value in the current study as they provide little historical data and the results cannot be easily compared. The 1998 Powells Creek Flood Study (Reference 2), however, is a comparable study to the current one and extensive use has been made of the data contained and results.

2.3. 1998 Powells Creek Flood Study (Reference 2)

The 1998 Powells Creek Flood Study was undertaken under the NSW Government Floodplain Management Program and used best practice techniques available at the time. A field survey was undertaken to provide approximately 100 cross sections of the creek channel as well as to collect historical flood height data. Some of the cross section data have been used in the current study and the historical flood height data is provided in Section 2.11.

The study area for determination of design flood levels was taken as:

Powells Creek:

- open channel from Homebush Bay Drive to Elva Street;
- Wentworth Road branch from Powells Creek to the M4 overpass;
- Strathfield Creek branch from Powells Creek to Newton Road;
- Albyn Road branch from Powells Creek to Alviston Street, including the sub-branch from Alviston Street to Victoria Street (Florence Street sub-branch) and from Alviston Street to Llandilo Avenue (Llandilo Avenue sub-branch).

Saleyards Creek:

- open channel from Homebush Bay Drive to Hampstead Road, including the sub-surface section to Mitchell Road;
- the Edgar Street sub-branch from Airey Park to Edgar Street.

A comprehensive data search was undertaken including:

- a review of previous studies;
- interviews with local residents;
- discussions with Council Officers;
- contact with SWC, the then Roads & Traffic Authority, the then State Rail Authority, the then Department of Land & Water Conservation and the UNSW;
- review of aerial photographs;
- provision of a questionnaire and review of all previous questionnaires;
- obtaining height and rainfall data from the stream and rainfall gauges operated by the UNSW and SWC.

2.3.1. ILSAX Model

An ILSAX hydrologic model of the entire Powells and Saleyards Creeks catchment was constructed using ILSAX files from some of the studies listed in Table 1. Unfortunately there is no record of the 1130 sub catchment delineation. Inflows from ILSAX were then input into the 1D HEC-RAS hydraulic model which determined flood levels and velocities. Flood extents were not defined, however this has subsequently been undertaken using the peak levels and ALS in Reference 5.

The ILSAX model was calibrated to the events of 3rd February, 7th February, 10th February, 17th February and 18th March 1990 using rainfall from two pluviometers at St Sabina College and at the Elva Street gauge. Calibration to the Elva Street gauge for the January 1996 event could not be undertaken as the gauge malfunctioned. The results are provided in Table 2 and adopted the St Sabina pluviometer as being representative of the catchment rather than the Elva Street gauge, except for the 18th March 1990 event.

Table 2: ILSAX Calibration Results from Reference 2

Event	Peak Flow (m3/s)			Volume (ML)			Runoff Co-efficient		Rainfall (mm)
	Actual	Model	% Diff	Actual	Model	% Diff	Actual	Model	
3 February 1990	15.5	15.6	<1%	205	196	-4%	0.76	0.73	110
7 February 1990	15.6	16.8	+8%	85	190	+123%	0.34	0.76	102
10 February 1990	20.9	20.8	<1%	94	110	+17%	0.69	0.80	56
17 February 1990	11.8	12.1	+2%	30	52	+73%	0.38	0.67	32
18 March 1990 St Sabina pluvi	23.3	20.2	-13%	70	91	+30%	0.58	0.76	49
18 March 1990 Elva St pluvi	23.3	24.7	+6%	70	105	+50%	0.52	0.78	55

The main features of the calibration were stated as:

- *there is a good match to the peak flows for all the February 1990 events. For 18th March 1990 a flow midway between the results from the two pluviographs would provide a good match,*
- *the timing and rate of rise of the modelled hydrographs is generally good. The exceptions are 18th March 1990 and 7th February 1990 (timing of streamflow gauge is incorrect),*
- *ILSAX provides a poor match to the volume of runoff. For the majority of events (the exception is 3rd February 1990) ILSAX overestimates the volume by up to 123%. It could be that ILSAX does not accurately represent the losses during the recession limb of the hydrograph. The poor match to the volume of runoff is of less relevance in this type of study than the match to the peak flow,*
- *the results were obtained with identical rainfall loss parameters for each event. A slightly better match may be achieved by varying these parameters but this would make it difficult to decide upon those to be adopted for design,*

- *the variation in actual runoff co-efficient (0.76 to 0.34) is difficult to explain. There are a number of possible reasons including:*
  - *malfunctions in the instrumentation (rainfall and streamflow),*
  - *the recorded rainfall at the pluviometer does not reflect the catchment rainfall. Records show that the rainfall can vary significantly across a short distance (such as between the two UNSW pluviometers),*
  - *the actual losses over the catchment can vary significantly between events.*

Overall the calibration was considered satisfactory and the model appropriate for use in design analysis.

2.3.2. HEC-RAS Model

Approximately 160 cross sections were included in the HEC-RAS model with the majority based on field survey and the remainder interpolated (generally these were required to define upstream and downstream of a structure). The following tailwater levels in Homebush Bay were adopted:

1% AEP	1.40 mAHD;
2% AEP	1.35 mAHD;
5% AEP	1.30 mAHD;
10% AEP	1.25 mAHD;
0.2 EY	1.20 mAHD;
0.5 EY	1.15 mAHD.

Detailed investigation of the peak historical level data revealed a number of problems:

- the majority of the historical recorded levels were for the two most recent events (1990 and 1996) but it was concluded that is unlikely that these were the largest floods. A summary of the historical data shows:
  - o January 1996 = 39 levels (rainfall data not available),
  - o February 1990 = 21 levels (assumed to be 10th February 1990),
  - o 1992 = 2 levels (rainfall data suggested this was only a minor event),
  - o 1989 = 2 levels (rainfall data suggested this was only a minor event),
  - o others = 9 levels (data unsuitable for calibration).
- as the depth of inundation was generally less than 0.4 m (the greatest depth was 0.8 m) a recorded level may reflect a local "low spot" or "ponding area" rather than being indicative of the level of the main flow,
- local structures (buildings, fences, gates, cars, drains blocked) are likely to have a significant effect upon the recorded levels. This effect may vary between floods (e.g. new fence, or gate open/closed),
- in many places there is a steep local gradient across a property which was not always represented by the survey data. This meant that it was difficult to match to data points not taken at cross-sections. The exact location of the recorded level within the property was also not always known.

The intention was to calibrate HEC-RAS to the January 1996 and February 1990 events but as the Elva Street gauge malfunctioned in January 1996 and rainfall data were not readily available calibration could only be undertaken for the February 1990 events.

The results of the calibration are shown in Table 3.

Table 3: HEC-RAS Calibration Results from Reference 2 for 10th February 1990

Location	Recorded Depth of Flow (m)	Recorded Level (mAHD)	Model Level (mAHD)	Model minus Recorded Level (m)
STRATHFIELD CREEK BRANCH:				
No. 56 Ismay Avenue	0.2	3.8	4.0	0.2
No. 41 Ismay Avenue	0.1	3.7	4.2	0.5
No. 51 Ismay Avenue	0.3	4.2	4.2	0.0
No. 55 Ismay Avenue	0.4	4.3	4.2	-0.1
No. 82 Underwood Road	0.5	5.0	4.9	-0.1
No. 12 Loftus Crescent	0.2	7.9	7.7	-0.2
No. 29 Burlington Road	not recorded	9.2	9.2	0.0
No. 38-46 Burlington Road	0.5	9.7	9.5	-0.2
No. 89 Rochester Street	0.1	12.8	12.7	-0.1
No. 28 Broughton Street	0.2	12.9	12.7	-0.2
No. 109 Rochester Street	0.4	14.3	14.3	0.0
No. 53 Beresford Road	0.1	15.3	15.4	0.1
No. 100 Beresford Road	0.1	15.9	15.9	0.0
No. 102 Beresford Road	0.1	16.4	16.4	0.0
No. 104 Beresford Road	0.6	17.0	16.7	-0.3
No. 108 Beresford Road	0.3	17.5	17.2	-0.3
No. 110 Beresford Road	0.4	17.5	17.2	-0.3
No. 137 Albert Street	not recorded	19.0	19.3	0.3
No. 137 Albert Street	not recorded	19.2	19.3	0.1
No. 141 Albert Street	0.3	19.5	19.3	-0.2
LLANDILO AVENUE BRANCH:				
No. 21 Llandilo Avenue d/s	0.8	28.8	28.9	0.1
No. 21 Llandilo Avenue u/s	0.1	29.9	30.6	0.7
SALEYARDS CREEK:				
No. 79 The Crescent	0.3	8.2	8.1	-0.1
No. 6 Kessell Avenue	not recorded	8.4	8.1	-0.3
POWELLS CREEK:				
No. 34 Ismay Avenue	0.4	2.6	2.4	-0.2
Elva Street Gauge	1.8	7.0	7.2	0.2

The main features of the calibration were stated as:

- *a reasonable match to all flood levels was obtained,*
- *the 0.6 m difference in level between adjacent properties at 102 and 104 Beresford Road could not be replicated. It is possible that there is an error with the records or the levels do not reflect the "mainstream" flow,*

- *the 1.1 m difference in level within 21 Llandillo Avenue could not be replicated.*

Overall the calibration was considered satisfactory and the model appropriate for use in design analysis. The report suggested that further calibration of the hydraulic model should be undertaken as more data become available. However, since 1998 there have been no significant floods suitable for model calibration.

The 2 hour duration was adopted as the critical storm duration for design events. Design flood results were provided in various formats and a comparison between runoff routing and flood frequency approaches (using the Elva Street gauge data) is shown in Table 4. The flood frequency analysis was undertaken by the University of New South Wales using the Flike program and fitting to a log Pearson III distribution.

Table 4: Comparison of Flood Frequency Analysis and Runoff Routing from Reference 2

AEP (%)	Flood Frequency		Runoff Routing (2h Duration)	
	Level (mAHD)	Flow (m^3/s) *	Level (mAHD)	Flow (m^3/s) *
20	7.2	23.8 (50%)	7.4	26.1 (55%)
10	7.5	29.3 (62%)	7.6	29.8 (63%)
5	7.8	34.6 (73%)	8.1	35.3 (75%)
2	#	41.7 (88%)	8.3	41.8 (89%)
1	#	47.2	8.9	47.2

Notes: * flow as a percentage of the 1% AEP event shown in brackets.

Levels for the flood frequency analysis are not provided for events greater than a 5% event. For such events the flow is above the coping of the channel and there are significant backwater influences from the bridges downstream. The extension of the UNSW rating curve used in their flood frequency analysis does not appear to reflect the backwater influence.

The following are some general comments regarding the results:

- *high velocities in the lined channel make it difficult to determine the true velocity and therefore the flow,*
- *the gauging station is well sited to reflect in channel flows but less so for overland flows, the majority of which may enter downstream of the gauge,*
- *the properties of the channel (area, Mannings "n" value, wetted perimeter) can be precisely measured but values above the channel are subject to considerable variation,*
- *ILSAX does not explicitly account for the considerable floodplain storage which occurs within most road reserves and within private property. The only exceptions to this are at Leicester Avenue and Airey Park where detention basins were explicitly included in the model.*

It was concluded that the differences between the design flood levels obtained from flood frequency and runoff routing could only be resolved once high flow calibration data are obtained. These data are difficult to obtain due to the rapid rise (1.8 m in 30 minutes) and fall of the water level. Flood levels from the runoff routing analysis have been adopted for design as the HEC-RAS model should provide a more accurate definition of the channel hydraulics at high flows.

2.3.3. Accuracy of the Design Flood Data

The study concluded that accuracy of the design flood data depended upon a number of factors including:

- **quality of the survey data.** How well do these data represent the floodplain? In an urban catchment the flow path can change dramatically over a short distance (fences, buildings, trees). In this study sections have been located to be representative of the typical flow path in the region.
- **downstream boundary conditions.** Changing the downstream boundary will affect flood levels upstream. This issue is not significant in this study as the main areas of interest are not affected by the downstream boundary.
- **accuracy of design rainfall data.** As the most up to date rainfall data have been used in this study this issue is unlikely to be significant. They may change as a result of climate change.
- **ability of the models to accurately represent the channel hydraulics.** This is likely to be a significant factor.
- **quantity and quality of available historical data.** The calibration of ILSAX to the flow data from the stream gauge provides a high degree of confidence in the results from the hydrological model at the gauge. Calibration of the HEC-RAS model is satisfactory but can be significantly improved if peak height data from future events can be replicated.

The main factors affecting the accuracy of the design data were considered to be the ability of the models to simulate the channel hydraulics and the quantity and quality of the historical data. Based upon the above considerations the accuracy of the design flood levels were considered to be ±0.4 m. This could be improved if further calibration of the models to future flood events was undertaken.

2.4. Comparison of Results with Previous Studies

A comparison of design peak flows from Reference 2 with other studies was shown in Table 5 and Table 6.

Table 5: Comparison of Design Peak Flows (m^3/s) from Reference 2

Location/Reference and ILSAX Branch/Reach (N/P = data not provided)	1% AEP		2% AEP		5% AEP	
	Ref	Ref 2	Ref	Ref 2	Ref	Ref 2
Strathfield Creek Branch: Railway Line (R/49T) (Ref. 3)	38	32	N/P	29	31	26
Saleyards Creek: Park Road (0/25Q) (Ref. 7)	76	47	68	43	61	38
Saleyards Creek: Wentworth Road (0/27Q) (Ref. 8)	76	55	N/P	50	N/P	44
Powells Creek: Homebush Bay (A/41Q) (Ref. 10)	140	182	120	165	105	148
Powells Creek: Pomeroy Street (A/38S) (Ref. 11)	77	97	N/P	90	59	82
Powells Creek: Confluence with Saleyards Creek (A/40S) (Ref. 11)	82	106	N/P	98	67	89
Powells Creek: d/s of conf. with Saleyards Creek (A/41Q) (Ref. 11)	139	182	N/P	165	101	148

Table 6: Comparison of Design Peak Levels (mAHD) from Reference 2

Location/Reference and HEC-RAS River Station Number (N/P = data not provided)	Design Events (AEP)					
	1%		2%		5%	
	Ref	Ref 2	Ref	Ref 2	Ref	Ref 2
Saleyards Creek: Park Road * (49) (Ref. 7)	4.60	4.31	4.50	4.12	4.10	3.91
Saleyards Creek: Wentworth Road (46) (Ref. 8)	2.90	2.59	N/P	2.58	N/P	2.57
Strathfield Creek Branch: 32-36 Burlington Road (84) (Ref. 9)	9.91	9.80	N/P	9.74	N/P	9.68
Powells Creek: Saleyards Creek confluence (1.5) (Ref. 10)	2.50	1.75	2.23	1.62	2.15	1.51
Powells Creek: Pomeroy Street (4.5) (Ref. 10)	3.00	3.15	2.85	3.11	2.75	3.05
Powells Creek: Lemnos Street (approx) (6) (Ref. 10)	3.25	3.11	3.14	3.07	3.03	3.03
Powells Creek: d/s of Pomeroy Street (4) (Ref. 11)	2.11	2.18	N/P	2.06	1.84	1.97
Powells Creek: u/s of Pomeroy Street(4.5) (Ref. 11)	2.80	3.15	N/P	3.11	N/P	3.05

Sensitivity analyses to changes in design rainfall intensities and parameters in ILSAX were also undertaken. Blockage was considered and was summarised in the following statement. *In the absence of any conclusive data on this issue and the fact that all previous studies assumed nil blockage, nil blockage was adopted for this study. As only a small percentage of flow is within the pipe system in a large flood, varying this parameter will have little impact on design flood levels.*

2.5. Data Sources

Data utilised in the present study has been sourced from a variety of organisations. Table 7 lists the type of data sourced and from where it has been extracted.

Table 7: Data Sources

Type of Data	Format Provided (Source)	Format Stored
Location, description and invert depths of pits, pipes and trunk drainage network	GIS (SWC and Councils)	DRAINS and TUFLOW models
Ground levels from ALS data	GIS (SWC and SMC)	GIS and TUFLOW model
Detailed survey data	GIS (SWC)	GIS and TUFLOW model
GIS information (cadastre, drainage pipe layout)	GIS (SWC and Councils)	GIS and TUFLOW model
Design rainfall	AR&R (1987)	DRAINS
Recorded flood data	Observation by SMC, SMC and previous reports	Report

2.6. Topographic Data

Airborne Laser Scanning (ALS) or Light Detection and Ranging (LiDAR) survey of the catchment and its immediate surroundings was provided for the study by SWC and SMC. It was indicated that the data were collected in 2007 by AAMHatch. These data typically have accuracy in the order of:

- +/- 0.15m (for 70% of points) in the vertical direction on clear, hard ground; and
- +/- 0.75m in the horizontal direction.

The accuracy of the ALS data can be influenced by the presence of open water or vegetation (tree or shrub canopy) at the time of the survey.

From this data, a Triangular Irregular Network (TIN) was generated by WMAwater. This TIN was sampled at a regular spacing of 1 m by 1 m to create a Digital Elevation Model (DEM), which formed the basis of the two-dimensional hydraulic modelling for the study.

2.7. Structure Survey

All bridges and structures within the open channel extent of the study area were inspected in May 2014. Survey data collected as part of Reference 2 were used to define the structures. Photographs on Figure 4 provide a descriptive overview of the key characteristics of the open channel system.

2.8. Rainfall Data

2.8.1. Overview

Rainfall data is recorded either daily (24hr rainfall totals to 9:00 am) or continuously (pluviometers measuring rainfall in small increments – less than 1 mm). Daily rainfall data have been recorded for over 100 years at many locations within the Sydney basin. In general, pluviometers have only been installed since the 1970's. Together these records provide a picture of when and how often large rainfall events have occurred in the past.

However, care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past events due to a combination of factors including local site conditions, human error, or limitations inherent to the type of recording instrument used. Examples of limitations that may impact the quality of data used for the present study are:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall and records of large events are often lost or misrepresented.
- Daily read information is usually obtained at 9:00 am in the morning. Thus if a single storm is experienced both before and after 9:00 am, then the rainfall is "split" between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00 am reading.
- The duration of intense rainfall required to produce overland flooding in the study area is typically less than 4 hours (though this rainfall may be contained within a longer period of rainfall). This is termed the "critical storm duration". For a larger catchment (such as the Parramatta River) the critical storm duration may be greater (say 12 hours). For the study area a short intense period of rainfall can produce flooding but if the rain stops quickly, the daily rainfall total may not necessarily reflect the magnitude of the intensity and subsequent flooding. Alternatively the rainfall may be relatively consistent throughout the day, producing a large total but only minor flooding.
- Rainfall records can frequently have "gaps" ranging from a few days to several weeks or

even years.

- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs. time) of rainfall events and have the advantage that the data can generally be analysed electronically. This data has much fewer limitations than daily read data. However, pluviometers can also fail during storm events due to the extreme weather conditions.
- Rainfall events which cause overland flooding (as opposed to mainstream flooding) in the Powells Creek catchment are usually localised and as such are only accurately represented by a nearby gauge. Gauges sited even only a kilometre away can show very different intensities and total rainfall depths.

2.8.2. Rainfall Stations

There are a number of daily read rainfall stations within the catchment and surrounding area. Data were not collected from these stations as more suitable data were available from six pluviometers (Table 8). The two UNSW pluviometers have operated since approximately 1977 but the dates shown in Table 8 are the periods for which digital data are available. No correction has been made in the digital records for the UNSW gauges to account for errors in the clock speed. Thus the time of the recorded rainfall can be out by several hours. This has not been corrected for in this report; however, Reference 6 provides an approach that can be used.

Table 8: Pluviometers

Gauge No.	Operator	Operating Period	Location
566005	UNSW	Mar 1981 to Feb 1996 (period when digital records available)	St Sabina College (Russell St, The Boulevarde)
566004	UNSW	Dec 1980 to June 1993 (period when digital records available)	Stream gauge at Elva St/Beresford Rd
566022	SWC	May 1969 to August 1983, July 1990 to Present	Homebush Bowling Club (Pomeroy St)
566020	SWC	Oct 1958 to Present	Enfield (Belfield Bowling Club - Margaret St)
566036	SWC	February 1970 to Present	Potts Hill Reservoir
566064	SWC	June 1988 to Present	Concord (Western Suburbs Club).

2.8.3. Analysis of Pluviometer Data

Rainfall data were collected from some of the available pluviometers for the significant recent flood events with the peak bursts provided in Table 9 and Figure 9. An estimate of the rainfall frequency for each event can be obtained from comparison with the design rainfalls (Table 10).

Table 9: Historical Rainfall - Maximum Rainfall Depths (mm)

	Duration						
	5 or 6 min	10 min	20 min	30 min	60 min	90 min	120 min
			2nd January 1996:				
Homebush	15	23	36	44	52	54	58
Enfield	17	25	45	57	81	83	88
Potts Hill	11	17	31	42	49	52	54
Concord	7	11	21	30	46	49	52
Elva Street	Instrument Failed						
St Sabina	11	22	37	50	64	n/a	71
			8th February 1992:				
Homebush	Instrument Failed						
Enfield	4	6	10	13	22	28	33
Elva Street	Instrument Failed						
St Sabina	2	5	6	11	16	n/a	n/a
			11th March 1991:				
Homebush	No Significant Rain						
Enfield	13	19	34	37	-	-	-
Potts Hill	11	18	33	35	-	-	-
Concord	10	16	24	24	-	-	-
Elva Street	Instrument Failed						
St Sabina	Instrument Failed						
			18th March 1990:				
Elva Street	20	34	41	44	45	47	50
St Sabina	8	23	26	31	36	43	46
			10th February 1990:				
Homebush	Gauge Not in Operation						
Enfield	11	15	23	26	40	45	50
Potts Hill	12	19	31	36	44	48	52
Concord	7	11	17	25	31	33	38
Elva Street	9	13	22	28	39	n/a	50
St Sabina	6	11	21	31	42	n/a	52
			4-6th August 1986:				
Homebush	Gauge Not in Operation						
Enfield	12	17	27	36	50	59	64
Potts Hill	11	16	27	37	52	60	64
Concord	Gauge Not in Operation						
Elva Street	10	13	17	21			
St Sabina	Very Little Rain						

Note: Data for January 1989 are not shown as the Enfield pluviometer record indicated no significant rainfall events.
Data from other pluviometers may be available but were not collected.

2.9. Design Rainfall

Design rainfall intensities were based on procedures in AR&R 1987 (Reference 4). Design rainfall intensities at the centre of the catchment are provided in Table 10.

Table 10: Design Rainfall Intensities at the Catchment Centroid (mm/hr)

	Duration						
Event	5 min	10 min	20 min	30 min	60 min	90 min	120 min
0.2 EY	144	111	81	66	45.4	35.6	29.9
10% AEP	161	124	91	74	51	40.2	33.8
5% AEP	184	142	104	85	59	46.3	39
2% AEP	213	165	121	99	69	54	45.7
1% AEP	236	182	134	110	76	60	51
0.5% AEP	258	200	148	121	84	66	56
0.2% AEP	288	224	165	135	94	75	63
PMP				440	326	248	208

Probable Maximum Precipitation (PMP) design rainfall depths were calculated using the 2003 BoM Generalised Short Duration Method (Reference 7) for durations up to 6 hours.

2.10. Stream Gauges

2.10.1. UNSW (Elva Street Gauge)

Flood levels have been recorded continuously from September 1958 at the Elva Street gauge (Photo 1) until 2010. Apart from this gauge there are no other long term flood records for the catchment. SWC operated a gauge on Powells Creek (under the M4) but records are only available from October 1995.

Photo 1: Powells Creek gauge at Elva Street

At the time of completion of the 1998 Powells Creek Flood Study (Reference 2) only a limited amount of water level and rainfall data were available from the UNSW as only parts of the historical records were digitised or quality checked.

Subsequently the entire water level and pluviometer record (both at St Sabina and at Elva Street) have been digitised and a rating table adopted to assign flows to the recorded levels.

However there are many gaps in the digital record and this means that the record is only complete to November 1997. The digital record has also not been corrected for timing errors. This timing error correction has not been undertaken for this study.

A summary of the water level data is provided on Figure 6 and below indicates the number of days where the water level has exceeded a threshold (1958 to November 1997):

- >3m - 1 day;
- >2.5m - 3 days;
- >2m - 6 days;
- >1.5m - 31 days;
- >1m - 116 days.

The coping of the channel is approximately 3m above the invert and thus only one event (February 1959) has exceeded the capacity of the channel in approximately 55 years of record (1958 to 2014). A review of Figure 6 indicates that since 1974 (40 years) no event has exceeded 2m on the gauge but 5 events did in the period from 1958 to 1974. Unfortunately this means that calibration can only be undertaken on events smaller than 2m gauge height as the two UNSW pluviometers were not in operation until 1980.

Reference 2 included Table 11 which listed the largest events recorded on the UNSW gauge above 2.0 m. These height data were obtained from inspection of the gauge charts or estimated from debris (Reference 6). The corresponding digital records are shown alongside in Table 11.

Table 11: UNSW Gauge at Elva Street - Major Floods (> 2.0 m) taken from Reference 2

Rank	Year	Date	Gauge Height (m)	RL(mAHD)	Gauge Height (m) from Digital Record
1	1961	18 Nov	4.18 *	9.43	**No Record**
2	1964	10 Jun	3.52 *	8.77	**1.8**
3	1959	18 Feb	3.29 *	8.54	**3.26**
4	1972	29 Oct	3.20	8.45	**0.9**
5	1970	9 Dec	3.09	8.34	**Gauge failed**
6	1963	13 Dec	2.40	7.65	**2.47**
7	1973	9 Apr	2.35	7.60	**0.7**
8	1974	25 May	2.34	7.59	**2.23**

* estimated from debris.
Gauge zero is RL 5.25 mAHD.

A limited number of gaugings (height v velocity measurements) have been undertaken enabling the construction of a rating curve (height versus flow). Whilst in theory this approach appears very simple it becomes complex for a number of reasons, including:

- the events occur within a few hours and thus it was very hard for the UNSW staff to get to the gauge whilst a flood was in progress;
- the above means that there are several low flow gaugings but very few high flow gaugings which are more relevant for use in a flood study;

- a gauging was taken by the UNSW at high flows which produced velocities above the rating of the instrument (say above 5 m/s). Thus even this gauging could not confidently determine the peak flow.

Rating curves from various sources are provided on Figure 7.

2.10.2. Sydney Water Gauge

This gauge, which is located on Powells Creek under the M4, has only recorded one significant flood (January 1996) since it was installed in 1995. The gauge zero is RL 2.15 mAHD and the January 1996 flood peaked at 2.04 m (4.19 mAHD) at 1405 hours. Three streamflow gaugings have been undertaken. All gaugings are below 0.1 m gauge height (flow <2 m^3/s). Extrapolation of the rating curve based on these data is not appropriate and as a result flow data from this gauge have not been used for calibration of the hydrologic model.

2.11. Flood Levels from Debris or Other Marks

2.11.1. Resident Interviews

As part of the 1998 Powells Creek Flood Study (Reference 2) and earlier studies (refer Table 1) questionnaires were distributed to local residents in order to collect information about past flood events. Prior to the 1998 Powells Creek Flood Study the responses were generally concerned with drainage issues (blocked pits, minor overland flow) and not with identifying historical flood levels. The only exception to this was at Airey Park (Saleyards Creek) for the January 1996 event.

Data obtained from residents should be used with caution for a number of reasons, including:

- residents may have only been in the study area for a short period;
- residents may have “missed” a flood whilst they were away;
- the more recent events are remembered more clearly than (say) a larger event several years ago;
- some events noted by residents may be as a result of a blocked drain or other local factors and are more typically referred to as local drainage problems rather than flood related;
- residents can easily forget the date of a flood or become confused about the extent and nature of the problem. Experience has shown that water entering a house may have resulted from a leak in the gutter or a local drainage problem in the yard rather than overbank flow from the main creek.

Table 12 provides the most widely remembered events (obtained from the results of the 1998 Powells Creek Flood Study (Reference 2) and previous questionnaire surveys).

Table 12: Significant Floods Obtained from 1998 Flood Study Questionnaire

Approximate Date	Comment
? 1930's	Infrequently mentioned.
1943	Infrequently mentioned.

18 February 1959	Infrequently mentioned.
? 1960's	Infrequently mentioned.
November 1961	Infrequently mentioned.
? 1964	Infrequently mentioned.
? 1973	Infrequently mentioned.
August 1986	Appears to be the largest event in the last 30 years
March/April and July 1988	Infrequently mentioned.
January 1989	Widely remembered.
February 1990	Widely remembered, larger than 1996 in Saleyards Creek
March 1990	Infrequently mentioned.
April 1990	Infrequently mentioned.
March 1991	Widely remembered.
2 December 1992	Infrequently mentioned.
February 1995	Infrequently mentioned.
October 1995	Infrequently mentioned.
June 1995	Infrequently mentioned.
December 1995	Infrequently mentioned.

Table 12 indicates that 50% of the most widely remembered events are in the 1990's. This figure could suggest that flooding in the 1990's has been a major issue compared to other periods. This is unlikely to be the case, and merely reflects some of the points noted previously regarding obtaining data from residents. Clearly the gauge record (Figure 6) indicates the period from 1958 to 1974 had more large floods.

As part of the 1998 Powells Creek Flood Study (Reference 2) 125 questionnaires were returned out of approximately 800 hand delivered or mailed (to non-resident owners) with some followed up by telephone or field interview. Table 13 summarises the results from this survey.

Table 13: 1998 Flood Study Questionnaire Results

Total number of questionnaires returned	**125 (approx.15%)**
Number who responded indicating that their property had been inundated by a water depth greater than 100 mm.	60 (49%)
Number not inundated.	65 (52%)
Number who could indicate a historical flood level.	39 (31%)
Number of buildings inundated above floor level*.	6 (5%)

Note: * Previous questionnaire surveys have indicated that other buildings have been inundated above floor level.

A questionnaire was distributed as part of the current study with several responses identified recent occurrences of flooding. The reported flooding was generally less than 0.1 m and would be considered nuisance flooding. It has been for general verification of model results. Further details of the community consultation are given in Section 2.13.

2.11.2. Surveyed Levels

A number of historical flood levels were collected from field interviews as part of the 1998 Powells Creek Flood Study (Reference 2). The majority of levels were for either the January

1996 or the February 1990 events. These are shown in Table 14 and on Figure 8.

Table 14: Historical Flood Data from Field Interviews in August 1997 as part of Reference 2

Address	Date of Flood	Depth (m)	Description	Flood Level (mAHD)
No. 21 Llandilo Avenue	Approx 1990	0.05-0.08	Garage Floor Level	29.96
	Approx. 1990	0.8	North-West Corner	28.8
No. 8 Agnes Street	Jan-96	0.1	Driveway and Front Boundary	26.71
No. 41 Albyn Road	Jan-96	0.08	Crest of Driveway	22.54
	Jan-96	0.35	Low Point along West. Boundary	21.64
No. 47 Albyn Road	Jan-96	0.25	Garage Floor Level	21.18
No. 35 Redmyre Road	Jan-96	0.05-0.1	Crest of Driveway	13.26
	Jan-96	0.5	Ground Level at Back Fence	12.13
No. 37 Redmyre Road	Jan-96	0.05-0.1	Crest of Driveway	13.27
	Jan-96	0.3	Ground Level at Garage	12.21
No. 45 Churchill Avenue	Jan-96	0.1	Base Steps at Front House	10.74
No. 60 Churchill Avenue	Jan-96	0.2	Ground Level at Path Granny Flat	11.49
No. 66 Churchill Avenue	18th February 1959	0.3	Floor Level	12.06
Upstream Railway crossing near Elva Street	Unknown		Top coping LHS looking Downstream	8.1
			Top coping RHS looking Downstream	7.83
Pharmacy adjoining Plaza Entrance, The Boulevarde	Jan-96		Floor Level - water entered shop	12.29
No. 11 The Boulevarde (Gumbleys Butchery - now gone)	Nov-61	0.3	Estimated Floor Level	12.55
No. 26 Barker Road	Regularly	0.1	Drive at Boundary	25.83
No. 65 Oxford Street	Jan-96	0.45	Carport Slab	24.16
No. 63 Oxford Street	Jan-96	0.3	South-West corner of house	23.75
No. 61 Oxford Street	Jan-96	0.5	Garage Floor Level	23.24
No. 59 Oxford Street	Jan-96	-	Patio Level	23.14
No. 141 Albert Street	Approx. 1990	0.3	Ground level along eastern fence	19.51
No. 135 Albert Street	Approx. 1990	0.5	Bottom steps rear of house	18.49
No. 137 Albert Street	Feb-90	-	Crest of driveway	19.24
	Feb-90	-	Water reached floor level	19.01
No. 100 Beresford Road	Feb-90	0.1	Driveway at entrance to house	15.91
No. 102 Beresford Road	Feb-90	0.12	Ground level at back door	16.43
No. 104 Beresford Road	Feb-90	0.55	Ground level rear house	17
No. 110 Beresford	Feb-90	0.35	Midway along eastern	17.5

Address	Date of Flood	Depth (m)	Description	Flood Level (mAHD)
Road			fence	
No. 53 Beresford Road	Feb-90	0.05	Garage floor level	15.29
No. 108 Beresford Road	Feb-90	0.34	Base steps rear house	17.49
No. 89 Rochester Street	Feb-90	0.1	Floor level shop	12.84
No. 107 Rochester Street	Jan-89	0.45	GL at rear of house	14.12
No. 109 Rochester Street	Feb-90	0.42	Base steps rear house	14.33
	Jan-96	0.24	Base steps rear house	14.15
No. 57 Rochester Street	Jan-96	0.41	Ground level back yard	9.92
No. 28 Broughton Road	Approx. 1992	0.24	North East corner of house	12.88
No. 33-35 Burlington Road	1989	0.3	Garage Floor Level	9.14
No. 38-46 Burlington Road(Hairdresser)	Feb-90	0.48	Ground level at rear shed	9.71
No. 48 Burlington Road	Jan-96	0.1	Ground Floor Level	9.55
No. 29 Burlington Road	Feb-90	-	Stormwater reached this level at rear of factory	9.16
No. 30 The Crescent (Unit No. 2)	Jan-96	0.4	Garage Floor Level	8.7
No. 31 The Crescent	Jan-96	0.2	Garage Floor Level	8.33
No. 79 The Crescent	Feb-90	0.3	Floor level	8.2
	Jan-96	0.28	Base patio at rear	7.75
No. 12 Loftus Crescent	Feb-90	0.15	Ground level backyard	7.87
No. 82 Underwood Road	Feb-90	0.45	Ground level at front house and driveway	4.97
No. 86 Underwood Road	Jan-96	0.3	Base steps front house	4.89
No. 90 Underwood Road	Jan-96	0.16	Base steps front of house	4.74
No. 22 Ismay Avenue	Approx. 1986	0.3	Ground at back fence	2.2
No. 34 Ismay Avenue	Jan-90	0.35	Path at back door	2.57
No. 60 Ismay Avenue	Jan-96	0.1	Ground level at front of house	3.83
No. 55 Ismay Avenue	Feb-90	0.37	Base front steps	4.3
	Jan-96	0.18	Base front steps	4.11
No. 51 Ismay Avenue	Feb-90	0.3	Base front steps	4.19
No. 56 Ismay Avenue	Feb-90	0.2	Base front steps	3.83
No. 49 Ismay Avenue	Jan-96	0.22	Base front steps	4.16
No. 48 Ismay Avenue	Jan-96	0.15	Base front steps	3.43
No. 41 Ismay Avenue	Feb-90	0.14	Base front steps	3.71
	Jan-96	0.07	Base front steps	3.64
No. 17 Pemberton Street	1992	0.4	Ground level backyard	16.95

Address	Date of Flood	Depth (m)	Description	Flood Level (mAHD)
No. 27 Pemberton Street	1992	0.17	Base steps rear house	18.72
No. 10 Mitchell Road	Jan-96	0.28	Ground level low side house	14.75
No. 6 Mitchell Road	Jan-96	0.24	Ground level low side house	14.35
No. 104 Arthur Street	Jan-96	0.27	Ground level front of house	13.87
No.106 Arthur Street	Jan-96	0.34	Ground level at boundary	13.85
No. 105 Arthur Street	Jan-96	0.55	Ground level at house steps side house	13.89
No. 29 Arthur Street	Jan-96	0.16	Base front steps	13.23
	Jan-96	0.4-0.5	Ground level at rear fence	12.98
No. 6 Kessell Avenue	Jan-96	0.44	Ground level at fence	7.76
	Feb-90	-	Water reached floor level	8.42
Airey Park Photos	Jan-96	0.75	Base wall No. 77	7.65

2.11.3. Sydney Water Data

SWC holds records of flooding on Powells Creek and the relevant information is provided in Table 15. These records show no instances of flooding in 1990 and only one record (Feb 1996) since 1988.

Table 15: Sydney Water Records of Flooding in the Powells Creek Catchment

Date Flooded From	Address	Depth (m)	Level Above Floor (m)	Level Above Coping (m)	Property Inundation	Comments
?/07/1952	135 Albert Road, Strathfield				Y	Flooding due to construction activity-water supply. Loss of goods.
6/05/1953	Lot 3, Allen St, Homebush					Flooding occurred where Council's bridge restricts the flow
6/05/1953	4-6 Elva St, Strathfield					Flooding occurred where the channel is deficient in capacity
6/05/1953	36 Minna St, Burwood					Flooding occurred where the channel & Council's subsidiary drainage works are deficient
6/05/1953	Lot 2 Bates St, Homebush (cnr The Crescent)					Flood waters crossed the road where Council's culvert is deficient in capacity
6/05/1953	103 Parramatta Rd, Strathfield					Flooding occurred where the channel is covered at coping level.
9/02/1956	8-10 Elva St, Strathfield			0.45	Y	At the future gauging site
9/03/1958	2A Belgrave St, Burwood	0.37				Flooding of road only?
9/03/1958	4-6 Elva St, Strathfield			0.75		Flooding
9/03/1958	9 Bold St, Burwood (Minna St, Burwood - west of its intersection with Bold St)	0.53			Y	Water banked up to a max. of 0.53m deep against the northern fence of Minna St.
9/03/1958	33 Nicholson St, Burwood	0.1				Flooding of road only?

Date Flooded From	Address	Depth (m)	Level Above Floor (m)	Level Above Coping (m)	Property Inundation	Comments
9/03/1958	20 Woodside Ave, Burwood	0.15				Flooding of road only?
9/03/1958	36A Nicholson St, Burwood	0.05			Y	Water (0.05) deep northern side Nicholson St & sewer surcharge in No. 6A
9/03/1958	24 The Boulevard, Strathfield	0.6			Y	Flood entered the shop and damaged the stock- insufficient inlets
17/02/1959	5 Bold St, Burwood		0.45		Y	Flooding occurred above garage floor level at rear of house, but 0.65m below floor level of house
17/02/1959	7 Bold St, Burwood		0.56		Y	Flooding occurred above garage floor level at rear of house, but .28m below floor level of house
18/02/1959	4-6 Elva St, Strathfield			1.14	Y	1.14m above the coping level of the Stormwater channel at Gauging Station. Floodwater entered the Elva Street and carried some of the timbers away
18/02/1959	2 Elva Street, Strathfield			1.24	Y	
18/02/1959	58 Churchill Avenue		1.5		Y	1.5 m above the kitchen floor. No damage was done and the kitchen floor is considerably lower than the back yard.
18/02/1959	66 Churchill Avenue		0.3		Y	0.3 m above the floor. Water coming from Redmyre Road has swept through the house and damaged carpets and furniture. Many premises had been flooded.
18/02/1959	27 Minna St, Burwood	0.84			Y	Flooding occurred above the yard level at N/W corner of house, but was 0.35m below floor level of house
30/10/1959	7 Bold St, Burwood					Slight flooding only. Flood water rose to 0.30m above footpath level, no houses flooded
17/11/1961	53 Ismay Ave, Homebush				Y	Flooding of homes reported.
19/11/1961	19 Oxford St, Burwood		0.15		Y	Above floor flooding
19/11/1961	21 Morwick St, Strathfield		0.3		Y	Above floor flooding
19/11/1961	26 Morwick St, Strathfield		0.025		Y	New block of home units, water rose to within .025m of floor level & 0.38m above laundry floor.
19/11/1961	41 Woodside Ave, Burwood				Y	Brick fence along the frontage collapsed
19/11/1961	19 Oxford St, Burwood		0.15		Y	Above floor flooding
19/11/1961	62/64 Oxford St, Burwood				Y	Extensive damage to fencing & back gardens
19/11/1961	4-6 Elva St, Strathfield		0.87		Y	Harrisons Timber P/L flooded. Damage to motors & furniture.
19/11/1961	8-10 Elva Street				Y	Flood water was just below the floor level. Garden was ruined. Photos available
19/11/1961	7 Bold St, Burwood.				Y	Severe flooding. Flood water rose to 0.75m above footpath level on North side of Minna St - 19th 4.00 a.m. The water was held back by the side palings of the house No.7 Bold Street but eventually found an

Date Flooded From	Address	Depth (m)	Level Above Floor (m)	Level Above Coping (m)	Property Inundation	Comments
						outlet through No. 27 Minna Street.
19/11/1961	27 Minna Street				Y	Water rose .1m below the floor level of the rear house
19/11/1961	35 Nicholson Street	0.73			Y	Water level was 0.73 m above ground level and .3 m below the floor level.
19/11/1961	11 The Boulevarde(Gumbleys Butchery), Strathfield.		0.3		Y	Water entered several shops & rose to about 0.30m above floor in Gumbleys Butchery at No. 11
19/11/1961	2 Elva St, Strathfield (U/S main Western Railway Line)					Considerable damage done along route of main channel. S/water unable to reach underground drains flowed over ground surface to low lying areas & followed course of original creek downstream.
7/05/1963	2 Elva Street, Strathfield			0.6	Y	Observed at 8.15am. High tide at 7.15 am= 1.4m?
20/12/1963	12, 13, 14, 15, 16 & 17 Brunswick St, Strathfield				Y	Flooding of roadway & front yards, did not enter premises. Date of rain-not clear
20/12/1963	2 Elva St, Strathfield , (Railway viaduct on Main Western Line)			0.75	Y	No apparent damage to properties.
9/06/1964	2 Elva St, Strathfield - Sydney Night Patrol			1.52	Y	Flooding caused by culvert under railway + 2 curves immediately upstream. Property flooding = .9m above ground
11/06/1964	2 Elva St, Strathfield - Sydney Night Patrol			0.46	Y	Flooding caused by culvert under railway + 2 curves immediately upstream.
15/04/1969	177 Parramatta Rd, Homebush				Y	A brick retaining wall collapsed at Saleyards Ck Bch. Poor foundation
29/10/1972	2 Elva St, Strathfield - Sydney Night Patrol				Y	Water rose to 1.22m above brickwork recently added to walls within this property. Vehicles were submerged & a wooden bridge lifted & dumped 9m downstream.
29/10/1972	11 Pilgrim Avenue				Y	Basement of a block oh home units was flooded - approximately 1 metre
29/10/1972	2 Elva St, Strathfield (Railway Culvert under the Main Western Line)					Embankment surcharged - see photo
17/03/1983	167-173 Parramatta Road, Homebush	0.3			Y	Flood level 300 mm above footpath. Above floor flood in one work shop-150mm
8/11/1984	7-9 Underwood Road, Homebush			0.6	Y	Debris mark on the fence
8/11/1984	Lot 2 Bates St, Strathfield (cnr The Crescent, Railway Culvert upstream)			0.6	Y	Debris on the embankment
29/04/1988	53 Ismay St, Homebush				Y	Surface flooding of 5 houses in Ismay Ave & overland flow at Powell St.
29/04/1988	Flemington Markets, Parramatta Rd, Homebush					Channel overflowed near markets.
29/04/1988	Lot 2 Bates St, Homebush (U/S of The Crescent, Homebush)			0.3	Y	Was contained within the banks. Flood debris 800 mm above the ground at upstream railway line culvert

Date Flooded From	Address	Depth (m)	Level Above Floor (m)	Level Above Coping (m)	Property Inundation	Comments
7/05/1988	32 The Crescent, Homebush				Y	Above floor flooding. Damage $10,000
2/02/1996	Lot C Allen St, Nth Strathfield					Debris on adjacent fences indicated water flowed 500mm above upstream headwall. Flooding confined to adjacent park.
2/02/1996	24 Pomeroy St, Strathfield			0.3	Y	

2.12. Flood Photographs

A number of flood photographs taken during floods were provided by SMC and these are shown on Figure 5.

2.13. Community Consultation

Community consultation was undertaken as part of the current study to inform the community about the study and gather information on historical flood events. A one-page newsletter detailing the study's purpose was sent to approximately 300 addresses in the study area. The newsletter, which was sent in July 2015, also described the floodplain management process and the flood study's role in managing the area's flood risk. The mailout also included a questionnaire requesting information on any experience of flooding, including the level of affectation and the date of the event. Accounts of flooding could then be used to add to verify the model behaviour and generally add to the knowledge of the area's flood behaviour.

From the questionnaire, twelve responses were received, constituting a response-rate of around 5%. The results from the questionnaires are as follows:

- All responses were from residential properties, with most having lived there for more than 15 years.
- 7 respondents had experienced flooding, with all instances involving water above floor levels of the house or other buildings.
- Approximately 9 events in the last 20 years were identified as causing flooding, with flooding reported in 1995, 1996, 1998, 2005, 2010, three times in 2014 and 2015. However, most events had only one reported instance of flooding, and apart from 0.3 m depth reported for 1995, all depths were 0.2 m or less. No event was consistently mentioned between responses, which suggests variation in flood behaviour between similar events, for example due to pit or pipe blockage, location of the rainfall burst or localised effects on flow behaviour.

Figure 8 shows the location of the respondents, alongside the previous consultation and the Sydney Water historical data.

3. APPROACH

The approach adopted in flood studies to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.). Whilst there is a limited flood record from the Elva Street gauge there is no extensive historical flood record elsewhere on Powells Creek or on Saleyards Creek. A flood frequency approach can be undertaken at the Elva Street gauge but reliance must also be made on the use of design rainfalls and establishment of a hydrologic/hydraulic modelling system. A diagrammatic representation of the flood study process undertaken in this manner is shown below.

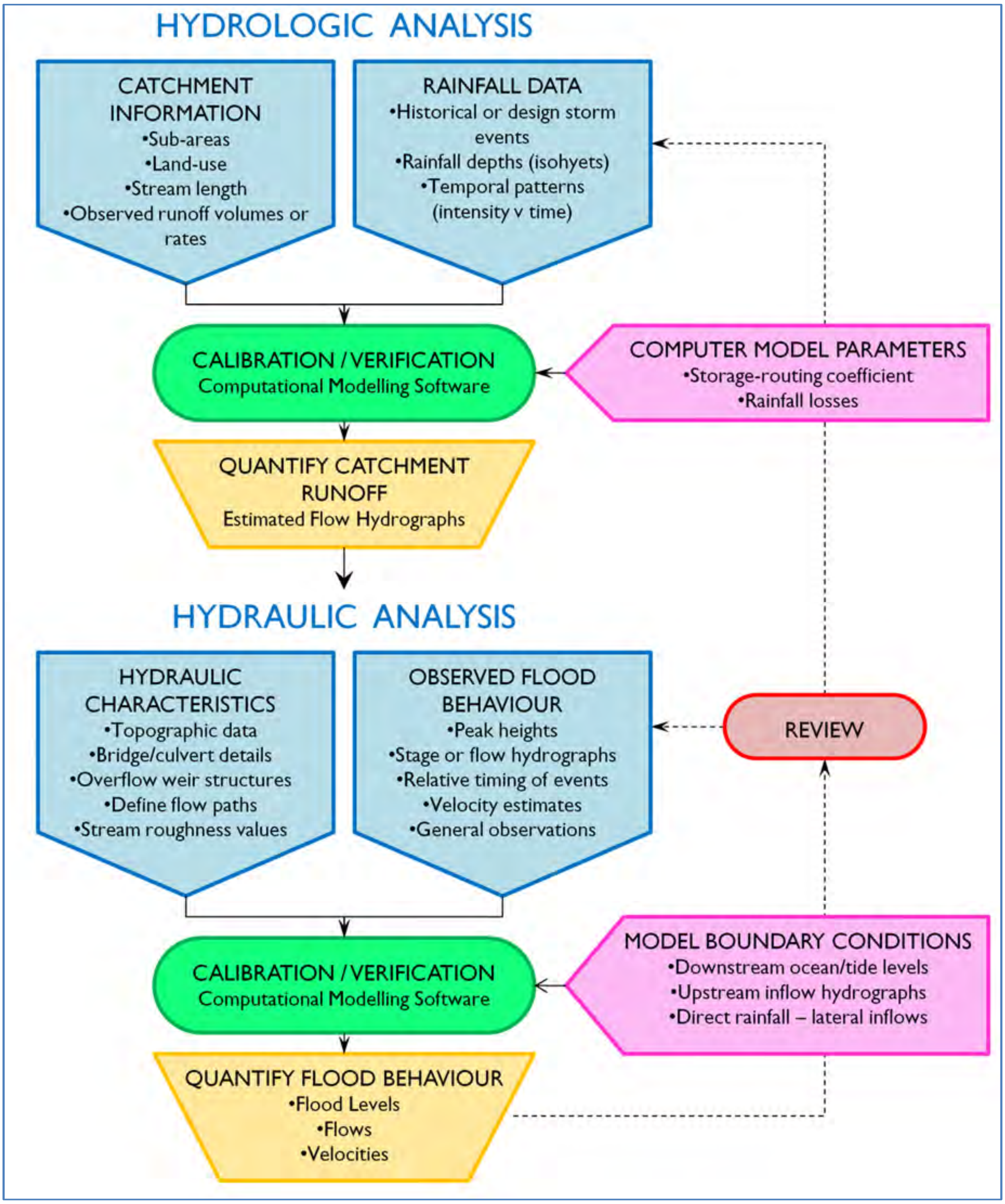


Diagram 2: Flood Study Process

The estimation of flood behaviour in a catchment is undertaken as a two-stage process, consisting of:

1. hydrologic modelling to convert rainfall estimates to overland flow and stream runoff; and
2. hydraulic modelling to estimate overland flow distributions, flood levels and velocities.

As such, the hydrologic model, DRAINS, was built and used to create flow boundary conditions for input into a two-dimensional unsteady flow hydraulic model, TUFLOW.

Good historical flood data facilitates calibration of the models and increases confidence in the estimates. The calibration process involves modifying the initial model parameter values to produce modelled results that concur with observed data. Validation is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Recorded rainfall and stream-flow data are required for calibration of the hydrologic model, while historic records of flood levels, velocities and inundation extents can be used for the calibration of hydraulic model parameters. In the absence of such data, model verification to peak level data is the only option and a detailed sensitivity analysis of the different model input parameters constitutes current best practice.

The use of a flood frequency approach for the estimation of design floods and/or independent calibration of the hydrologic model is possible for the Powells Creek catchment using the Elva Street gauge data.

Flood estimation in urban catchments generally presents challenges for the integration of the hydrologic and hydraulic modelling approaches, which have been treated as two distinct tasks as part of traditional flood modelling methodologies. As the main output of a hydrologic model is the flow at the outlet of a catchment or sub-catchment, it is generally used to estimate inflows from catchment areas upstream of an area of interest, and the approach does not lend itself well to estimating flood inundation in mid- to upper-catchment areas, as required for this study. The aim of identifying the full extent of flood inundation can therefore be complicated by the separation of hydrologic and hydraulic processes into discrete models. As such, these processes are increasingly being combined in a single modelling approach.

In view of the above, the broad approach adopted for this study was to use a widely utilised and well-regarded hydrologic model to conceptually model the rainfall concentration phase (including runoff from roof drainage systems, gutters, etc.). The hydrologic model used design rainfall patterns specified in AR&R 1987 (Reference 4) and the runoff hydrographs were then used in a hydraulic model to estimate flood depths, velocities and hazard in the study area.

The sub-catchments in the hydrologic model were kept small such that the overland flow behaviour for the study was generally defined by the hydraulic model. This joint modelling approach was then verified against previous studies and historical data.

3.1. Hydrologic Model

Inflow hydrographs are required as inputs at the boundaries of the hydraulic model. Typically in flood studies a rainfall-runoff hydrologic model (converts rainfall to runoff) is used to provide these inflows. A range of runoff routing hydrologic models is available as described in AR&R 1987 (Reference 4). These models allow the rainfall depth to vary both spatially and temporarily over the catchment and readily lend themselves to calibration against recorded data.

DRAINS is a hydrologic/hydraulic model that can simulate the full storm hydrograph and is capable of describing the flow behaviour of a catchment and pipe system for real storm events, as well as statistically based design storms. It is designed for analysing urban or partly urban catchments where artificial drainage elements have been installed.

The DRAINS model is broadly characterised by the following features:

- the hydrological component is based on the same theory applied in the ILSAX model which has seen wide usage and acceptance in Australia;
- its application of the hydraulic grade line method for hydraulic analysis throughout the drainage system; and
- the graphical display of network connections and results.

DRAINS generates a full hydrograph of surface flows arriving at each pit and routes these through the pipe network or overland, combining them where appropriate. Consequently, it avoids the "partial area" problems of the Rational Method and additionally it can model detention basins (unsteady flow rather than steady state).

Runoff hydrographs for each sub-catchment area are calculated using the time area method and the conveyance of flow through the drainage system is then modelled using the Hydraulic Grade Line method. Application of the Hydraulic Grade Line method is recommended in AR&R 1987 (Reference 4) for the design of pipe systems. The method allows pipes to operate under pressure or to "surcharge", meaning that water rises within pits, but does not necessarily overflow out onto streets. This provides improved prediction of hydraulic behaviour, consistency in design, and greater freedom in selecting pipe slopes. It requires more complicated design procedures, since pipe capacity is influenced by upstream and downstream conditions.

DRAINS cannot however adequately account for an elevated downstream tailwater level which would drown out the lower reaches of a drainage system (it can if the upstream pit is above the tailwater level but not if it is below). For this reason flooding within reaches affected by elevated water levels is more accurately assessed using the TUFLOW model.

It should be noted that DRAINS is not a true unsteady flow model and therefore does not account for the attenuation effects of routing through temporary floodplain storage (down streets or in yards). As such the use of DRAINS within the study is limited to some minor upstream routing and development of hydrological inputs into the downstream TUFLOW model.

3.2. Hydraulic Model

The availability of high quality LiDAR/ALS data means that the study area is suitable for two-dimensional (2D) hydraulic modelling. Various 2D software packages are available and the TUFLOW package (Reference 8) was adopted as it is widely used in Australia and WMAwater has extensive experience with the model.

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions. The TUFLOW software is produced by BMT WBM and has been widely used for a range of similar projects. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short duration events and a combination of supercritical and subcritical flow behaviour.

The Powells Creek study area consists of a wide range of developments, with residential, commercial and open space areas. For this catchment, the study objectives require accurate representation of the overland flow system including kerbs and gutters and defined drainage controls.

For the hydraulic analysis of complex overland flow paths (such as the present study area where overland flow occurs between and around buildings), an integrated 1D/2D model such as TUFLOW provides several key advantages when compared to a 1D only model. For example, a 2D approach can:

- provide localised detail of any topographic and/or structural features that may influence flood behaviour,
- better facilitate the identification of the potential overland flow paths and flood problem areas,
- dynamically models the interaction between hydraulic structures such as culverts and complex overland flowpaths; and
- inherently represent the available floodplain storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into planning activities. The model developed for the present study provides a flexible modelling platform to properly assess the impacts of any overland flow management strategies within the floodplain as part of the ongoing floodplain management process.

In TUFLOW the ground topography is represented as a uniformly-spaced grid with a ground elevation and a Manning's "n" roughness value assigned to each grid cell. The grid cell size is determined as a balance between the model result definition required and the computer run time (which is largely determined by the total number of grid cells).

3.3. Assessment of Data from UNSW Elva Street Gauge

3.3.1. Overview

It is important that the best possible use is made of the available data as this is the only urban catchment in Sydney where there is a long term record for use in flood frequency analysis and which can be used to calibrate hydrologic (flows) and hydraulic (water level) models. However, there are a number of issues with the data and these are discussed below.

3.3.2. Gaugings and Rating Curve

The cross-sectional area of the channel has not changed (lined ‘U’ shaped channel) since 1958 although the coping has been raised. The gauge zero is at RL 5.25 mAHD and over 29 stream gaugings have been taken. The channel is well gauged below 1 m (RL 6.25 mAHD); there are 14 gaugings below 0.5 m (RL 5.75 mAHD); 14 gaugings between 0.5 m and 1.0 m; and the highest gauging is at 1.35 m (RL 6.6 mAHD). The gaugings show very little scatter and fit as a smooth line on log-log paper. Above 0.2 m the flow tends to be supercritical and velocities are very high (above 4 m/s). This is the greatest source of uncertainty in the gauging as the velocity is above the normal range of the current meter used to take velocity measurements.

There are three known rating curves (Figure 7) as indicated below but the Reference 2 and digital record curves are practically identical and shown as the same:

- used in Reference 6 and taken from UNSW records at the time;
- used in the 1998 Powells Creek Flood Study (Reference 2);
- used in the digital records.

As part of the present study a rating curve is produced from the TUFLOW model (Figure 7). All the prior curves, whilst based on various velocity gaugings aimed to extend the rating curve beyond the highest flow gauging height of 1.35 m (RL 6.6 mAHD).

It is interesting to note that the Reference 2 rating curve and the TUFLOW model rating curves are relatively similar in magnitude at a given height. The TUFLOW model rating produces a smaller flow up to approximately 1.8 m before transitioning to produce larger flows than the Reference 2 rating above this level.

Uncertainty between the prior rating curves listed above increases once the flow breaks out of the channel (approximately at 2.5 m or RL 7.75 mAHD). The channel may also choke downstream at very high depths. This is not the case with the TUFLOW model rating which performs equally well for both in and out of bank floods. Since approximately 2000 there have been significant changes in the number and size of the bridges across the channel in the immediate reach upstream from the railway line. There is no complete record of the dates when bridges have been removed or installed. The presence of bridges will influence the high flow rating but for the majority of the record the events were not above the coping and thus not influenced by these changes.

3.3.3. For Use in Flood Frequency Analysis

Flood frequency analysis is the fitting of statistical distribution to either the annual maxima peaks or a partial series which are events above a threshold. Partial series analysis is not possible for this study as there are too many gaps in the record. Whilst the gaps in the record also affect the annual maxima series it is expected that this approach will still provide a robust result.

Derivation of the annual maxima needs to address whether the record should be based on just the digital record or whether it should be extended to include the data shown in Table 11, and whether the record should be extended from the end of the digital record (1997) to date. It is known that there have been no large events since 1997.

A tabulation of the annual maxima from the various sources is provided on Table 16.

Table 16: Annual Maxima Peaks

Year	Peak Stage (m) from Reference 6	Peak Stage (m) from Digital Records	Difference in Peak Stage (m)	Peak Flows from Reference 6 (m^3/s)	Peak Flows from 1998 Flood Study Reference 2 (m^3/s)	Peak Flows from Digital Record (m^3/s)
1958		1.48			16.0	16.1
1959	3.29	3.26	0.03	29.9	48.2	49.1
1960	1.30	1.12	0.18	11.1	10.8	10.6
1961	4.18	0.79	3.39	38.3	7.0	5.9
1962	1.69	1.74	-0.05	14.8	20.0	20.3
1963	2.40	2.47	-0.07	22.0	33.0	32.1
1964	3.52	1.88	1.64	32.1	25.3	22.5
1965	1.02	0.88	0.14	8.0	8.8	7.2
1966	1.28	1.23	0.05	10.9	12.6	12.3
1967	1.52	1.40	0.12	13.2	17.2	14.9
1968	0.84	0.70	0.14	5.9	5.3	4.7
1969	1.71	1.62	0.09	15.1	18.3	18.4
1970	3.09	1.43	1.66	28.0	17.4	15.4
1971	1.93	1.10	0.83	17.8	12.1	10.3
1972	3.20	2.76	0.44	29.1	38.0	37.3
1973	2.35	2.17	0.18	21.5	33.5	27.1
1974	2.34	2.23	0.11	21.4	28.9	28.0
1975	1.58	1.52	0.06	13.8	17.0	16.7
1976	1.70	1.25	0.45	14.9	14.9	12.6
1977	1.15	1.49	-0.34	9.6	16.5	16.3
1978	1.47	1.38	0.09	12.7	15.1	14.6
1979	1.27	1.22	0.05	10.8	12.6	12.1
1980	1.26	1.27	0.00	10.7	12.7	12.8
1981	1.41	1.38	0.03	12.1	14.6	14.6
1982	1.71	1.67	0.04	15.1	19.3	19.1
1983	1.83	1.80	0.03	16.8	21.3	21.2
1984	1.84	1.81	0.03	16.9	21.3	21.4
1985	1.30	1.21	0.09	11.1	13.1	11.9
1986	1.93	1.73	0.20	17.8	20.2	20.1
1987		1.18			11.8	11.4
1988		1.92			23.1	23.1
1989		1.28			13.9	13.0
1990		1.92			23.3	23.1
1991		1.68			19.2	19.2
1992		1.53			17.1	16.9
1993		1.88				22.4
1994		1.44			6.9	15.4
1995		1.31			13.3	13.4
1996		0.90			7.8	7.4
1997		0.86			7.6	6.9

3.4. Calibration and Verification of the Modelling Process

3.4.1. Approach

As flow data is available from the Elva Street gauge this means that the catchment hydrology (flows) can be calibrated and verified at this location. This is a significant advantage for this catchment as this is possible for only approximately 10 urban catchments in Australia and less than 5 in NSW. TUFLOW model peak levels and the shape of the hydrograph can also be calibrated to water level data from the Elva Street gauge.

In addition, peak levels from TUFLOW can be calibrated to observed water level data provided by Council and Sydney Water (Section 2.11 and Figure 8).

The stages in the model calibration approach were as follows:

1. collect available historical rainfall and water level data;
2. select events for calibration and verification based on the quality and quantity of available data;
3. input historical rainfall data for calibration event to DRAINS;
4. input output of above DRAINS model to TUFLOW;
5. run TUFLOW for historical event;
6. compare output from TUFLOW for calibration event at the Elva Street gauge and other locations where historical flood height data are available;
7. re run steps 3 to 6 and adjust model parameters until a suitable match is obtained;
8. re run steps 3 to 6 for verification events without adjustment of model parameters;
9. compare output from TUFLOW from verification events at the Elva Street gauge and other locations where historical flood height data are available;
10. re-run steps 3 to 9 until a satisfactory calibration/verification is achieved.

3.4.2. Calibration Events

The choice of floods used in calibration depends upon a number of factors including the:

- *time since the flood occurred.* The longer the time since a flood occurred, the greater the likelihood of subsequent changes to the catchment. The major changes in recent times have been construction/alterations to buildings and fences in the floodplain and to the piped drainage system. The most significant change in recent times at the Elva Street gauge is construction of several bridges across the channel. However, as all the recent events suitable for calibration did not overtop the coping the impact of new bridges is not relevant;
- *quantity and quality of rainfall and streamflow data which are available*. This should have been of lesser importance in this study as data are available from two well placed pluviometers and the Elva Street water level gauge. However, problems with the UNSW rainfall and water level data meant that this became the most important factor in determining the choice of events;
- *quantity, quality and location of recorded levels along the creeks*. It may be preferable to use a small flood with several levels which define a profile rather than a large flood with only one level. This issue is of little significance as there are few events with suitable recorded levels, apart from at the gauge;
- *magnitude of the flood levels*. The larger the flood the more suitable it is for calibration as it is closer to the larger design flood events.

The following is a summary of the available data considered suitable for calibration.

2 January 1996

- Elva Street water level gauge malfunctioned and the Elva Street pluviometer had no digital record. The St Sabina pluviometer recorded 62 mm in 45 minutes;
- only record available for Sydney Water gauge under the M4;
- 39 flood levels are available (Table 14);
- at Enfield this event approached a 1% AEP (20 min to 60 min duration) but was approximately only a 5% AEP (or less) at the other gauges.

8 or 9 February 1992

- the Elva Street gauge recorded a peak of 1.5 m and it would appear from the available pluviometer records that this was not a large event. For this reason it is not suitable for calibration purposes.

11 March 1991

- the Elva gauge recorded a peak of 1.7 m and the rainfall intensity approached a 10% AEP (30 minute duration) at Enfield but the lack of other flood height data and failure of both the UNSW pluviometers meant this flood was not suitable for calibration purposes.

18 March 1990

- the flood was approximately a 30% AEP event at the St Sabina pluviometer and a 5% AEP (30 minute duration) at the Elva Street pluviometer. The peak levels and flows at the Elva Street gauge are 1.92 m and approximately 23 m^3/s (based on the UNSW rating curve),
- the availability of water level and pluviometer records from the UNSW gauges meant that this event could be used for calibration at the Elva Street gauge. However, no flood height data were available for calibration of the TUFLOW model elsewhere.

February 1990

- four peaks occurred during February 1990 (3rd, 7th, 10th and 17th). The water level and pluviometer data (UNSW gauges) are shown on Figure 9. The peak levels and flows (based on the UNSW rating curve) at the Elva Street gauge are:
  - 3rd Feb 1990 - 1.4 m - 14 m^3/s,
  - 7th Feb 1990 - 1.4 m - 15 m^3/s,
  - 10th Feb 1990 - 1.8 m - 21 m^3/s,
  - 17th Feb 1990 - 1.1 m - 11 m^3/s,
- several flood levels (assumed to be for 10th February 1990) are available (Table 14),
- the 10th February event was slightly less than a 20% AEP rainfall event (30 minute and 60 minute durations);
- the water level records indicates a peak on the morning of 8th February 1990. This is not compatible with the rainfall record which indicates that the peak was approximately 24 hours earlier. It has been assumed that the timing on the water level gauge malfunctioned;
- the availability of pluviometer and water level data from the UNSW gauges meant that all four events could be used for calibration at the Elva Street gauge. The largest event

(10th February) was used for calibration of the TUFLOW model as it is presumed the recorded flood levels relate to this event.

4-6 August 1986:

- digital records from the Elva Street gauge shown no record for this event. However Reference 2 indicates a peak of 1.95 m obtained from data collected as part of Reference 6,
- the St Sabina pluviometer malfunctioned and the Elva Street pluviometer recorded a maximum of 21 mm in 30 minutes which is only modest rainfall. For this reason this event could not be used for calibration.

Summary

Five events (3rd, 7th, 10th and 17th February 1990 and 18th March 1990) were available for calibration of the Elva Street gauge and two events (10th February 1990 and 2nd January 1996) for calibration of the TUFLOW model.

3.5. Design Flood Modelling

Following model establishment and calibration the following steps were undertaken:

- design tributary inflows were obtained from the DRAINS hydrologic model and included in the TUFLOW model;
- flood frequency of the Elva Street gauge records;
- assessment of the design event causing the maximum water levels which is termed the critical storm duration;
- sensitivity analyses to assess the effect of changing model parameters and the assumed water level in the Parramatta River;
- assessment of possible effects of climate change on design flood levels.

4. HYDROLOGIC MODELLING

4.1. Sub-catchment Definition

The total catchment represented by the current DRAINS model is 8.45 km^2. This area has been represented by 749 sub-catchments (Figure 10) giving an average sub-catchment size of approximately 1.13 hectares. The sub-catchment delineation ensures that where hydraulic controls exist that these are accounted for and able to be appropriately incorporated into hydraulic routing. The pit and pipe network is shown on Figure 11. The drainage system defined in the model comprises:

- 2,156 pipes;
- 1,847 inlet pits;
- 96 upstream inlet pits;
- 317 junction pits.

4.2. Impervious Surface Area

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occurs significantly faster than from vegetated surfaces. This results in a faster concentration of flow within the downstream area of the catchment and increased peak flow in some situations. It is therefore necessary to estimate the proportion of the catchment area that is covered by impervious surfaces.

DRAINS categorises these surface areas as either:

- paved areas (impervious areas directly connected to the drainage system);
- supplementary areas (impervious areas not directly connected to the drainage system; instead connected to the drainage system via the pervious areas), and
- grassed areas (pervious areas).

Within the Powells Creek catchment, a uniform 5% was adopted as a supplementary area across the catchment. The remaining 95% was attributed to impervious (or paved areas) and pervious surface areas, as estimated for each individual sub-catchment. This was undertaken by determining the proportion of the sub-catchment area allocated to a land-use category and the estimated impervious percentage of each land-use category, summarised in Table 17.

Table 17: Impervious Percentage per Land-use

Land-use Category	Impervious Percentage
Residential/Commercial property	60% Impervious
Non-bitumen road reserve	60% Impervious
Vacant land	0% Impervious
Green space (such as public parks)	0% Impervious
Roadway/Car parks	100% Impervious
Waterways	0% Impervious

4.3. Rainfall Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in AR&R (Reference 4). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed areas are comprised of an initial loss and a continuing loss. The continuing loss is calculated from an infiltration equation curve incorporated into the model and is based on the selected representative soil type and antecedent moisture condition. The catchment soil was assumed to have a slow infiltration rate and the antecedent moisture condition was considered to be “rather wet”.

The adopted parameters are summarised in Table 18. These are consistent with the parameters adopted in previous studies undertaken by WMAwater.

Table 18: Adopted DRAINS Hydrologic Model Parameters

RAINFALL LOSSES	
Paved Area Depression Storage (Initial Loss)	1.0 mm
Grassed Area Depression Storage (Initial Loss)	5.0 mm
SOIL TYPE	**3**
Slow infiltration rates. This parameter, in conjunction with the AMC, determines the continuing loss	
ANTECEDENT MOISTURE CONDITONS (AMC)	**3**
Description	Rather wet
Total Rainfall in 5 Days Preceding the Storm	12.5 to 25 mm

4.4. Design Rainfall Data

Rainfall intensities were derived from the BoM website using AR&R (Reference 4) data. Calculation of the Probable Maximum Precipitation (PMP) was undertaken using the Generalised Short Duration Method (GSDM) according to Reference 7.

For the PMP estimate the following criteria applied:

- as the catchment area is less than 1000 km^2 and located in the coastal transitional area the Generalised Short Duration Method (GSDM) was adopted;
- zero adjustment for elevation was assumed as the catchment topography is less than 1500 mAHD;
- a moisture adjustment factor of 0.7 was adopted;
- the catchment is considered to be 100% 'smooth'.

5. HYDRAULIC MODELLING

5.1. TUFLOW

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water equations in two dimensions. The TUFLOW software has been widely used for a range of similar floodplain projects both internationally and within Australia and is capable of dynamically simulating complex overland flow regimes. The TUFLOW model build used in this study is 2013-12-AC-w64 and further details regarding TUFLOW software can be found in the User Manual (Reference 8).

The model uses a regularly spaced computational grid, with a cell size of 2 m by 2 m. This resolution was adopted as it provides an appropriate balance between providing sufficient detail for roads and overland flow paths, while still resulting in workable computational run-times. The model grid was established by sampling from a DEM generated from a triangulation of filtered ground points from the ALS dataset, discussed in Section 2.6 and shown in Figure 3.

The TUFLOW hydraulic model includes the Powells Creek catchment to Homebush Bay with the open channel in 1D and the overland areas in 2D. The total area included in the 2D model is approximately 10 km^2. The extents of the TUFLOW model are shown in Figure 12.

5.2. Boundary Locations

5.2.1. Inflows and Downstream Boundary

Local runoff hydrographs were extracted from the DRAINS model for inclusion within the TUFLOW model domain. These were applied to the downstream end of the sub-catchments within the 2D domain of the hydraulic model. The inflow locations typically corresponded with inlet pits on the roadway as this is where most rainfall is directed.

The downstream boundary was located at the Parramatta River, as shown in Figure 12.

5.3. Roughness Co-efficient

The hydraulic efficiency of the flow paths within the TUFLOW model is represented in part by the hydraulic roughness or friction factor formulated as Manning's "n" values. This factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features which may affect the hydraulic performance of the particular flow path.

The Manning's "n" values adopted, including flowpaths (overland, pipe and in-channel), are shown in Table 19 and were based on site inspection and past experience in similar floodplain environments.

Table 19: Manning's "n" values adopted in TUFLOW

Material	Manning's n Value
Bitumen road reserve and some car parks	0.02
Green Space - Golf Course, Parks, Vacant Lots	0.04
Residential/urban area	0.03
Non-bitumen road reserve	0.032
Waterways	0.015
Pipes	0.012

5.4. Hydraulic Structures

5.4.1. Buildings

Buildings and other significant features likely to act as flow obstructions were incorporated into the model network based on building footprints, defined using aerial photography. These types of features were modelled as impermeable obstructions to the floodwaters.

5.4.2. Fencing and Obstructions

Smaller localised obstructions within or bordering private property, such as fences, were not explicitly represented within the hydraulic model, due to the relative impermanence of these features. The cumulative effects of these features on flow behaviour were assumed to be addressed partially by the adopted roughness parameters.

5.4.3. Bridges

Key hydraulic structures were included in the hydraulic model, as shown in Figure 12, bridges were modelled as 1D features within the 1D channels, with the purpose of maintaining continuity within the model.

The modelling parameter values for the culverts and bridges were based on the geometrical properties of the structures, which were obtained from detailed survey, photographs taken during site inspections, and previous experience modelling similar structures.

5.5. Blockage Assumptions

Blockage of hydraulic structures can occur with the transportation of a number of materials by flood waters. This includes vegetation, garbage bins, building materials and cars, the latter occurred in the Newcastle area in June 2007. However, the disparity in materials that may be mobilised within a catchment can vary greatly.

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the AEP of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration.

The potential effects of blockage include:

- decreased conveyance of flood waters through the blocked hydraulic structure or drainage system;
- variation in peak flood levels;
- variation in flood extent due to flows diverting into adjoining flow paths; and
- overtopping of hydraulic structures.

Existing practices and guidance on the application of blockage can be found in:

- the Queensland Urban Drainage Manual (Department of Natural Resources and Water, 2008);
- AR&R Revision Project 11 Blockage of Hydraulic Structures (Engineers Australia, 2013); and
- the policies of various local authorities and infrastructure agencies.

The guidelines proposed by the AR&R Revision Project 11 utilise generic blockage factors presented in Table 20.

Table 20: Suggested 'Design' and 'Severe' Blockage Conditions for Various Structures (AR&R Revision Project 11, 2013)

Type of structure		**Blockage conditions**	
		Design blockage	**Severe blockage**
Sag Kerb Inlet	Kerb slot inlet only Grated inlet only Combined inlets	0/20% 0/50% [1]	100% (all cases)
On-grade kerb inlets	Kerb slot inlet only Grated inlet only (longitudinal bars) Grated inlet only (transverse bars) Combined inlets	0/20% 0/40% 0/50% [2]	100% (all cases)
Field (drop) inlets	Flush mounted Elevated (pill box) horizontal grate Dome screen	0/80% 0/50% 0/50%	100% (all cases)
Pipe inlets and waterway culverts	*Inlet height < 3m and width < 5m* Inlet Chamber	0/20% [3]	100% [4]
	Inlet height > 3m and width > 5m Inlet Chamber	0/10% [3]	25% [3]
	Culverts and pipe inlets with effective debris control features	As above	As above
	Screened pipe and culvert inlets	0/50%	100%
Bridges	Clear opening height < 3 m Clear opening height > 3 m Central piers	[5] 0% [7]	100% [6] [7]
Solid handrails and traffic barriers associated with bridges and culverts		100%	100%
Fencing across overland flow paths		[8]	100%
Screened stormwater outlets		100%	100%

Current modelling has been undertaken assuming no blockage of pipes, culverts and bridges greater than 300 mm in diameter. Pipes less than or equal to 300 mm in diameter were conservatively assumed to be completely blocked.

Various scenarios have been investigated to assess the catchment's sensitivity to 20% and 50% blockage and the results of this are discussed in Section 9. These scenarios included blockage of all pipes, blockage of bridges/culverts over the open channel, and blockage of the drainage infrastructure. Blockage was assumed to occur laterally across the cross-section. Alternative applications of blockage include reducing the cross-sectional area upwards from the invert. This is perhaps more relevant to vegetated open channels that are subject to sedimentation rather than the concrete lined open channels present in the Powells Creek catchment.

No historical evidence of blocking in the catchment is available; however, it is possible that changed activities on the floodplain may mean that there may be a higher chance of blockage today than in the past. For example, colourbond fencing is much less permeable and less likely to collapse than the more traditional paling fencing. Individual palings becoming mobile in a flood are also less likely to cause blockage than a panel of colourbond fencing. In some council areas garbage bins are known to become mobile during floods and can cause blockage. In summary, it is impossible to accurately determine whether blockage will or will not be an issue in the next flood.

5.6. Ground Truthing

Inspection of the above-ground features along the catchment's overland flowpaths was undertaken following calibration and verification of the hydraulic model. This entailed producing design flood results and mapping the peak flood depth in detail across the catchment. This allowed identification of features (largely buildings) that blocked or partially blocked overland flow. Model schematisation of these features was then compared to the actual features on a site visit, and the model was updated where any discrepancy was identified. Changes were minor and only impacted results in the vicinity of the modification. The most common change was to areas where two houses had been represented as a single impermeable barrier in the model grid, which was amended to allow flow between the buildings.

6. MODEL CALIBRATION AND VERIFICATION

6.1. Introduction

It is important that the performance of the overall modelling system be substantiated prior to defining design flood behaviour.

Typically in urban areas such information is lacking. Issues which may prevent a thorough calibration of hydrologic and hydraulic models are:

- there is only a limited amount of historical flood information available for the study area; and
- rainfall records for past floods are limited and there is a lack of temporal information describing historical rainfall patterns within the catchment.

6.2. Results

The results of the calibration and verification process using the six historical events are shown on Figure 13 (Elva Street Gauge) and Figure 14 (across catchment) and on Table 21 (Elva Street Gauge) and Table 22 (across catchment).

Table 21: Calibration Results - Elva Street Gauge

Date	Recorded Level (m AHD)	Modelled Level St Sabina Pluviometer (m AHD)	Difference (m)	Modelled Level Elva St Pluviometer (m AHD)	Difference (m)
3-Feb-90	6.67	6.59	-0.08	6.61	-0.06
7-Feb-90	6.68	6.68	0.00	6.77	0.09
10-Feb-90	7.00	6.80	-0.20	7.01	0.01
17-Feb-90	6.41	6.46	0.05		
18-Mar-90	7.13	6.75	-0.38		
2-Jan-96		8.06			

Table 22: Calibration Results - Peak Heights

Address	Location	Surveyed Level 1990 February 10 (mAHD)	Surveyed Level 1996 January 2 (mAHD)	Modelled Level 1990 February 10 (mAHD)	Modelled Level 1996 January 2 (mAHD)	Difference-1990 February 10 (mAHD)	Difference-1996 January 2 (mAHD)
21 Llandilo Avenue	Garage Floor Level	29.9	N/A	30.03	N/A	0.13	N/A
21 Llandilo Avenue	North-West Corner	28.8	N/A	28.69	N/A	-0.11	N/A
8 Agnes Street	Driveway and Front Boundary	N/A	26.71	N/A	26.66	N/A	-0.05
41 Albyn Road	Crest of Driveway	N/A	22.54	N/A	22.48	N/A	-0.06
41 Albyn Road	Low Point along West. Boundary	N/A	21.64	N/A	21.58	N/A	-0.06
47 Albyn Road	Garage Floor Level	N/A	21.18	N/A	21.16	N/A	-0.02
37 Redmyre Road	Crest of Driveway	N/A	13.27	N/A	13.10	N/A	-0.17
37 Redmyre Road	Ground Level at Garage	N/A	12.21	N/A	12.44	N/A	0.23
35 Redmyre Road	Crest of Driveway	N/A	13.26	N/A	13.12	N/A	-0.14
35 Redmyre Road	Ground Level at Back Fence	N/A	12.13	N/A	12.07	N/A	-0.06
45 Churchill Avenue	Base Steps at Front House	N/A	10.74	N/A	11.02	N/A	0.28
60 Churchill Avenue	Ground Level at Path Granny Flat	N/A	11.49	N/A	11.42	N/A	-0.07
Pharmacy adjoining Plaza Entrance, The Boulevarde		N/A	12.29	N/A	12.70	N/A	0.41
65 Oxford Street	Carport Slab	N/A	24.16	N/A	23.98	N/A	-0.18
63 Oxford Street	South-West corner of house	N/A	23.75	N/A	23.60	N/A	-0.15
61 Oxford Street	Garage Floor Level	N/A	23.24	N/A	22.99	N/A	-0.25
59 Oxford Street	Patio Level	N/A	23.14	N/A	23.06	N/A	-0.08
141Albert Street	Ground level along eastern fence	19.51	N/A	19.31	N/A	-0.20	N/A
135 Albert Street	Bottom steps rear of house	18.49	N/A	18.26	N/A	-0.23	N/A
137 Albert Street	Crest of driveway	19.24	N/A	19.06	N/A	-0.18	N/A
137 Albert Street	Water reached floor level	19.01	N/A	18.93	N/A	-0.08	N/A
100 Beresford Road	Driveway at entrance to house	15.91	N/A	15.80	N/A	-0.11	N/A
102 Beresford Road	Ground level at back door	16.43	N/A	16.46	N/A	0.03	N/A
104 Beresford Road	Ground level rear house	17	N/A	16.81	N/A	-0.19	N/A
110 Beresford Road	Midway along eastern fence	17.5	N/A	17.63	N/A	0.13	N/A
108 Beresford Road	Base steps rear house	17.49	N/A	17.33	N/A	-0.16	N/A

Address	Location	Surveyed Level 1990 February 10 (mAHD)	Surveyed Level 1996 January 2 (mAHD)	Modelled Level 1990 February 10 (mAHD)	Modelled Level 1996 January 2 (mAHD)	Difference- 1990 February 10 (mAHD)	Difference- 1996 January 2 (mAHD)
53 Beresford Road	Garage floor level	15.29	N/A	15.17	N/A	-0.12	N/A
89 Rochester Street	Floor level shop	12.84	N/A	12.70	N/A	-0.14	N/A
109 Rochester Street	Base steps rear house	14.33	N/A	14.23	N/A	-0.10	N/A
109 Rochester Street	Base steps rear house	N/A	14.15	N/A	14.33	N/A	0.18
57 Rochester Street	Ground level back yard	N/A	9.92	N/A	10.45	N/A	0.53
38-46 Burlington Road	Ground level at rear shed	9.71	N/A	9.93	N/A	0.22	N/A
48 Burlington Road	Ground Floor Level	N/A	9.55	N/A	9.49	N/A	-0.06
29 Burlington Road	Stormwater reached this level at rear of factory	9.16	N/A	8.97	N/A	-0.19	N/A
30 The Crescent	Garage Floor Level	N/A	8.7	N/A	8.58	N/A	-0.12
31 The Crescent	Garage Floor Level	N/A	8.33	N/A	8.23	N/A	-0.10
79 The Crescent	Floor level	8.2	N/A	7.13	N/A	-1.07	N/A
79 The Crescent	Base patio at rear	N/A	7.75	N/A	7.8	N/A	0.05
12 Loftus Crescent	Ground level backyard	7.87	N/A	Local runoff	N/A	Local runoff	N/A
86 Underwood Road	Base steps front house	N/A	4.89	N/A	5.02	N/A	0.13
82 Underwood Road	Ground level at front house and driveway	4.97	N/A	4.50	N/A	-0.47	N/A
90 Underwood Road	Base steps front of house	N/A	4.74	N/A	4.95	N/A	0.21
60 Ismay Avenue	Ground level at front of house	N/A	3.83	N/A	3.80	N/A	-0.03
55 Ismay Avenue	Base front steps	4.3	4.11	4.02	4.27	-0.28	0.16
51 Ismay Avenue	Base front steps	4.19	N/A	3.94	N/A	-0.25	N/A
56 Ismay Avenue	Base front steps	3.83	N/A	3.78	N/A	-0.05	N/A
49 Ismay Avenue	Base front steps	N/A	4.16	N/A	3.97	N/A	-0.19
48 Ismay Avenue	Base front steps	N/A	3.43	N/A	3.43	N/A	0.00
41 Ismay Avenue	Base front steps	3.71	N/A	Local runoff	N/A	Local runoff	N/A
10 Mitchell Road	Ground level low side house	N/A	14.75	N/A	14.7	N/A	-0.05
6 Mitchell Road	Ground level low side house	N/A	14.35	N/A	14.33	N/A	-0.02
104 Arthur Street	Ground level front of house	N/A	13.87	N/A	13.72	N/A	-0.15
106 Arthur Street	Ground level at boundary	N/A	13.85	N/A	13.78	N/A	-0.07
105 Arthur Street	Ground level at house steps side house	N/A	13.89	N/A	13.94	N/A	0.05
29 Arthur Street	Base front steps	N/A	13.23	N/A	13.36	N/A	0.13
29 Arthur Street	Ground level at rear fence	N/A	12.98	N/A	12.88	N/A	-0.10

Address	Location	Surveyed Level 1990 February 10 (mAHD)	Surveyed Level 1996 January 2 (mAHD)	Modelled Level 1990 February 10 (mAHD)	Modelled Level 1996 January 2 (mAHD)	Difference-1990 February 10 (mAHD)	Difference-1996 January 2 (mAHD)
6 Kessell Avenue	Ground level at fence	N/A	7.76	N/A	7.80	N/A	0.04
6 Kessell Avenue	Water reached floor level	8.42	N/A	8.15	N/A	-0.27	N/A

Note: Local runoff denotes when the flooding is very localised and is therefore not identified in the TUFLOW model.
Highlighted values are referred to in discussion of results across the catchment.

6.3. Discussion of Results

6.3.1. Elva Street Gauge

Apart from 18th March 1990 and to a lesser extent 10th February 1990, there is a good match to the peak at the Elva Street gauge using the St Sabina pluviometer. The use of the Elva Street pluviometer significantly improves the match for the 10th February 1990 event compared to using the St Sabina pluviometer.

For all events the relative timings of the water level gauge and the pluviometer are incorrect due to timing errors with the instruments. This was recognised in Reference 6 and an attempt was made to correct this by assuming that the "clocks" decrease or increase in speed linearly (this can be calculated as the on and off times are recorded and the elapsed real time can be compared to the chart time).

In general the gauge shows a much more rapid rise and fall than the model results, particularly on the falling limb. Thus the model assumes a greater volume of runoff than actually occurs.

Where comparisons can be made, the results from the St Sabina and Elva Street pluviometer show similar shapes of hydrographs. The timing of the two pluviometers are also similar suggesting that the error in timing is the water level gauge. The two pluviometers are only 800 m apart but timing differences may reflect the passage of a storm across the area.

6.3.2. Across the Catchment

For the historical event of 10th February 1990, most of the differences between surveyed and modelled levels were within 0.2 m. However, the modelled flood level at 79 The Crescent was 1.07 m below the level recorded at the floor. The ALS at this location was 7.05 mAHD which was far lower than the recorded flood level of 8.2 mAHD.

The differences were also generally within 0.2 m for the historical event of 2nd January 1996. The recorded flood level at the ground level at 57 Rochester Street was 0.53 m lower than the modelled level. This cannot be explained as the location is a major flow path with depths up to 0.8m deep. The ALS at the Pharmacy adjoining Plaza Entrance indicates ground levels of 12.49 mAHD, which is higher than the recorded level and the reason that the modelled level was 0.41 m higher.

7. DESIGN EVENT MODELLING

7.1. Overview

There are two basic approaches to determining design flood levels, namely:

- *flood frequency analysis* – based upon a statistical analysis of the flood events, and
- *rainfall and runoff routing* – design rainfalls are processed by hydrologic and hydraulic computer models to produce estimates of design flood behaviour.

The *flood frequency* approach requires a reasonably complete homogenous record of flood levels and flows over a number of decades to give satisfactory results. Powells Creek is one of the two catchments in the Sydney basin that has a reasonably reliable water level record over a long period and has had velocity gaugings undertaken (required to derive a rating curve). Thus flood frequency analysis can be undertaken. However this approach only provides results at the gauge location and a *rainfall and runoff routing* approach, using DRAINS model results, is also required to derive inflow hydrographs to the TUFLOW hydraulic model, which determines design flood levels, flows and velocities in areas beyond the actual gauge location. This approach reflects current engineering best practice and is consistent with the quality and quantity of available data.

7.2. Critical Duration for Rainfall Runoff Approach

To determine the critical storm duration for various parts of the catchment, modelling of the 1% AEP event was undertaken for a range of design storm durations from 15 minutes to 4.5 hours, using temporal patterns from AR&R (1987). An envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

It was found that a combination of the 25 minute, 1 hour and 2 hour design storm durations produce the highest flood levels across the entire catchment for the 1% AEP event. However, having a combination of storm durations is difficult to manage (for example which event produces the peak velocity or peak hazard). It is therefore preferable to adopt a single storm duration for design flood estimation.

The 25 minute design storm duration was mostly higher in areas of shallow overland flow (92% of the area having a peak flood depth no greater than 0.3 m). As such, the 25 minute storm does not reflect the areas of deeper flow which are considered more hazardous. The 2 hour storm duration was selected as it was the critical storm over a greater area than the 1 hour storm duration. However, the height difference between the two durations was within ± 0.025 m across 90% of the area affected by these two durations.

Additionally, the critical storm duration was determined for the PMF event for a range of storm durations, ranging from 30 minutes to 6 hours. Similarly, an envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area. It was found that the 1 hour storm duration was critical in the

PMF event.

7.3. Downstream Boundary Conditions

In addition to runoff from the catchment, downstream areas can also be influenced by high water levels at the confluence of the Parramatta River and Powells Creek. Consideration must therefore also be given to accounting for the joint probability of coincident flooding from both catchment runoff and backwater effects.

A full joint probability analysis to consider the interaction of these two mechanisms is beyond the scope of the present study. It is accepted practice to estimate design flood levels in these situations using a 'peak envelope' approach that adopts the highest of the predicted levels from the two mechanisms. However, the 1986 Parramatta River Flood Study (Reference 9) indicates that in this reach of the river the design water level is determined by the tide level and no design flood levels are provided. For the present study a constant water level of 1m AHD was applied to the downstream boundary for each design rainfall event. As the typical tidal in Homebush Bay is +0.6 m AHD to -0.4 m AHD a tailwater level of 1m AHD is relatively high. The maximum ocean tide in a year is 1.1 mAHD.

7.4. Design Results

The results from this study are presented as:

- Peak flood level profiles in Figure 16;
- Peak flood depths and level contours in Figure 17;
- Peak flood velocities in Figure 18;
- Provisional hydraulic hazard in Figure 19; and
- Provisional hydraulic categorisation in Figure 20.

The definition and methodology used to derive these categorisations from the results are discussed below.

7.4.1. Summary of Results

Peak flood levels, depths and flows at key locations within the catchment are summarised in Table 23, Table 24 and Table 25 for design events. These key locations coincide with the key locations used for the sensitivity analysis discussed in Section 9 and are shown on Figure 12.

Table 23: Peak Flood Levels (m AHD) at Key Locations – Design Events

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H01	Open Channel Upstream of Underwood Road	1.49	1.62	1.73	1.87	2.02	2.13	2.21	2.31	3.72
H02	Park Road	3.45	3.47	3.50	3.53	3.55	3.57	3.61	3.65	5.01
H03	Parramatta Road	3.32	3.55	3.65	3.76	3.87	3.96	4.04	4.15	5.25
H04	The Crescent	6.97	7.31	7.46	7.66	7.83	7.99	8.13	8.32	11.25
H05	Allan Davidson	9.38	9.39	9.40	9.41	9.43	9.53	9.62	9.69	11.26
H06	Arthur Street	13.10	13.15	13.17	13.21	13.24	13.27	13.30	13.34	13.88
H07	Open Channel Upstream of Pomeroy Street	1.80	2.07	2.21	2.44	2.53	2.61	2.67	2.78	4.02
H08	Beresford Road	15.25	15.27	15.29	15.32	15.34	15.36	15.39	15.43	15.79
H09	Pilgrim Avenue	9.18	9.28	9.33	9.38	9.43	9.47	9.51	9.56	12.11
H10	Brunswick Avenue	16.17	16.28	16.33	16.40	16.44	16.49	16.54	16.59	17.10
H11	Redmyre Road	12.36	12.47	12.53	12.61	12.70	12.84	12.94	13.08	14.36
H12	Torrington Road	27.48	27.48	27.48	27.48	27.49	27.49	27.49	27.49	27.51
H13	Morwick Street	13.53	13.70	13.77	13.86	13.91	13.98	14.03	14.10	15.08
H14	Russell Street	14.89	15.05	15.13	15.22	15.30	15.37	15.42	15.49	16.26
H15	Wentworth Road	16.22	16.43	16.51	16.59	16.65	16.71	16.76	16.82	17.53
H16	Norwood Street	17.35	17.47	17.53	17.61	17.66	17.72	17.78	17.85	18.49
H17	Woodside Avenue	19.37	19.43	19.50	19.59	19.65	19.71	19.77	19.85	20.38
H18	Nicholson Street	21.17	21.23	21.25	21.29	21.35	21.40	21.45	21.51	22.05
H19	Belgrave Street	22.35	22.42	22.45	22.50	22.54	22.58	22.61	22.66	23.19
H20	Minna Street	23.49	23.57	23.63	23.68	23.73	23.77	23.80	23.84	24.22

Table 24: Peak Flood Depths (m) at Key Locations – Design Events

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H01	Open Channel Upstream of Underwood Road	1.16	1.29	1.40	1.53	1.68	1.79	1.88	1.98	3.38
H02	Park Road	0.15	0.17	0.20	0.23	0.25	0.28	0.31	0.35	1.71
H03	Parramatta Road	0.74	0.93	1.01	1.12	1.23	1.32	1.40	1.51	2.61
H04	The Crescent	0.24	0.58	0.72	0.92	1.09	1.25	1.40	1.58	4.52
H05	Allan Davidson	0.07	0.09	0.09	0.11	0.13	0.23	0.32	0.38	1.96
H06	Arthur Street	0.06	0.11	0.13	0.18	0.21	0.23	0.26	0.30	0.84
H07	Open Channel Upstream of Pomeroy Street	1.35	1.62	1.76	1.99	2.08	2.16	2.22	2.33	3.57
H08	Beresford Road	0.05	0.06	0.08	0.11	0.13	0.15	0.18	0.22	0.58
H09	Pilgrim Avenue	0.17	0.27	0.31	0.36	0.41	0.46	0.49	0.54	3.09
H10	Brunswick Avenue	0.46	0.57	0.62	0.68	0.73	0.77	0.83	0.88	1.39
H11	Redmyre Road	0.02	0.13	0.19	0.27	0.36	0.50	0.60	0.74	2.02
H12	Torrington Road	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.06
H13	Morwick Street	0.19	0.36	0.43	0.51	0.57	0.64	0.69	0.76	1.74
H14	Russell Street	0.11	0.27	0.35	0.45	0.52	0.59	0.64	0.71	1.48
H15	Wentworth Road	0.49	0.71	0.79	0.87	0.93	0.99	1.03	1.10	1.81
H16	Norwood Street	0.10	0.23	0.28	0.36	0.42	0.47	0.53	0.61	1.24
H17	Woodside Avenue	0.03	0.09	0.16	0.25	0.31	0.37	0.43	0.51	1.04
H18	Nicholson Street	0.06	0.12	0.14	0.18	0.24	0.29	0.34	0.40	0.94
H19	Belgrave Street	0.19	0.26	0.29	0.34	0.38	0.42	0.45	0.50	1.03
H20	Minna Street	0.19	0.27	0.32	0.38	0.42	0.46	0.50	0.54	0.91

Table 25: Peak Flows (m3/s) at Key Locations – Design Events

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Q01	Underwood Road	21.00	29.01	33.61	39.12	44.56	50.84	56.08	63.00	165.62
Q02	Park Road	17.47	24.39	27.95	32.33	36.55	40.26	43.97	48.93	117.70
Q03	Parramatta Road	17.59	26.46	31.73	39.08	46.73	53.51	59.55	71.79	250.72
Q04	The Crescent	13.45	19.80	21.32	23.52	25.88	27.66	29.68	32.18	59.92
Q05	Allan Davidson	10.29	14.88	17.85	21.78	23.66	26.57	30.69	37.86	147.25
Q06	Arthur Street	2.67	4.37	5.42	6.99	8.42	9.93	11.39	13.53	48.88
Q07	Pomeroy Street	29.48	42.52	49.63	64.59	73.99	84.32	93.76	109.61	396.62
Q08	Beresford Road	2.54	3.64	4.51	5.65	6.63	7.52	8.68	10.41	31.42
Q09	Pilgrim Avenue	2.67	8.14	12.37	18.21	24.04	29.62	35.01	43.30	200.52
Q10	Brunswick Avenue	2.67	6.82	8.09	10.48	12.37	14.54	17.25	20.07	58.44
Q11	Redmyre Road	1.88	5.10	7.32	10.36	13.35	16.29	19.50	23.64	110.73
Q12	Torrington Road	0.17	0.23	0.27	0.31	0.35	0.39	0.44	0.49	1.10
Q13	Morwick Street	1.51	5.75	8.23	11.82	14.93	18.82	22.13	27.24	113.79
Q14	Russell Street	1.36	4.98	7.64	10.91	14.00	17.29	20.61	25.52	102.96
Q15	Wentworth Road	2.80	6.18	8.47	11.51	14.33	17.41	20.27	24.52	89.37
Q16	Norwood Street	3.45	8.21	9.49	11.56	14.09	17.14	20.04	24.19	82.18
Q17	Woodside Avenue	2.21	3.30	4.57	6.91	8.83	11.44	13.58	17.40	64.57
Q18	Nicholson Street	0.43	1.92	2.86	4.19	5.75	7.38	9.10	11.44	39.63
Q19	Belgrave Street	1.42	2.87	4.27	5.53	6.77	8.30	9.47	11.13	34.83
Q20	Minna Street	1.79	3.71	4.32	5.33	6.26	7.43	8.52	9.81	30.02

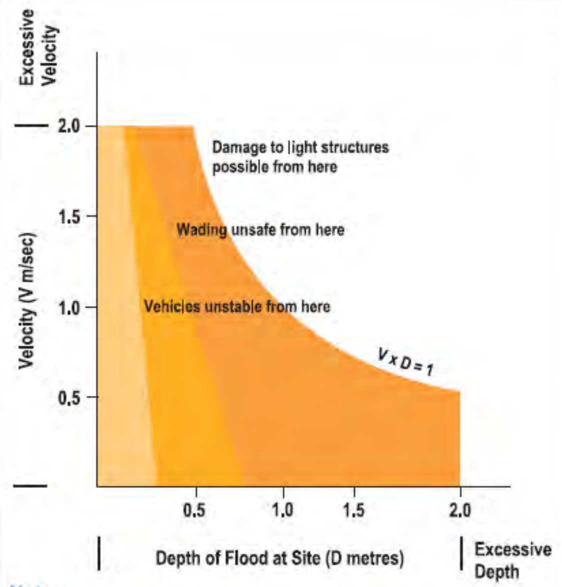
7.4.2. Duration of Inundation

Duration of flooding has also been mapped on Figure 22, which shows the duration for which different locations have greater than 0.3 m of depth in the 1% AEP 2 hour event. The figure shows that for this duration, the majority of the inundation is drained quickly, typically in less than 30 minutes. Although the mapped data is for a design event with an idealised temporal pattern and duration, the results are useful as giving indicative values of duration and for showing areas where flooding is more prolonged relative to the wider catchment.

7.4.3. Provisional Flood Hazard Categorisation

Hazard categories were determined in accordance with Appendix L of the NSW Floodplain Development Manual (Reference 1), the relevant section of which is shown in Diagram 3. For the purposes of this report, the transition zone presented in Diagram 3 (L2) was considered to be high hazard.

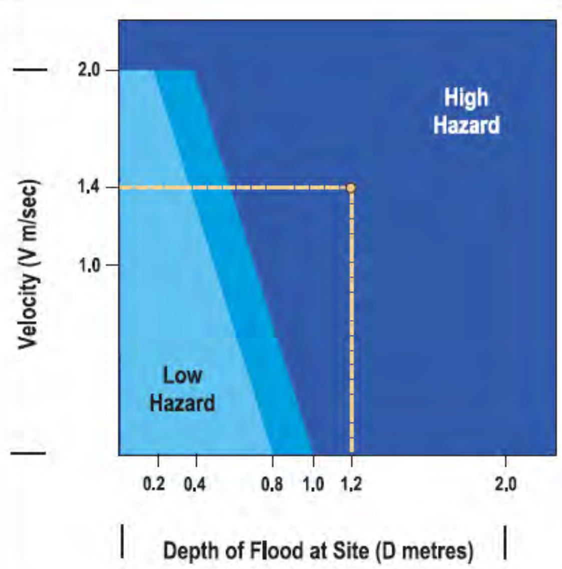
Diagram 3: (L1) Velocity and Depth Relationship; (L2) Provisional Hydraulic Hazard Categories (NSW State Government, 2005)



Notes

1. At velocities in excess of 2.0 m/s, the stability of foundations and poles can be affected by scour. Also, grass and earth surfaces begin to scour and can become rough and unstable
2. The velocity of floodwaters passing between buildings can produce a hazard, which may not be apparent if only the average velocity is considered. For instance, the velocity of floodwaters in a model test has risen from an average of 1 m/sec to 3 m/sec between houses.
3. Vehicle instability is initially by buoyancy.
4. At floodwater depths in excess of 2.0 meters and even at low velocities, there can be damage to light-framed buildings from water pressure, flotation and debris impact.

Derived from laboratory testing and flood conditions which caused damage.



Notes

The degree of hazard may be either -

- reduced by establishment of an effective flood evacuation procedure.
- increased if evacuation difficulties exist.

In the transition zone highlight by the median colour, the degree of hazard is dependant on site conditions and the nature of the proposed development.

Example:

If the depth of flood water is **1.2 m**
and the velocity of floodwater is **1.4 m/sec**
then the provisional hazard is **high**

7.4.4. Provisional Hydraulic Categorisation

The hydraulic categories, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (Reference 1). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study catchment in question.

For this study, hydraulic categories were defined by the following criteria, which has been adopted by consultants in a number of flood studies in NSW:

- Floodway is defined as areas where:
  - o the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s **AND** peak velocity > 0.25 m/s, **OR**
  - o peak velocity > 1.0 m/s **AND** peak depth > 0.15 m.

The remainder of the floodplain is either Flood Storage or Flood Fringe,

- Flood Storage comprises areas outside the floodway where peak depth > 1 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 1 m.

7.4.5. Preliminary Flood Emergency Response Classification of Communities

The Floodplain Development Manual, 2005 requires flood studies to address the management of continuing flood risk to both existing and future development areas. As continuing flood risk varies across the floodplain so does the type and scale of emergency response problem and therefore the information necessary for effective Emergency Response Planning (ERP). Classification provides an indication of the vulnerability of the community in flood emergency response and identifies the type and scale of information needed by the SES to assist in emergency response planning (ERP).

Criteria for determining flood ERP classifications and an indication of the emergency response required for these classifications are provided in the Floodplain Risk Management Guideline, 2007 (Flood Emergency Response Planning: Classification of Communities). Table 26 summarises the response required for areas of different classification. However, these may vary depending on local flood characteristics and resultant flood behaviour, i.e. in flash flooding or overland flood areas.

Table 26: Response Required for Different Flood ERP Classifications

Classification	**Response Required**		
	Resupply	**Rescue/Medivac**	**Evacuation**
High Flood Island	Yes	Possibly	Possibly
Low Flood Island	No	Yes	Yes
Area with Rising Road Access	No	Possibly	Yes
Area with Overland Escape Routes	No	Possibly	Yes
Low Trapped Perimeter	No	Yes	Yes
High Trapped Perimeter	Yes	Possibly	Possibly
Indirectly Affected Areas	Possibly	Possibly	Possibly

The criteria for classification of floodplain communities are generally more applicable to riverine flooding where significant flood warning time is available and emergency response action can be taken prior to the flood. In urban areas like the Powells Creek Catchment, flash flooding from local catchment and overland flow will generally occur as a direct response to intense rainfall without significant warning. For most (if not all) flood affected properties in the catchment, remaining inside the building is likely to present less risk to life than attempting to drive or wade through floodwaters, as flow velocities and depths are likely to be greater in the roadway.

ERP classification for the study area is shown in Figure 23. The study area has limited exposure to embankments resulting in no Low/High Trapped Perimeter (LTP/HTP) areas. There is a small area classified as a High Flood Island (HFI) along The Boulevarde, where some properties are surrounded by flood water but are not inundated in the PMF event. Areas of Rising Road Access (RRA) are present on the fringes of the flood extent, particularly within the southern portion of the study area. In areas where a main flow path is present, the majority of the properties were classified as a Low Flood Island (LFI).

8. FLOOD FREQUENCY ANALYSIS

8.1. Overview

Flood frequency analysis (FFA) enables the magnitudes of floods (5%, 1% AEP etc.) to be estimated based on statistical analysis of recorded flows. It can be undertaken graphically or using a mathematical distribution.

The reliability of the flood frequency approach depends largely upon the length and quality of the observed record and accuracy of the rating curve. In addition, flood frequency inherently accounts for many assumptions which are required in rainfall-runoff routing for determining the magnitude of floods for annual exceedance probabilities.

This approach has the following advantages in design flood estimation:

- no assumptions are required regarding the relationship between probabilities of rainfall and runoff;
- all factors affecting flood magnitude are already integrated into the data;
- estimation of rainfall losses is not required;
- confidence limits can be estimated;
- historic rainfall data is not required.

The flood frequency approach does, however, have some limitations. These are:

- there is no "perfect" distribution", thus different distributions will provide different answers;
- as most flood records are relatively short (compared to the design event for which a magnitude is required) there is considerable uncertainty. Whilst rainfall records at a particular location are also short, data can be used by the BoM from other gauges to accurately estimate design intensities much greater than the period of record at a single gauge;
- changes to the local topography such as levee banks, hydraulic controls and the construction of retarding basins or bridges can affect the homogeneity of the data set;
- short to medium term climatic changes may influence the flood record; and
- there are many issues with the accuracy of rating curves, especially at high flows. However, this is less of an issue with the use of hydraulic models based on high quality survey (ALS) to obtain site rating curves.

While some of these factors can affect the quality of the flood frequency analysis, for the purpose of providing confirmation for the runoff routing results they are considered reasonable.

8.2. Examined Annual Series

Utilising the data presented in Table 16, various data sets of annual maximum levels are available for converting to flows for the purpose of FFA. These levels can be converted into flows using one of the rating curves described in Section 3.3.2 and presented in Figure 7. Eight potential scenarios have been evaluated for FFA with the tested combinations presented in Table 27 and described below.

Table 27: Flow (m^3/s) Data Sets Used in FFA

Year	Data Set #1*	Data Set #3**	Data Set #5	Data Set #6	Data Set #7	Data Set #8
1958	16.09	12.66	12.66	12.66	12.66	12.66
1959	49.07	54.56	54.56	54.56	54.56	53.9
1960	10.57	10.06	10.06	10.06	10.06	7.34
1961	5.87	83.07	3.47	83.07	3.47	3.47
1962	20.3	19.04	19.04	19.04	19.04	21.24
1963	32.06	35.74	35.74	35.74	35.74	37.06
1964	22.48	61.01	61.01	26.39	26.39	26.39
1965	7.16	6.01	6.01	6.01	6.01	4.38
1966	12.3	9.74	9.74	9.74	9.74	8.95
1967	14.91	13.52	13.52	13.52	13.52	11.45
1968	4.75	3.96	3.96	3.96	3.96	2.66
1969	18.39	19.89	19.89	19.89	19.89	16.4
1970	15.35	50.46	50.46	50.46	50.46	11.82
1971	10.33	27.57	27.57	27.57	27.57	7.06
1972	37.3	52.65	52.65	52.65	52.65	42.85
1973	27.12	34.82	34.82	34.82	34.82	31.63
1974	28.03	34.64	34.64	34.64	34.64	32.67
1975	16.72	15.12	15.12	15.12	15.12	13.52
1976	12.56	19.46	19.46	19.46	19.46	9.26
1977	16.31	7.76	7.76	7.76	7.76	12.86
1978	14.6	12.47	12.47	12.47	12.47	11.25
1979	12.15	9.58	9.58	9.58	9.58	8.8
1980	12.78	9.42	9.42	9.42	9.42	9.58
1981	14.58	11.56	11.56	11.56	11.56	11.25
1982	19.11	19.89	19.89	19.89	19.89	18.24
1983	21.21	24.98	24.98	24.98	24.98	24.03
1984	21.39	25.28	25.28	25.28	25.28	24.36
1985	11.92	10.06	10.06	10.06	10.06	8.65
1986	20.14	27.57	27.57	27.57	27.57	20.78
1987	11.4	8.2	8.2	8.2	8.2	8.2
1988	23.08	27.35	27.35	27.35	27.35	27.35
1989	13	9.74	9.74	9.74	9.74	9.74
1990	23.11	27.35	27.35	27.35	27.35	27.35
1991	19.21	18.63	18.63	18.63	18.63	18.63
1992	16.89	13.76	13.76	13.76	13.76	13.76
1993	22.38	26.39	26.39	26.39	26.39	26.39
1994	15.45	11.97	11.97	11.97	11.97	11.97
1995	13.41	10.23	10.23	10.23	10.23	10.23
1996	7.35	4.6	4.6	4.6	4.6	4.6
1997	6.87	4.17	4.17	4.17	4.17	4.17
Average	**17.4**	**22.1**	**20.1**	**21.3**	**19.3**	**16.7**

* Data Set #2 uses the same data as Data Set #1 however incorporates 17 additional years of data as mentioned in Section 8.2.1.

** Data Set #4 uses the same data as Data Set #3 however incorporates 17 additional years of data as mentioned in Section 8.2.1.

Digitally Record Flows

1. Entire Period of Record (EPR);
2. EPR with data from 1998 incorporated using Bayesian methods (see Section 8.2.1).

Reference 6 **Levels Converted with TUFLOW Rating**

3. EPR with missing years 1958 and 1987 - 1997 completed using the Digital Record;
4. EPR with missing years 1958 and 1987 - 1997 completed using the Digital Record with data from 1998 incorporated using Bayesian methods (see Section 8.2.1);
5. As 4. but with 1961 event stage replaced by digital record stage;
6. As 4. but with 1964 event stage replaced by digital record stage;
7. As 4. but with 1961 and 1964 events stage replaced by digital record stage.

Digital Record Stage

8. Digital record stage converted to flow using TUFLOW rating with additional data from 1998 incorporated using Bayesian methods (see Section 8.2.1).

8.2.1. Inclusion of Incomplete Data from 1998 to 2014

As mentioned in Section 2.10.1, the Elva Street gauge's digital records after November 1997 are incomplete. Accordingly data from this period cannot be used as part of an annual series for FFA purposes. However, use of Bayesian methods (an interpretation of the concept of probablity) method now allow historic events of unknown magnitude to be included into the FFA. Essentially, Bayesian methods allow events to be added above and below a threshold value for use in the analysis.

Anecdotal evidence suggests that there have been no significant flood events in the period of 1998 to 2014. As the exact magnitude of these events is unknown, an assumption has been made as to the likely maximum flow achieved in at least one of these events. This has been determined to be the average of the digital data set flows for each data set (see the last row of Table 27) which varies depending on the data set being analysed. Using Bayesian methods, data from the period of 1998 to 2014 (17 years of additional data), have been incorporated into the FFA by assuming that they have not exceeded this threshold value.

8.2.2. Adopted Data Set

FFA of the eight data sets presented in Table 27 has been performed with the results presented in Appendix B. Further examination of the data sets was undertaken to determine which provides the most reasonable representation of annual maximum flows for FFA. This analysis is presented below.

Data Sets #1 and #3

With new computational technology and Bayesian statistical methods it seems appropriate that the incomplete data from 1998 to 2014 (see Section 8.2.1) be incorporated into the FFA. Accordingly, Data Sets #1 and #3 have been discounted from further consideration as Data Sets #2 and #4 use the same annual series but incorporate this additional data.

It is interesting to compare design flow results from Data Set #1 to the Reference 2 FFA results as FFA has been performed on the same data set and should therefore produce similar results. Table 28 presents this flow comparison and shows that as expected the results are similar. Minor differences in the larger design flows are due to differences in the applied statistical distribution fitting method.

Table 28: Comparison of Reference 2 and Data Set #1 FFA Design Flows

AEP (%)	Reference 2 Design Flows (m^3/s)	Data Set #1 Design Flows (m^3/s)
20	23.8	24.0
10	29.3	29.7
5	34.6	35.2
2	41.7	42.6
1	47.2	48.2

Data Set #2

Due to the uncertainties associated with the digital record rating curve described in Section 3.3.2, the TUFLOW model rating is preferred for converting levels to flows. As Data Set #2 uses the digital record rating curve this data set has been discounted.

Data Sets #4, #5 and #6

As presented in Table 11, a number of events used debris marks to estimate peak flood level. In particular, the 1961 and 1964 events. Reference 6 levels were obtained from flood marks as no digital gauge data was available. Peak flood marks obtained from reported debris are considered less reliable than those recorded by the gauge. To test the veracity of the magnitude of the 1961 and 1964 events, daily and pluviometer rainfall data for these events were examined for proximate gauges. It should be noted that at the time of these events rainfall data and particularly sub-daily rainfall data (pluviometer) was sparse.

This analysis could not confirm the estimated magnitude of these events as the estimated rainfall AEP was generally much less than the estimated flow AEP for these events. This led to the 1961 and 1964 events being discounted for FFA purposes. The 1959 event peak flood level was also estimated from debris however the reported Reference 2 and Reference 6 peak gauge heights are effectively the same giving credit to the true magnitude of this event.

In light of these findings, Data Sets #4, #5 and #6 have been excluded from the design flow estimates.

Data Set #7 and #8

FFA results of Data Sets #7 and #8 were analysed to determine which of these two data sets should be used to produce design flows. Two variables were examined, namely, the goodness of fit of the:

- Annual series data to the distribution; and
- TUFLOW model design flows to the distribution.

Appendix B, Figures B7 and B8 presents the annual series, distributions and TUFLOW model design flows for both Data Sets. For both examined variables, Data Set #8 displayed better correlation than Data Set #7 and was thus selected in preference.

8.3. Probability Distribution

AR&R (Reference 4) recommends that FFA should be applied to peak flows rather than heights. In frequency analysis of flows, the fitting of a particular distribution may be carried out analytically or by fitting a probability distribution. The data may consist of an annual series, where the largest peak in each year is used, or a partial series, where all flows above a selected base value are used. The relative merits of each method are discussed in detail in AR&R. In general, an annual series is preferable as there are more methods and experience available.

Many probability distributions have been applied to FFA and this is a very active field of research. However, it is not possible to determine the "correct" form of the distribution as there is no robust evidence that any particular distribution is more appropriate than another. AR&R provides further discussion on this issue.

Since publication of AR&R (Reference 4) in 1987 there have been significant developments in the field of FFA both in Australia and overseas. The approach adopted in this study reflects these developments. Recent research has suggested that the fitting method is as important as the adopted distribution. The traditional fitting method has generally been based on moments and this makes the fit very sensitive to the highest and lowest values. Recent research has shown that L-moment and Bayesian likelihood approaches are much more robust than traditional moment fitting and are now the recommended methods.

For this analysis a Bayesian maximum likelihood approach has been adopted in preference to L-moments because the method readily lends itself to include limited information about events outside the continuous period of record. The Flike flood frequency analysis software developed by Kuczera (Reference 10) uses the Bayesian approach and was utilised in this study.

The rating curve (height-discharge relationship) adopted for the estimation of streamflows from the recorded gauge heights is critical to the success of FFA. The FFA was conducted using the rating curve derived from the calibrated hydraulic model (refer subsequent sections) as well as that obtained from the digital records (see Section 3.3.2).

Two probability distributions were tested, Log Pearson III (LP3) and Generalised Extreme Value (GEV) distributions and it was found that the LP3 distribution produced a better curve fit to the data.

8.4. Design Flow Results

The results of the FFA are provided in Table 29 and shown on Figure 21 for the LP3 distribution. The choice of distribution was found to have some influence on design flow estimates. It was found that the LP3 distribution fit the annual series data better than the GEV distribution and was therefore selected in preference for determining design flows.

Table 29: Flood Frequency Analysis – Powells Creek Elva Street gauge

Design Flood Event	Peak Flow FFA (m^3/s)	
	LP3 Distribution	GEV Distribution
0.5 (1 in 2 year) EY	11.4	11.6
0.2 (1 in 5 year) EY	20.9	20.5
10% (1 in 10 year) AEP	28.5	28.1
5% (1 in 20 year) AEP	36.9	37.1
2% (1 in 50 year) AEP	49.1	51.7
1% (1 in 100 year) AEP	59.5	65.4

8.5. Reconciling Flood Frequency and Rainfall Runoff Results

When compared to FFA design flow estimates those from TUFLOW (Figure 21) overestimate flows for more frequent events and underestimate flow in the 2% AEP event or greater.

There are many explanations as to why the flood frequency and rainfall runoff modelling do not reconcile. These are primarily due to data limitations as well as the adequacy of the hydrologic model in representing the runoff routing behaviour of the catchment. Some of the main limitations of the FFA are the limited period of record as well as rating curve errors. Due to the nature of the rating curve, high flow estimates at the Elva Street gauge are very sensitive to small changes in the water level.

In addition to potential uncertainty of the analysis it is important to realise that the flood frequency relationship may not be representative of the greater Powells Creek catchment given that the Elva Street catchment only covers a proportion of the catchment.

As FFA estimates become more uncertain for less frequent flooding such as the 1% AEP which is generally adopted for development control purposes, flow estimates from TUFLOW modelling were adopted for the current study.

9. SENSITIVITY ANALYSIS

9.1. Overview

The following sensitivity analyses were undertaken to establish the variation in design flood levels and flow that may occur if different parameter assumptions were made:

- Manning's "n": The hydraulic roughness values were increased and decreased by 20%;
- Blockage (pipes): Sensitivity to blockage of all pipes was assessed for 20% and 50% blockage;
- Climate change (rainfall increase): Sensitivity to rainfall/runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30% as recommended under current guidelines;
- Climate change (sea level rise): Sea level rise scenarios (elevated levels in the Parramatta River) of 0.4 m and 0.9 m were assessed.

These sensitivity scenarios were undertaken for the 1% AEP rainfall event with a tailwater level of 1 mAHD in the Parramatta River.

9.2. Climate Change Background

Intensive scientific investigation is ongoing to estimate the effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) are having on the average earth surface temperature. Changes to surface and atmospheric temperatures may affect climate and sea levels. The extent of any permanent climatic or sea level change can only be established with certainty through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change, evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing greenhouse gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase;
- global sea level has risen about 0.1 m to 0.25 m in the past century;
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

9.2.1. Rainfall Increase

The BoM has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however, this information is not of sufficient accuracy for use as yet (Reference 11).

Any increase in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation index. Although mean daily rainfall intensity is not observed to differ significantly between Indian Pacific Oscillation phases, runoff is significantly reduced during periods with fewer rain days.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the Powells Creek catchment under warmer climate scenarios.

In light of this uncertainty, the NSW State Government (Reference 11) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

9.2.2. Sea Level Rise

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009 (Reference 12). This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (Reference 13) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments* (Reference 14).

The Policy Statement says:

> *"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… However, the 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible"* (Reference 13).

In light of this uncertainty, the NSW State Government's advice is subject to periodical review. As of October 2012 the NSW State Government withdrew endorsement of sea level rise predictions but still require sea level rise to be considered. This was taken as a 0.4 m rise by the year 2050 and a 0.9 m rise by the year 2100.

9.3. Results

The sensitivity scenario results were compared to the 1% AEP rainfall event and a summary of peak flood level and peak flow differences at various locations are provided in the sections below.

Comparison of peak flood levels have been highlighted such that yellow highlighting indicates that the magnitude of the change is greater than 0.1 m, while red highlighting indicates changes greater than 0.3 m in magnitude.

9.3.1. Roughness Variations

Overall peak flood level results were shown to be relatively insensitive to variations in the roughness parameter. Generally, these results were found to be within ± 0.1 m.

Table 30: Results of Roughness Variation – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Decrease roughness by 20%	Increase roughness by 20%
H01	Open Channel Upstream of Underwood Road	1.16	-0.11	0.07
H02	Park Road	0.15	0.01	0.01
H03	Parramatta Road	0.74	0.04	-0.07
H04	The Crescent	0.24	0.02	0.11
H05	Allan Davidson	0.07	0.05	0.07
H06	Arthur Street	0.06	0.01	0.02
H07	Open Channel Upstream of Pomeroy Street	1.35	-0.05	0.04
H08	Beresford Road	0.05	-0.01	0.02
H09	Pilgrim Avenue	0.17	-0.02	0.02
H10	Brunswick Avenue	0.46	-0.02	0.03
H11	Redmyre Road	0.02	0.03	-0.02
H12	Torrington Road	0.02	0.00	0.00
H13	Morwick Street	0.19	0.00	0.01
H14	Russell Street	0.11	0.01	-0.01
H15	Wentworth Road	0.49	0.00	0.00
H16	Norwood Street	0.10	-0.01	0.00
H17	Woodside Avenue	0.03	0.01	-0.01
H18	Nicholson Street	0.06	-0.02	0.00
H19	Belgrave Street	0.19	0.00	0.00
H20	Minna Street	0.19	0.00	0.00

Table 31: Results of Roughness Variation – Change in Flow

ID	Location	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
			Decrease roughness by 20%	Increase roughness by 20%
Q01	Underwood Road	50.84	1.32	-5.02
Q02	Park Road	40.26	1.32	-3.93
Q03	Parramatta Road	53.51	1.81	-0.82
Q04	The Crescent	27.66	0.66	-2.02
Q05	Allan Davidson	26.57	0.98	-0.08
Q06	Arthur Street	9.93	0.53	-0.37
Q07	Pomeroy Street	84.32	-1.12	-2.14
Q08	Beresford Road	7.52	0.81	-0.46
Q09	Pilgrim Avenue	29.62	1.13	-1.03
Q10	Brunswick Avenue	14.54	0.56	-0.03
Q11	Redmyre Road	16.29	1.15	-0.82
Q12	Torrington Road	0.39	0.09	0.00
Q13	Morwick Street	18.82	1.41	-0.62
Q14	Russell Street	17.29	1.11	-0.30
Q15	Wentworth Road	17.41	1.01	-0.74
Q16	Norwood Street	17.14	0.90	-0.56
Q17	Woodside Avenue	11.44	0.85	-0.39
Q18	Nicholson Street	7.38	0.11	-0.24
Q19	Belgrave Street	8.30	0.39	-0.31
Q20	Minna Street	7.43	0.33	-0.48

9.3.2. Blockage Variations

Peak flood level results were found to be relatively insensitive to blockage of pipes; although generally peak flood levels increased in the upstream areas and decreased in the downstream areas (due to the retarding effect in the upstream areas). The two locations where peak flood level increases were recorded were Redmyre Road and Woodside Avenue.

Woodside Avenue is located at the confluence of two flow paths from the south-east and south-west; with both inflows and outflows serviced by SWC major drainage lines. The buildings crossing the overland flow path downstream of the roadway constrict the overland flow path exiting Woodside Avenue, resulting in accumulation of flood waters and increased flood levels. The flow accumulation that occurred at Woodside Avenue resulted in less pronounced increased peak flood levels at downstream locations such as Norwood Street and Wentworth Road.

Redmyre Road is highly dependent on the pipe network as the buildings downstream (Strathfield Plaza and other commercial premises) are highly constrictive to overland flow. The location is subject to a complex collection of pipes operated by SWC, Burwood Council and Strathfield Municipal Council. With a large collection of pipes, the Redmyre Road location was more sensitive to blockage of the pipe network.

Table 32: Results of Blockage Variation – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Pipe Blockage of 20%	Pipe Blockage of 50%
H01	Open Channel Upstream of Underwood Road	1.16	-0.02	-0.05
H02	Park Road	0.15	0.01	0.01
H03	Parramatta Road	0.74	-0.01	-0.02
H04	The Crescent	0.24	-0.02	-0.06
H05	Allan Davidson	0.07	-0.01	-0.03
H06	Arthur Street	0.06	0.01	0.04
H07	Open Channel Upstream of Pomeroy Street	1.35	-0.02	-0.05
H08	Beresford Road	0.05	0.01	0.03
H09	Pilgrim Avenue	0.17	0.01	0.03
H10	Brunswick Avenue	0.46	0.02	0.03
H11	Redmyre Road	0.02	0.06	0.17
H12	Torrington Road	0.02	0.00	0.00
H13	Morwick Street	0.19	0.02	0.06
H14	Russell Street	0.11	0.02	0.08
H15	Wentworth Road	0.49	0.01	0.05
H16	Norwood Street	0.10	-0.01	0.00
H17	Woodside Avenue	0.03	0.05	0.13
H18	Nicholson Street	0.06	0.03	0.09
H19	Belgrave Street	0.19	0.03	0.07
H20	Minna Street	0.19	0.02	0.05

Table 33: Results of Blockage Variation – Change in Flow

ID	Location	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
			Pipe Blockage of 20%	Pipe Blockage of 50%
Q01	Underwood Road	50.84	-0.47	-0.76
Q02	Park Road	40.26	0.13	-0.34
Q03	Parramatta Road	53.51	-1.16	-3.99
Q04	The Crescent	27.66	0.00	-0.69
Q05	Allan Davidson	26.57	0.22	0.95
Q06	Arthur Street	9.93	0.27	0.78
Q07	Pomeroy Street	84.32	-2.17	-6.63
Q08	Beresford Road	7.52	0.36	1.01
Q09	Pilgrim Avenue	29.62	2.57	4.89
Q10	Brunswick Avenue	14.54	0.55	1.13
Q11	Redmyre Road	16.29	1.51	4.10
Q12	Torrington Road	0.39	0.00	0.00
Q13	Morwick Street	18.82	1.10	3.54
Q14	Russell Street	17.29	0.99	5.29
Q15	Wentworth Road	17.41	0.69	2.97
Q16	Norwood Street	17.14	0.56	2.20
Q17	Woodside Avenue	11.44	1.43	3.86
Q18	Nicholson Street	7.38	1.11	2.36
Q19	Belgrave Street	8.30	0.35	0.97
Q20	Minna Street	7.43	0.42	0.87

9.3.3. Sea Level Rise Variations

The sea level rise scenarios were found to have an insignificant effect on peak flood levels, except in the most downstream reaches of the catchment. The open channel upstream of Underwood Road and Pomeroy Street had channel inverts of 0.35 m AHD and 0.45 m AHD (respectively) and were therefore tidally affected under current tidal conditions. Under sea level rise conditions, these locations were found to have increased peak flood levels; although the increase in peak flood level was found to be diffused, such that a 0.9 m increase in sea levels resulted in a lesser flood level increase of 0.25 m. The attenuation of sea level rise impacts was found to be the result of the retarding effect of the downstream mangroves and the restrictive effect of bridge structures crossing the open channel.

Table 34: Results of Sea Level Rise – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Tailwater increase to 1.4 m AHD	Tailwater increase to 1.9 m AHD
H01	Open Channel Upstream of Underwood Road	1.16	0.08	0.25
H02	Park Road	0.15	0.00	0.00
H03	Parramatta Road	0.74	0.00	0.00
H04	The Crescent	0.24	0.00	0.00
H05	Allan Davidson	0.07	0.00	0.00
H06	Arthur Street	0.06	0.00	0.00
H07	Open Channel Upstream of Pomeroy Street	1.35	0.03	0.10
H08	Beresford Road	0.05	0.00	0.00
H09	Pilgrim Avenue	0.17	0.00	0.00
H10	Brunswick Avenue	0.46	0.00	0.00
H11	Redmyre Road	0.02	0.00	0.00
H12	Torrington Road	0.02	0.00	0.00
H13	Morwick Street	0.19	0.00	0.00
H14	Russell Street	0.11	0.00	0.00
H15	Wentworth Road	0.49	0.00	0.00
H16	Norwood Street	0.10	0.00	0.00
H17	Woodside Avenue	0.03	0.00	0.00
H18	Nicholson Street	0.06	0.00	0.00
H19	Belgrave Street	0.19	0.00	0.00
H20	Minna Street	0.19	0.00	0.00

Table 35: Results of Sea Level Rise – Change in Flow

ID	Location	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
			Tailwater increase to 1.4 m AHD	Tailwater increase to 1.9 m AHD
Q01	Underwood Road	50.84	-0.44	-0.98
Q02	Park Road	40.26	-0.04	0.22
Q03	Parramatta Road	53.51	0.09	0.11
Q04	The Crescent	27.66	0.10	0.00
Q05	Allan Davidson	26.57	0.00	0.00
Q06	Arthur Street	9.93	0.00	0.00
Q07	Pomeroy Street	84.32	0.54	0.90
Q08	Beresford Road	7.52	0.00	0.00
Q09	Pilgrim Avenue	29.62	0.04	0.04
Q10	Brunswick Avenue	14.54	0.00	0.08
Q11	Redmyre Road	16.29	0.09	0.10
Q12	Torrington Road	0.39	0.00	0.00
Q13	Morwick Street	18.82	0.09	0.08
Q14	Russell Street	17.29	0.08	0.04
Q15	Wentworth Road	17.41	0.07	0.11
Q16	Norwood Street	17.14	0.08	0.12
Q17	Woodside Avenue	11.44	0.16	0.18
Q18	Nicholson Street	7.38	0.00	0.00
Q19	Belgrave Street	8.30	0.00	0.00
Q20	Minna Street	7.43	-0.06	-0.06

9.3.4. Rainfall Variations

The effect of increasing the design rainfalls by 10%, 20% and 30% have been evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the study area (shown in Table 36). Generally speaking, each incremental 10% increase in rainfall results in an approximately 0.05 m increase in peak flood levels at most of the locations analysed. The 1% AEP event with a rainfall increase of 30% is approximately equivalent to a 0.2% AEP event in present day rainfall conditions and a significant impact on flood levels is not unexpected.

Table 36: Results of Rainfall Increase – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)		
			Increase in rainfall by 10%	Increase in rainfall by 20%	Increase in rainfall by 30%
H01	Open Channel Upstream of Underwood Road	1.16	0.08	0.16	0.23
H02	Park Road	0.15	0.02	0.04	0.07
H03	Parramatta Road	0.74	0.06	0.12	0.20
H04	The Crescent	0.24	0.09	0.23	0.37
H05	Allan Davidson	0.07	0.02	0.10	0.14
H06	Arthur Street	0.06	-0.01	0.01	0.05
H07	Open Channel Upstream of Pomeroy Street	1.35	0.06	0.14	0.21
H08	Beresford Road	0.05	0.00	0.03	0.06
H09	Pilgrim Avenue	0.17	0.03	0.07	0.11
H10	Brunswick Avenue	0.46	0.03	0.07	0.11
H11	Redmyre Road	0.02	0.11	0.20	0.29
H12	Torrington Road	0.02	0.00	0.00	0.00
H13	Morwick Street	0.19	0.05	0.10	0.14
H14	Russell Street	0.11	0.05	0.10	0.15
H15	Wentworth Road	0.49	0.04	0.08	0.13
H16	Norwood Street	0.10	0.04	0.09	0.14
H17	Woodside Avenue	0.03	0.04	0.09	0.15
H18	Nicholson Street	0.06	0.01	0.06	0.10
H19	Belgrave Street	0.19	0.00	0.04	0.08
H20	Minna Street	0.19	0.01	0.04	0.07

Table 37: Results of Rainfall Increase – Change in Flow

ID	Location	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)		
			Increase in rainfall by 10%	Increase in rainfall by 20%	Increase in rainfall by 30%
Q01	Underwood Road	50.84	1.62	6.46	10.99
Q02	Park Road	40.26	2.43	5.68	8.94
Q03	Parramatta Road	53.51	5.91	13.56	21.50
Q04	The Crescent	27.66	1.19	3.34	5.26
Q05	Allan Davidson	26.57	0.57	5.63	9.78
Q06	Arthur Street	9.93	-0.55	0.89	2.28
Q07	Pomeroy Street	84.32	9.09	19.63	32.70
Q08	Beresford Road	7.52	0.29	1.19	2.39
Q09	Pilgrim Avenue	29.62	5.27	11.11	17.49
Q10	Brunswick Avenue	14.54	1.23	3.44	5.44
Q11	Redmyre Road	16.29	3.26	5.90	9.34
Q12	Torrington Road	0.39	-0.02	0.02	0.06
Q13	Morwick Street	18.82	3.35	6.73	10.50
Q14	Russell Street	17.29	3.03	6.00	10.20
Q15	Wentworth Road	17.41	2.21	4.93	8.08
Q16	Norwood Street	17.14	2.06	4.41	7.76
Q17	Woodside Avenue	11.44	1.43	3.38	6.03
Q18	Nicholson Street	7.38	0.40	2.19	3.78
Q19	Belgrave Street	8.30	0.27	1.26	2.47
Q20	Minna Street	7.43	0.33	1.07	2.14

10. PRELIMINARY FLOOD PLANNING AREAS

10.1. Background

Land use planning is considered to be one of the most effective means of minimising flood risk and damages from flooding. The Flood Planning Area (FPA) identifies land that is subject to flood related development controls via Section 149(2) notifications under the 1979 EP&A Act. The Flood Planning Level (FPL) is the minimum floor level applied to new developments within the FPA.

The process of defining FPA's and FPL's is somewhat complicated by the variability of flow conditions between mainstream and local overland flow, particularly in urban areas. The more traditional approaches typically having been developed for riverine environments and mainstream flow.

Defining the area of flood affectation due to overland flow (which by its nature includes shallow flow) often involves determining at which point it becomes significant enough to classify as "flooding". The difference in peak flood level between events of varying magnitude may be minor in areas of overland flow, such that applying the typical freeboard can result in a FPL greater than the Probable Maximum Flood (PMF) level.

The FPA should include properties where future development would result in impacts on flood behaviour in the surrounding area and areas of high hazard that pose a risk to safety or life. Further to this, the FPL is determined with the purpose to decrease the likelihood of over-floor flooding of buildings and the associated damages.

The Floodplain Development Manual suggests that the FPL generally be based on the 1% AEP event plus an appropriate freeboard. The typical freeboard cited in the manual is that of 0.5 m; however it also recognises that different freeboards may be deemed more appropriate due to local conditions. In these circumstances, some justification is called for where a lower value is adopted.

The FPA is classified as 'provisional' as it is based on results from the current study, and may be re-assessed as part of a floodplain risk management study for the catchment. Such a study would review the area's existing planning policies with respect to floodplain management, and then make recommendations (including adoption of a Flood Planning Area and Flood Planning Level) via a floodplain risk management plan. It may also be that the same assessment for the LGA's other catchments be undertaken so that a single LGA-wide FPA/FPL can be adopted.

10.2. Methodology and Criteria

The methodology used in this report is consistent with that adopted in a number of previous studies. It divides flooding between Mainstream flooding and Overland flooding using the following criteria:

- Mainstream flooding: Any percentage of the cadastral area is affected by mainstream flooding in the 1% AEP event. This has been defined as the peak flood level within the open channel section of Powells Creek plus a 0.5 m freeboard, with the level extended perpendicular to the flow direction.

- Overland flooding: Greater than or equal to 10% of the "active" cadastral area is affected by the 1% AEP peak flood depth of greater than 0.15 m. The "active" cadastral area was considered to be the cadastral area excluding the building area that was modelled as impermeable.

In situations where a cadastral lot is subject to both mainstream flooding and overland flooding, the mechanism that produces the highest Flood Planning Level is given precedence, although both levels have been provided.

Furthermore, a "ground truthing" exercise was undertaken to ensure that the properties identified as subject to flood related development controls were located within a continuous flow path area.

10.3. Results

The provisional FPA is shown in Figure 24. The mainstream flood affectation was limited to the Strathfield LGA (not reported herein); with only overland flood affectation within the Burwood LGA portion of the Powells Creek Catchment.

A total of 212 properties were identified for flood related development controls in Burwood. This results in total averages of 1.6 properties per hectare for the Burwood LGA portion of the Powells Creek Catchment.

Properties that are not identified as part of this process may not be excluded from development controls. It is advisable that new developments (regardless of whether they are identified as flood liable or not) have habitable floor levels a minimum of 300 mm above the surrounding ground level to minimise affectation due to local overland flow.

11. HOTSPOT DISCUSSION

Hotspots in the area are defined as those locations where there is a known flood issue. They are identified by considering accounts of previous floods, and by examining the flood behaviour. The latter involves identifying areas of high hazard flow where flooding of property occurs, where inundation of main roads occurs and through consideration of subsurface drainage capacity. As described in Section 2, the catchment has a history of flooding and is well understood through both the community's experience and the hydraulic model results.

11.1. Minna Street to Norwood Street

From the Minna Street – Bold Street intersection to the Norwood Street – Oxford Street intersection, there is a natural depression that results in flow occurring in a north-westerly direction. This flow often occurs perpendicular to the roadway alignment and through private property. Flood risk arises from over-floor flooding and risk to pedestrians and vehicles on road crossings.

The peak flood depths and levels across this location are shown in Table 38 and Table 39. The 5% AEP and 1% AEP peak flood depths and level contours are shown on Figure C 1 and Figure C 2.

Table 38: Minna Street – Peak Flood Levels (m AHD)

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H16	Norwood Street	17.35	17.47	17.53	17.61	17.66	17.72	17.78	17.85	18.49
H17	Woodside Avenue	19.37	19.43	19.50	19.59	19.65	19.71	19.77	19.85	20.38
H18	Nicholson Street	21.17	21.23	21.25	21.29	21.35	21.40	21.45	21.51	22.05
H19	Belgrave Street	22.35	22.42	22.45	22.50	22.54	22.58	22.61	22.66	23.19
H20	Minna Street	23.49	23.57	23.63	23.68	23.73	23.77	23.80	23.84	24.22

Table 39: Minna Street – Peak Flood Depths (m)

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H16	Norwood Street	0.10	0.23	0.28	0.36	0.42	0.47	0.53	0.61	1.24
H17	Woodside Avenue	0.03	0.09	0.16	0.25	0.31	0.37	0.43	0.51	1.04
H18	Nicholson Street	0.06	0.12	0.14	0.18	0.24	0.29	0.34	0.40	0.94
H19	Belgrave Street	0.19	0.26	0.29	0.34	0.38	0.42	0.45	0.50	1.03
H20	Minna Street	0.19	0.27	0.32	0.38	0.42	0.46	0.50	0.54	0.91

Flooding is likely to be short duration (less than one hour) but occur with little to no warning. This is shown in the flood level hydrographs on Figure C 3.

The majority of the hotspot has low hazard flow, with high hazard limited to the centre of the flow path in the hotspot and likely to occur where flow is forced through gaps between buildings.

The peak flood flows across this location are shown in Table 40.

Table 40: Minna Street – Peak Flows (m^3/s)

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Q16	Norwood Street	3.45	8.21	9.49	11.56	14.09	17.14	20.04	24.19	82.18
Q17	Woodside Avenue	2.21	3.30	4.57	6.91	8.83	11.44	13.58	17.40	64.57
Q18	Nicholson Street	0.43	1.92	2.86	4.19	5.75	7.38	9.10	11.44	39.63
Q19	Belgrave Street	1.42	2.87	4.27	5.53	6.77	8.30	9.47	11.13	34.83
Q20	Minna Street	1.79	3.71	4.32	5.33	6.26	7.43	8.52	9.81	30.02

11.2. Wentworth Road

The intersection of Wentworth Road and Hornsey Street is a topographical low point. The upstream flow path originates from the south-east and has a contributing catchment area of approximately 84 ha.

Located to the west of Wentworth Road, the sporting field for Santa Sabina College is bounded by a ridge along the Wentworth Road and northern boundaries that in some locations is 1.5 m higher than the road elevation. The only two means for flow to enter the sporting field from Wentworth Road is for flooding to backwater up to the south-east corner of the sporting field (where the roadway elevation and sporting field elevation is approximately equal and no ridge is present) or for the ridge to be overtopped. As such, the sporting field is not inundated in events up to and including the 0.2% AEP event, although it is inundated in the PMF event.

In events up to and including the 0.2% AEP event, flow is conveyed downstream to the north-west of Wentworth Road via stormwater pipes and overland between Hornsey Street and Russell Street. The egress overland flow path is constricted by buildings and therefore accumulates and backwaters along Wentworth Road.

The peak flood depths and levels at this location are shown in Table 41. The 5% AEP and 1% AEP peak flood depths and level contours are shown on Figure C 4 and Figure C 5; and the flood level hydrographs are shown on Figure C 6.

Table 41: Wentworth Road – Peak Flood Levels (m AHD) and Depths (m)

ID	Location	Type	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H15	Wentworth Road	Level (mAHD)	16.22	16.43	16.51	16.59	16.65	16.71	16.76	16.82	17.53
		Depth (m)	0.49	0.71	0.79	0.87	0.93	0.99	1.03	1.10	1.81

The peak flood flows at this location are shown in Table 42.

Table 42: Wentworth Road – Peak Flows (m^3/s)

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Q15	Wentworth Road	2.80	6.18	8.47	11.51	14.33	17.41	20.27	24.52	89.37

11.3. Russell Street and Russell Lane

Russell Lane receives flow from Wentworth Road to the south-east and discharges flow onto Russell Street to the north-west. Russell Street is at the confluence of two flow paths; from the south-east via Russell Lane and from the south-west via The Boulevarde.

Russell Lane is in a slight depression comparative to the downstream Russell Street, resulting in accumulation on Russell Lane. The lowest topographical point along Russell Street is between Wentworth Road and The Boulevarde; with ground elevation differences of 2.7 m and 4.1 m respectively. Flow discharging from Russell Street to the north is perpendicular to the roadway alignment and is constricted by the buildings.

The peak flood depths and levels at this location are shown in Table 43. The 5% AEP and 1% AEP peak flood depths and level contours are shown on Figure C 7 and Figure C 8; and the flood level hydrographs are shown on Figure C 9.

Table 43: Russell Street – Peak Flood Levels (m AHD) and Depths (m)

ID	Location	Type	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H14	Russel Street	Level (mAHD)	14.89	15.05	15.13	15.22	15.30	15.37	15.42	15.49	16.26
		Depth (m)	0.11	0.27	0.35	0.45	0.52	0.59	0.64	0.71	1.48

The peak flood flows at this location are shown in Table 44.

Table 44: Russell Street – Peak Flows (m^3/s)

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Q14	Russell Street	1.36	4.98	7.64	10.91	14.00	17.29	20.61	25.52	102.96

11.4. Morwick Street to Lyons Street

Morwick Street receives flow from Russell Street to the south-east and conveys flow through a natural depression towards the intersection of Lyons Street and The Boulevarde. This flow intersects a number of properties within this block, with notable accumulation of flow upstream of contiguous buildings between The Boulevarde and Bells Lane.

The peak flood depths and levels at this location are shown in Table 45. The 5% AEP and 1% AEP peak flood depths and level contours are shown on Figure C 10 and Figure C 11; and the flood level hydrographs are shown on Figure C 12.

Table 45: Morwick Street – Peak Flood Levels (m AHD) and Depths (m)

ID	Location	Type	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H13	Morwick Street	Level (mAHD)	13.53	13.70	13.77	13.86	13.91	13.98	14.03	14.10	15.08
		Depth (m)	0.19	0.36	0.43	0.51	0.57	0.64	0.69	0.76	1.74

The peak flood flows at this location are shown in Table 46.

Table 46: Morwick Street – Peak Flows (m^3/s)

ID	Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Q13	Morwick Street	1.51	5.75	8.23	11.82	14.93	18.82	22.13	27.24	113.79

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7. Bureau of Meteorology
The Estimate of Probable Maximum Precipitation in Australia: Generalised Short Duration Method
June 2003

8. TUFLOW User Manual
Version 2013-12-AE
BMT WBM, 2011

9. Public Works Department
Lower Parramatta River Flood
February 1985

10. Kuczera, G
Bayesian Flood Frequency Analysis Software (Version 4.50)
Department of Civil Surveying Environmental Engineering, University of Newcastle, NSW, 2001

11. NSW Department of Environment and Climate Change
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October 2007

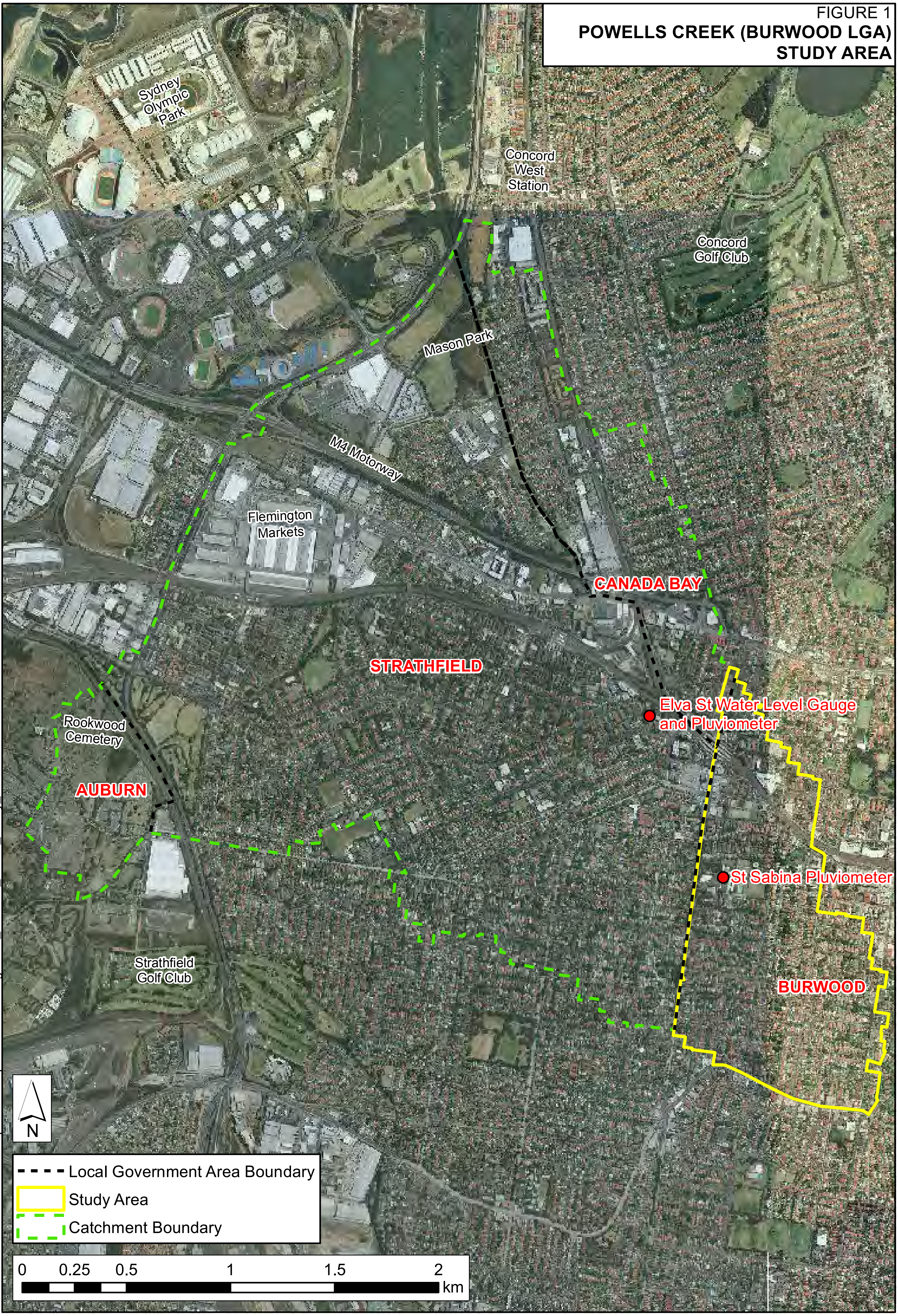
12. **NSW Sea Level Rise Policy Statement**
New South Wales Government, October 2009

13. Department of Environment, Climate Change and Water
Derivation of the NSW Government's Sea Level Rise Planning Benchmarks
October 2009

14. Department of Environment, Climate Change and Water
Flood Risk Management Guide
August 2010

Figures

FIGURE 1
POWELLS CREEK (BURWOOD LGA) STUDY AREA



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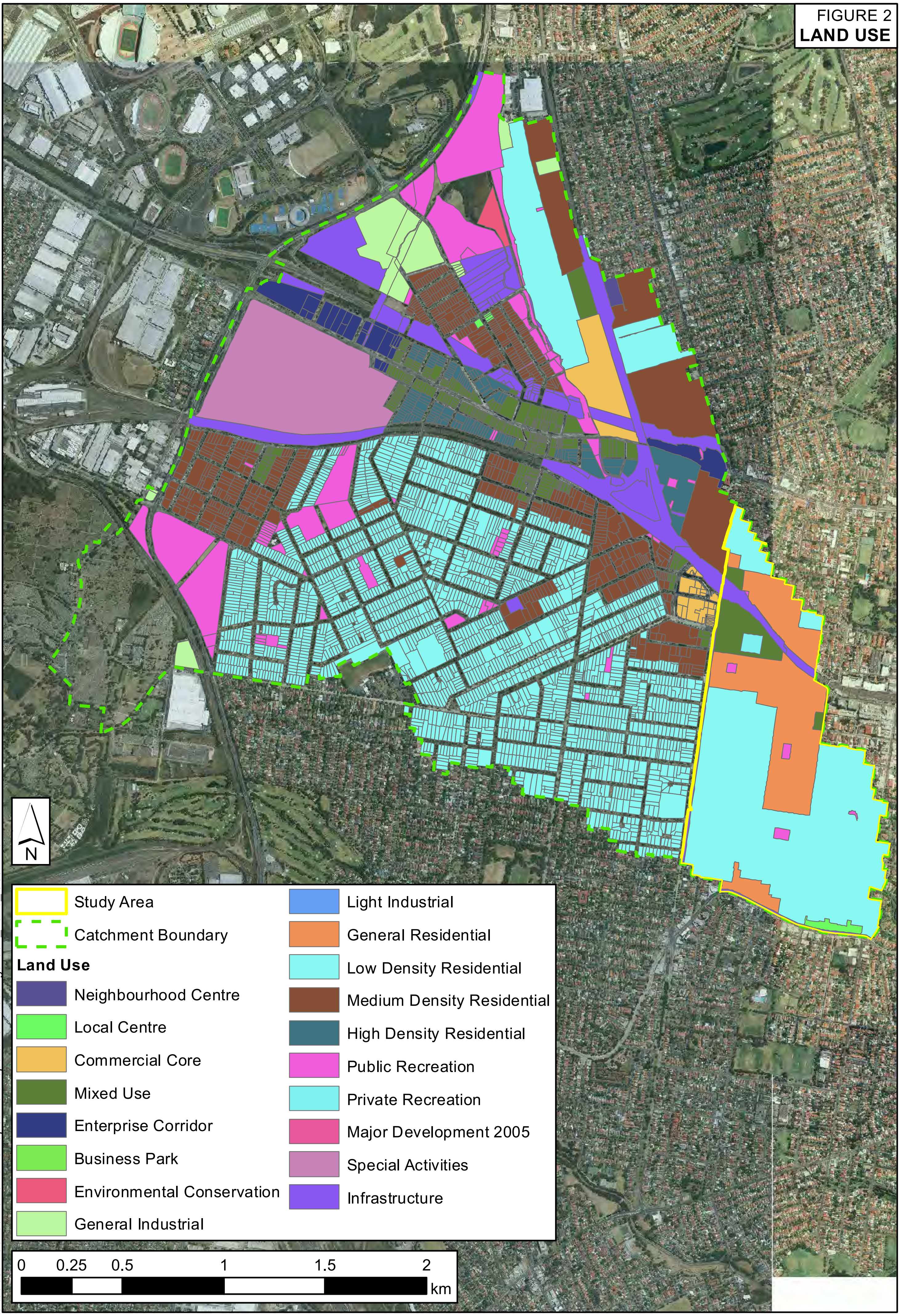
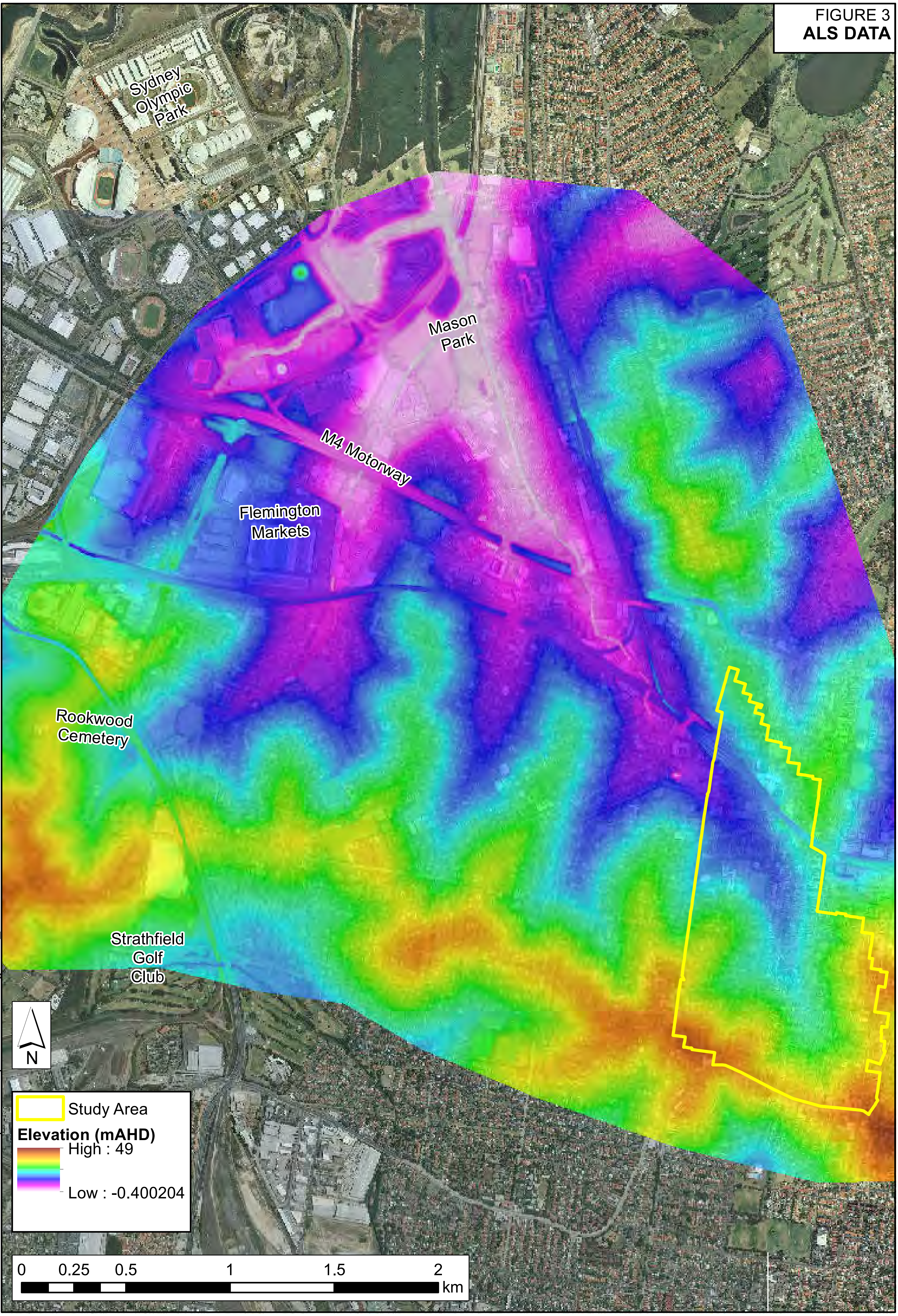


FIGURE 2
LAND USE

J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure02_Land_Use.mxd

FIGURE 3
ALS DATA



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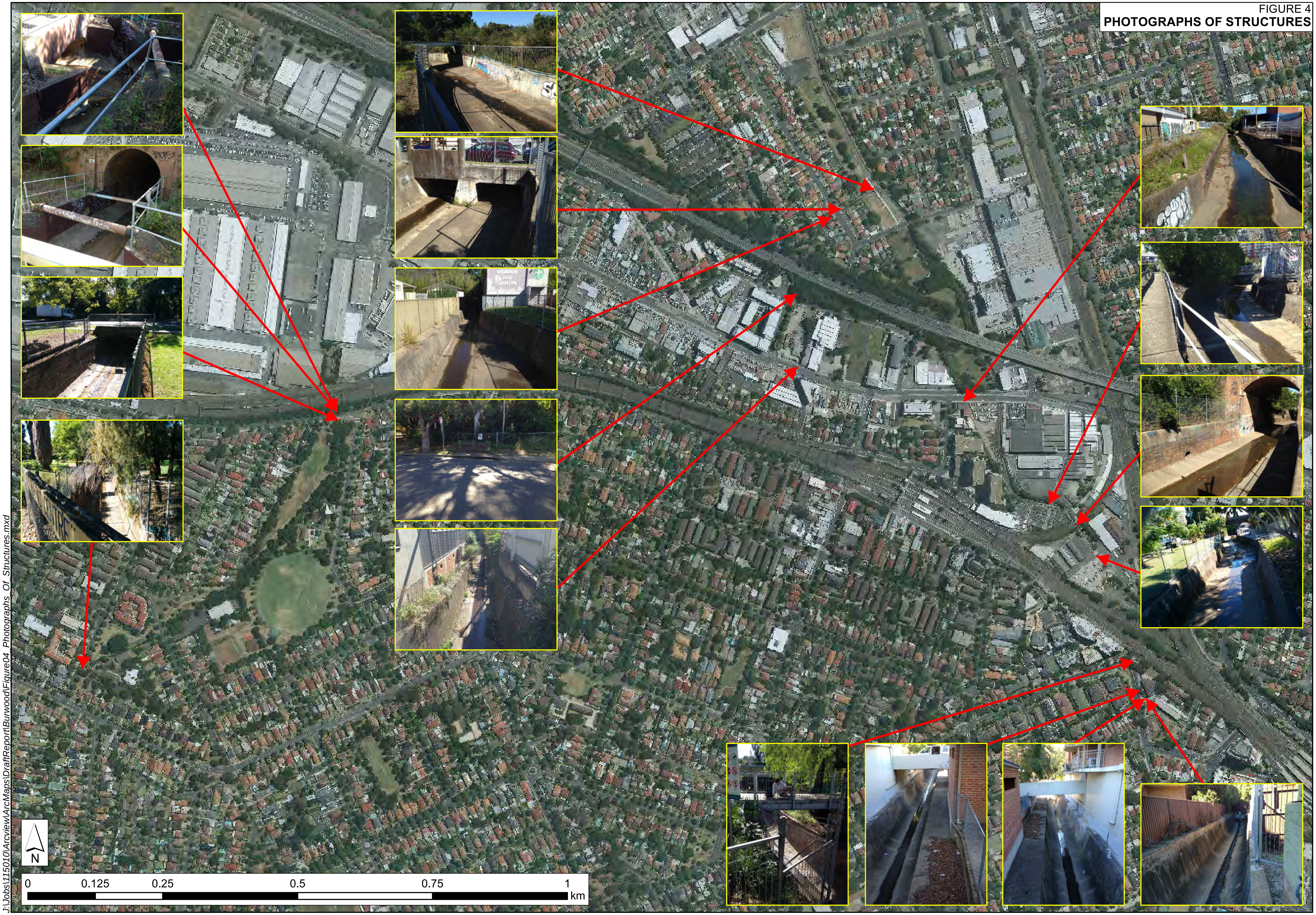


FIGURE 4
PHOTOGRAPHS OF STRUCTURES

FIGURE 5a
HISTORICAL FLOOD PHOTOGRAPHS
SHEET 1


Airey Park 2/01/96


Airey Park 2/01/96


The Crescent opposite Airey Park 2/01/96


19 Shortland Ave 10/02/1990


Airey Park The Crescent 2/01/96


Oxford Road 2/01/96


1 Heyde Ave 2/01/96


Rochester Street eastern side, Mirabooka Ave & Broughton Rd

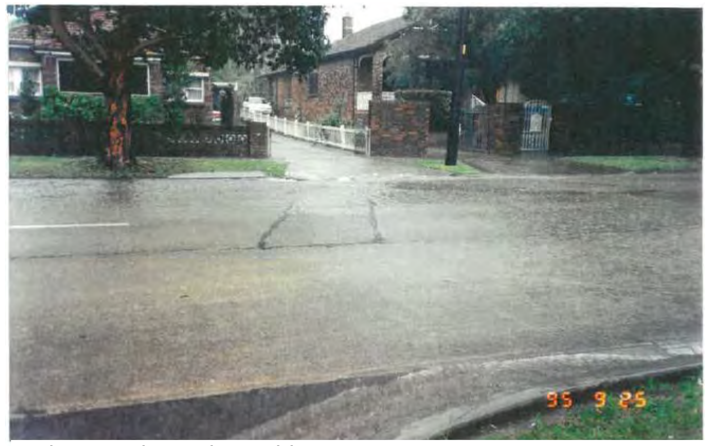

Redmyre Road 2/01/96


62 Beresford Road 10/02/1990


19 Shortland Ave 10/02/1990


Corner of Todman Ave; and Oxford Rd: eastern side

FIGURE 5b
HISTORICAL FLOOD PHOTOGRAPHS
SHEET 2


Barker Road, Southern side


Todman Ave; at Barker Road

Corner of Badgery Ave; and Bates Street


29 Badgery Avenue


Outside 29 Badgery Avenue


139 Albert Road 10.2.90


139 Albert Road 10.2.90


139 Albert Road 10.2.90


139 Albert Road 10.2.90

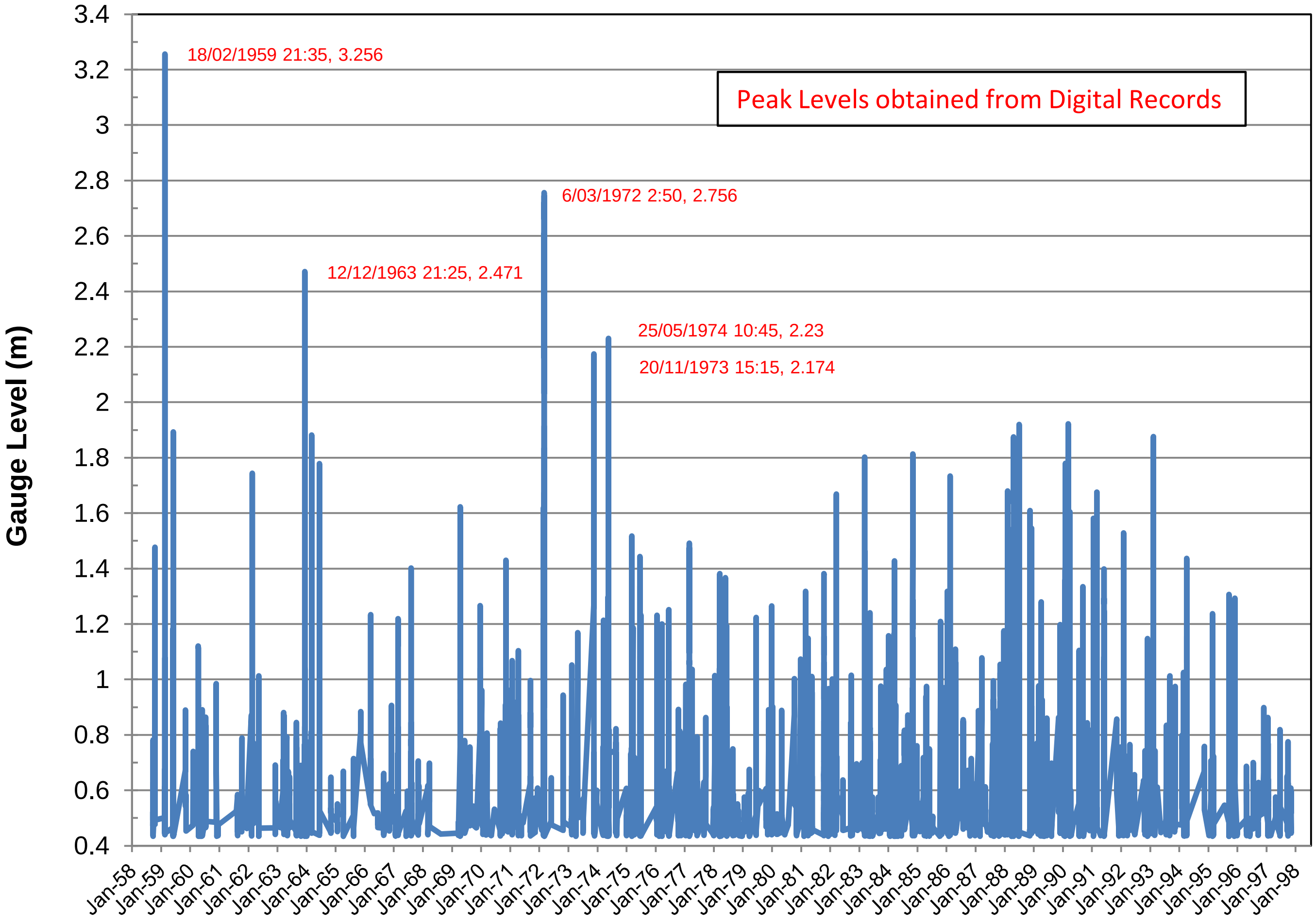

139 Albert Road 10.2.90

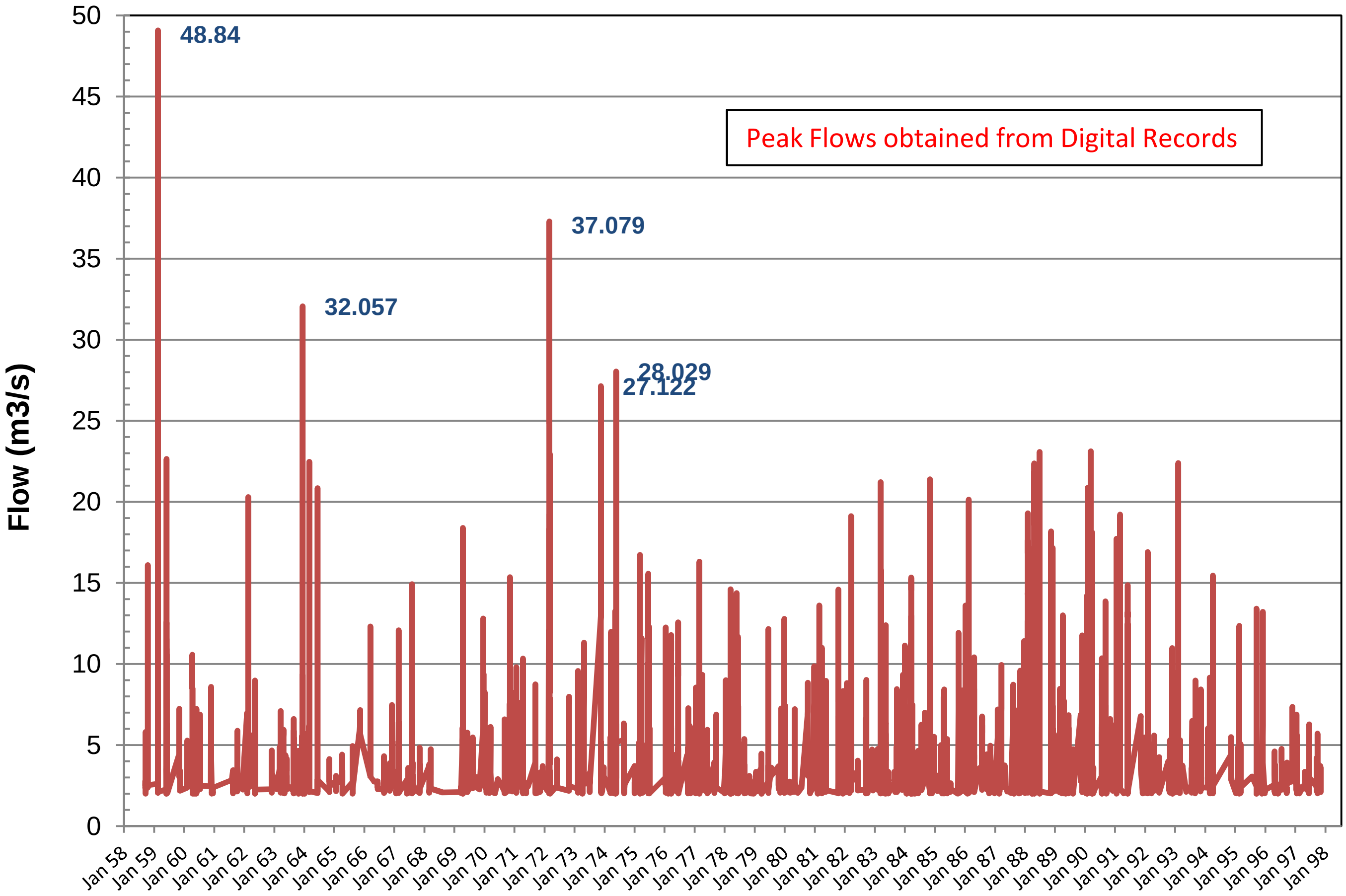

Underwood Road 18/03/1990


Underwood Road 18/03/1990

FIGURE 6

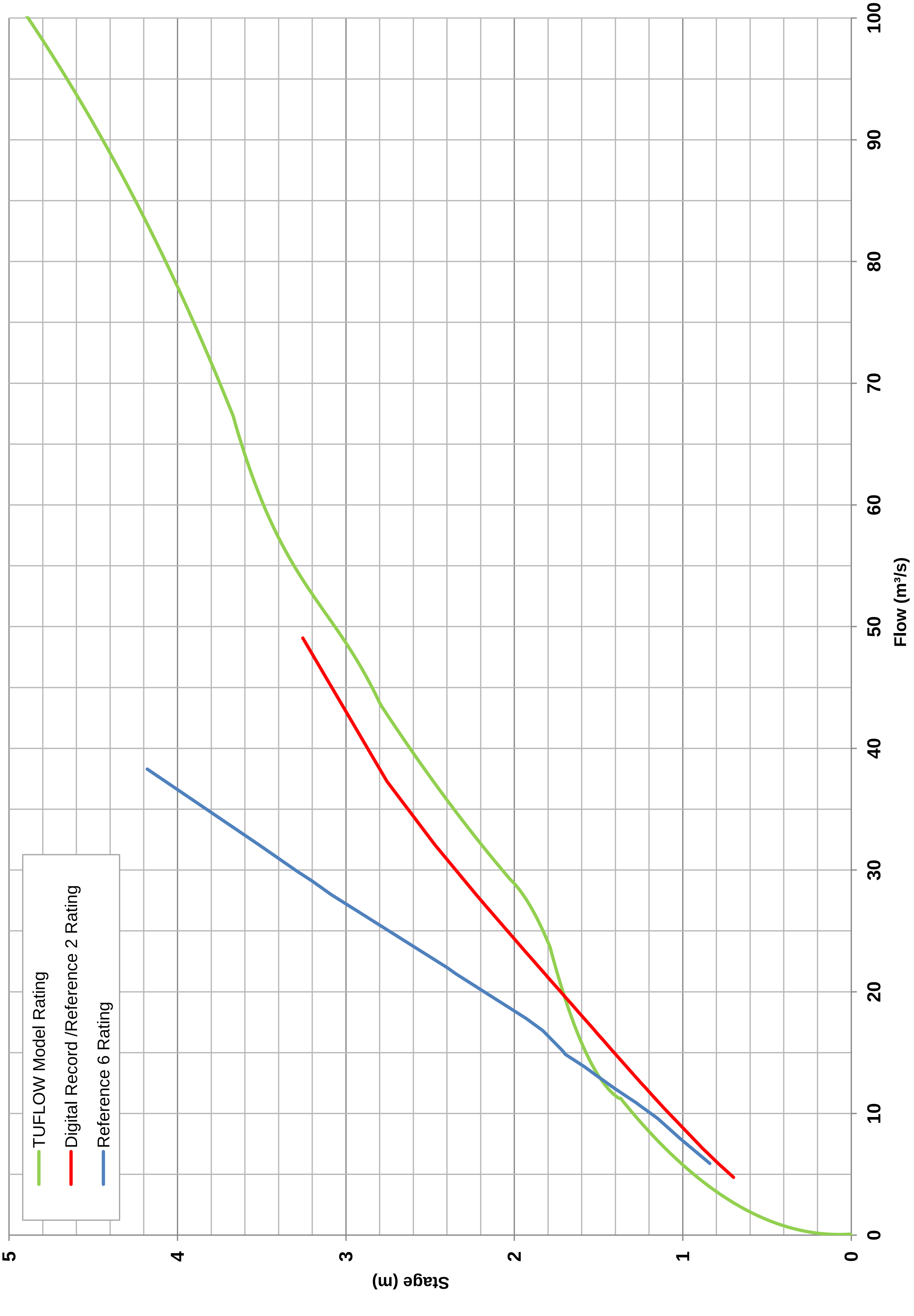
WATER LEVEL GAUGE RECORDS





J:\Jobs\114021\ElvaStGauge\PowellsCkWaterlevel.xlsx

FIGURE 7
RATING CURVES AT ELVA STREET GAUGE

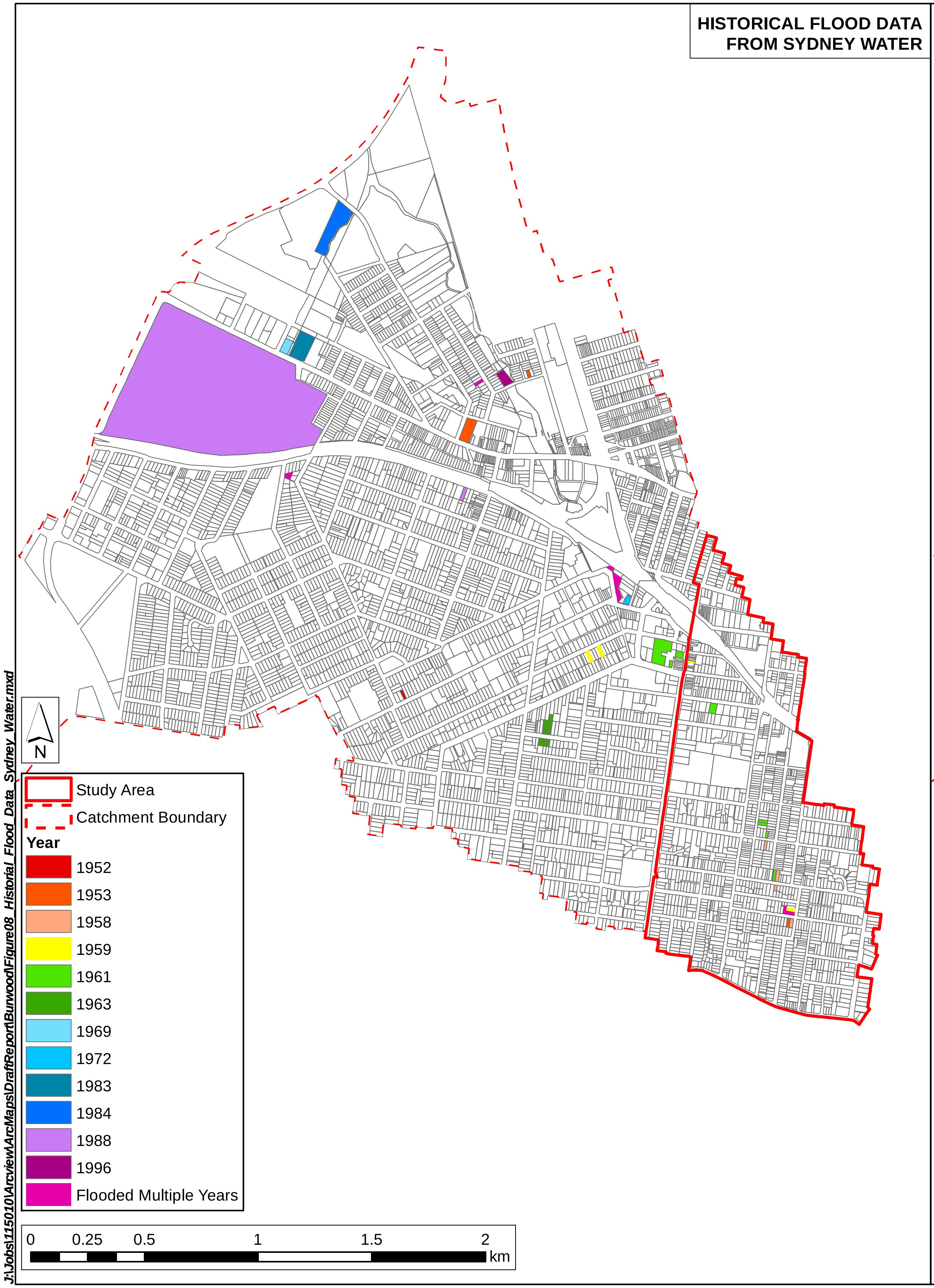


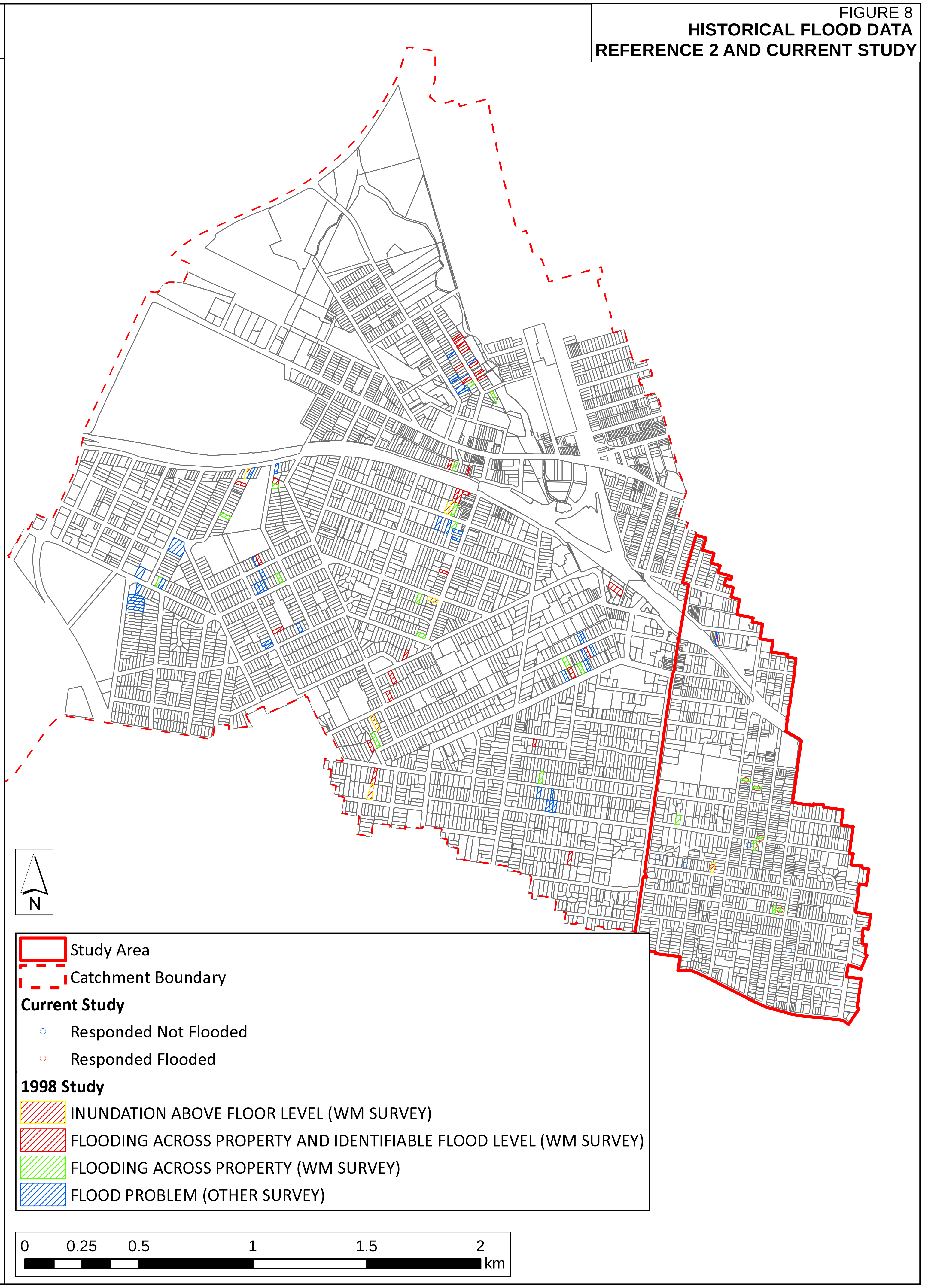
J:\Jobs\114021\TUFLOW\results\Frequency_Analysis\Frequency_Analysis.xlsx

FIGURE 8

HISTORICAL FLOOD DATA REFERENCE 2 AND CURRENT STUDY

HISTORICAL FLOOD DATA FROM SYDNEY WATER

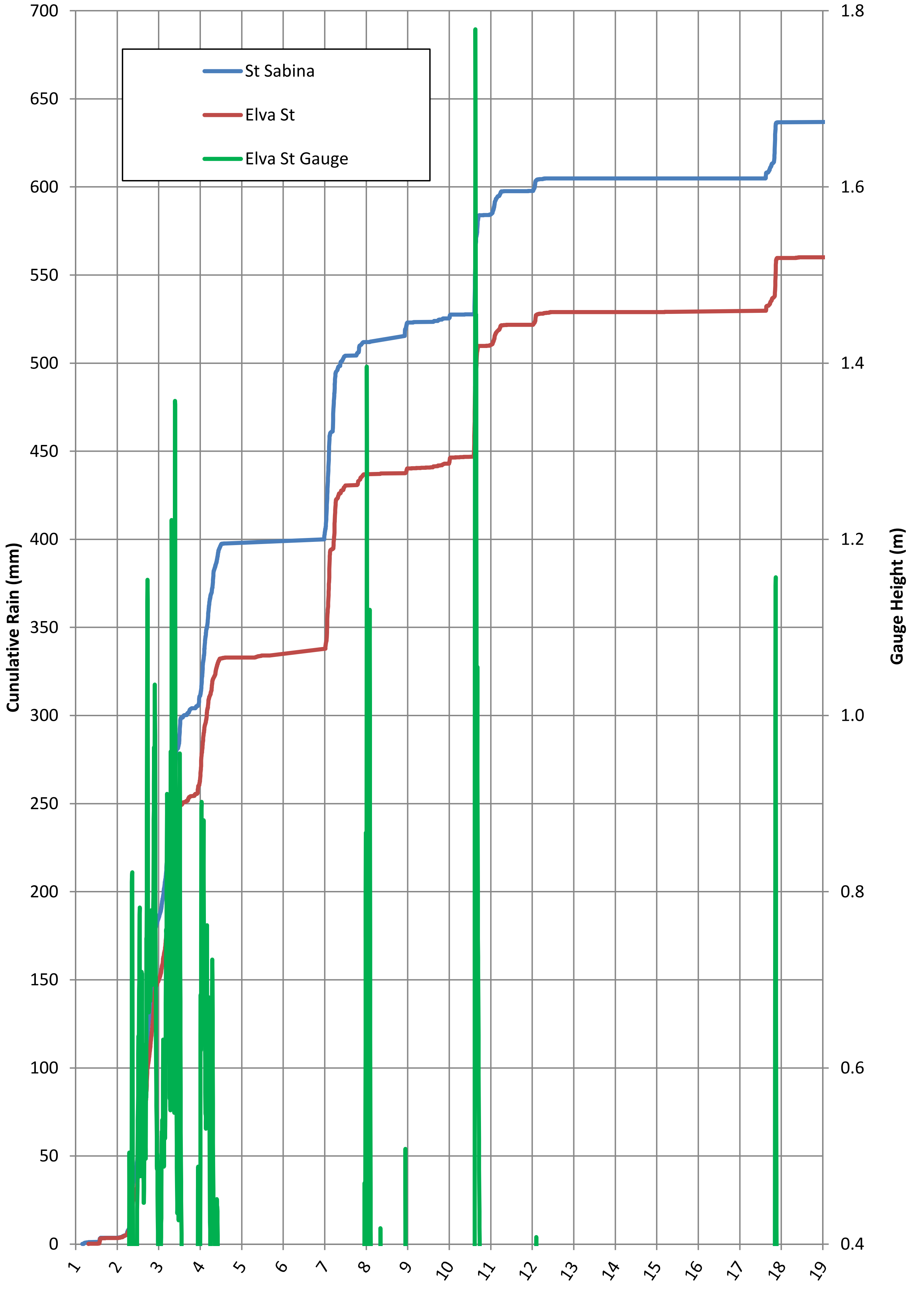




J:\Jobs\115010\Arcview\ArcMaps\DraftReportBurwood\Figure08_Historical_Flood_Data_Sydney_Water.mxd

FIGURE 9a

EVENTS OF FEBRUARY 1990



J:\Jobs\114021\ElvaStGauge\PowellsCkWaterlevel.xlsx

FIGURE 9b

PLUVIOMETER DATA
2-4 FEBRUARY 1990

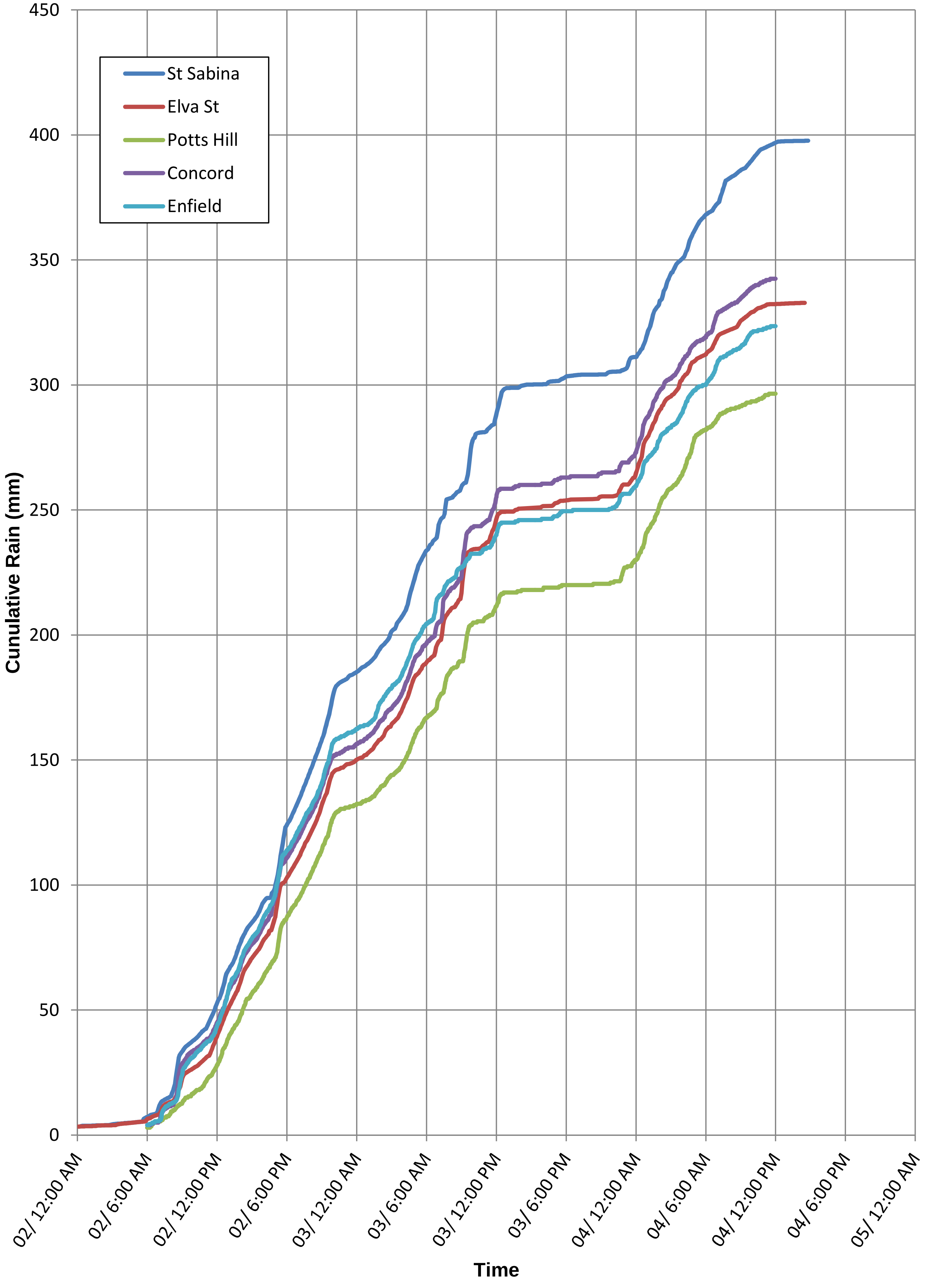
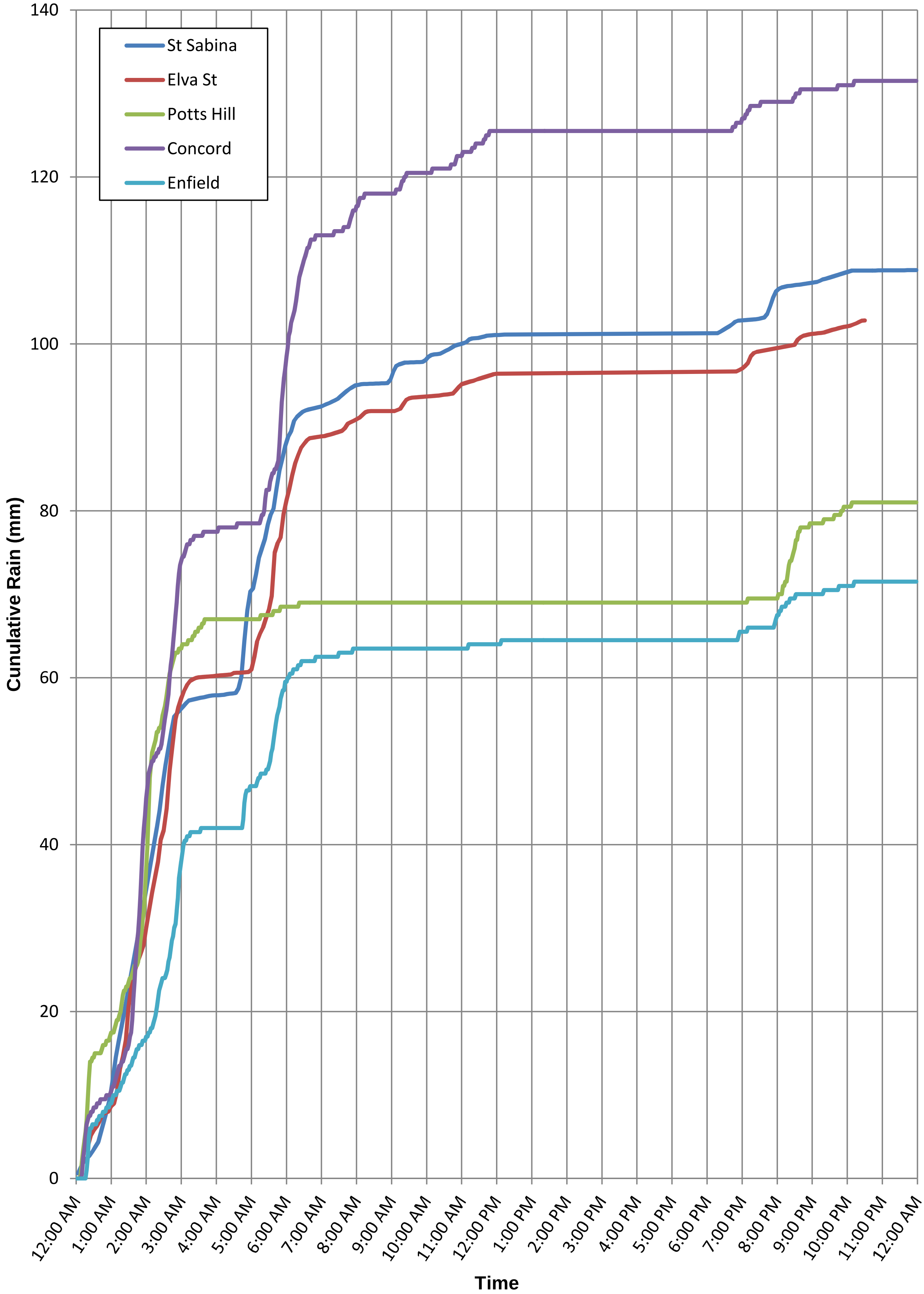
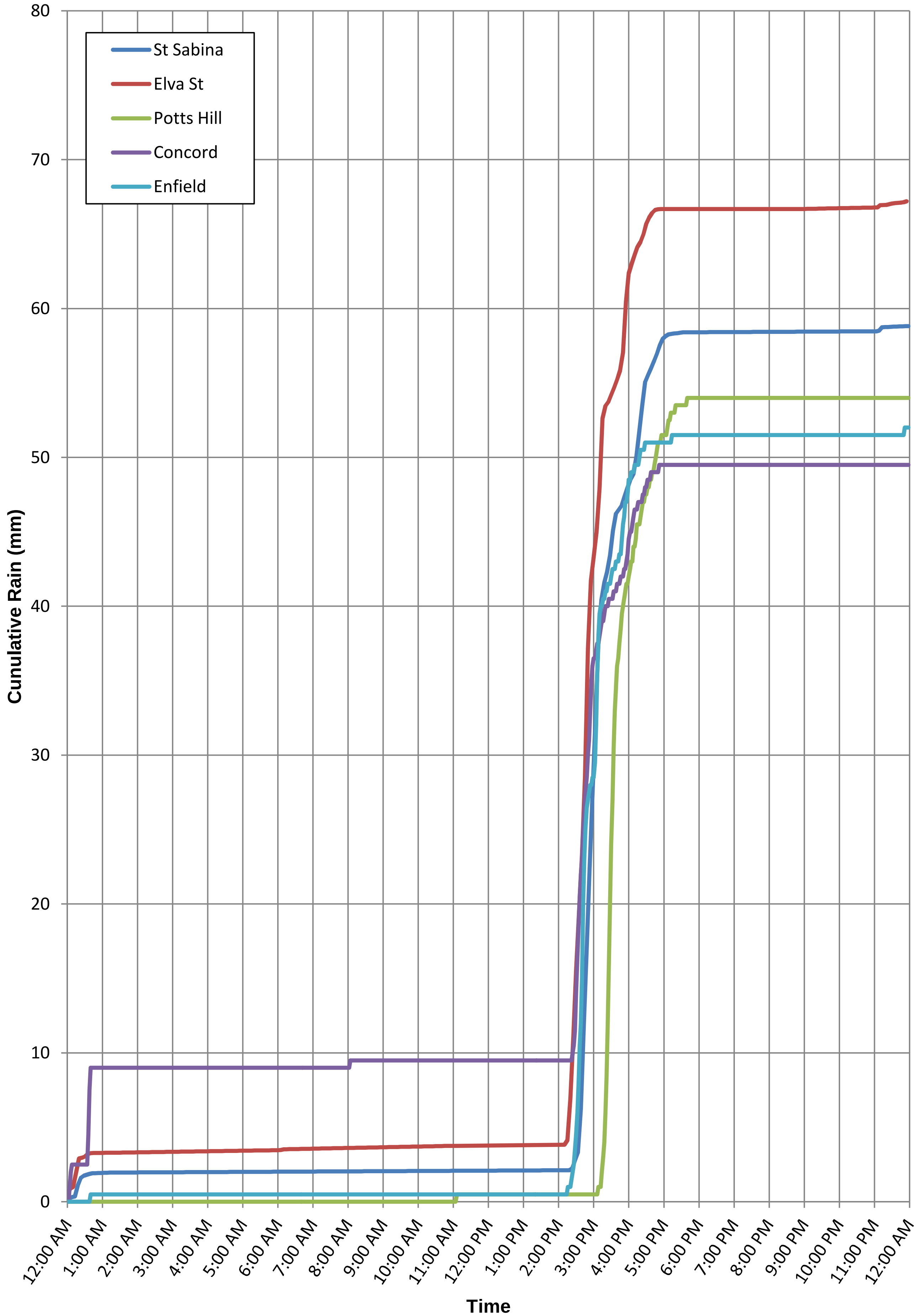


FIGURE 9c
PLUVIOMETER DATA
7 FEBRUARY 1990



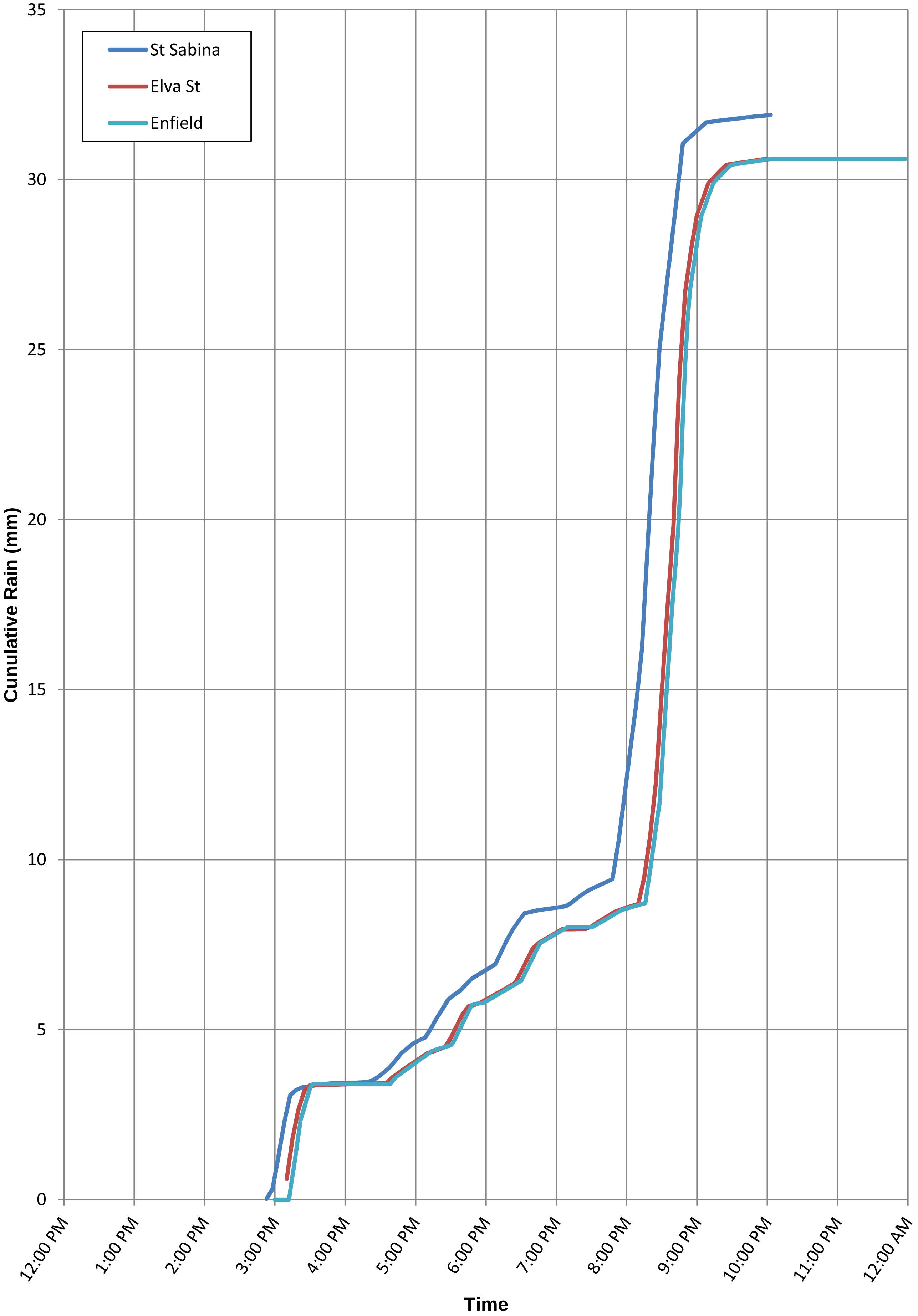
J:\Jobs\114021\ElvaStGauge\PowellsCkWaterlevel.xlsx

FIGURE 9d
PLUVIOMETER DATA
10 FEBRUARY 1990



J:\Jobs\114021\ElvaStGauge\PowellsCkWaterlevel.xlsx

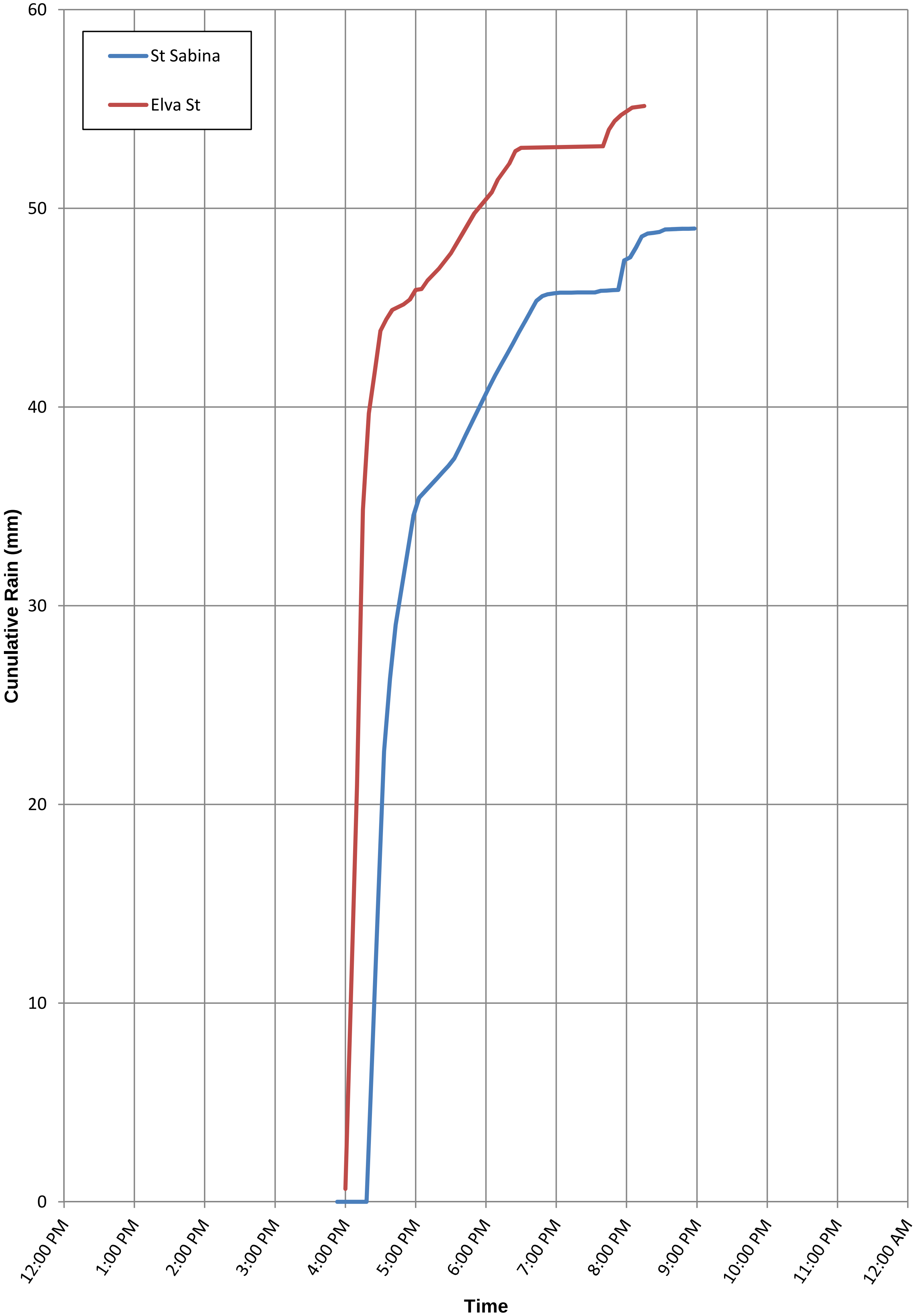
FIGURE 9e
PLUVIOMETER DATA
17 FEBRUARY 1990



J:\Jobs\114021\ElvaStGauge\PowellsCkWaterlevel.xlsx

FIGURE 9f

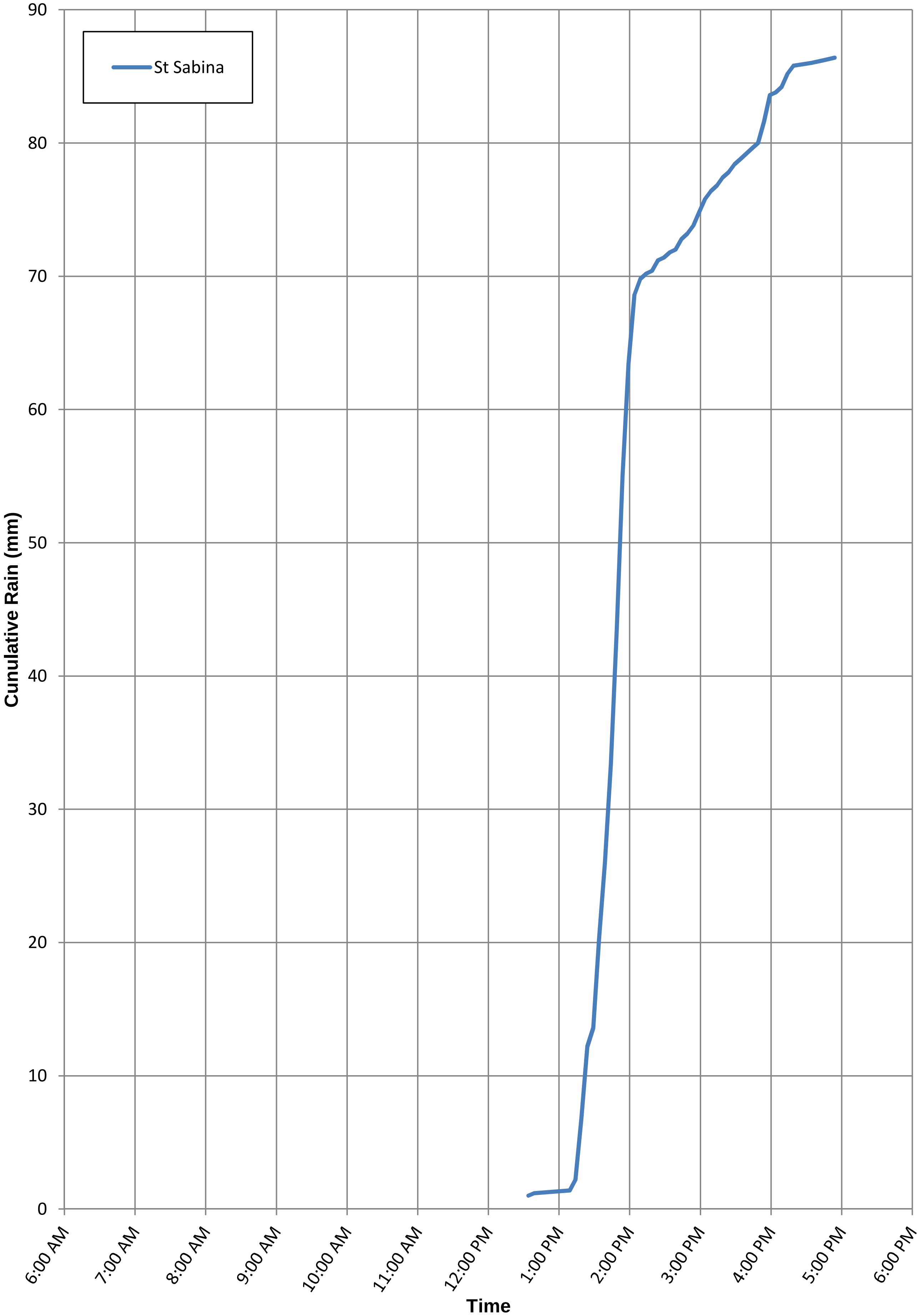
PLUVIOMETER DATA
18 MARCH 1990



J:\Jobs\114021\ElvaStGauge\PowellsCkWaterlevel.xlsx

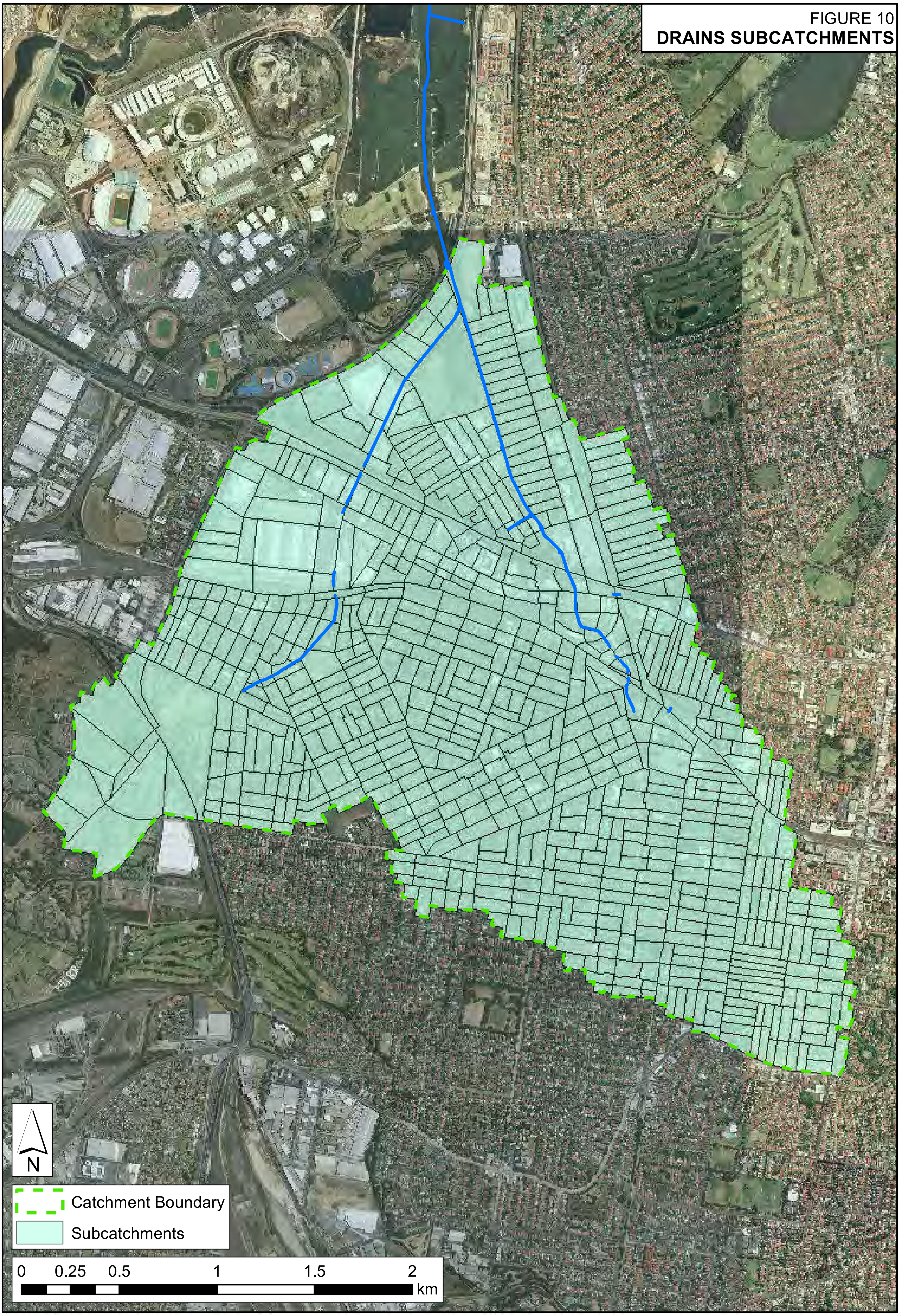
FIGURE 9g

PLUVIOMETER DATA
2 JANUARY 1996



J:\Jobs\114021\ElvaStGauge\PowellsCkWaterlevel.xlsx

FIGURE 10
DRAINS SUBCATCHMENTS



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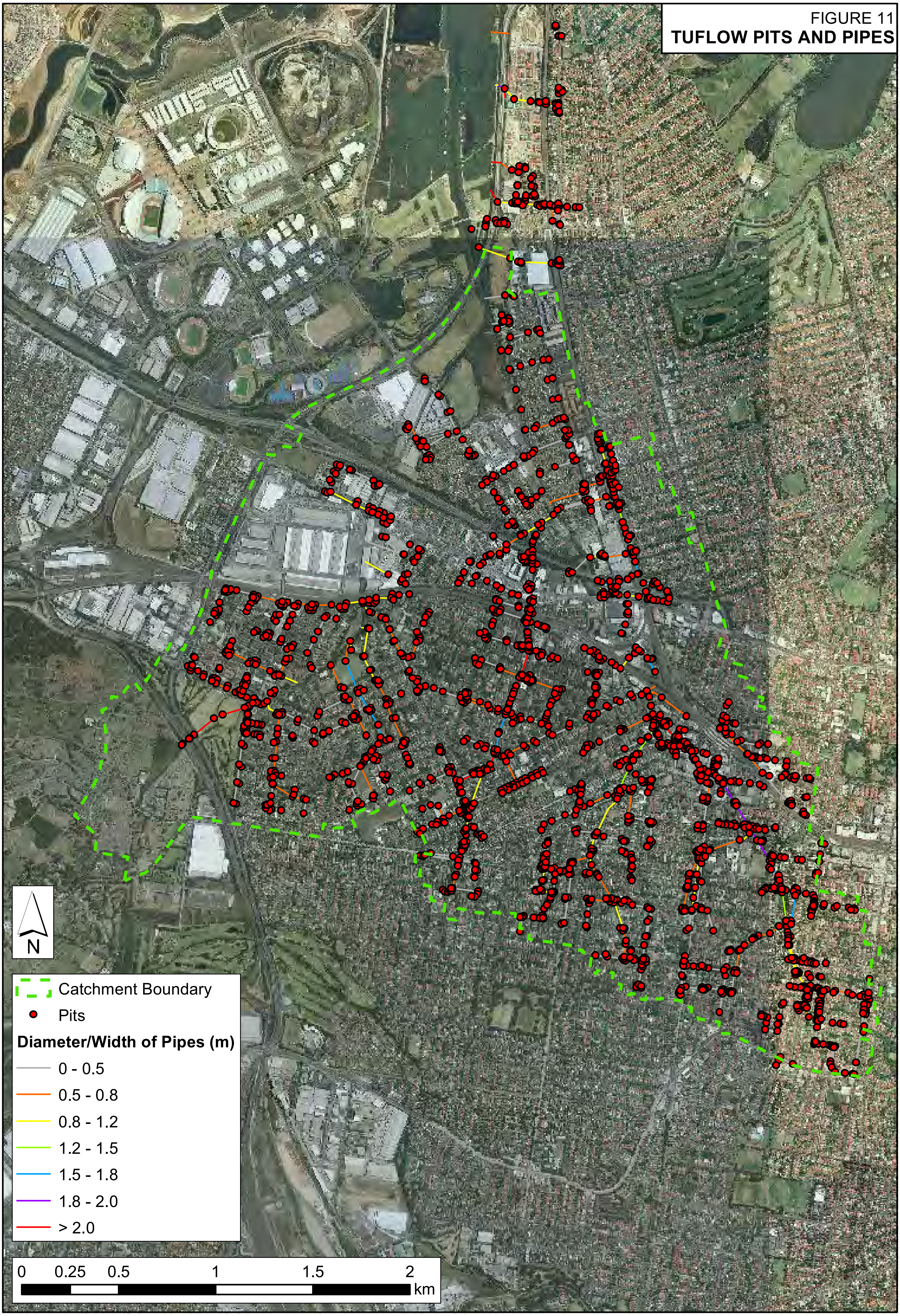

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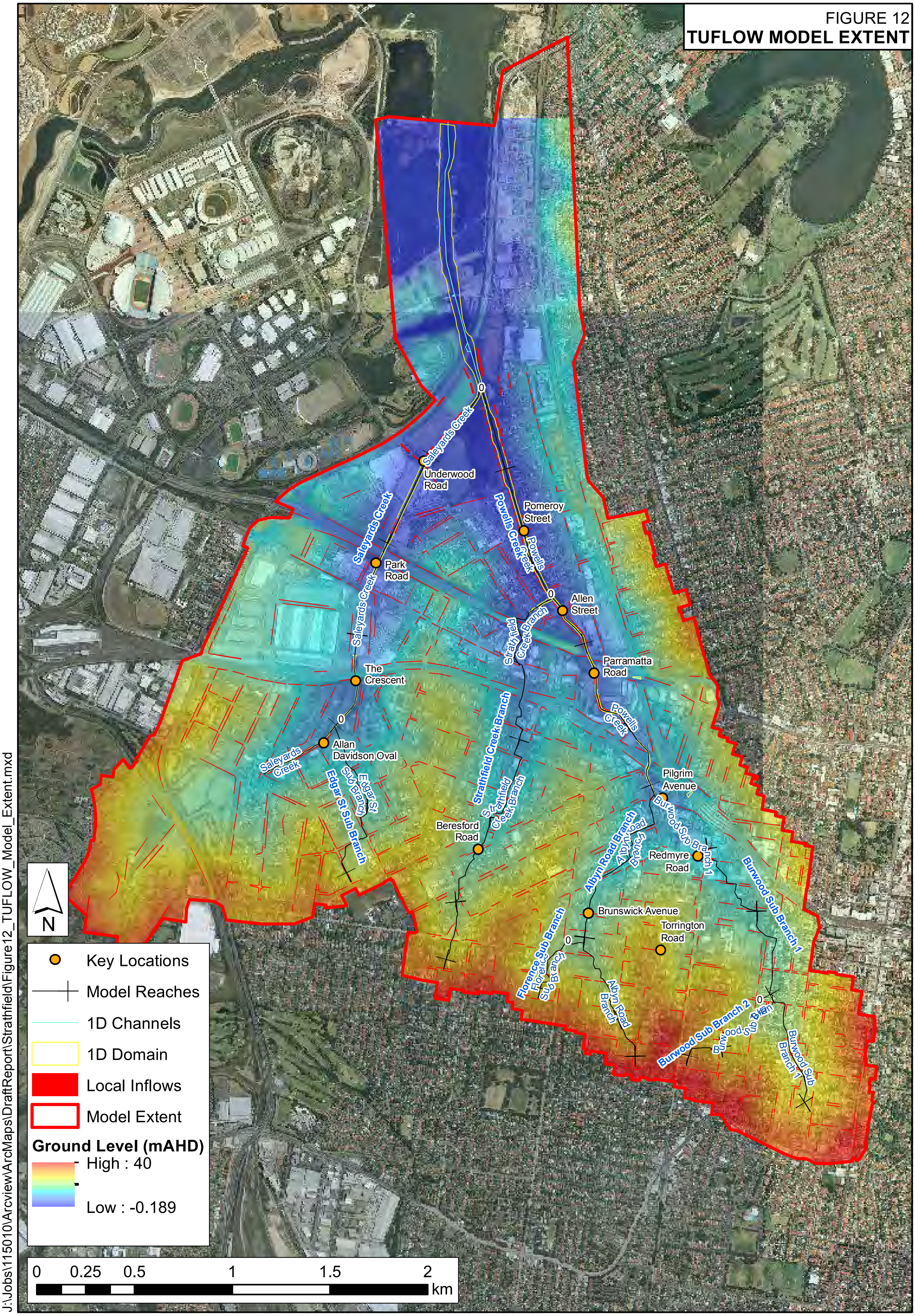
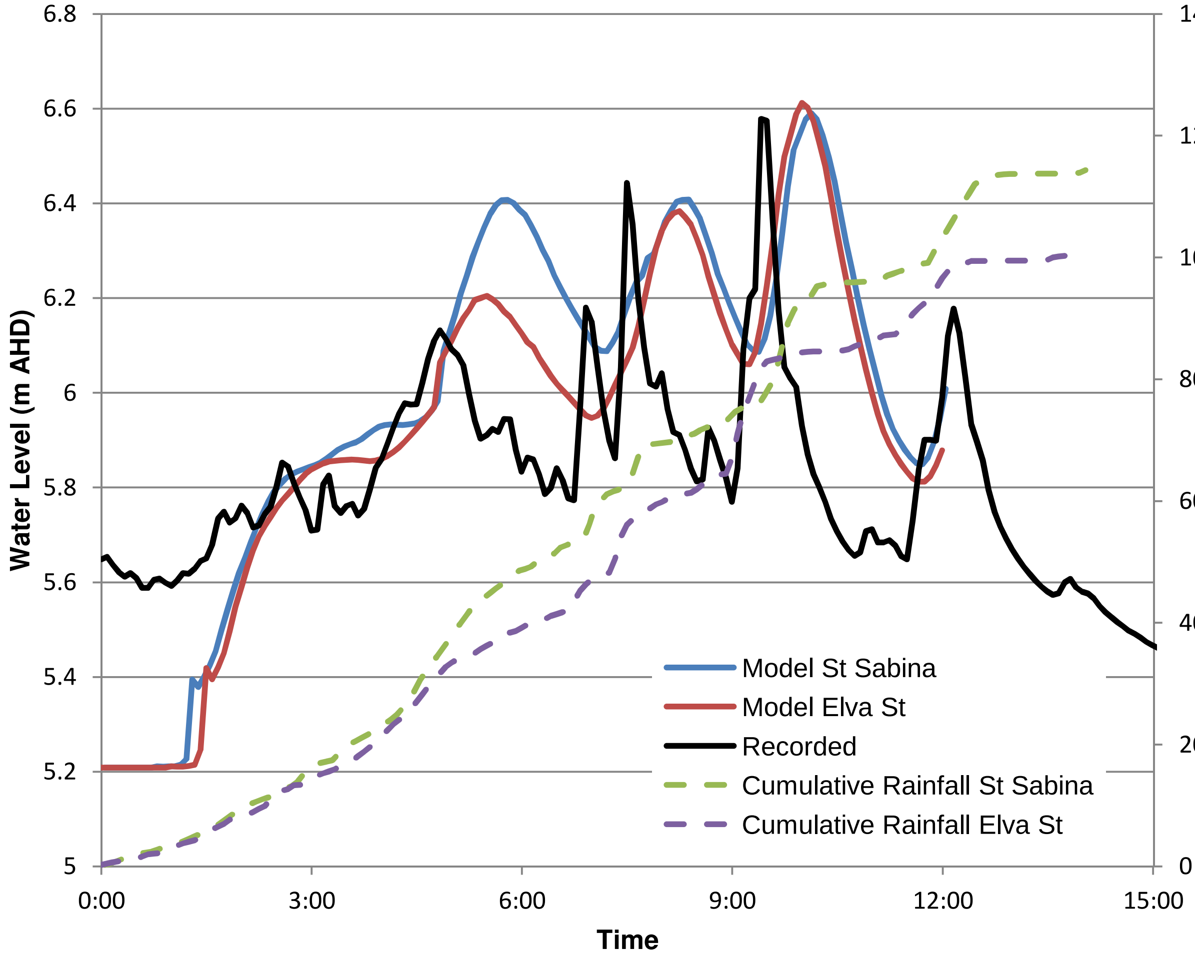
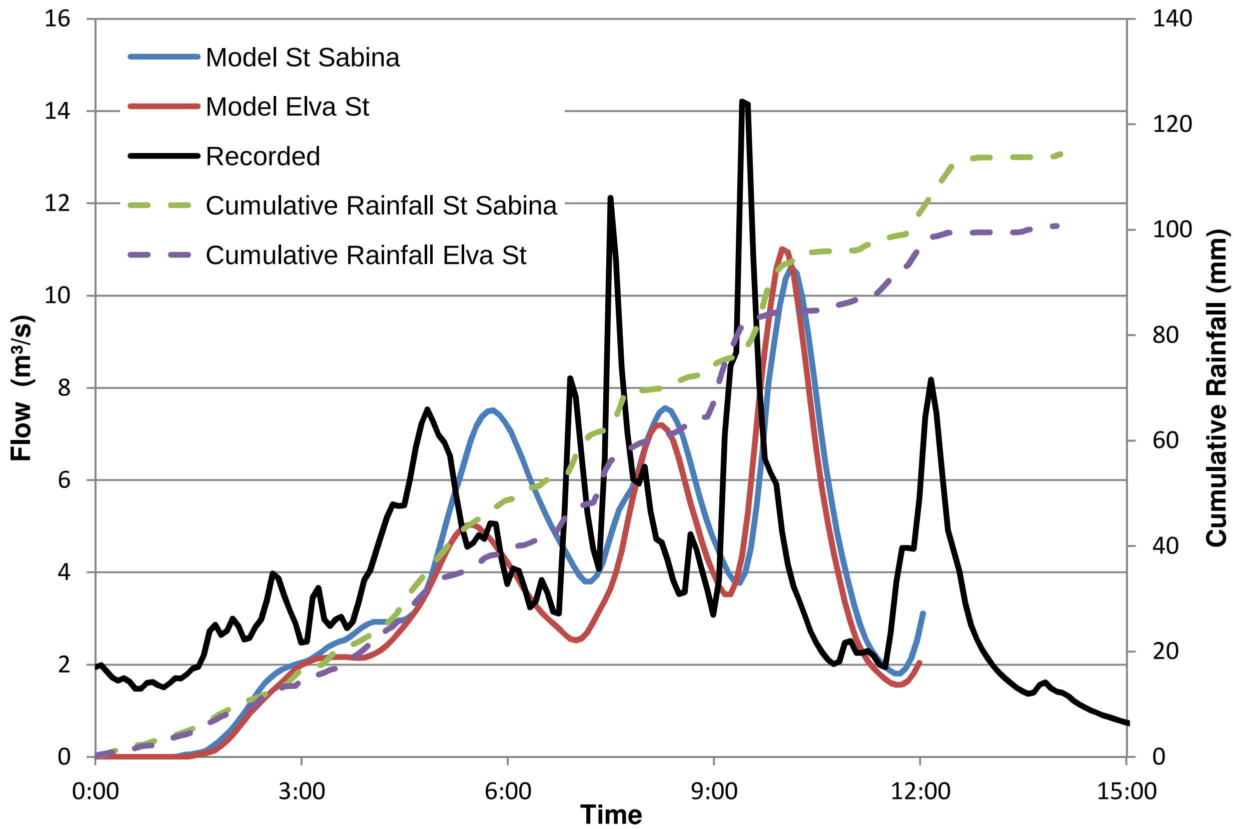


FIGURE 12
TUFLOW MODEL EXTENT
Saleyards Creek
Underwood Road
Pomeroy Street
Powells Creek
Park Road
Allen Street
Strathfield Creek Branch
Parramatta Road
The Crescent
Allan Davidson Oval
Edgar St Sub Branch
Beresford Road
Pilgrim Avenue
Burwood Sub Branch 1
Redmyre Road
Albyn Road Branch
Brunswick Avenue
Torrington Road
Florence Sub Branch
Burwood Sub Branch 2
Key Locations
Model Reaches
1D Channels
1D Domain
Local Inflows
Model Extent
Ground Level (mAHD)
High : 40
Low : -0.189
0 0.25 0.5 1 1.5 2 km
N
J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Strathfield\Figure12_TUFLOW_Model_Extent.mxd

FIGURE 13a
CALIBRATION RESULTS--ELVA STREET GAUGE
3 FEBRUARY 1990





J:\Jobs\114021\TUFLOW\results\Calibration\19900203\19900203.xlsx

FIGURE 13b

CALIBRATION RESULTS--ELVA STREET GAUGE

7 FEBRUARY 1990

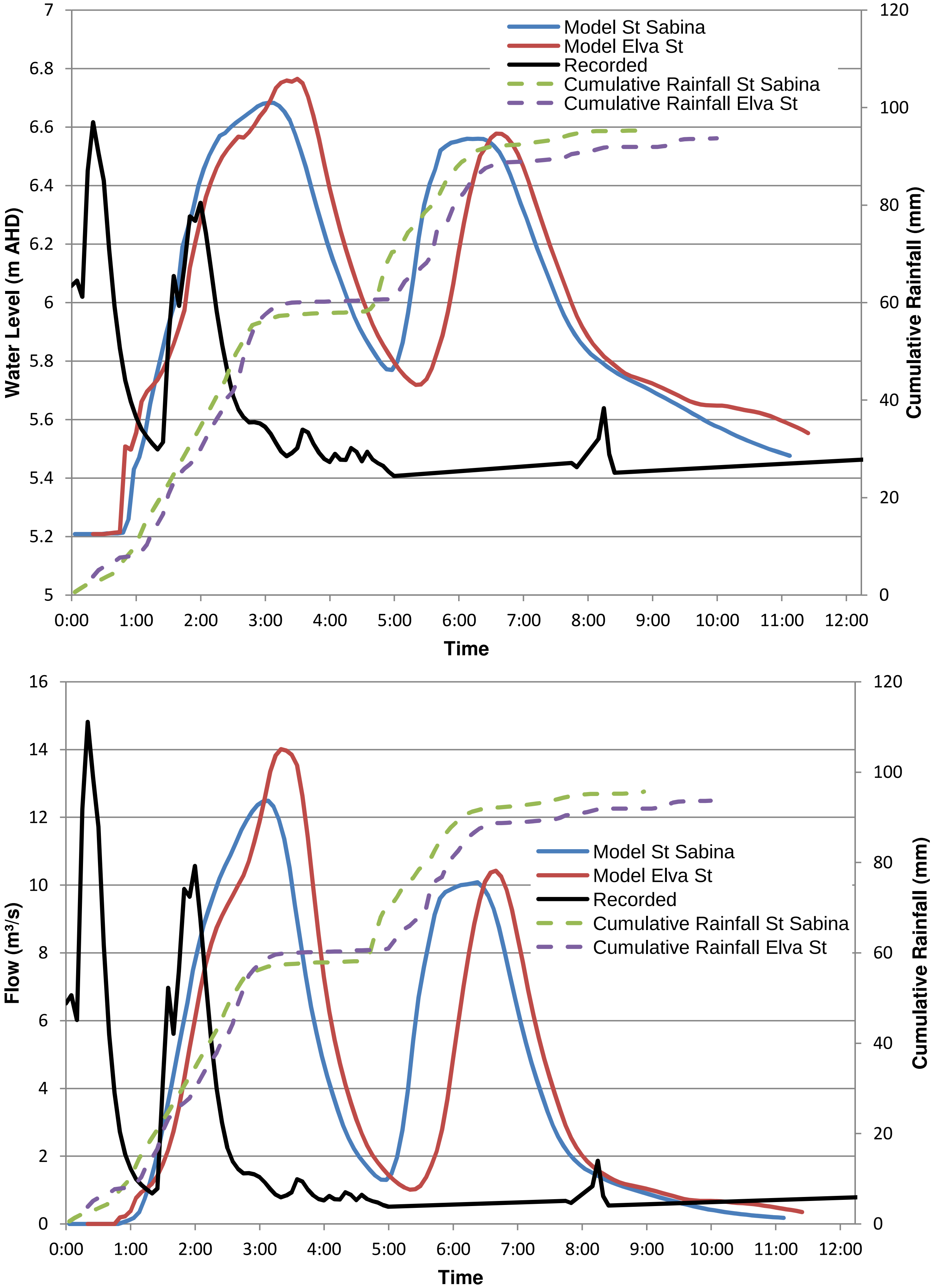


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FIGURE 13c

CALIBRATION RESULTS--ELVA STREET GAUGE
10 FEBRUARY 1990

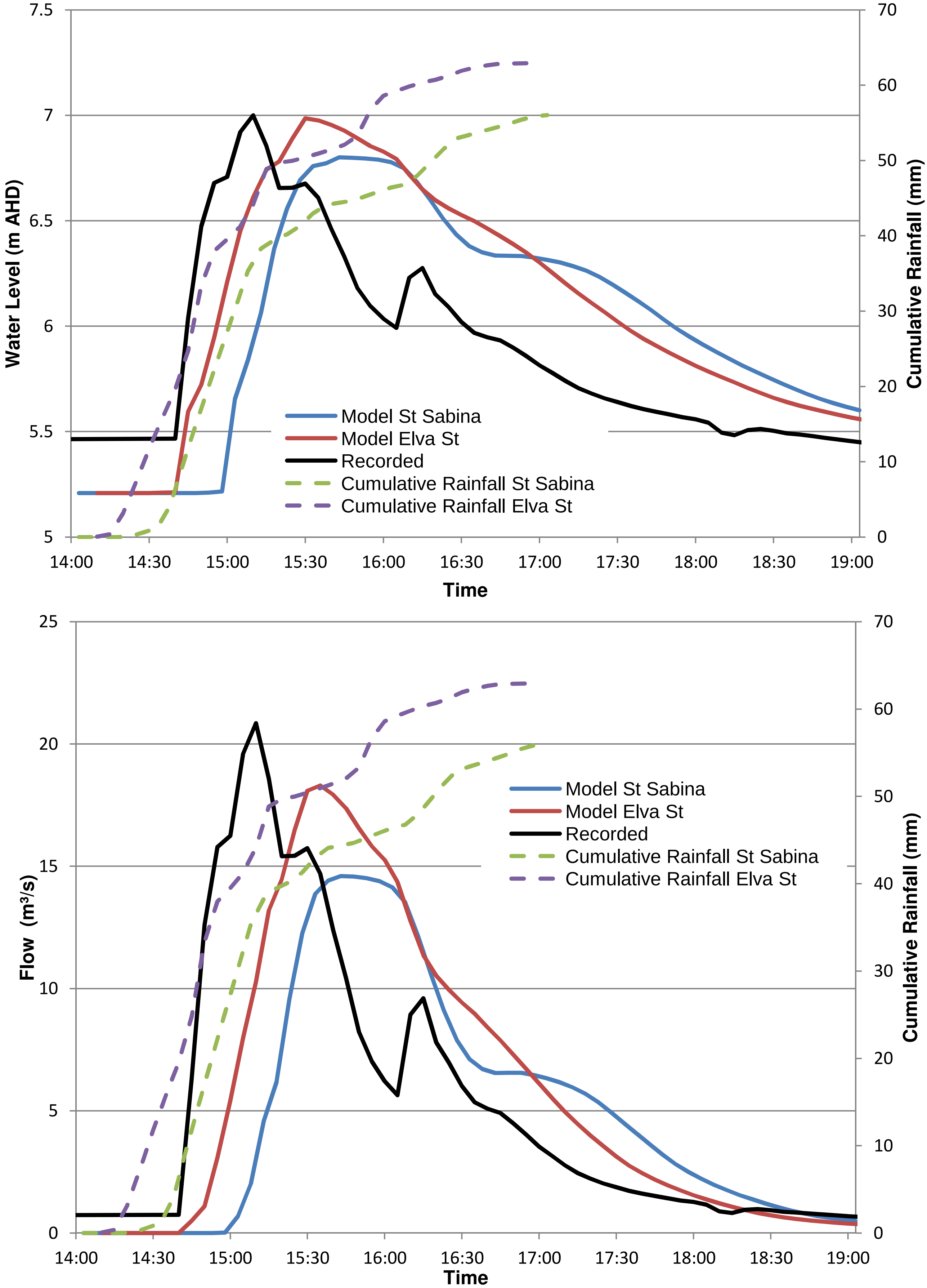

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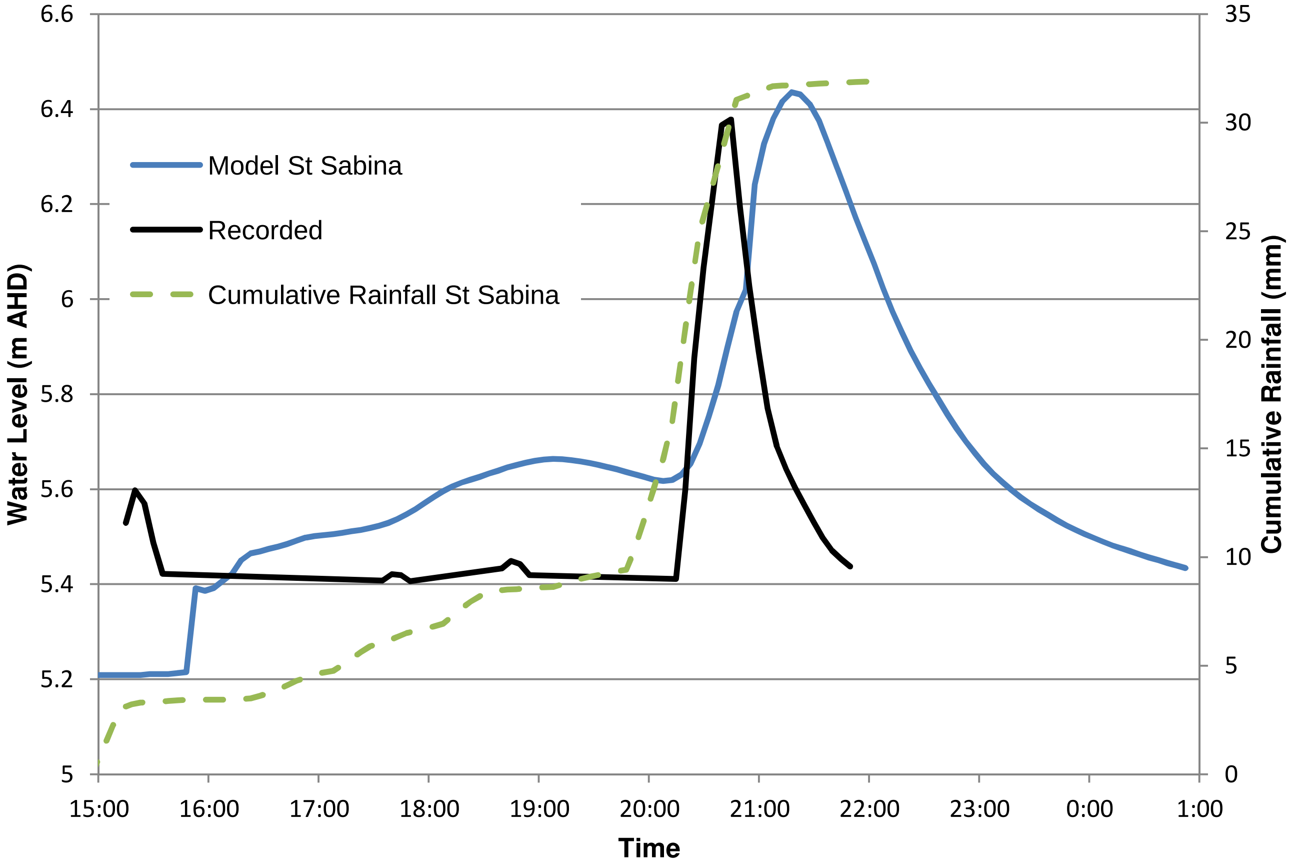
FIGURE 13d

CALIBRATION RESULTS--ELVA STREET GAUGE
17 FEBRUARY 1990



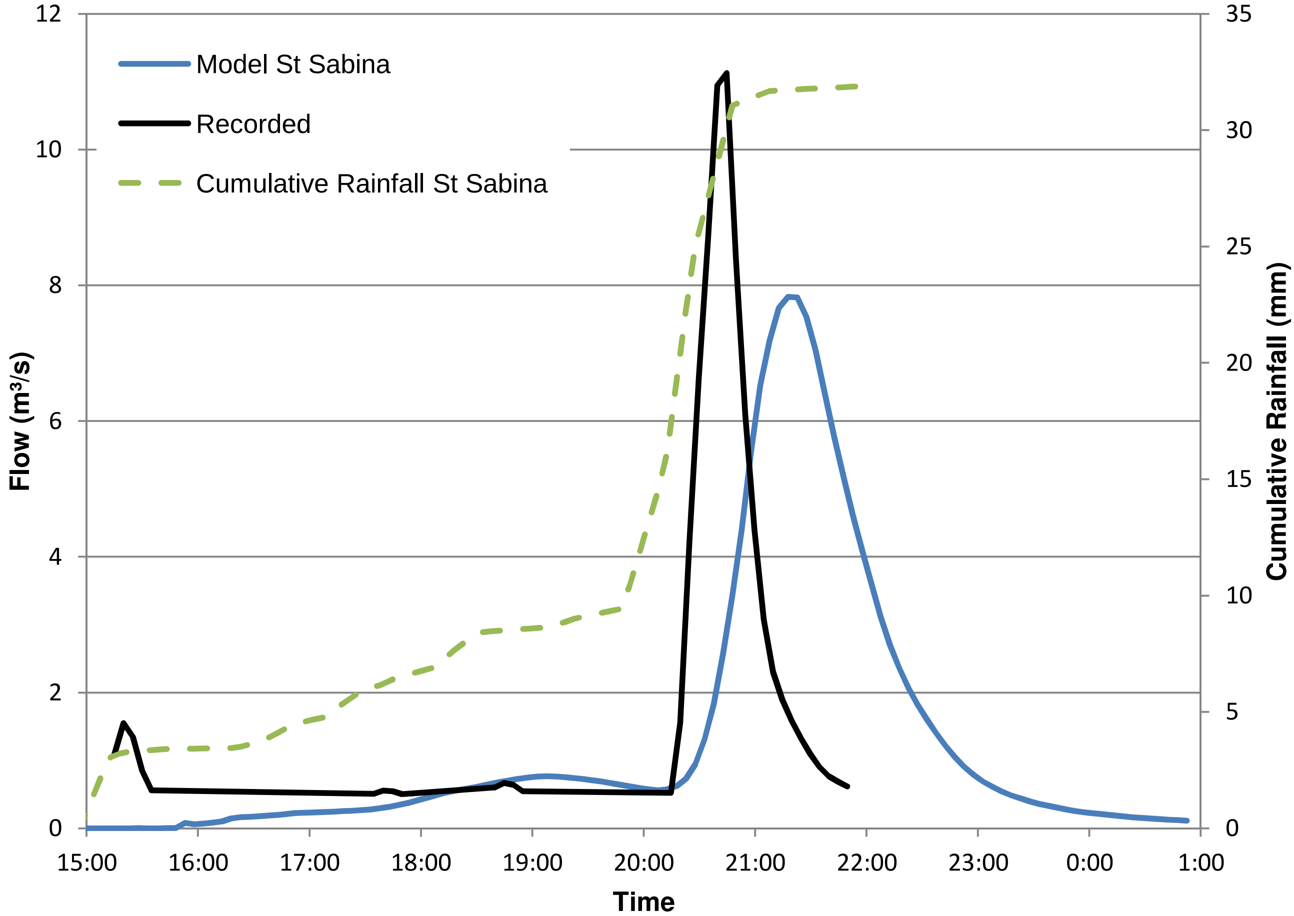


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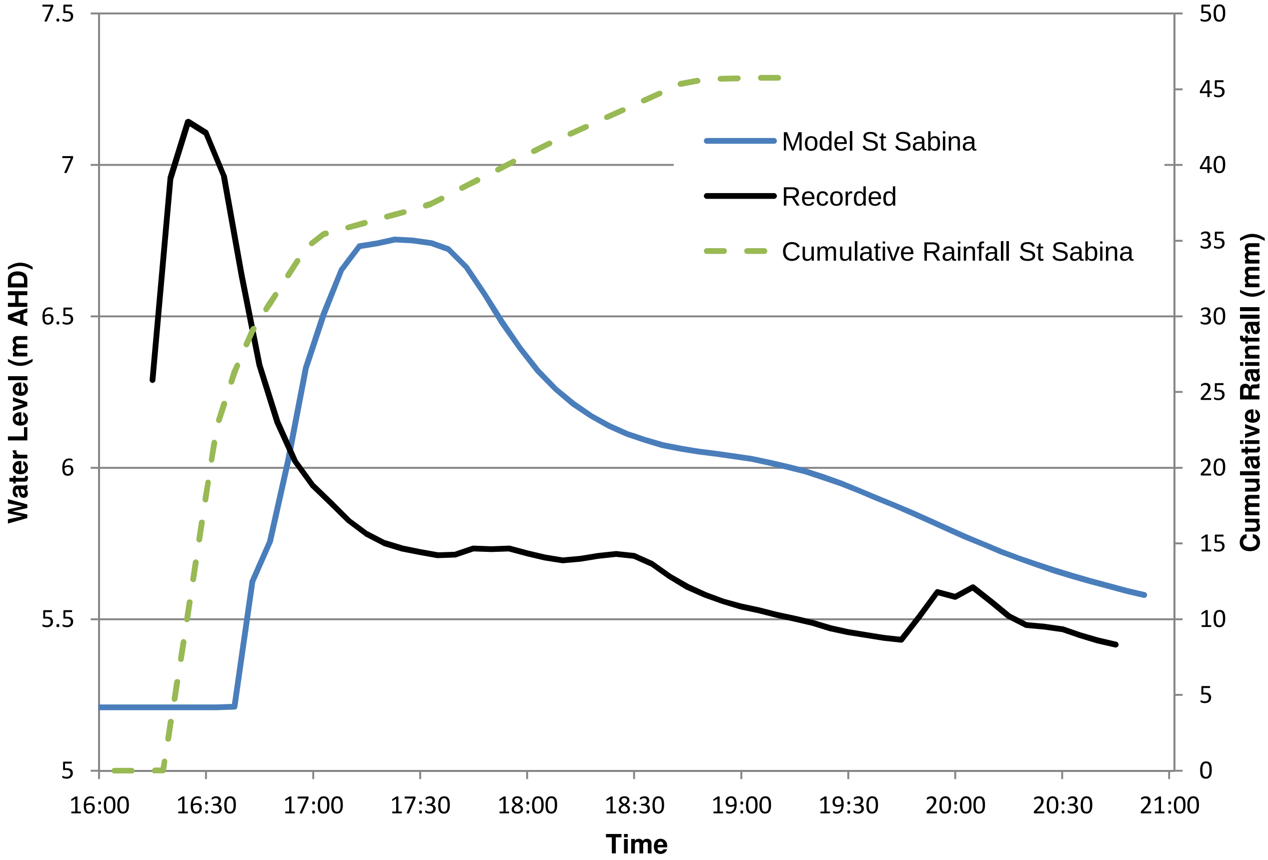
FIGURE 13e

CALIBRATION RESULTS--ELVA STREET GAUGE

18 MARCH 1990



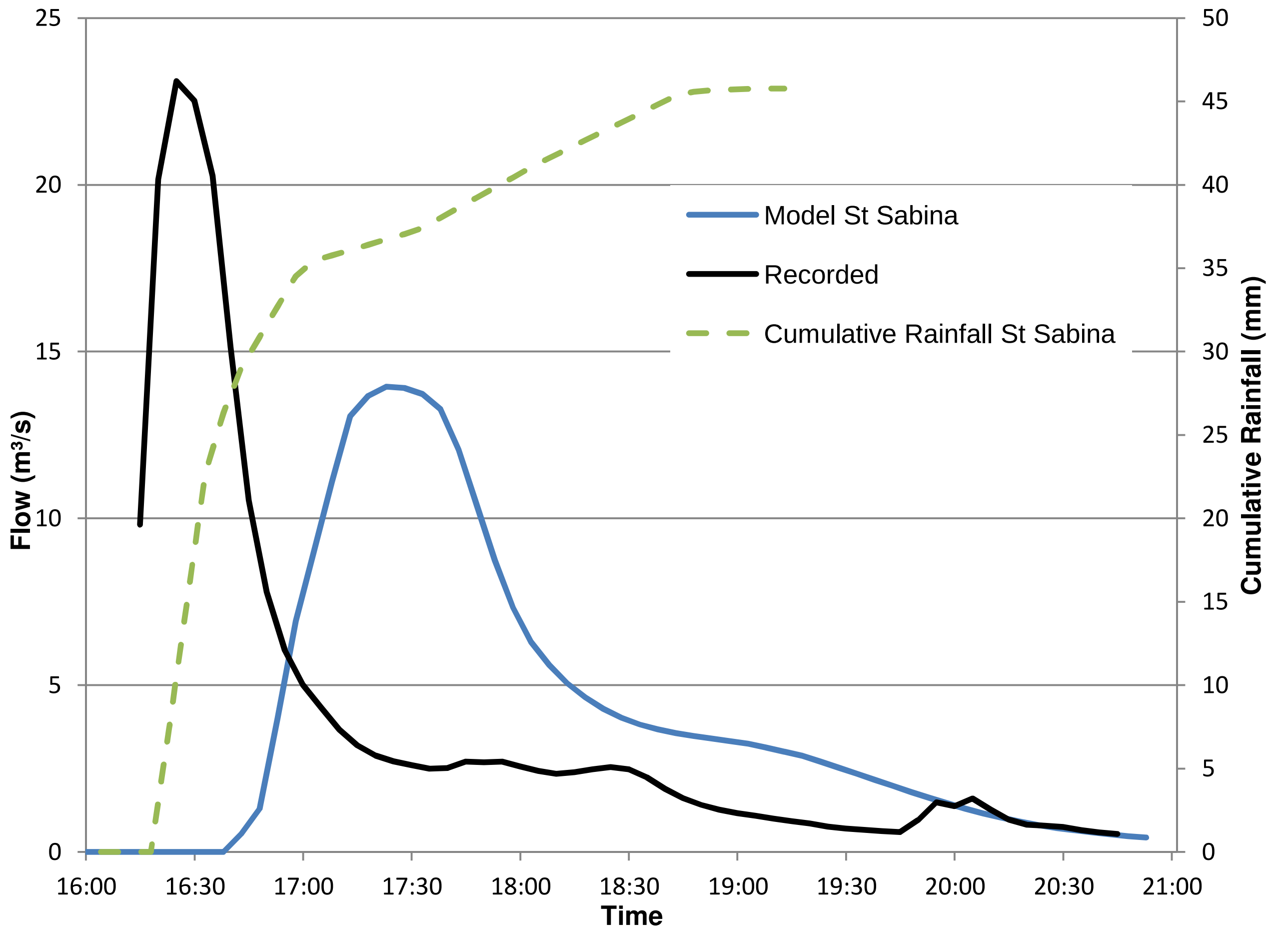


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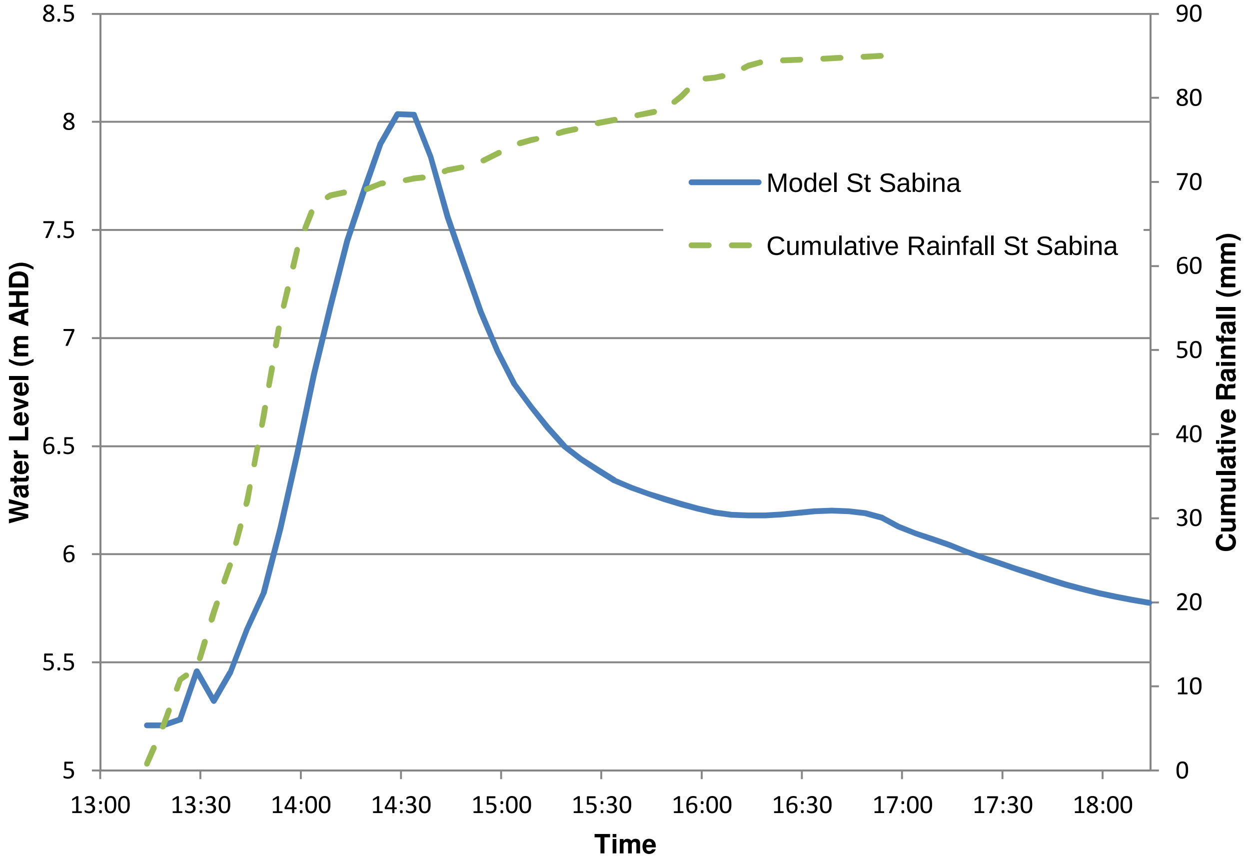
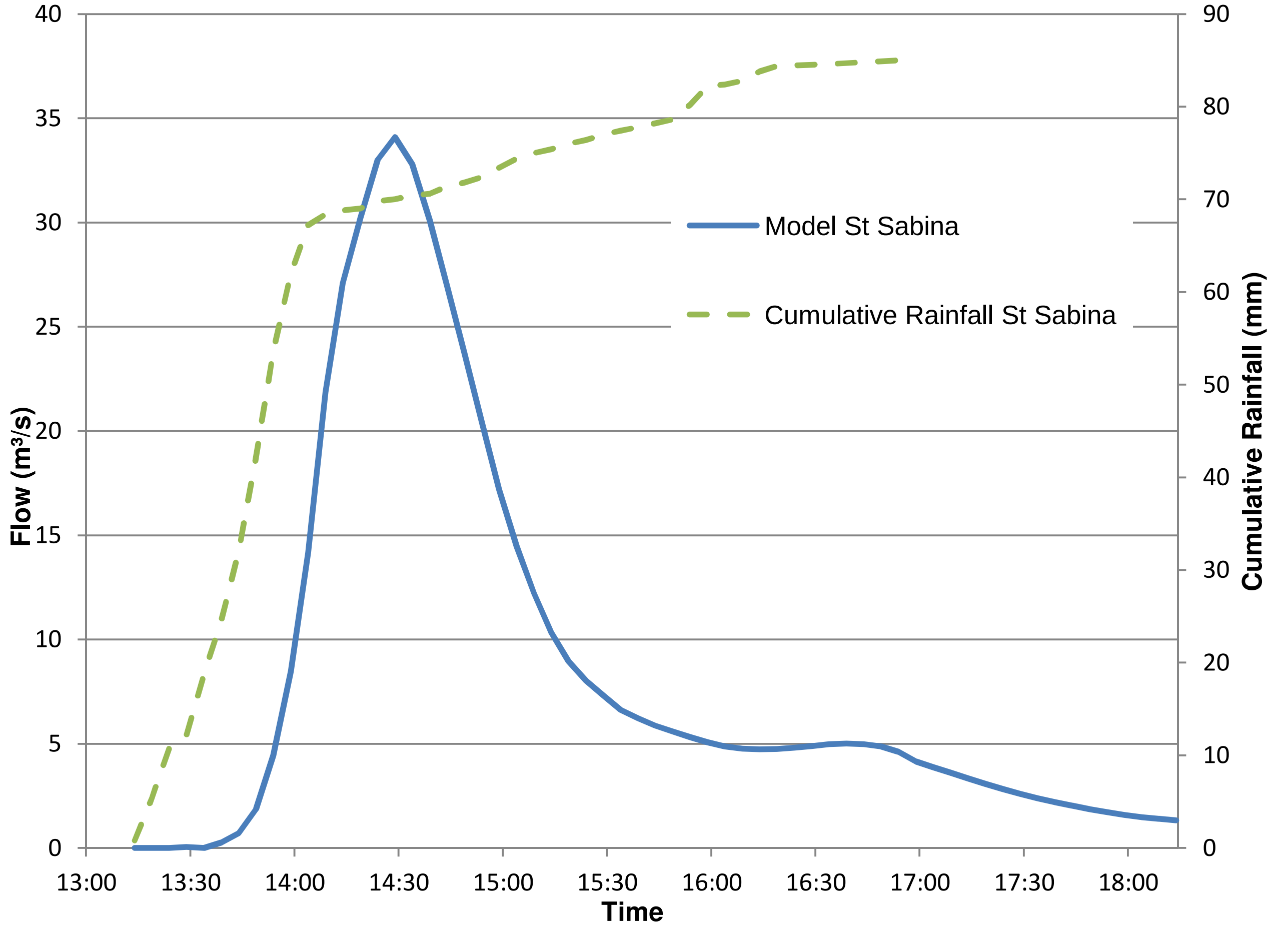
FIGURE 13f

CALIBRATION RESULTS--ELVA STREET GAUGE
2 JANUARY 1996





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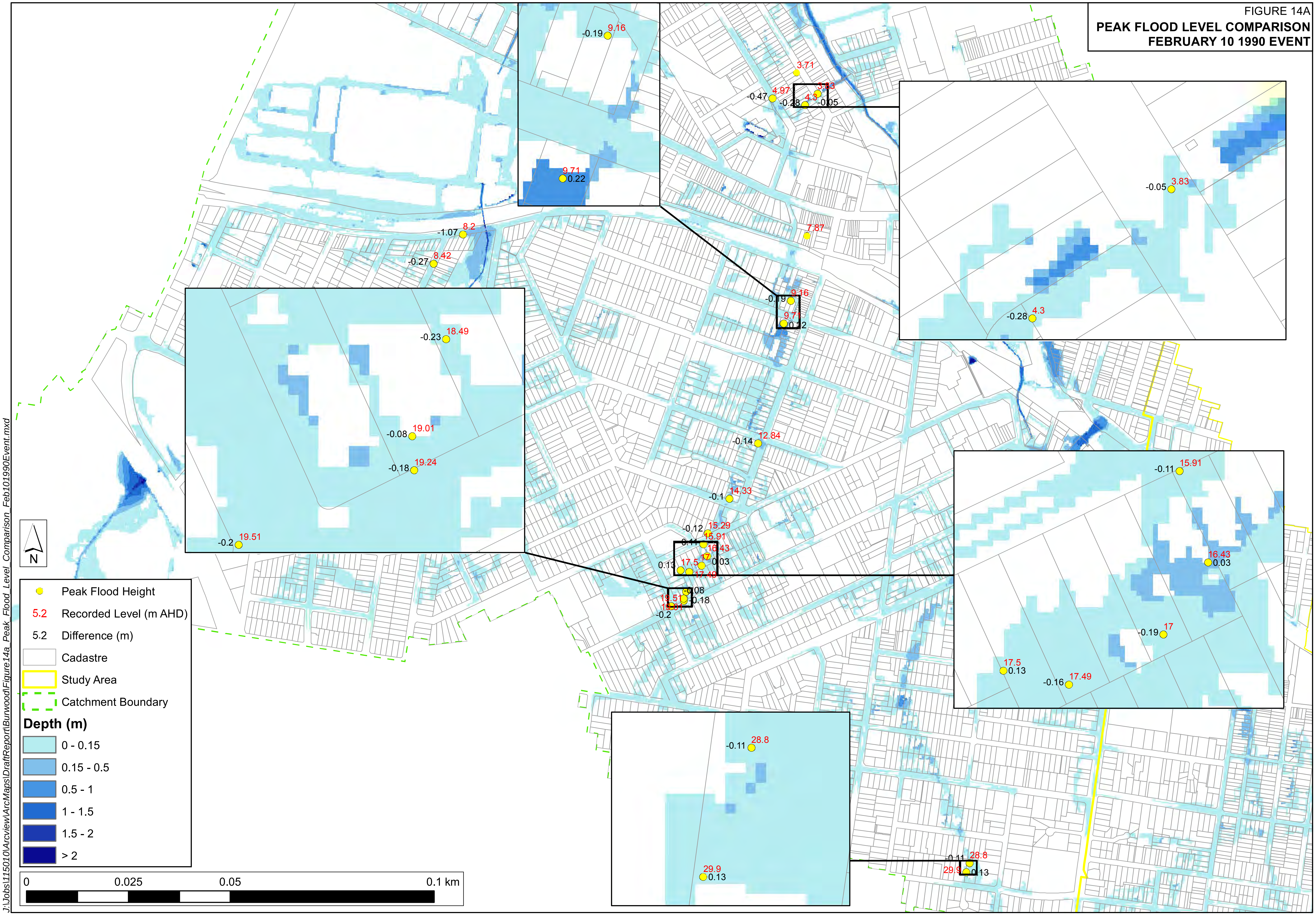


FIGURE 14A
PEAK FLOOD LEVEL COMPARISON
FEBRUARY 10 1990 EVENT
Peak Flood Height
5.2 Recorded Level (m AHD)
5.2 Difference (m)
Cadastre
Study Area
Catchment Boundary
Depth (m)
0 - 0.15
0.15 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
> 2
0 0.025 0.05 0.1 km
N
J:\Jobs\115010\Arcview\ArcMaps\DraftReportBurwood\Figure14a_Peak_Flood_Level_Comparison_Feb101990Event.mxd

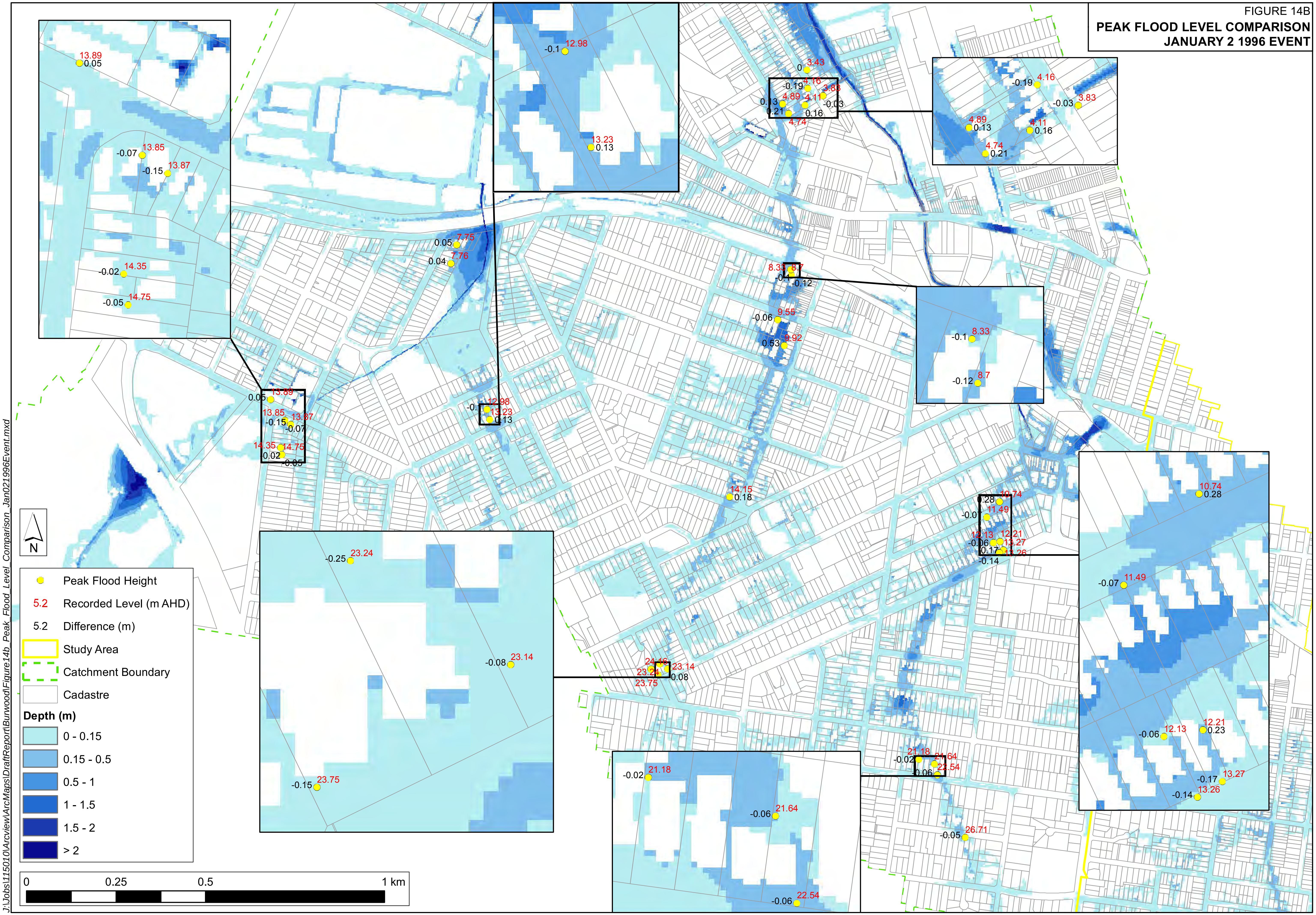
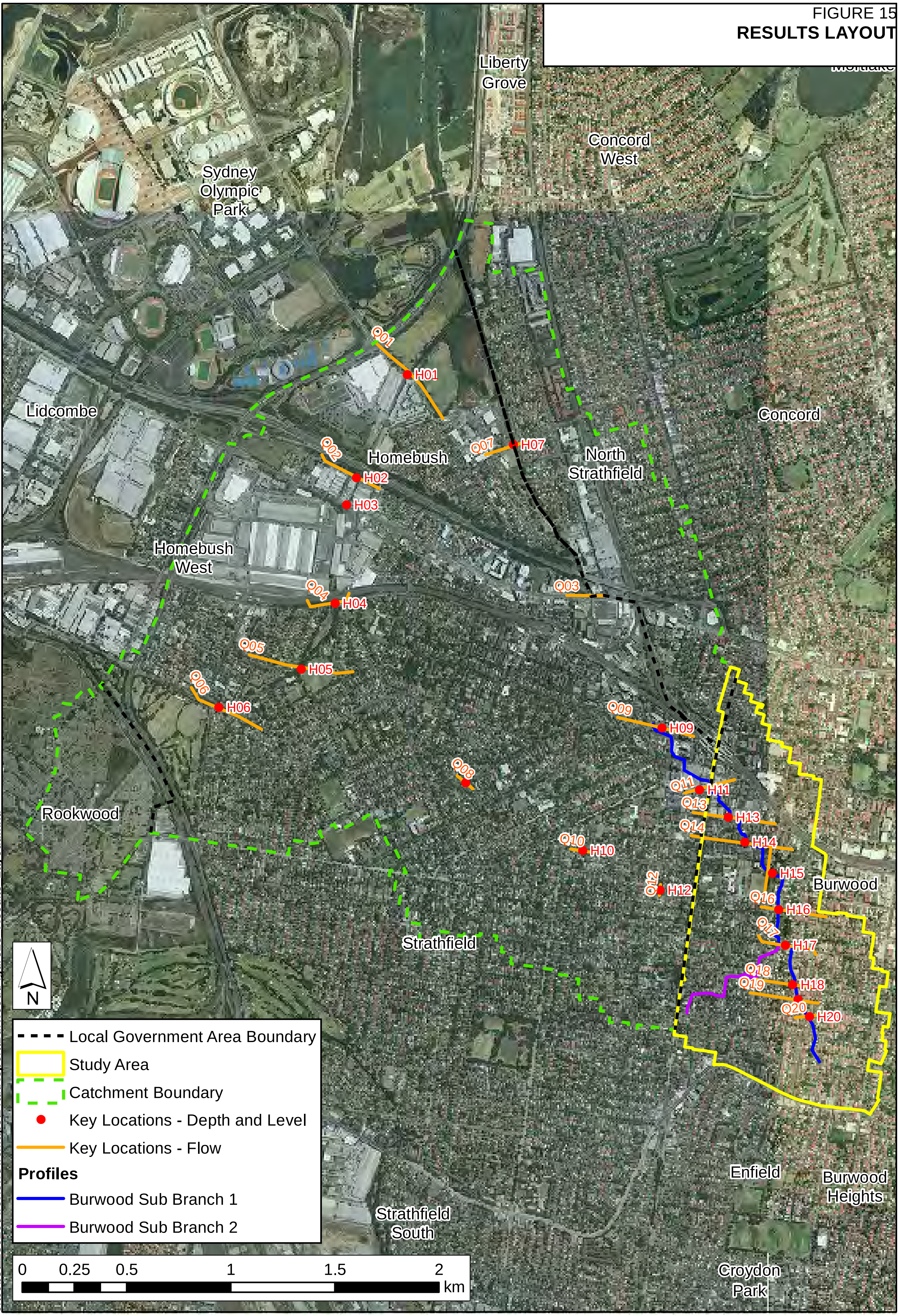


FIGURE 14B
PEAK FLOOD LEVEL COMPARISON
JANUARY 2 1996 EVENT
Peak Flood Height
5.2 Recorded Level (m AHD)
5.2 Difference (m)
Study Area
Catchment Boundary
Cadastre
Depth (m)
0 - 0.15
0.15 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
> 2
0 0.25 0.5 1 km
N
J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure14b_Peak_Flood_Level_Comparison_Jan021996Event.mxd

FIGURE 15
RESULTS LAYOUT



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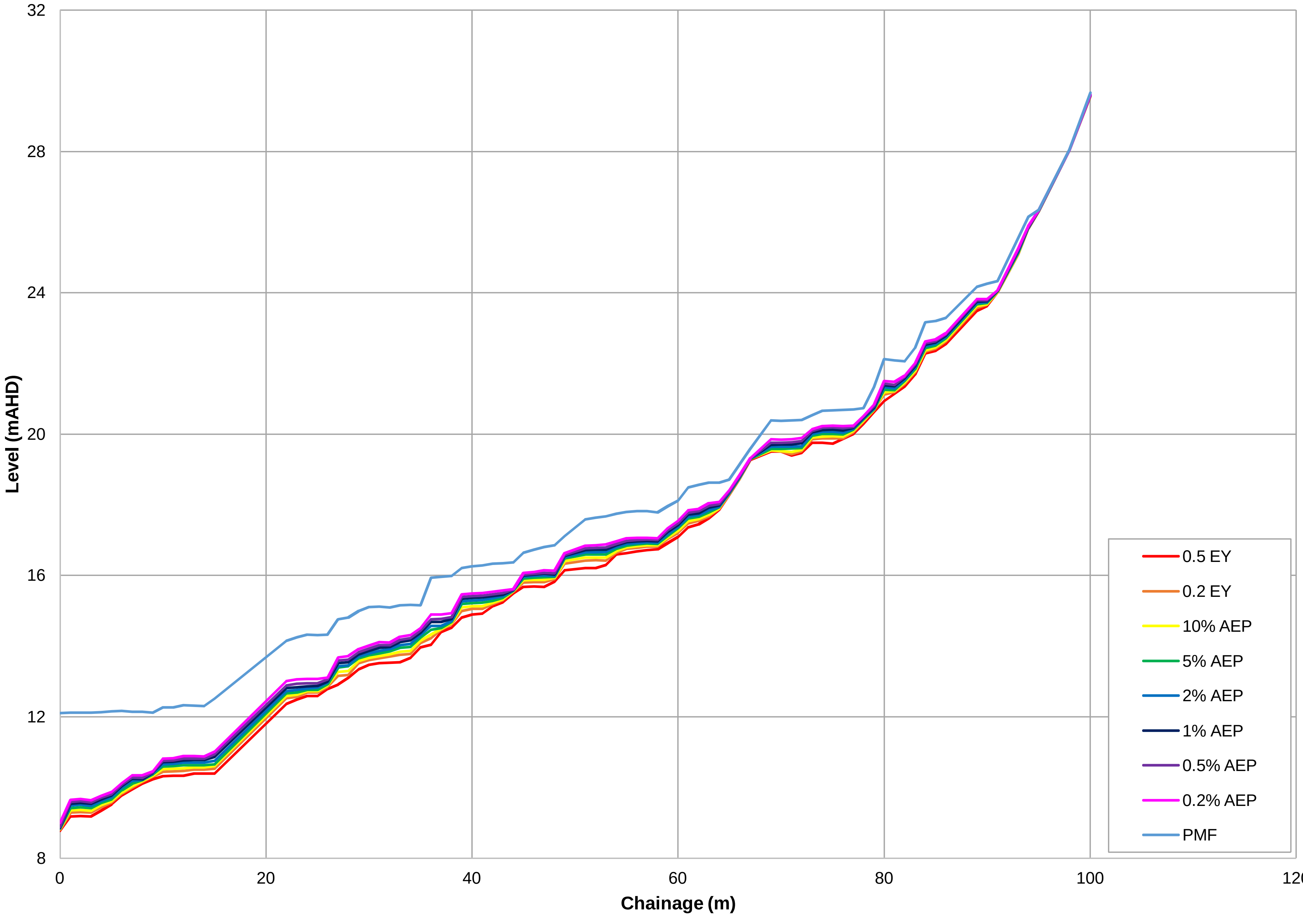
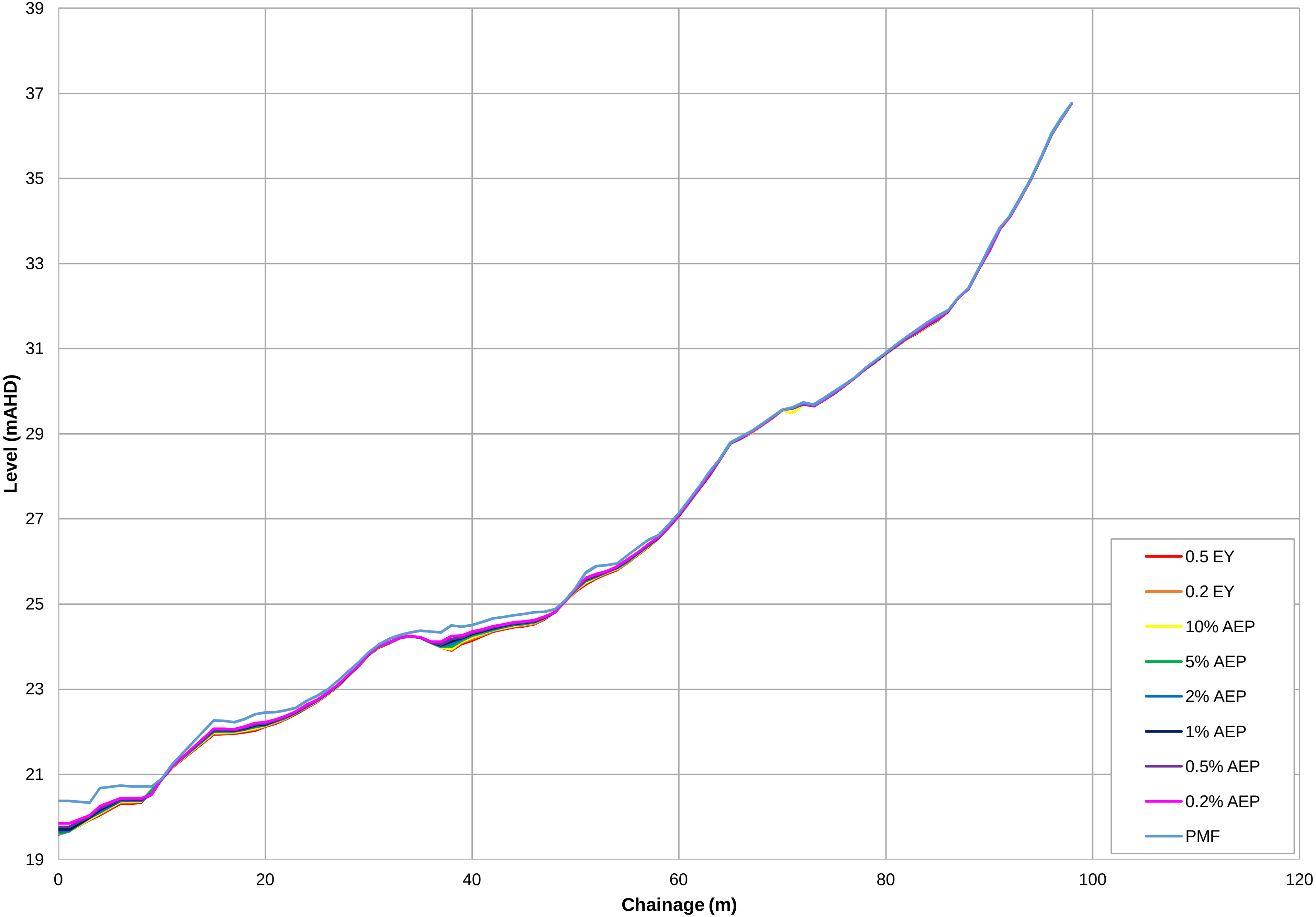


J:\Jobs\115010\TUFLOW\results\Profile\Profile2_005.xlsx

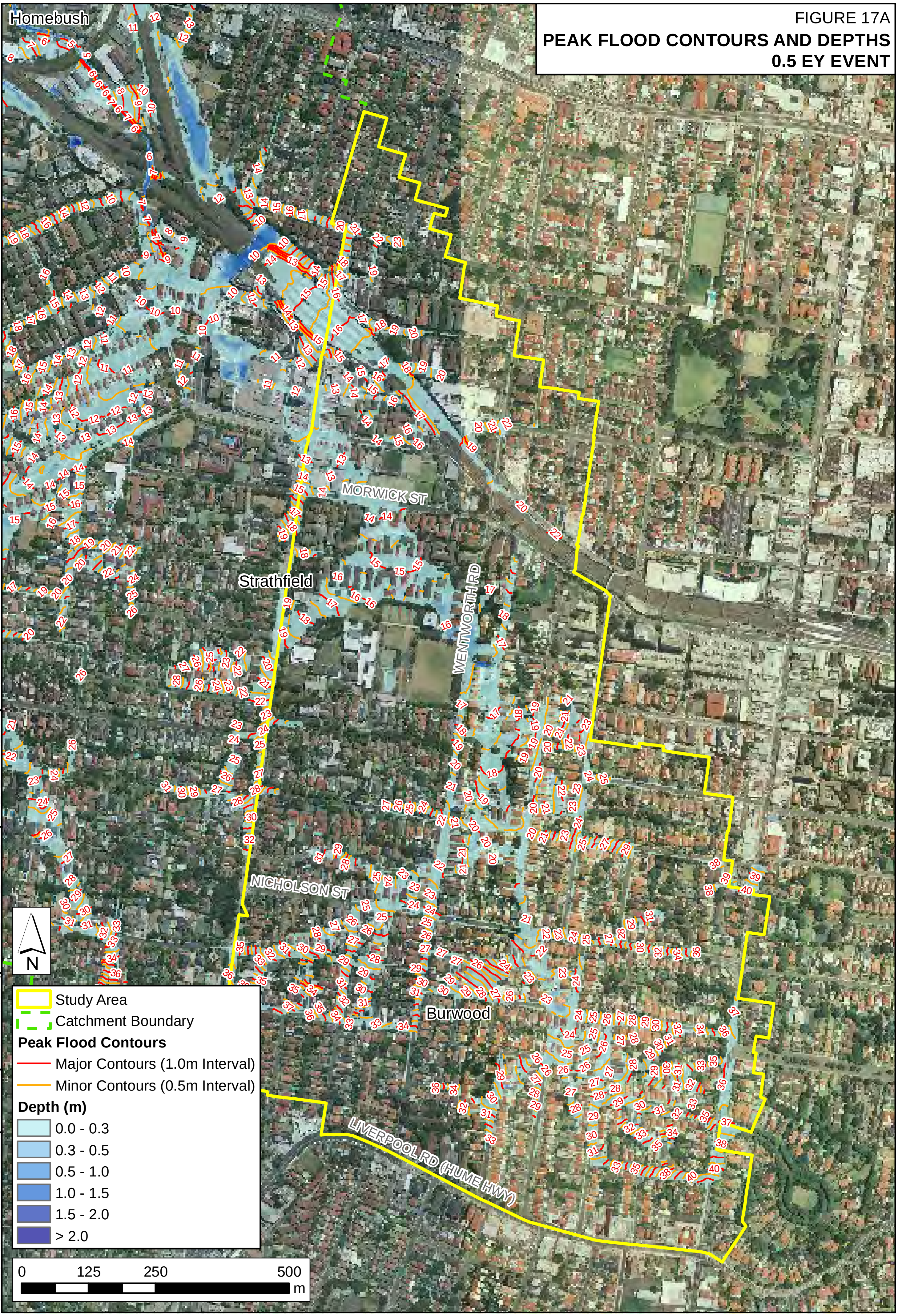
FIGURE 16A
DESIGN RESULTS
PEAK HEIGHT PROFILES - BURWOOD SUB BRANCH 1



J:\Jobs\115010\TUFLOW\results\Profile\Profile2_005.xlsx

FIGURE 16B
DESIGN RESULTS
PEAK HEIGHT PROFILES - BURWOOD SUB BRANCH 2

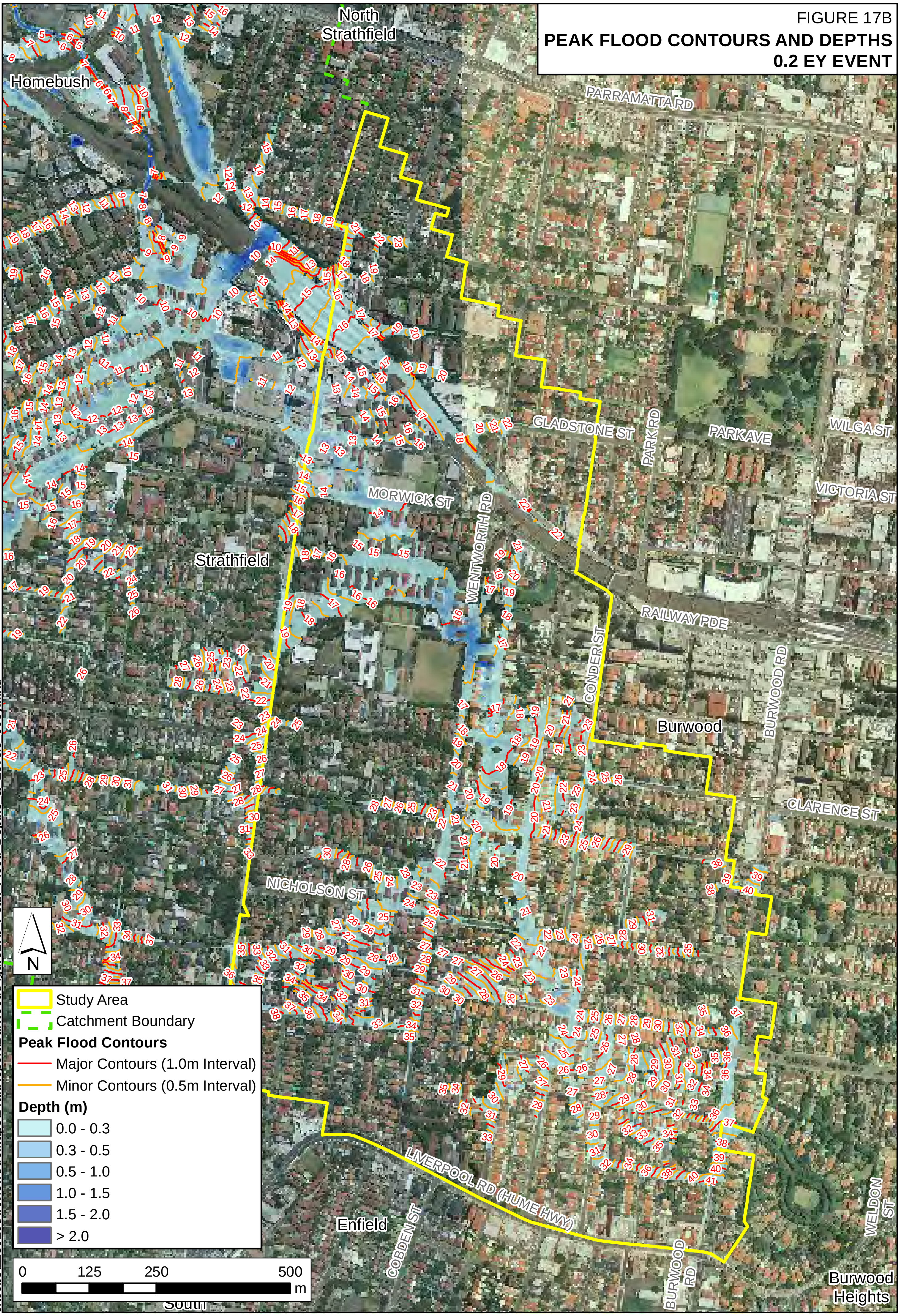
FIGURE 17A
PEAK FLOOD CONTOURS AND DEPTHS 0.5 EY EVENT



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure17a_Peak_Flood_Depths_&_Levels_002y.mxd

FIGURE 17B

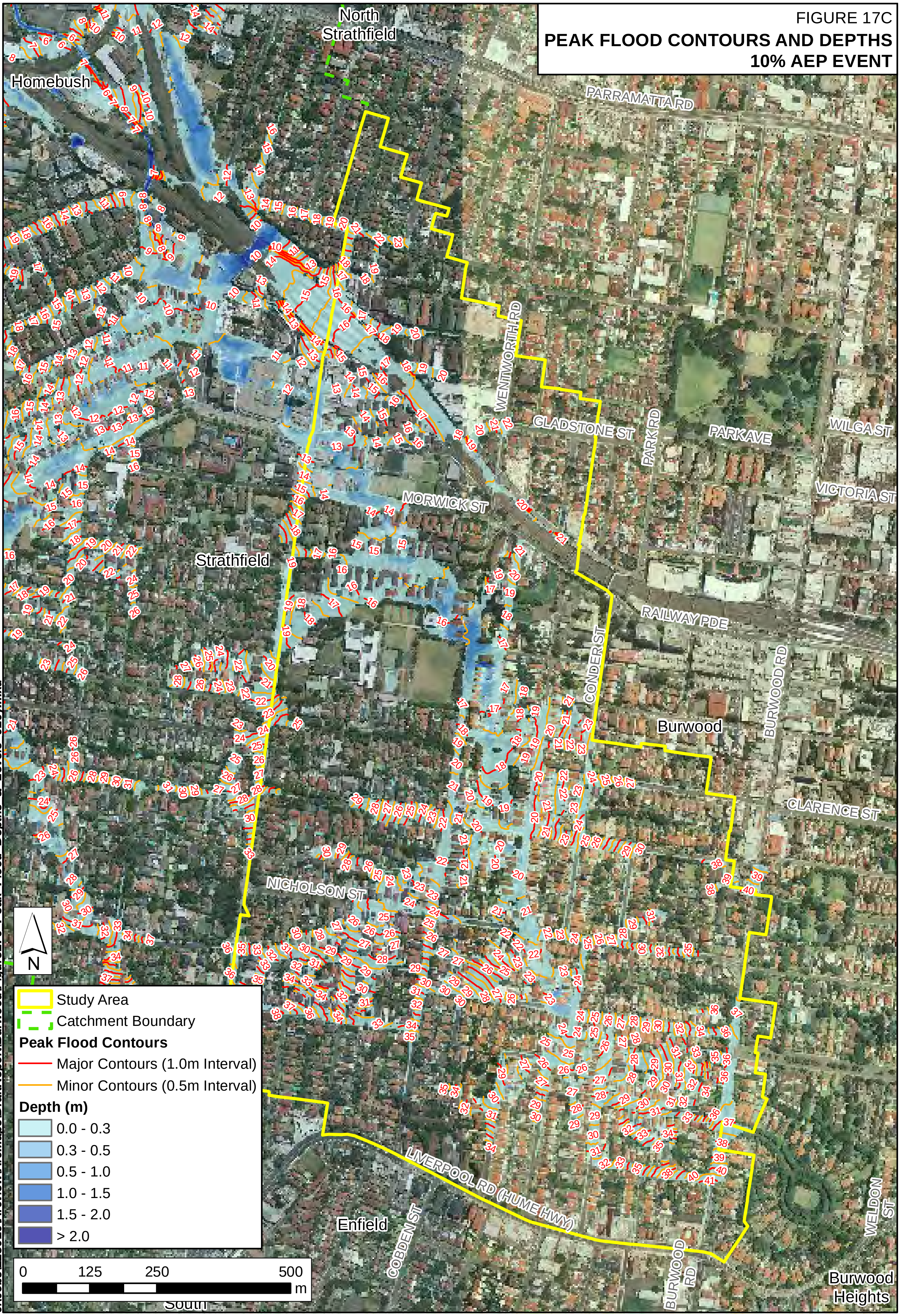
PEAK FLOOD CONTOURS AND DEPTHS
0.2 EY EVENT



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure17b Peak Flood Depths & Levels 005y.mxd

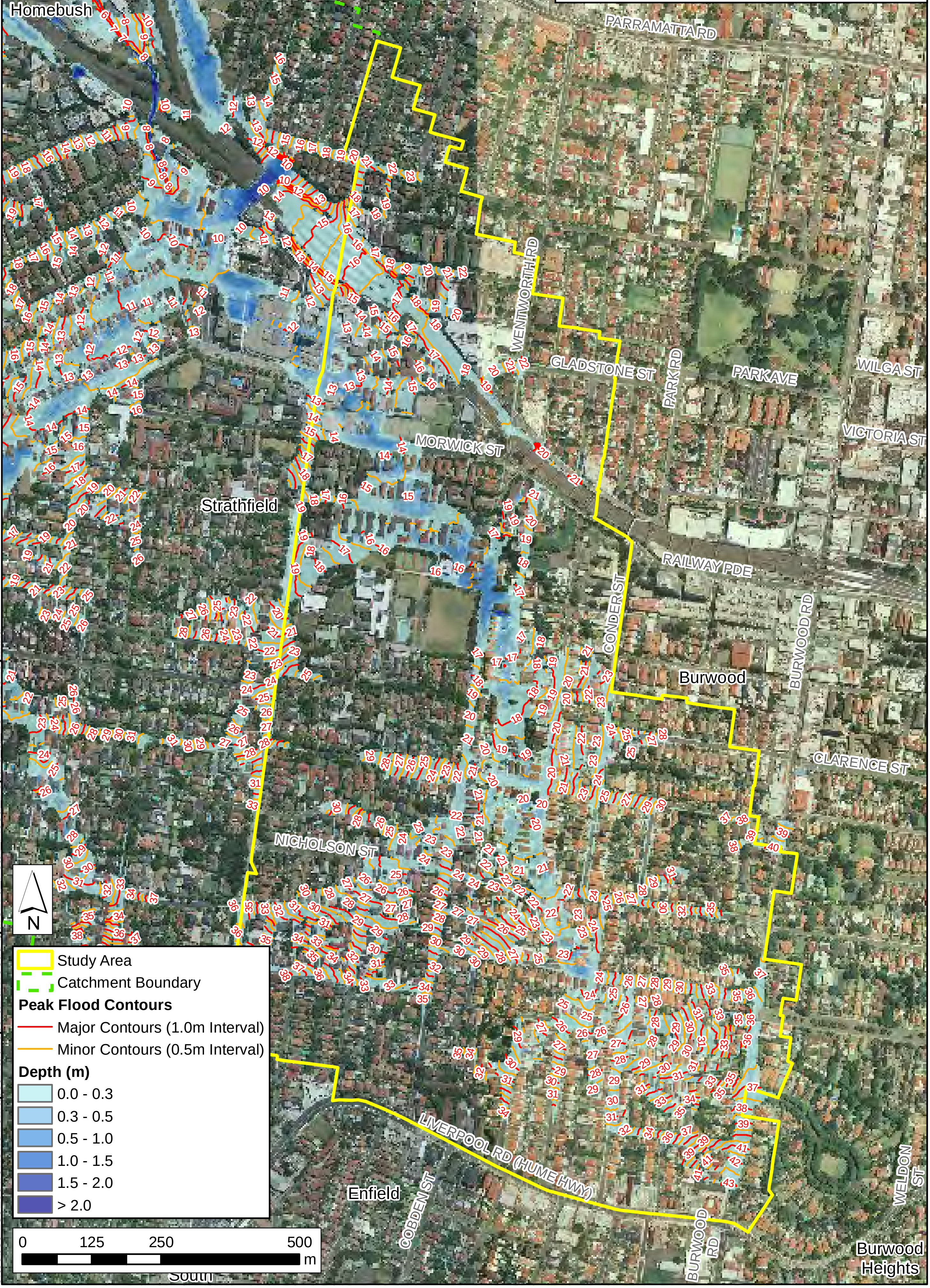
FIGURE 17C

PEAK FLOOD CONTOURS AND DEPTHS
10% AEP EVENT



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure17c_Peak_Flood_Depths_&_Levels_010y.mxd

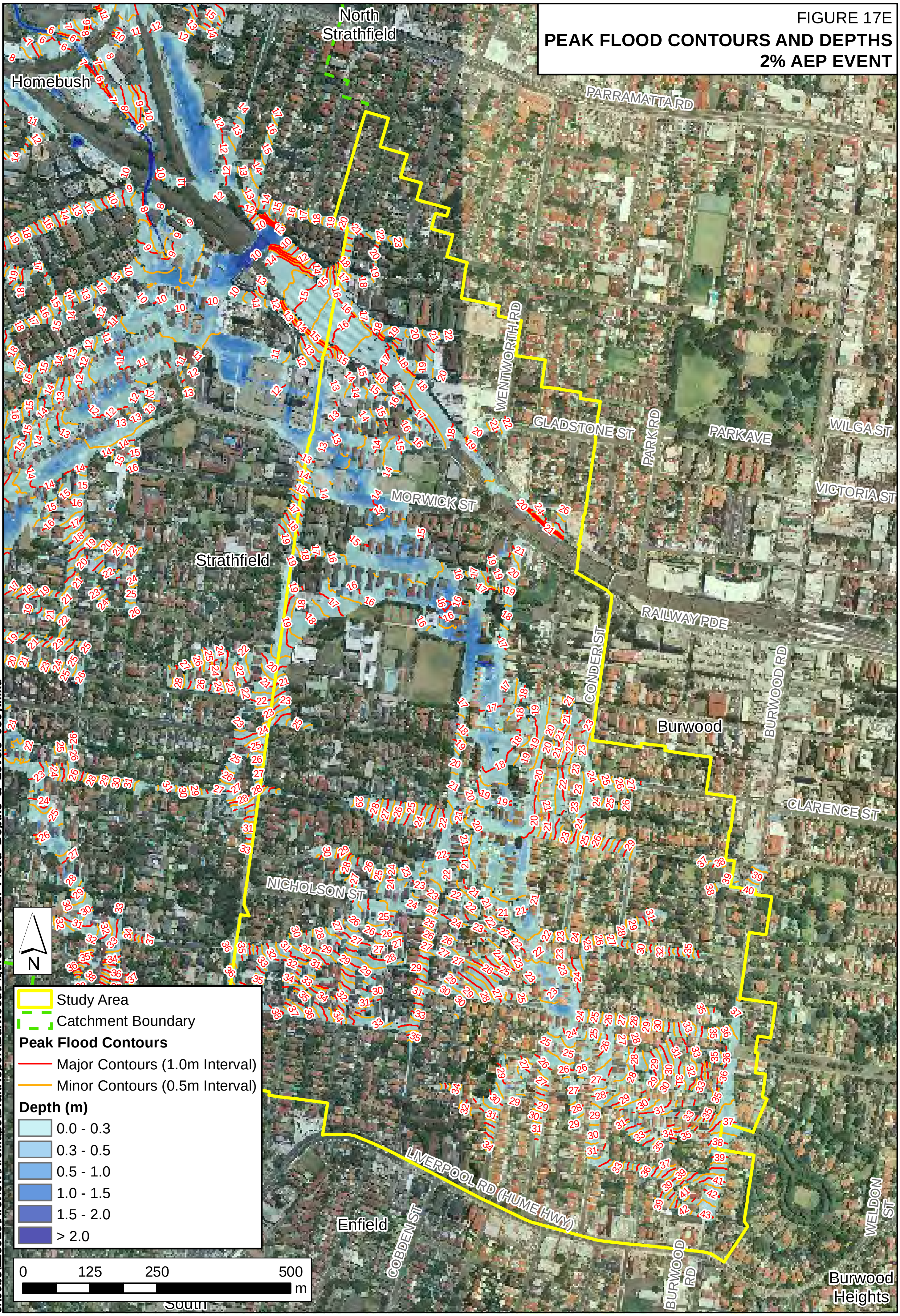
FIGURE 17D
PEAK FLOOD CONTOURS AND DEPTHS
5% AEP EVENT



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure17d Peak Flood Depths & Levels 020y.mxd

FIGURE 17E

PEAK FLOOD CONTOURS AND DEPTHS 2% AEP EVENT



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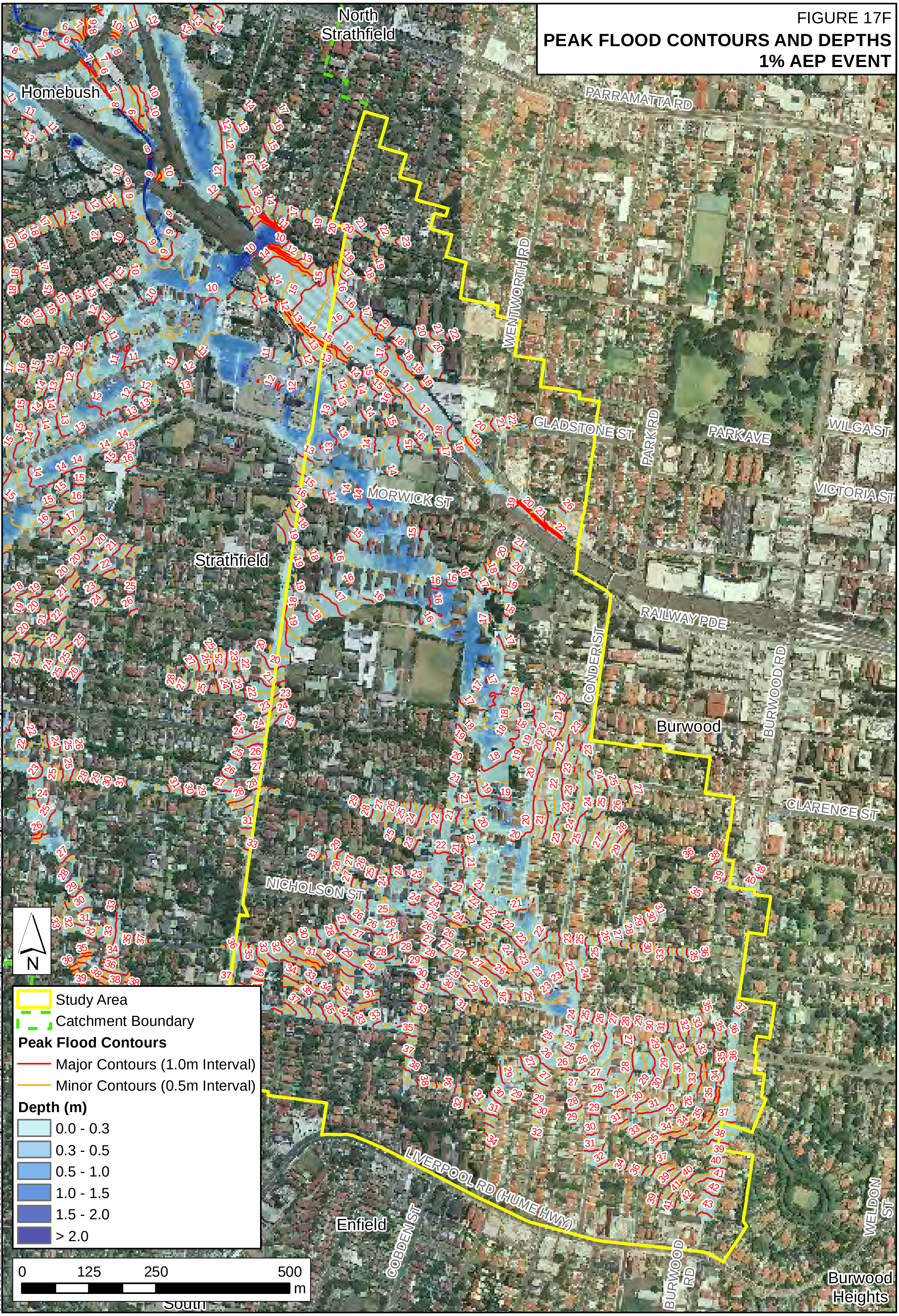


J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure17f_Peak_Flood_Depths_&_Levels_100y.mxd

FIGURE 17G
PEAK FLOOD CONTOURS AND DEPTHS
0.5% AEP EVENT

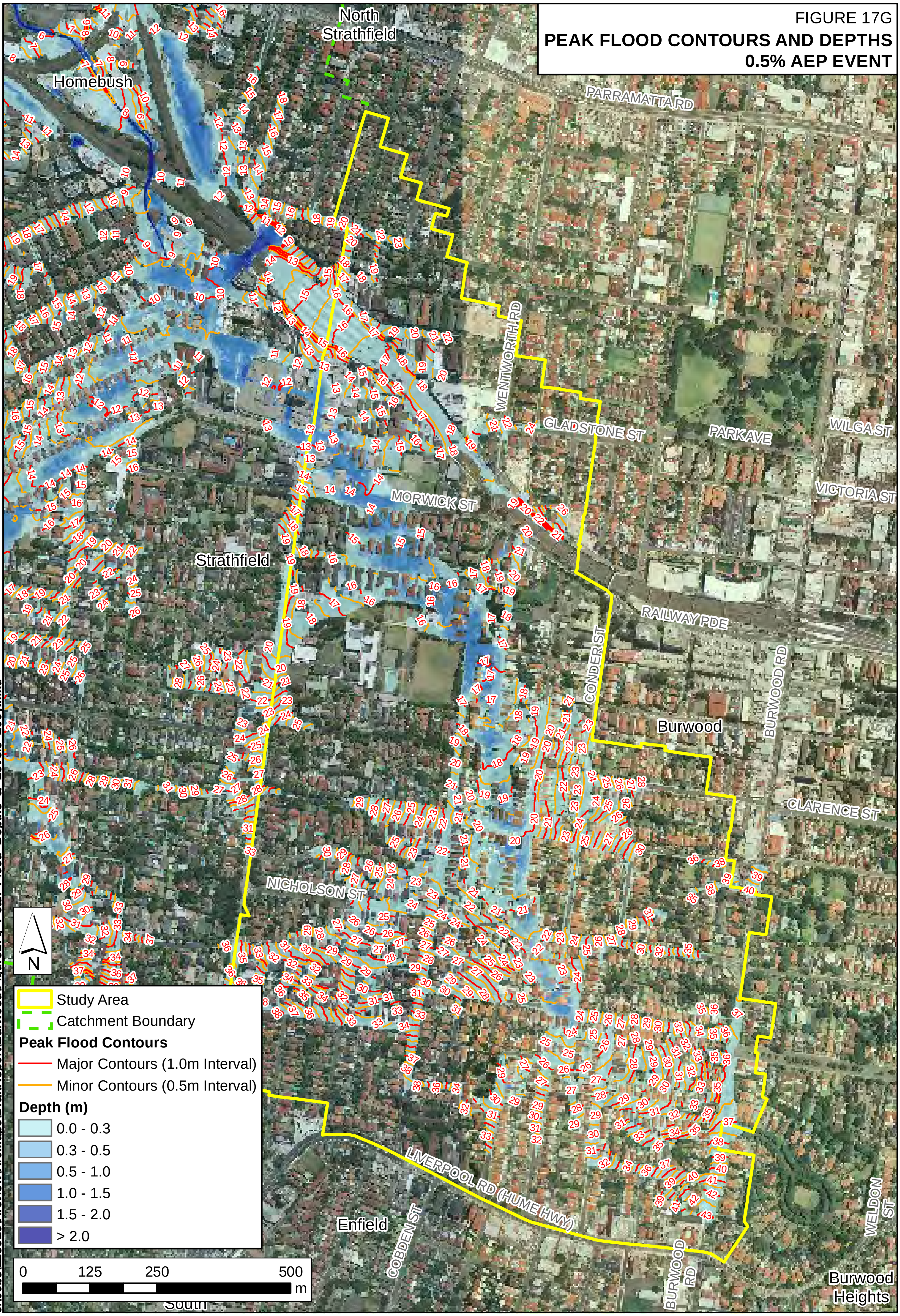
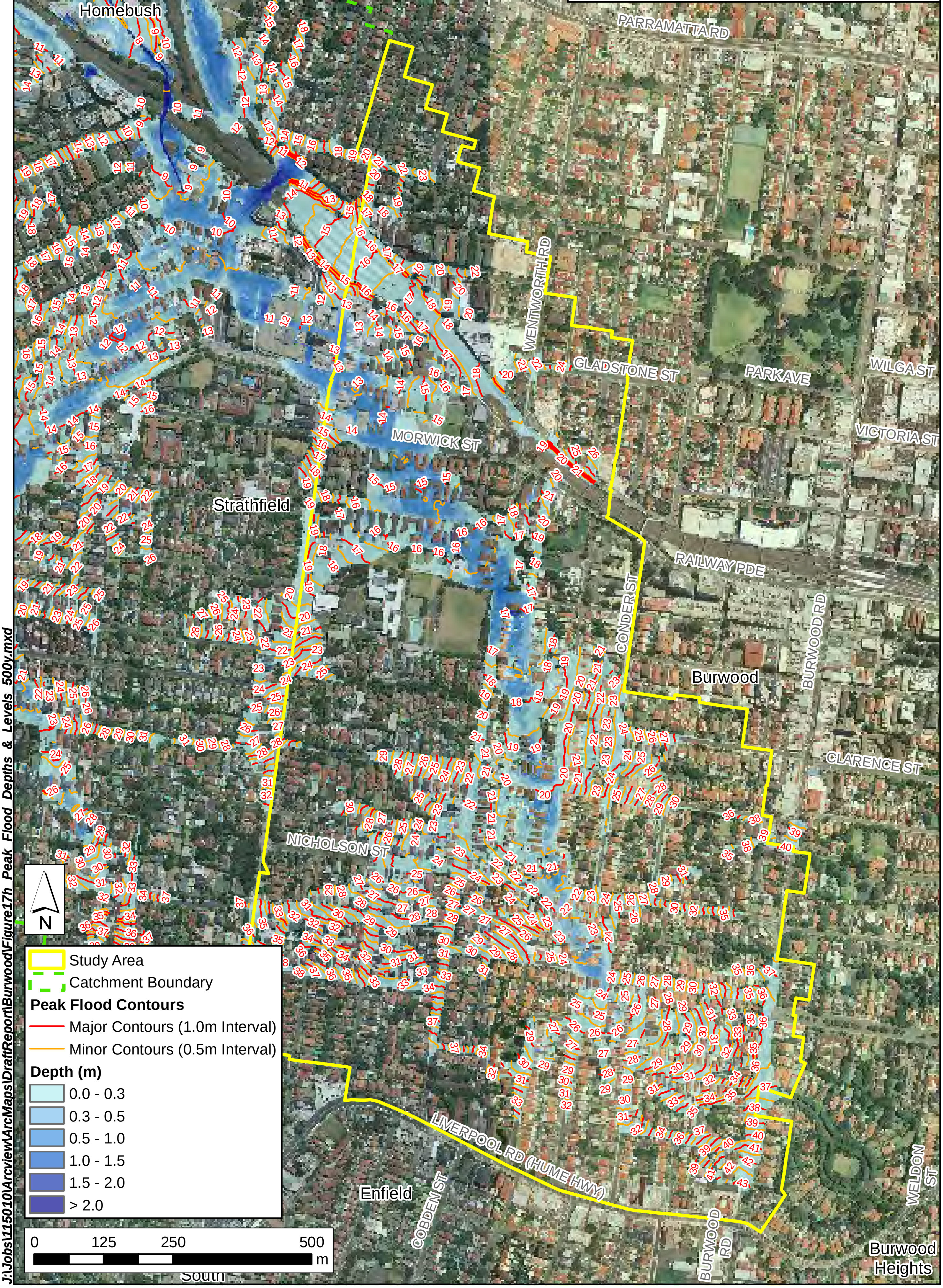


FIGURE 17H

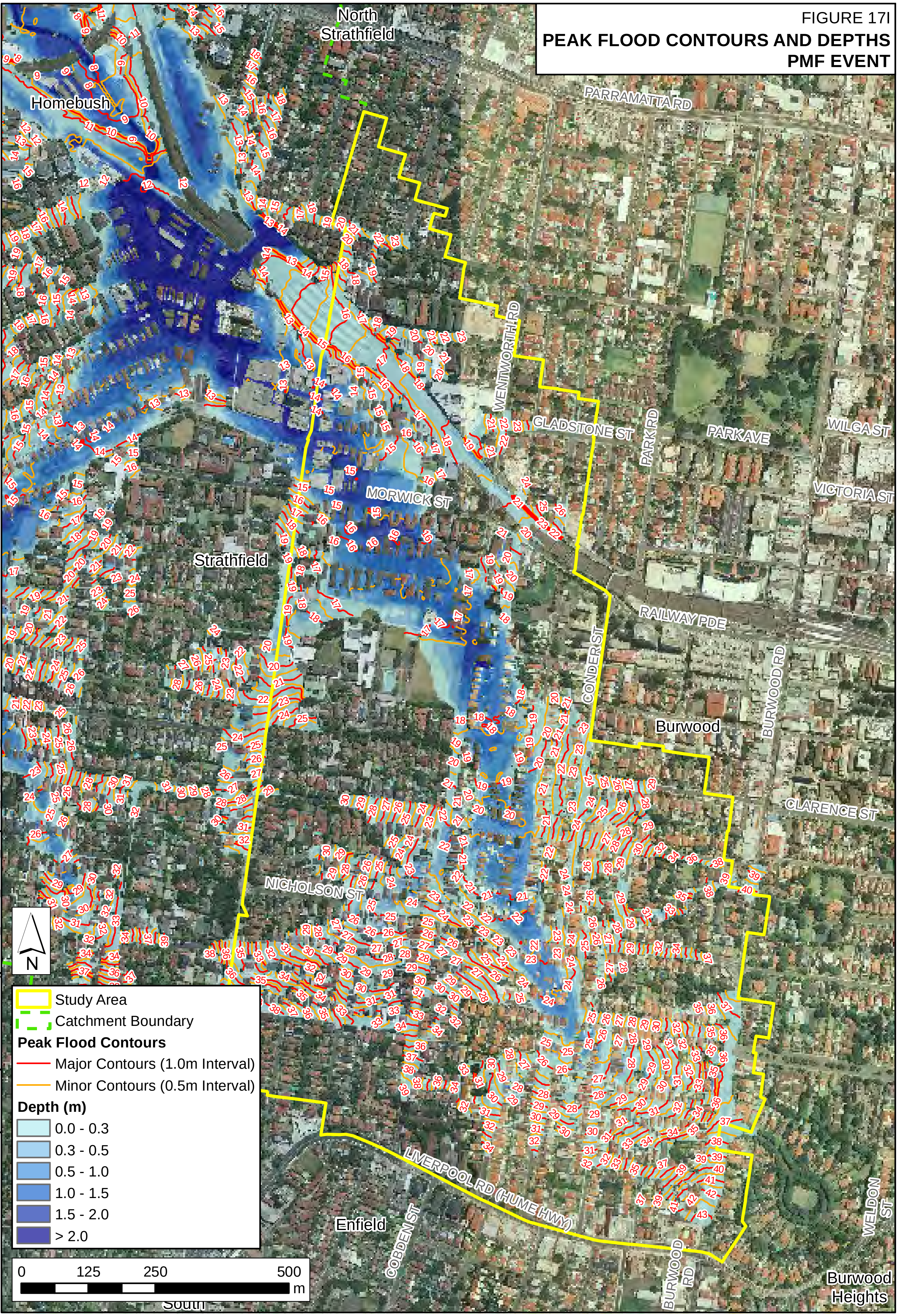
PEAK FLOOD CONTOURS AND DEPTHS
0.2% AEP EVENT



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure17h Peak Flood Depths & Levels 500y.mxd

FIGURE 17I

PEAK FLOOD CONTOURS AND DEPTHS PMF EVENT



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure17I_Peak_Flood_Depths_&_Levels_PMF.mxd

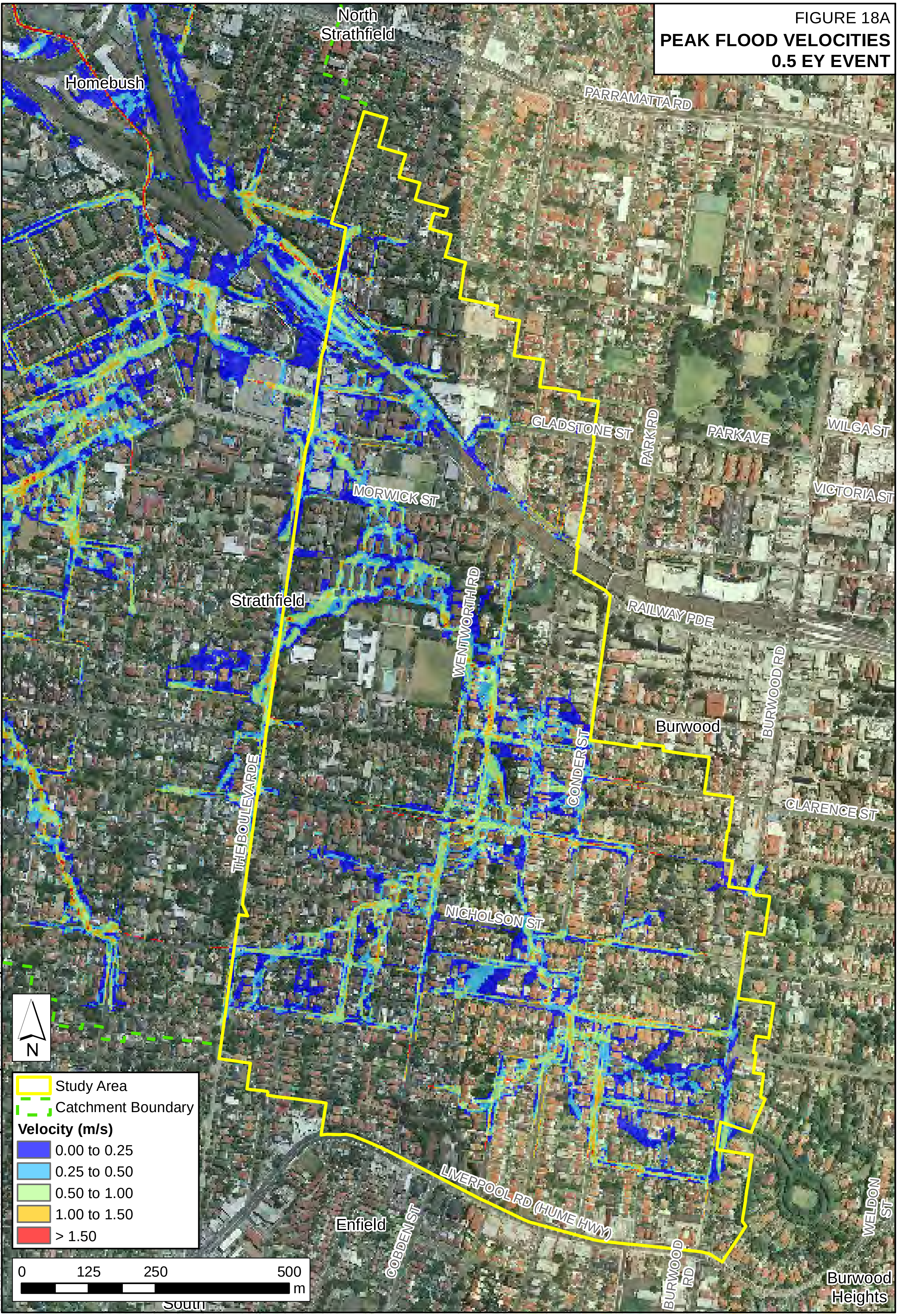


FIGURE 18A
PEAK FLOOD VELOCITIES
0.5 EY EVENT
North Strathfield
Homebush
PARRAMATTA RD
GLADSTONE ST
PARK RD
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
RAILWAY PDE
WENTWORTH RD
Strathfield
Burwood
BURWOOD RD
CONDER ST
CLARENCE ST
THE BOULEVARDE
NICHOLSON ST
LIVERPOOL RD (HUME HWY)
Enfield
COBDEN ST
WELDON ST
Burwood Heights
N
Study Area
Catchment Boundary
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0 125 250 500
m
J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure18a_Peak_Flood_Velocities_002y.mxd

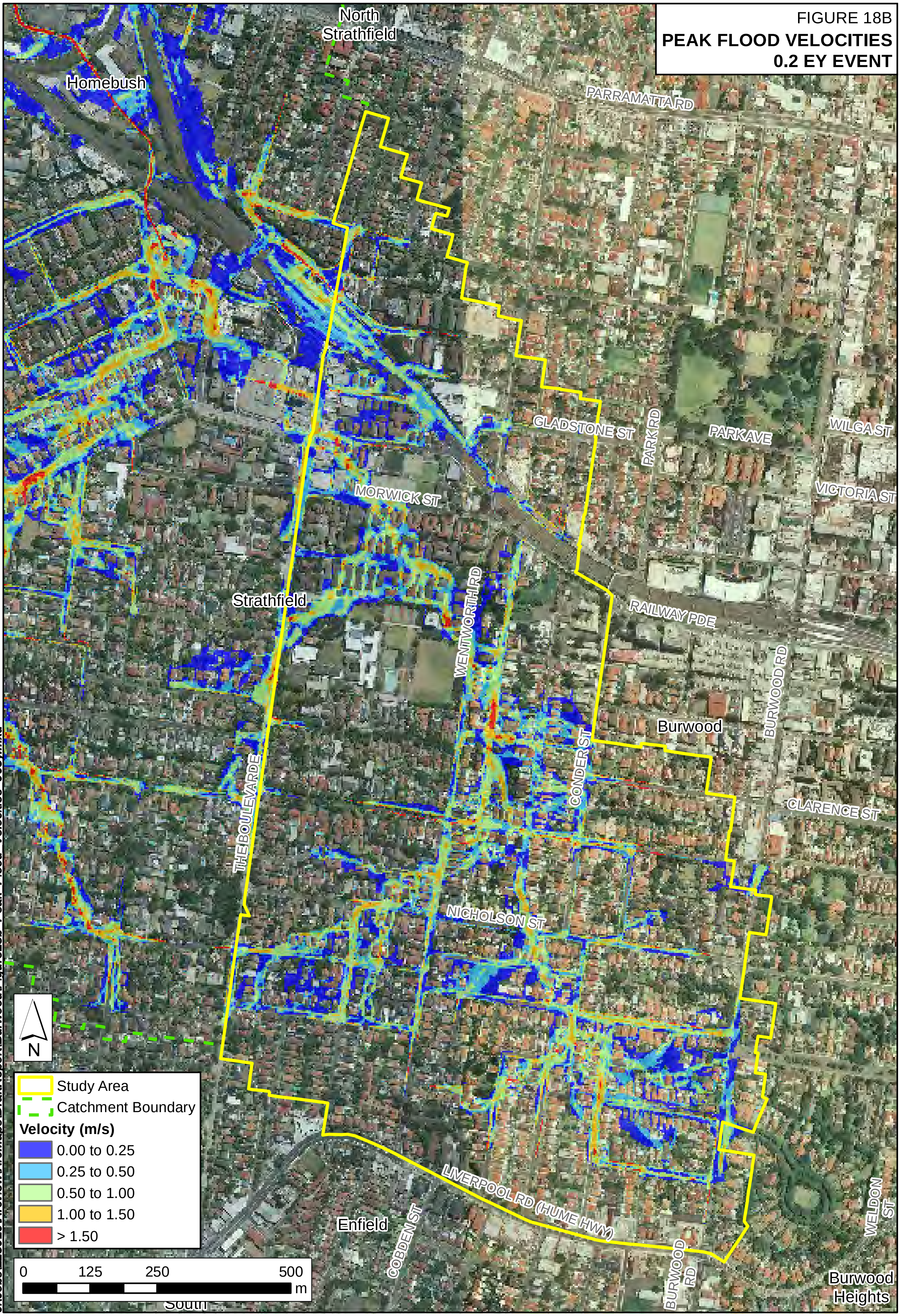


FIGURE 18B
PEAK FLOOD VELOCITIES
0.2 EY EVENT
North Strathfield
Homebush
PARRAMATTA RD
GLADSTONE ST
PARK RD
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
RAILWAY PDE
Strathfield
WENTWORTH RD
BURWOOD RD
Burwood
CONDER ST
CLARENCE ST
THE BOULEVARDE
NICHOLSON ST
LIVERPOOL RD (HUME HWY)
Enfield
COBDEN ST
BURWOOD RD
WELDON ST
Burwood Heights
South
N
Study Area
Catchment Boundary
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0
125
250
500
m
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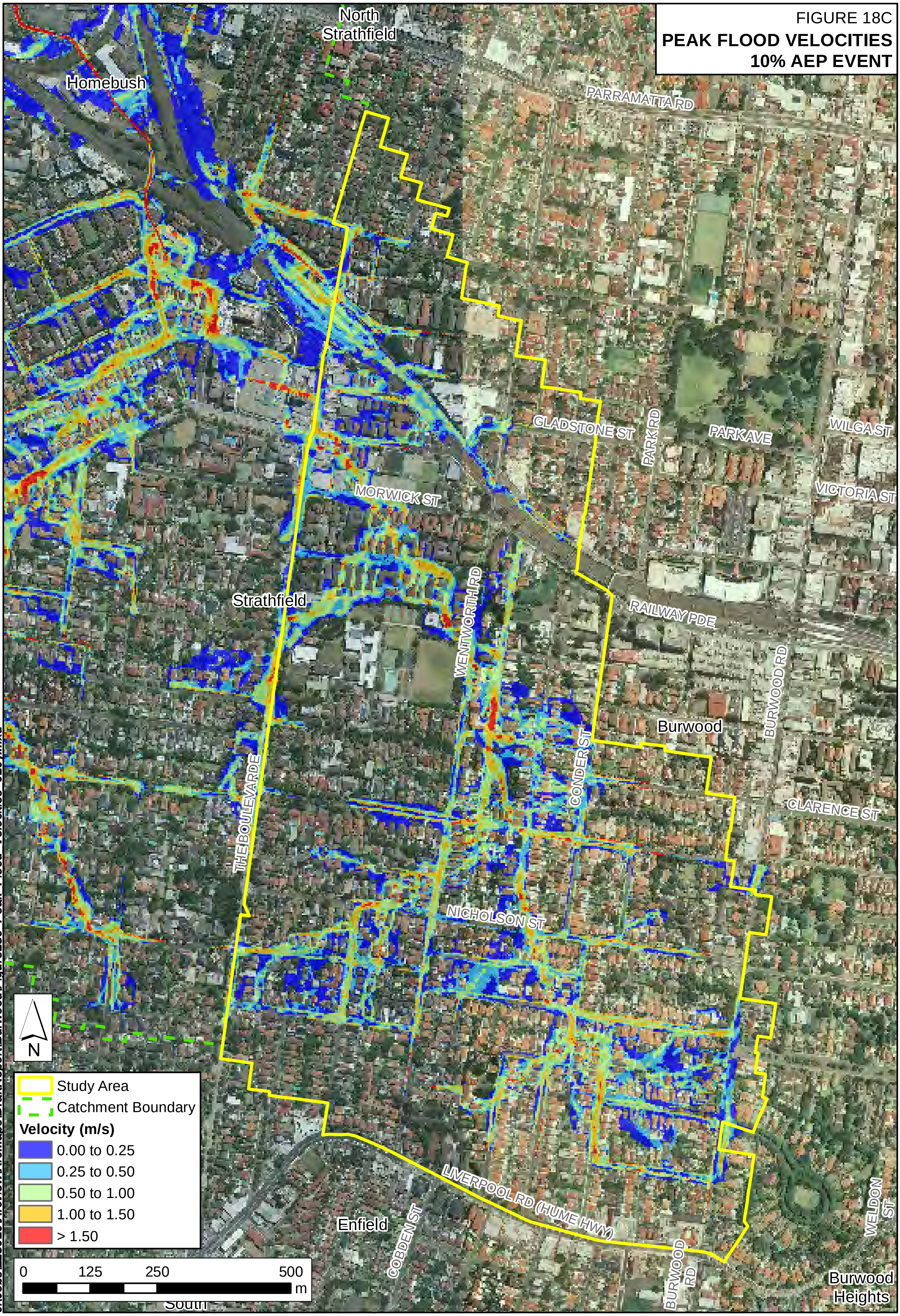

FIGURE 18C
PEAK FLOOD VELOCITIES
10% AEP EVENT
North Strathfield
Homebush
PARRAMATTA RD
GLADSTONE ST
PARK RD
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
RAILWAY PDE
Strathfield
WENTWORTH RD
BURWOOD RD
Burwood
CONDER ST
CLARENCE ST
THE BOULEVARDE
NICHOLSON ST
LIVERPOOL RD (HUME HWY)
Enfield
COBDEN ST
BURWOOD RD
WELDON ST
Burwood Heights
South
N
Study Area
Catchment Boundary
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0
125
250
500
m
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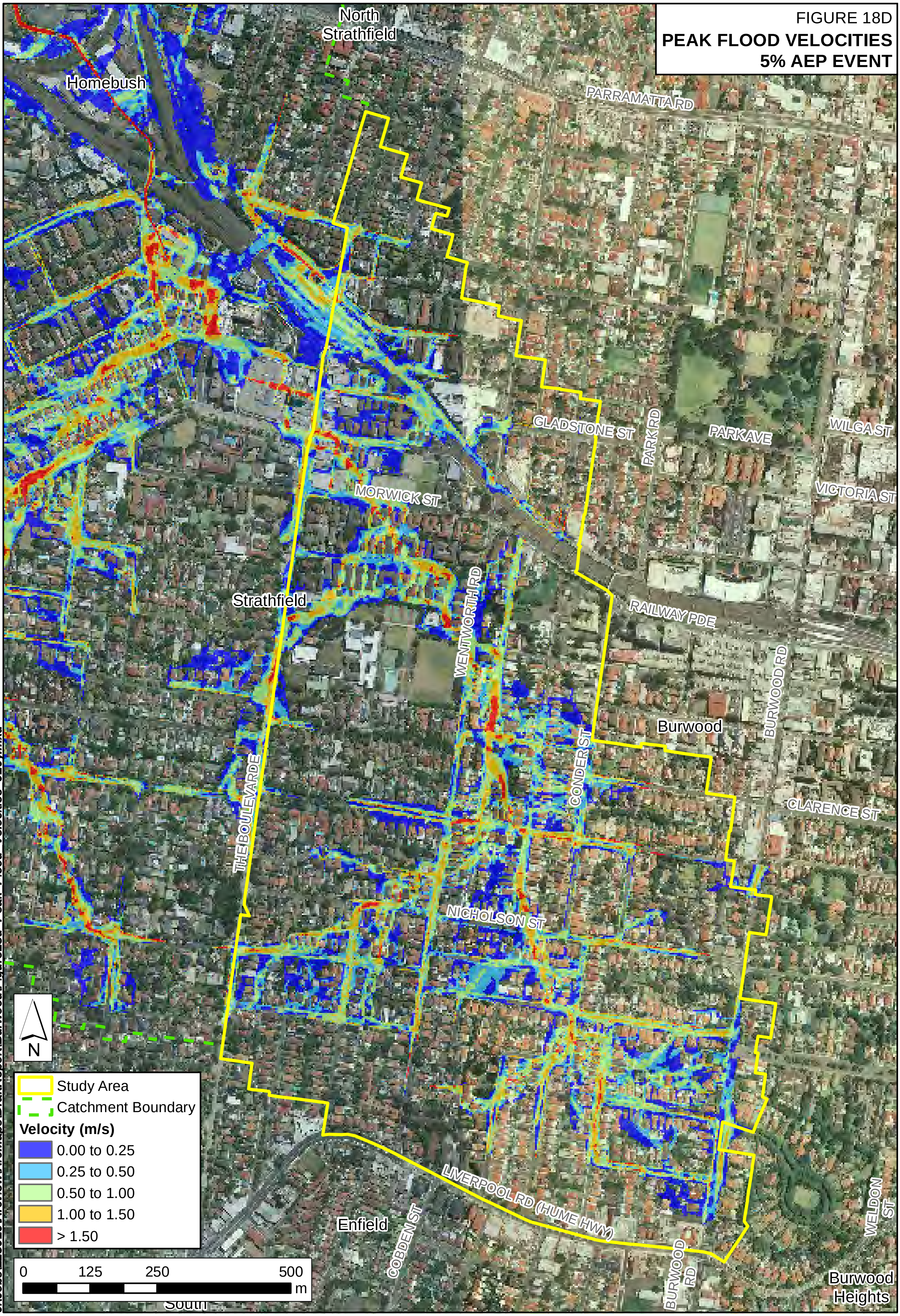
FIGURE 18D
PEAK FLOOD VELOCITIES
5% AEP EVENT



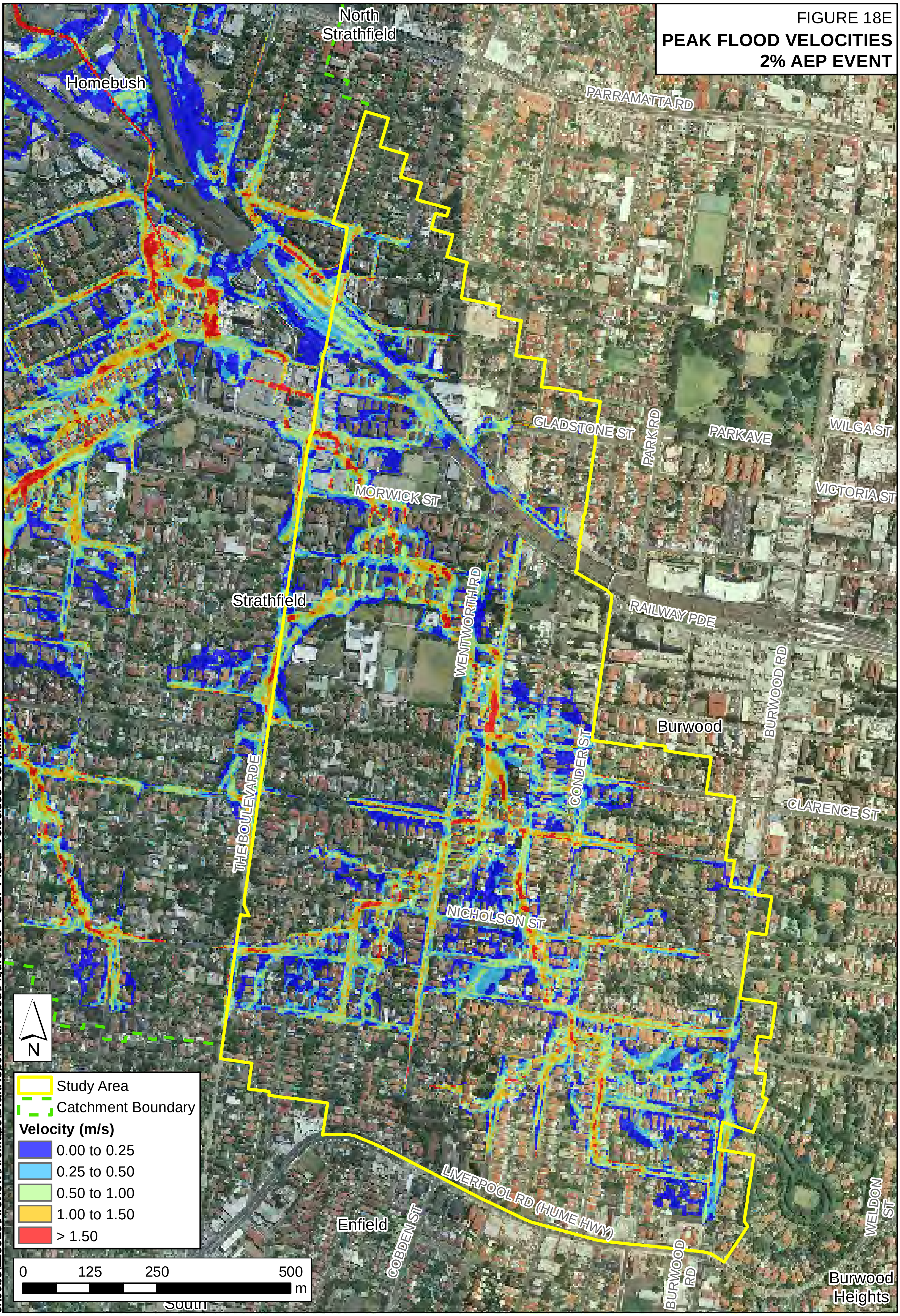
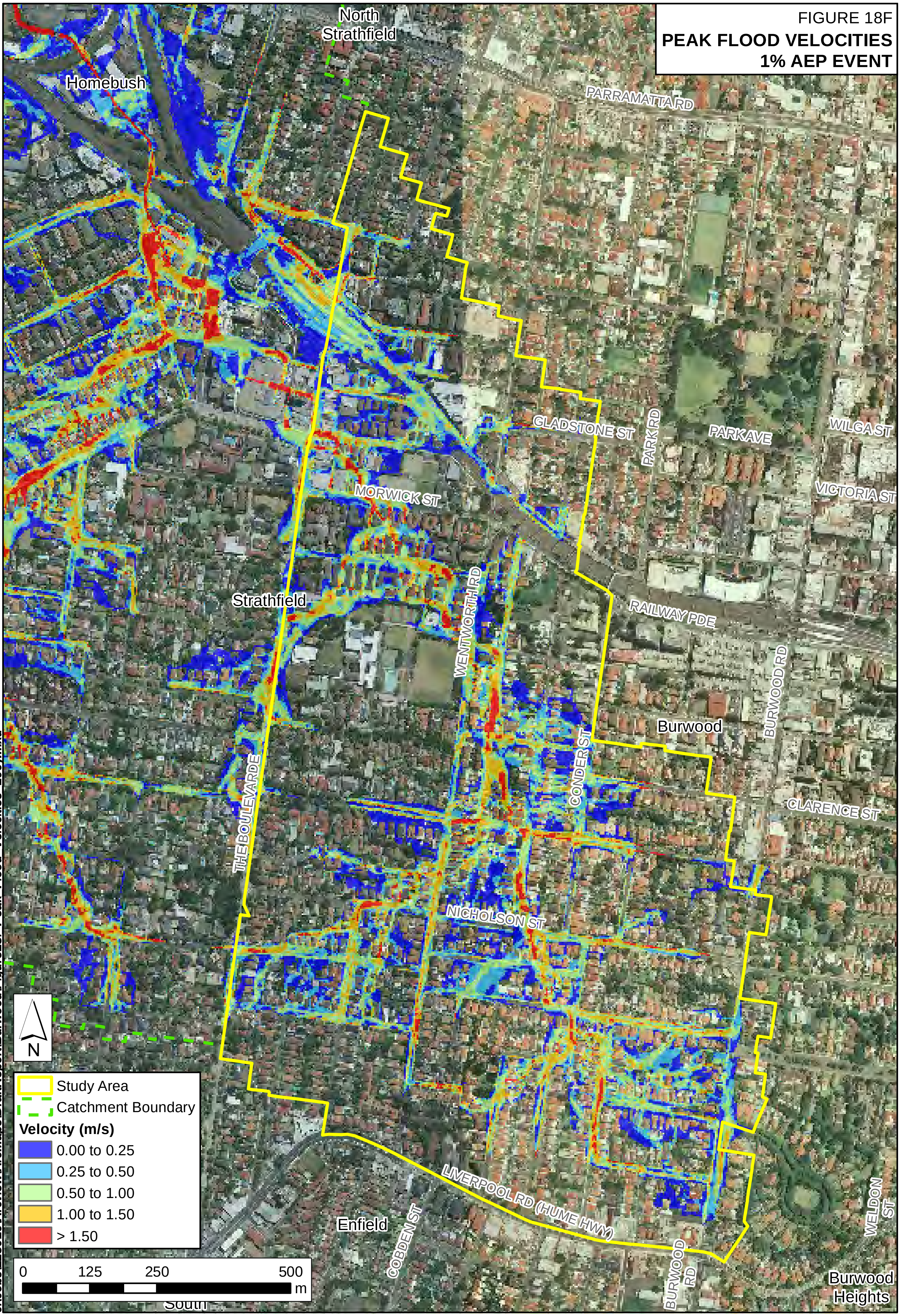


FIGURE 18E
PEAK FLOOD VELOCITIES
2% AEP EVENT
North Strathfield
Homebush
PARRAMATTA RD
GLADSTONE ST
PARK RD
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
Strathfield
WENTWORTH RD
RAILWAY PDE
BURWOOD RD
Burwood
CONDER ST
CLARENCE ST
THE BOULEVARDE
NICHOLSON ST
LIVERPOOL RD (HUME HWY)
Enfield
COBDEN ST
BURWOOD RD
WELDON ST
Burwood Heights
South
N
Study Area
Catchment Boundary
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0
125
250
500
m
J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure18e_Peak_Flood_Velocities_050y.mxd

FIGURE 18F
PEAK FLOOD VELOCITIES
1% AEP EVENT



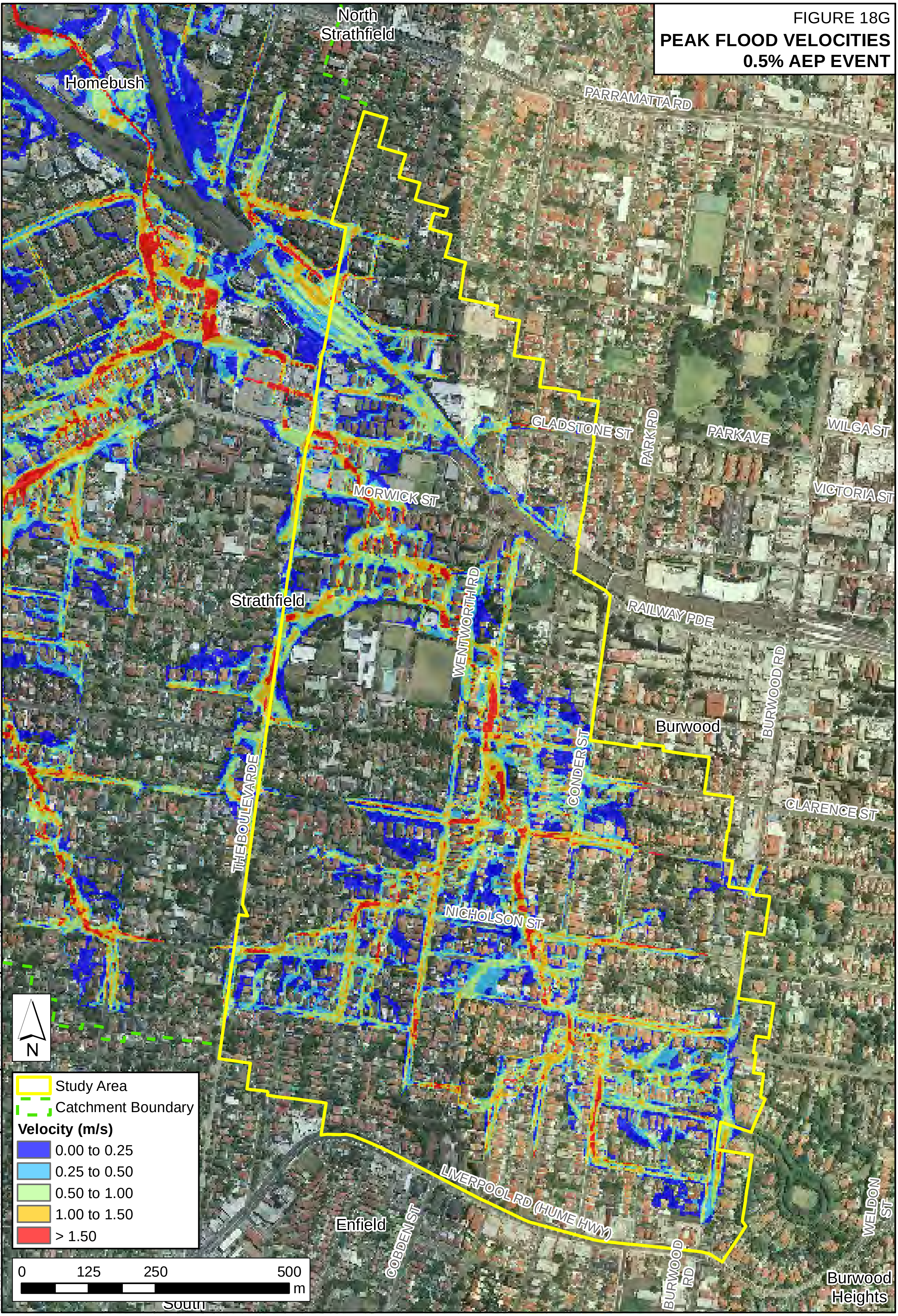


FIGURE 18G
PEAK FLOOD VELOCITIES 0.5% AEP EVENT

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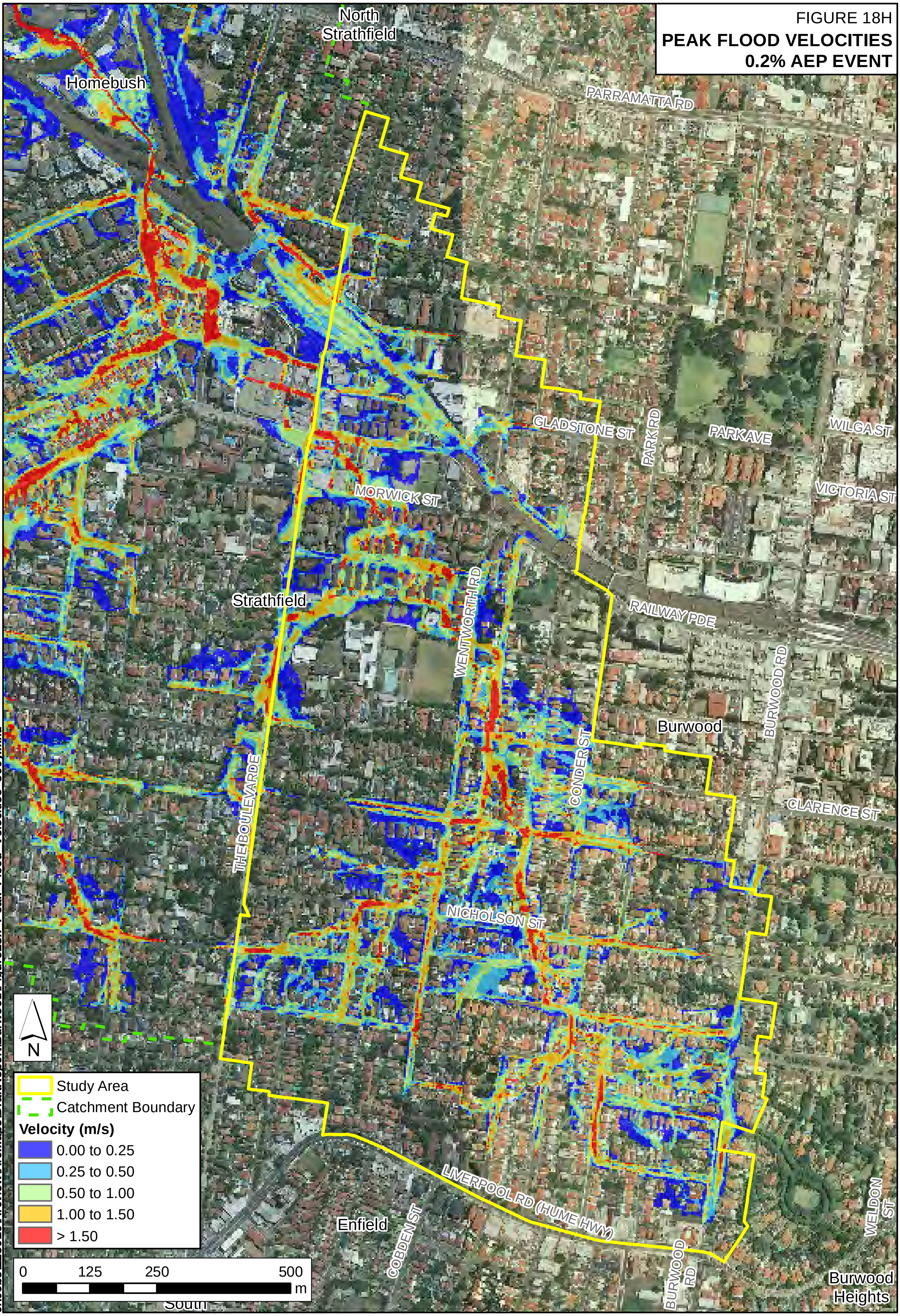

FIGURE 18H
PEAK FLOOD VELOCITIES
0.2% AEP EVENT
North Strathfield
Homebush
PARRAMATTA RD
GLADSTONE ST
PARK RD
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
WENTWORTH RD
Strathfield
RAILWAY PDE
BURWOOD RD
Burwood
CONDER ST
CLARENCE ST
THE BOULEVARDE
NICHOLSON ST
LIVERPOOL RD (HUME HWY)
Enfield
COBDEN ST
BURWOOD RD
WELDON ST
Burwood Heights
South
N
Study Area
Catchment Boundary
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0 125 250 500
m
J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure18h_Peak_Flood_Velocities_500y.mxd

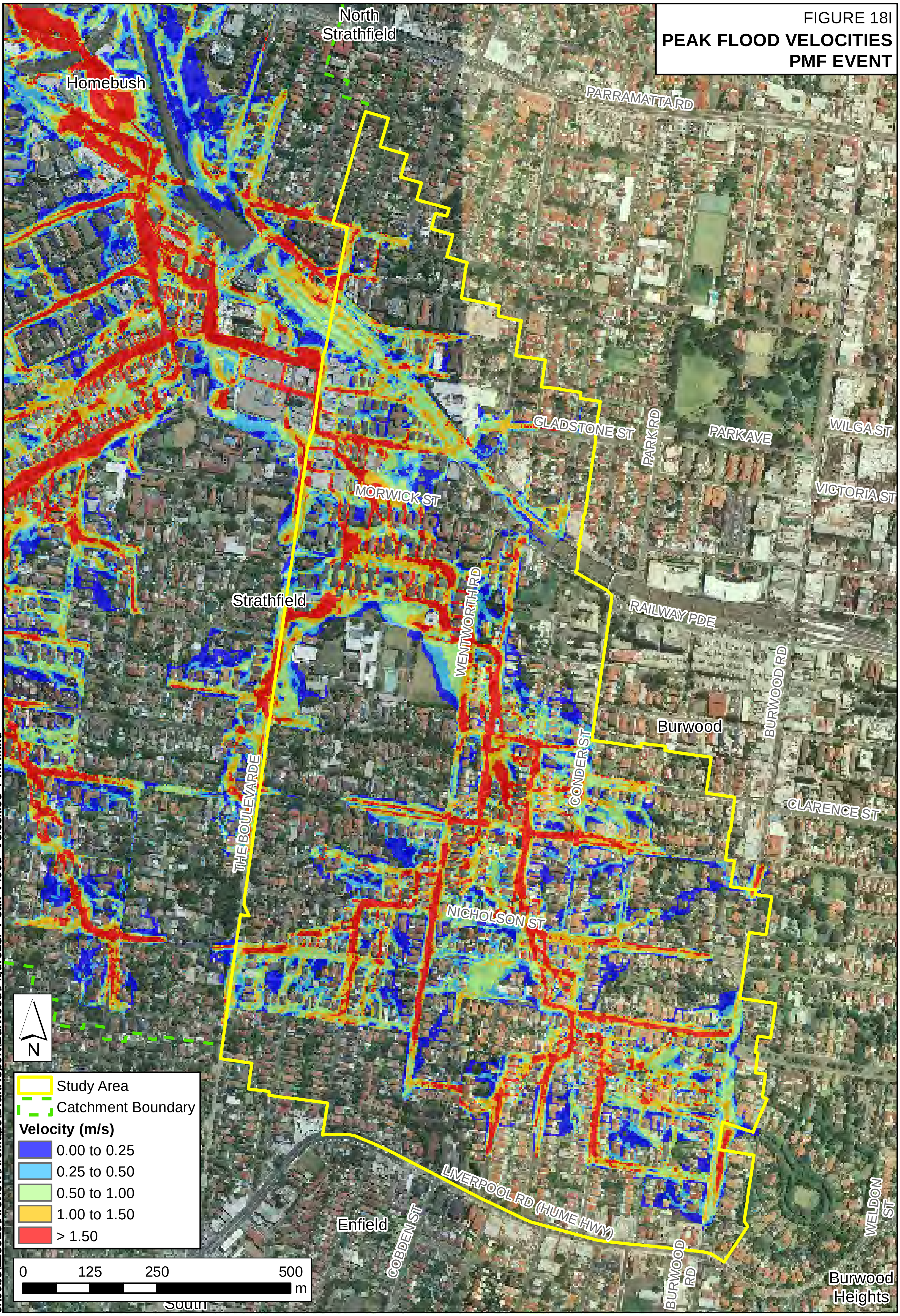

FIGURE 18I
PEAK FLOOD VELOCITIES
PMF EVENT
North Strathfield
Homebush
PARRAMATTA RD
GLADSTONE ST
PARK RD
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
WENTWORTH RD
Strathfield
RAILWAY PDE
BURWOOD RD
Burwood
CONDER ST
CLARENCE ST
THE BOULEVARDE
NICHOLSON ST
LIVERPOOL RD (HUME HWY)
Enfield
COBDEN ST
BURWOOD RD
WELDON ST
Burwood Heights
South
N
Study Area
Catchment Boundary
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0
125
250
500
m
J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure18i_Peak_Flood_Velocities_PMF.mxd

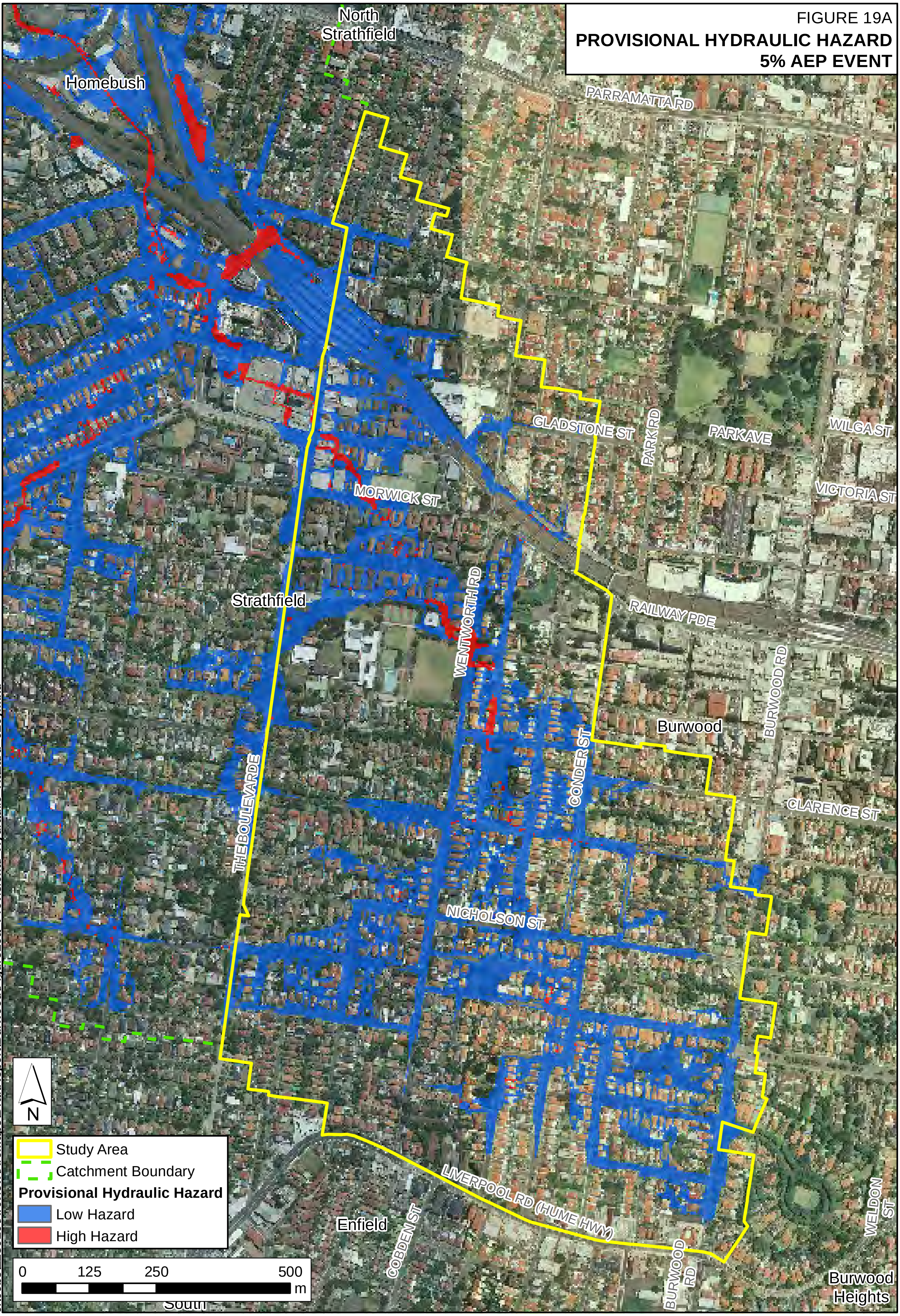

FIGURE 19A
PROVISIONAL HYDRAULIC HAZARD 5% AEP EVENT

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FIGURE 19B
PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT

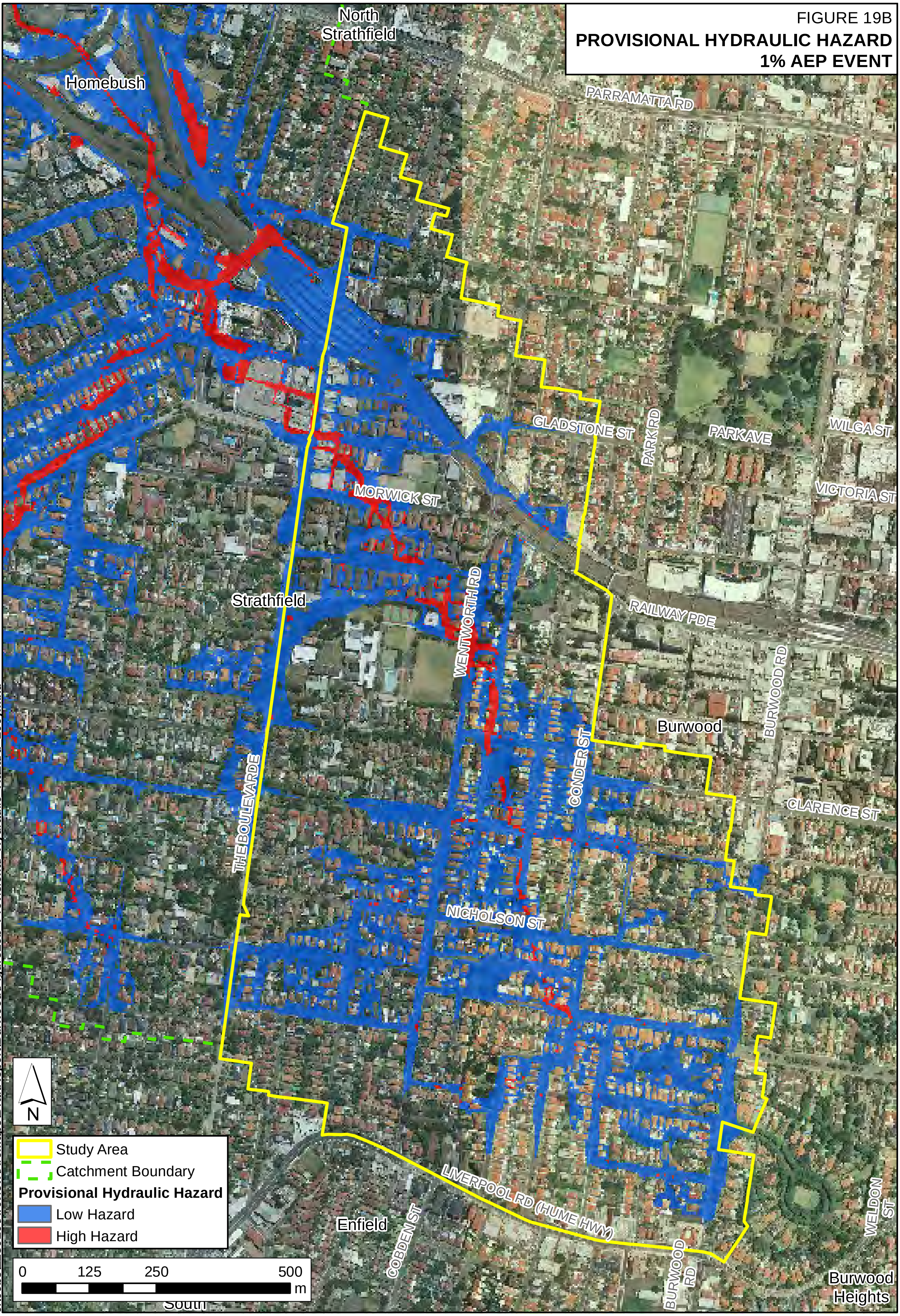

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FIGURE 19C
PROVISIONAL HYDRAULIC HAZARD
PMF EVENT

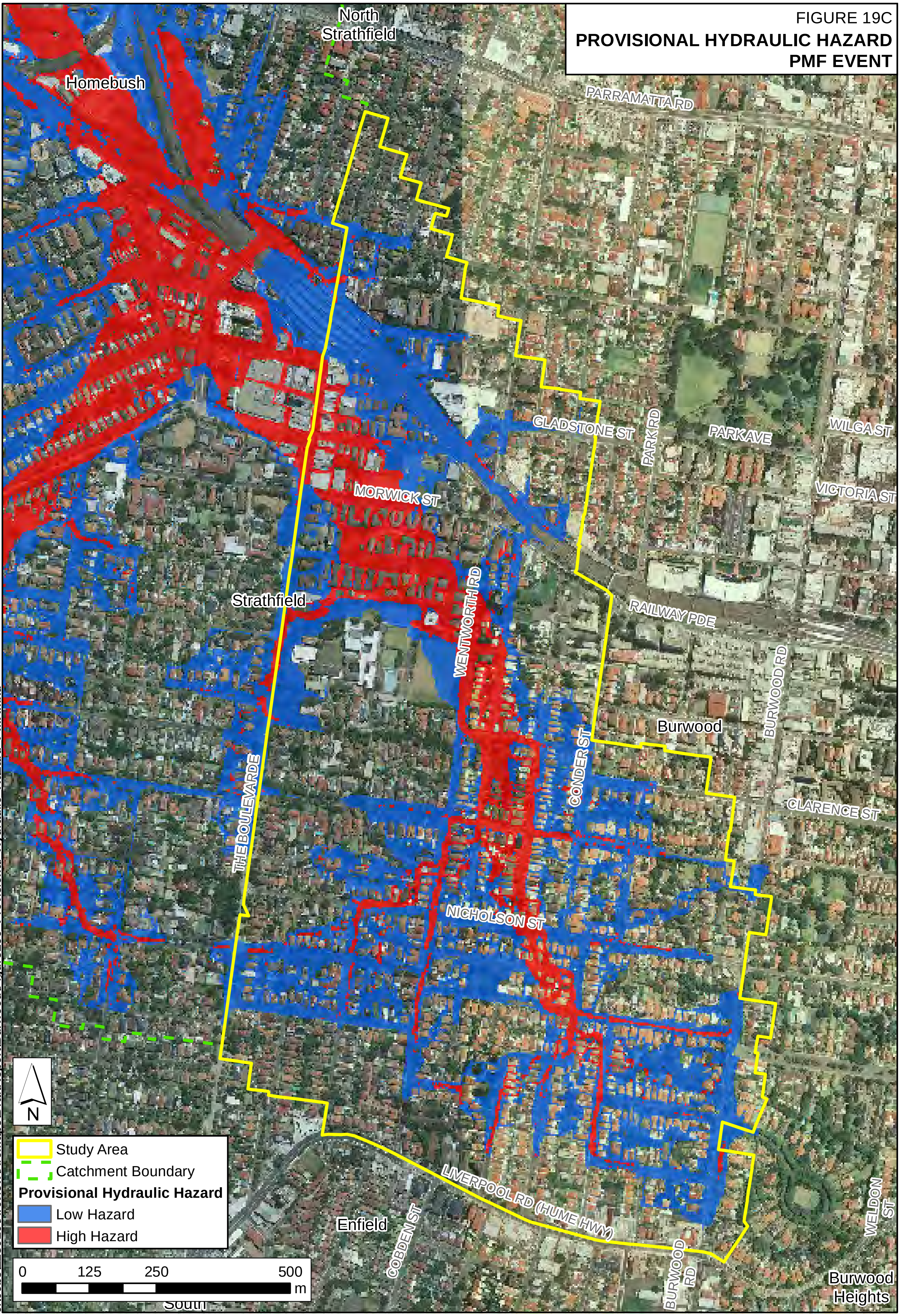

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FIGURE 20A
PROVISIONAL HYDRAULIC CATEGORISATION
5% AEP EVENT

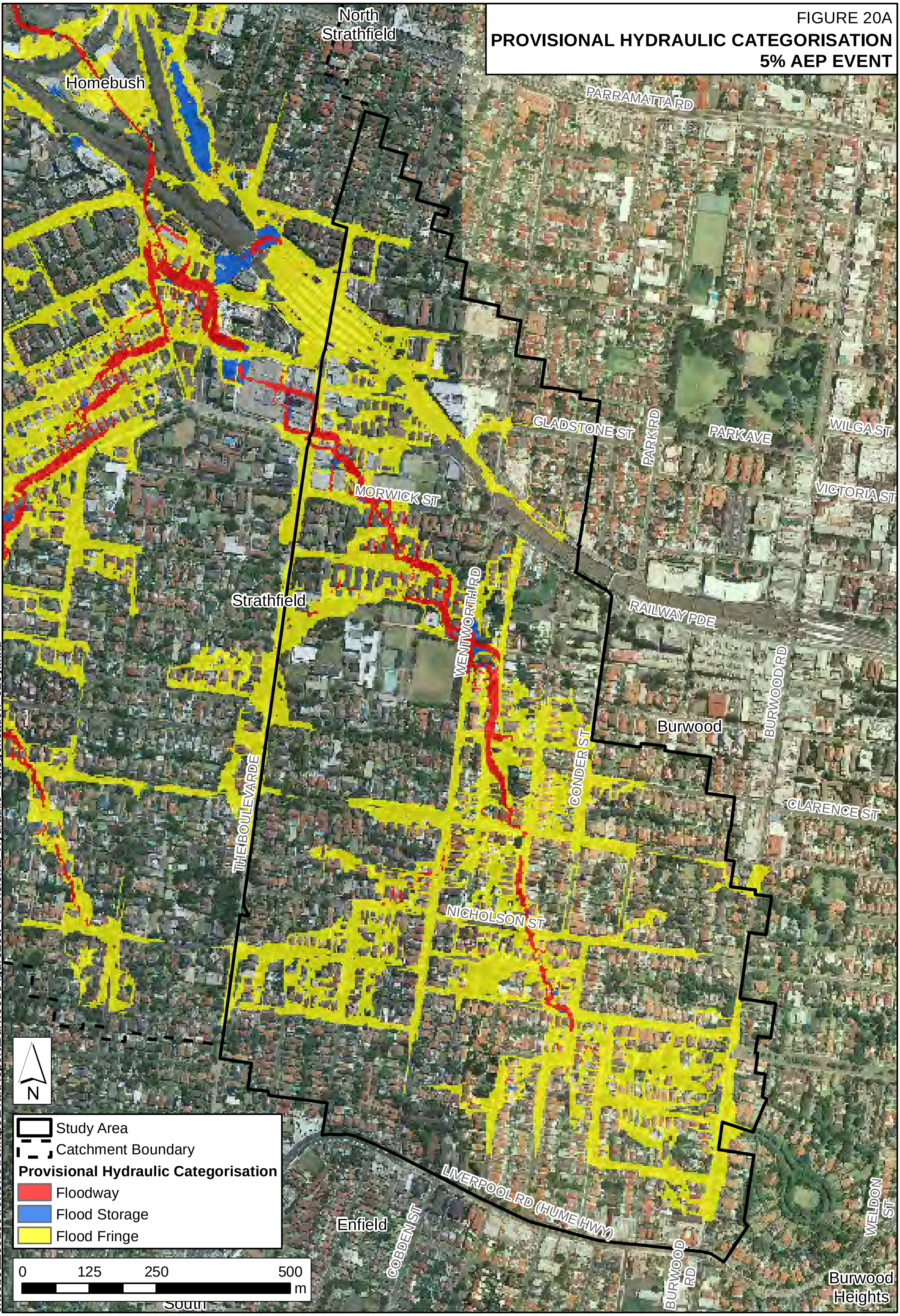

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FIGURE 20B

PROVISIONAL HYDRAULIC CATEGORISATION 1% AEP EVENT

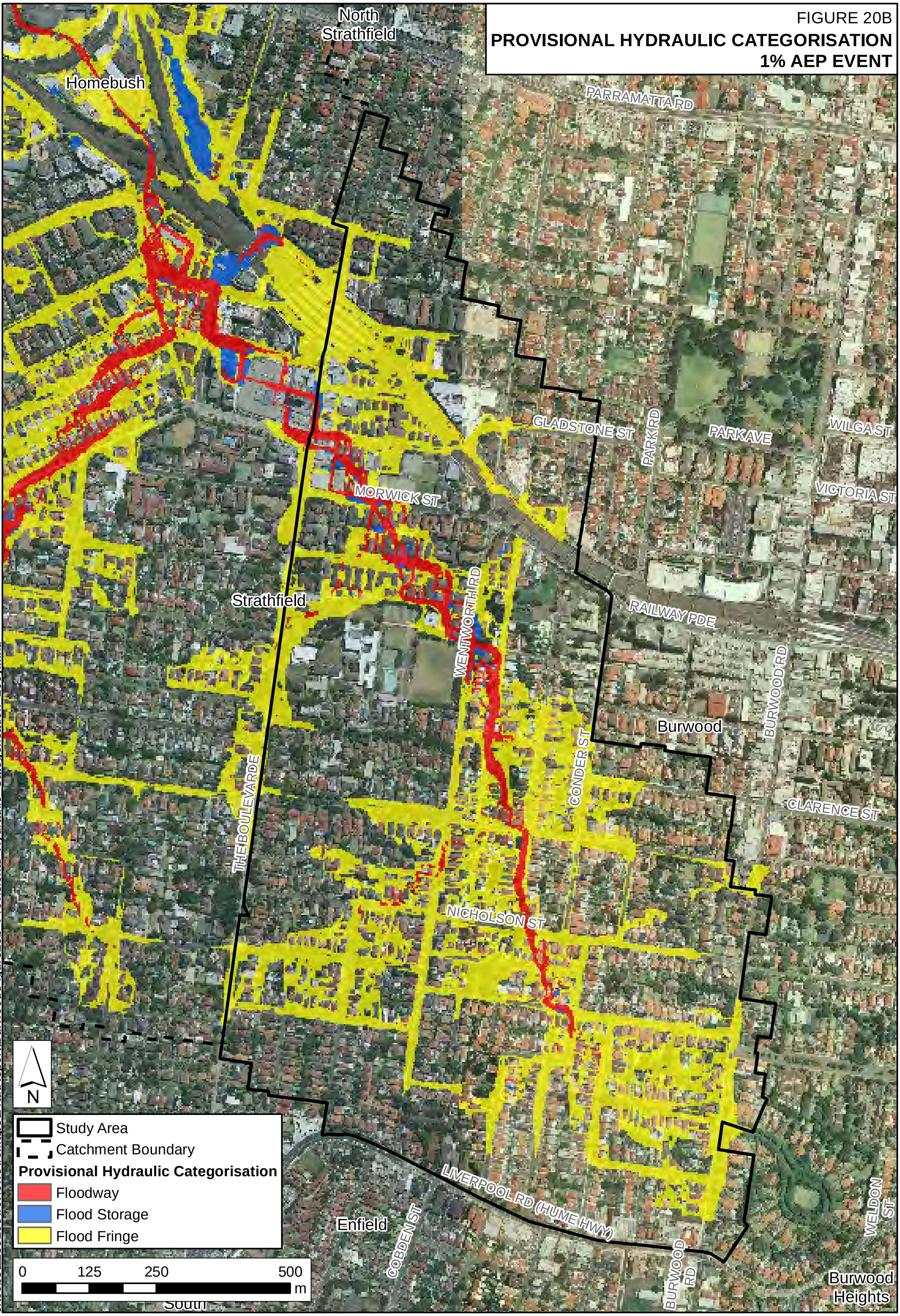

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FIGURE 20C
PROVISIONAL HYDRAULIC CATEGORISATION
PMF EVENT

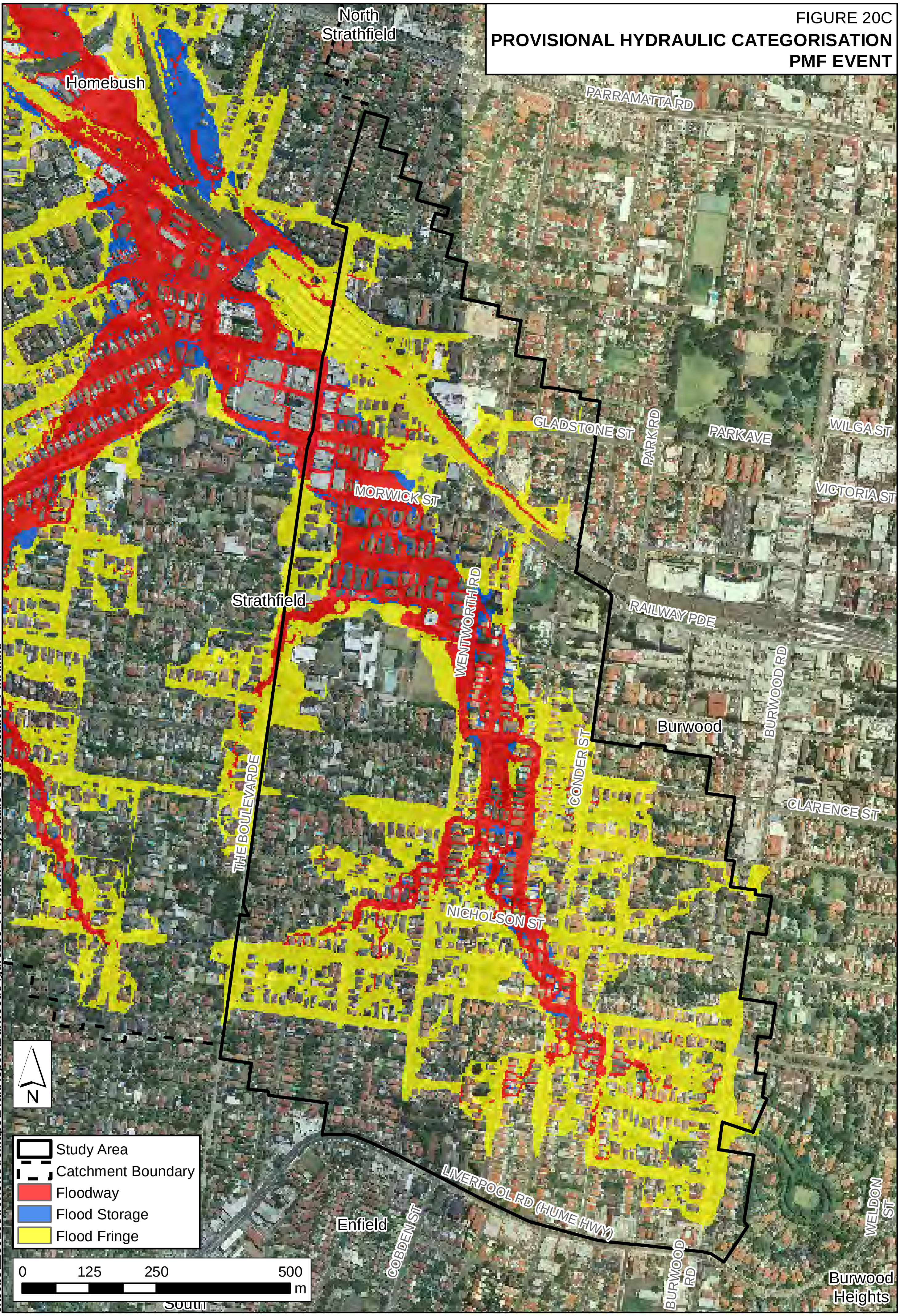

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FIGURE 21

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

LP3 ANALYSIS - BAYESIAN

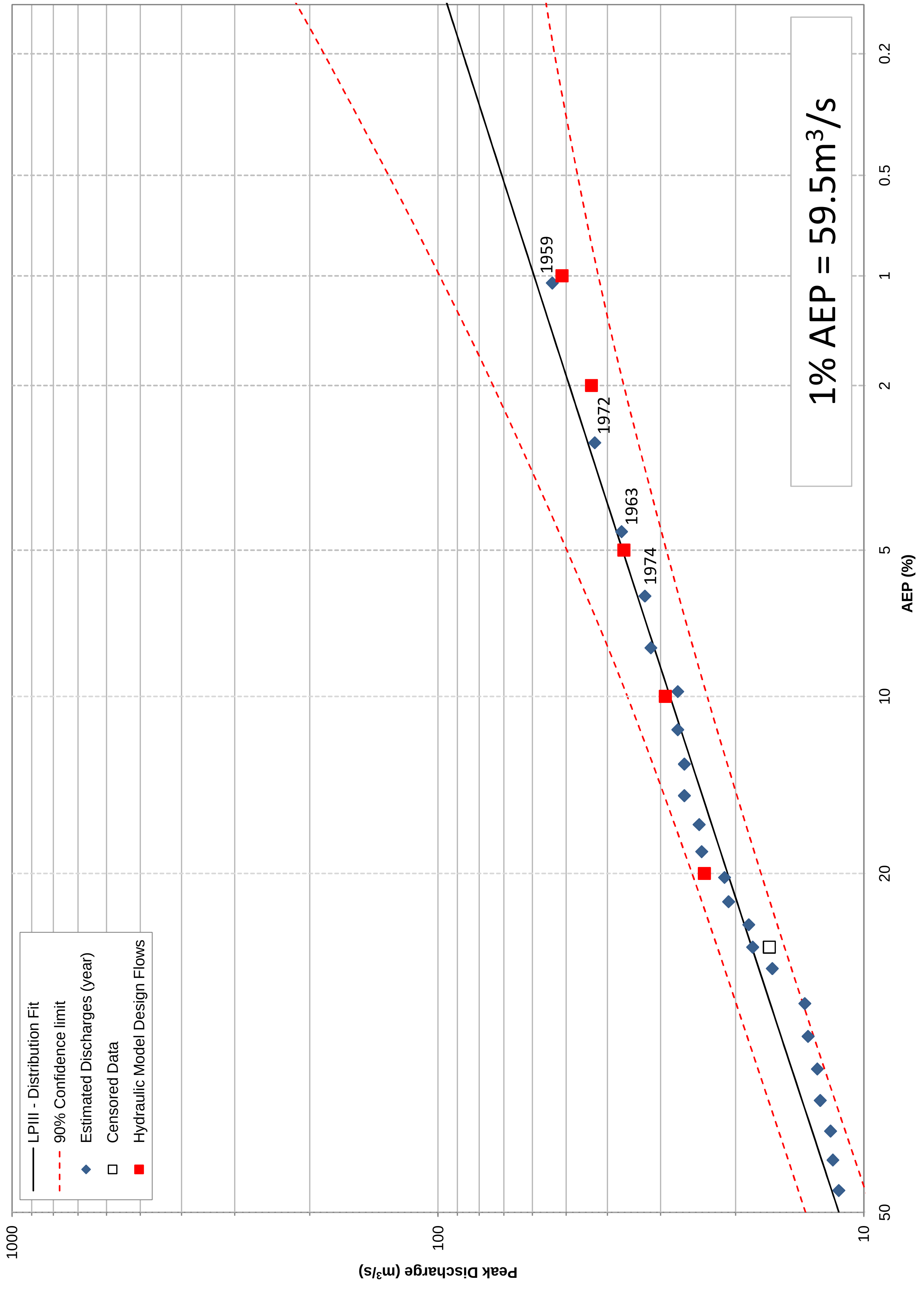

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FIGURE 22
POWELLS CREEK - BURWOOD LGA
DURATION OF INUNDATION
1% AEP EVENT

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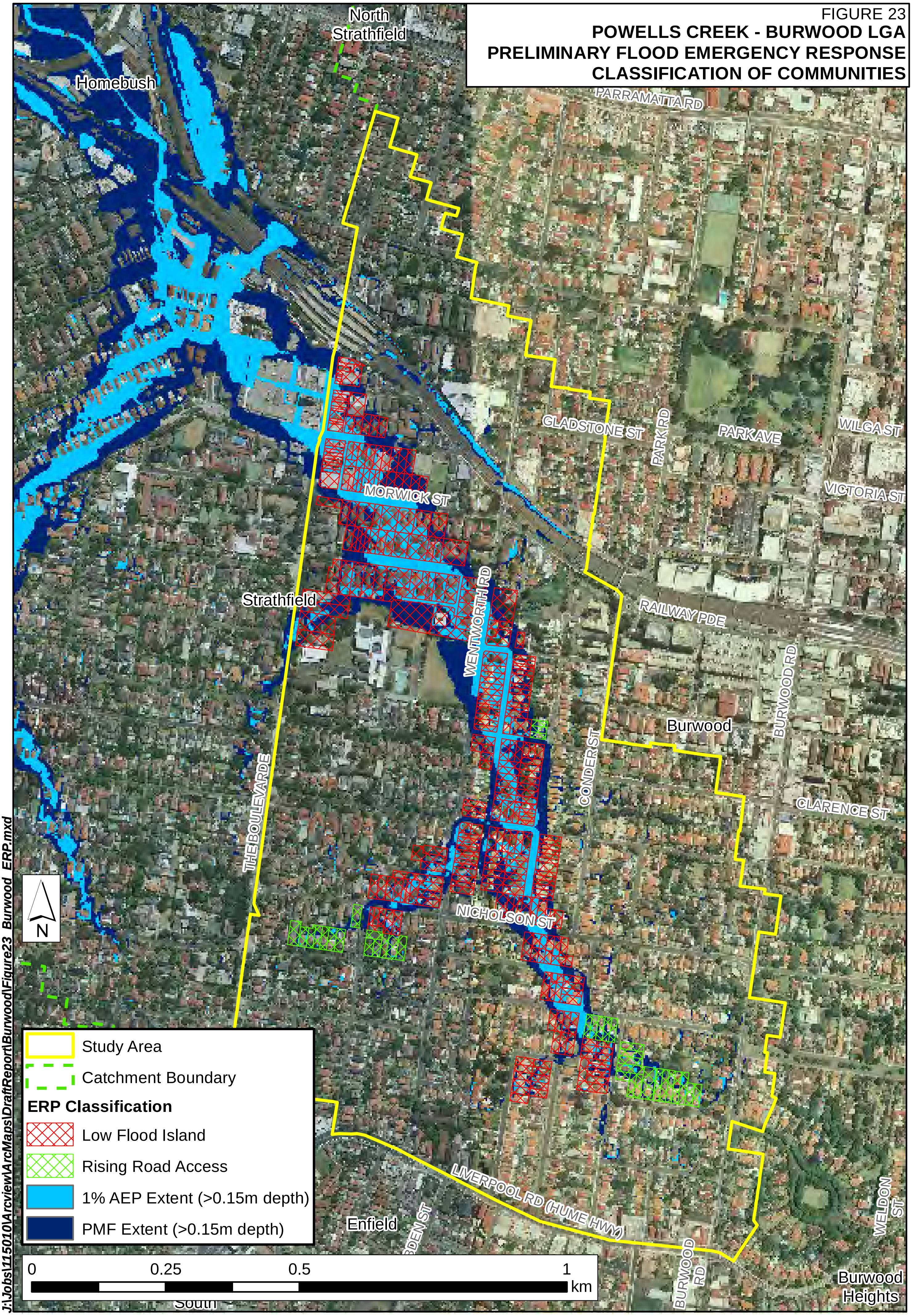
FIGURE 23
POWELLS CREEK - BURWOOD LGA
PRELIMINARY FLOOD EMERGENCY RESPONSE
CLASSIFICATION OF COMMUNITIES
North Strathfield
Homebush
PARRAMATTA RD
GLADSTONE ST
PARK RD
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
Strathfield
WENTWORTH RD
RAILWAY PDE
BURWOOD RD
Burwood
CONDER ST
CLARENCE ST
THE BOULEVARDE
NICHOLSON ST
LIVERPOOL RD (HUME HWY)
Enfield
WELDON ST
Burwood Heights
South
Study Area
Catchment Boundary
ERP Classification
Low Flood Island
Rising Road Access
1% AEP Extent (>0.15m depth)
PMF Extent (>0.15m depth)
0
0.25
0.5
1
km
N
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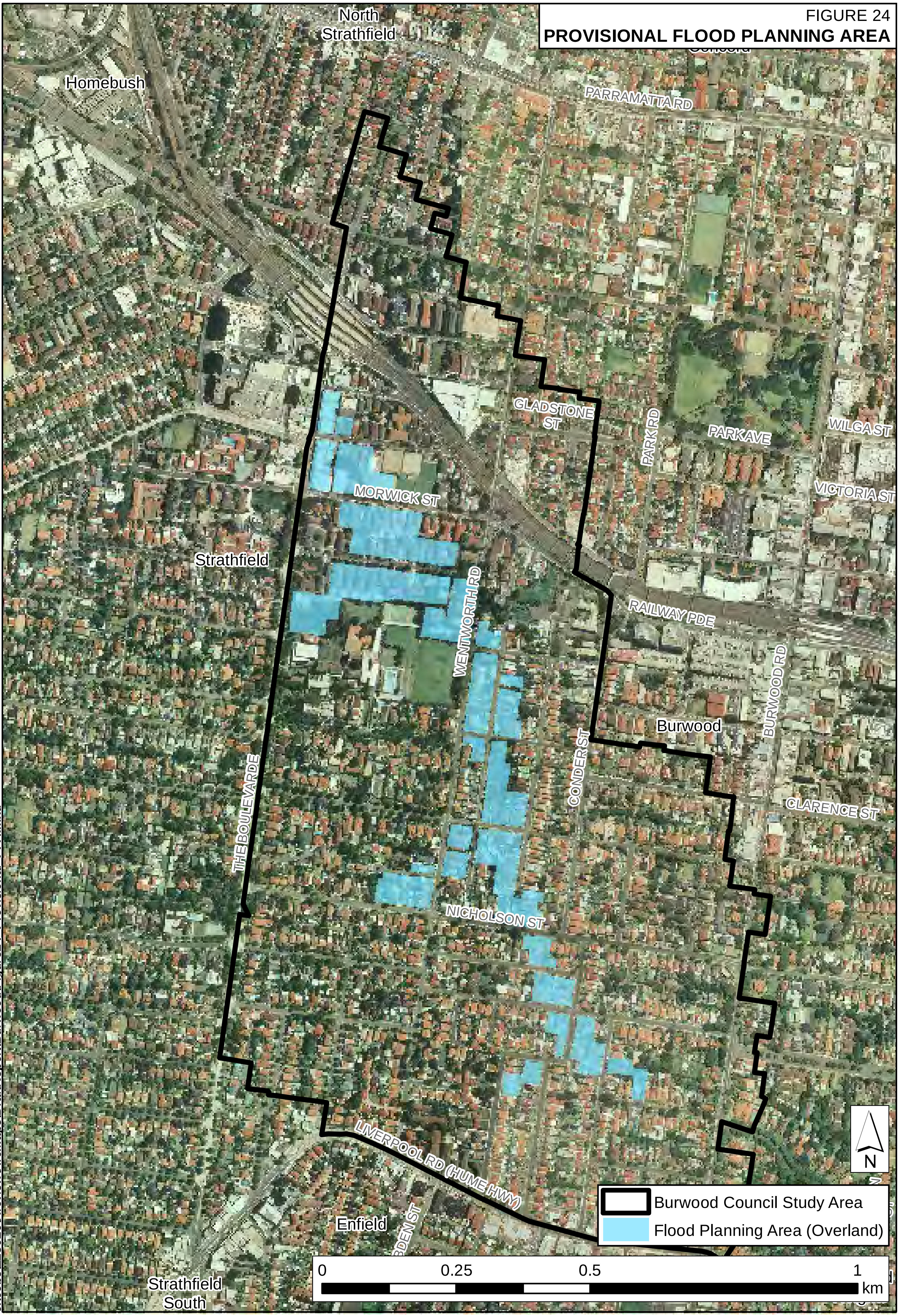
FIGURE 24
PROVISIONAL FLOOD PLANNING AREA



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Appendix A

APPENDIX A: GLOSSARY of TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate 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. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
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 LG 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 DIPNR, 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 the 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).
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 the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
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 State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the

	Manual.
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	Are 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. For the purpose of this manual 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 0.3 m (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 flow paths 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 floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock

	and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to "water level". Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
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.

Appendix B

FIGURE B1

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

DATA SET #1

LP3 ANALYSIS - BAYESIAN

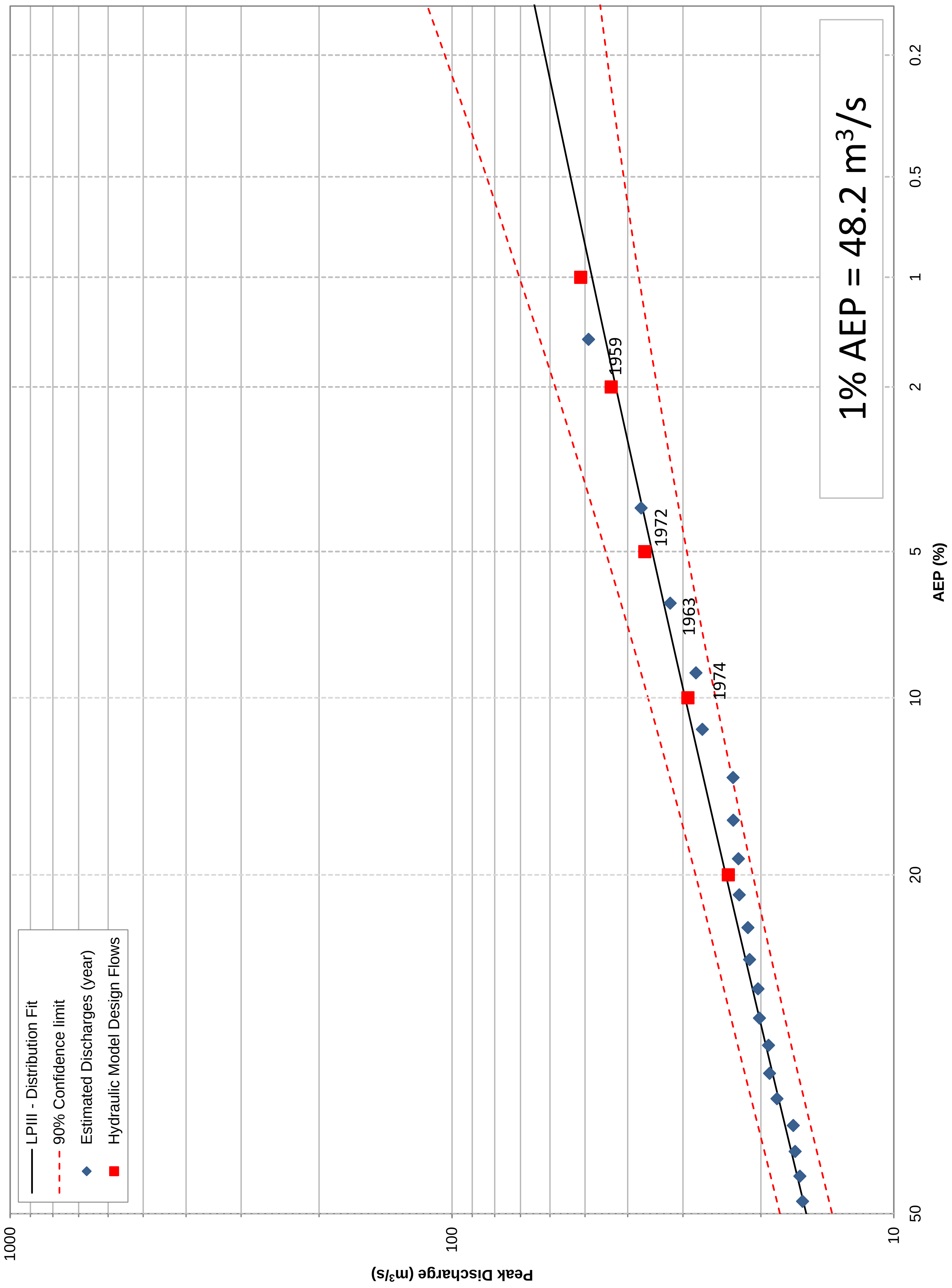


FIGURE B2

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

DATA SET #2

LP3 ANALYSIS - BAYESIAN

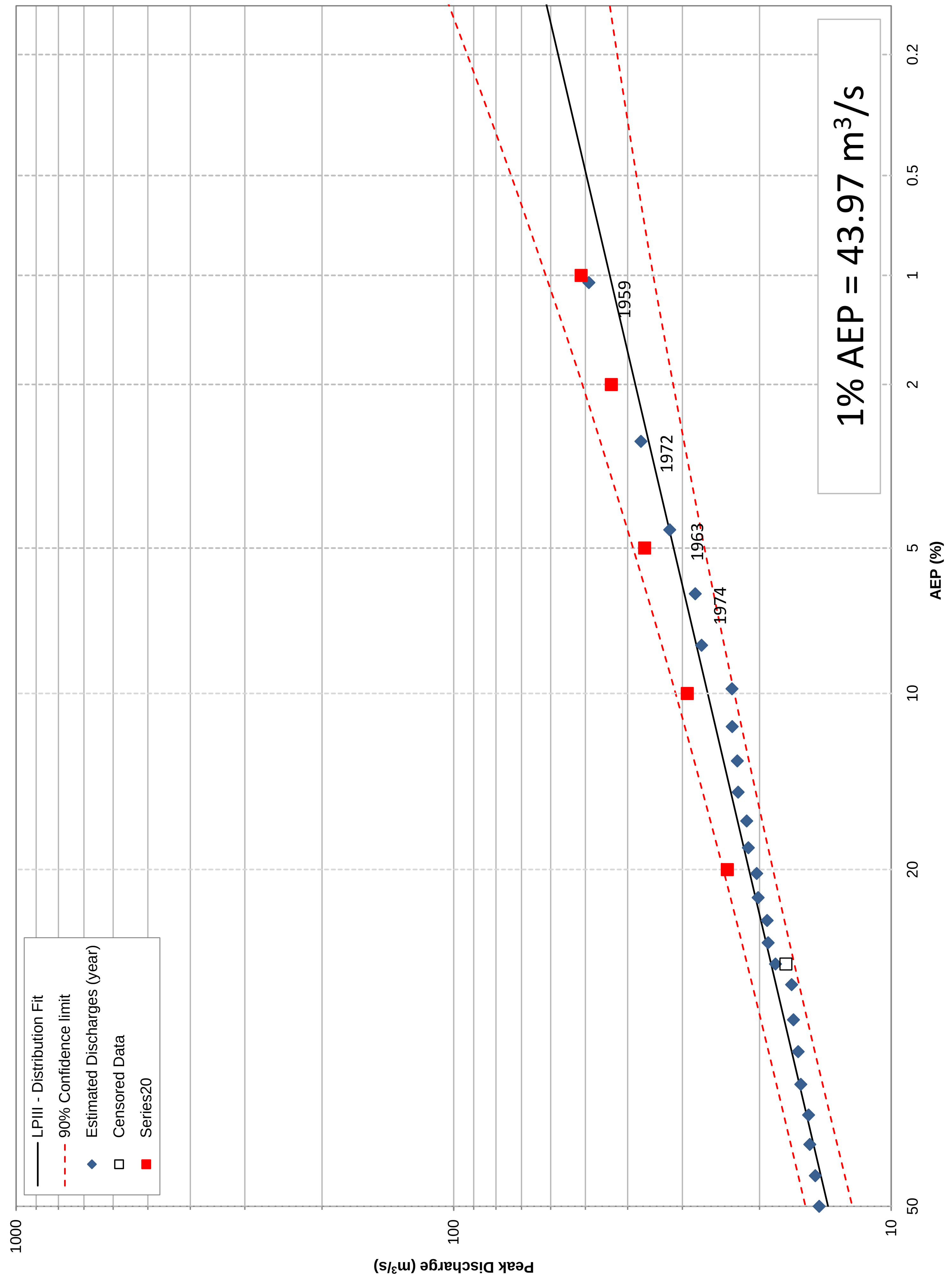


FIGURE B3

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

DATA SET #3

LP3 ANALYSIS - BAYESIAN

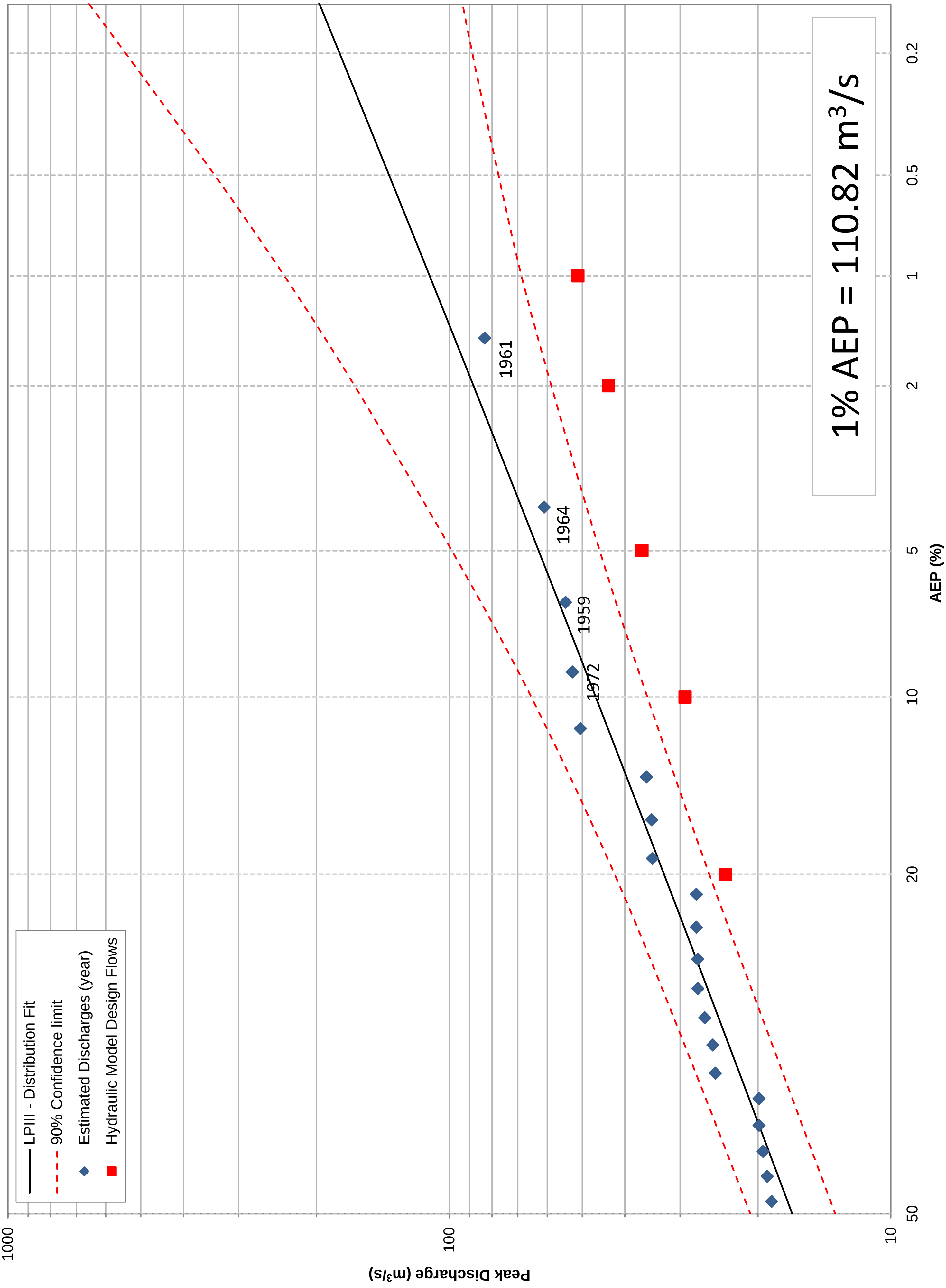


FIGURE B4

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

DATA SET #4

LP3 ANALYSIS - BAYESIAN

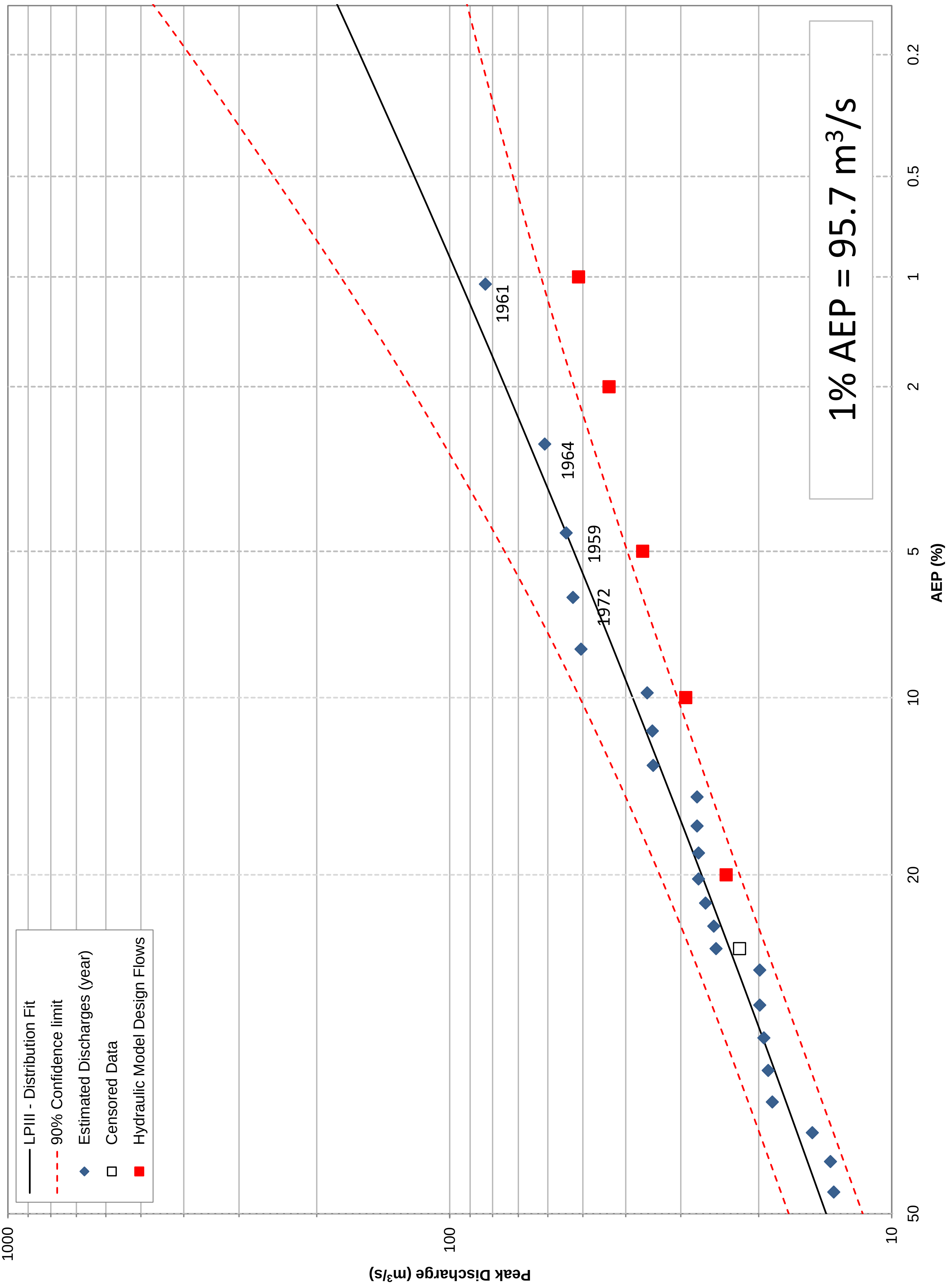


FIGURE B5

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

DATA SET #5

LP3 ANALYSIS - BAYESIAN

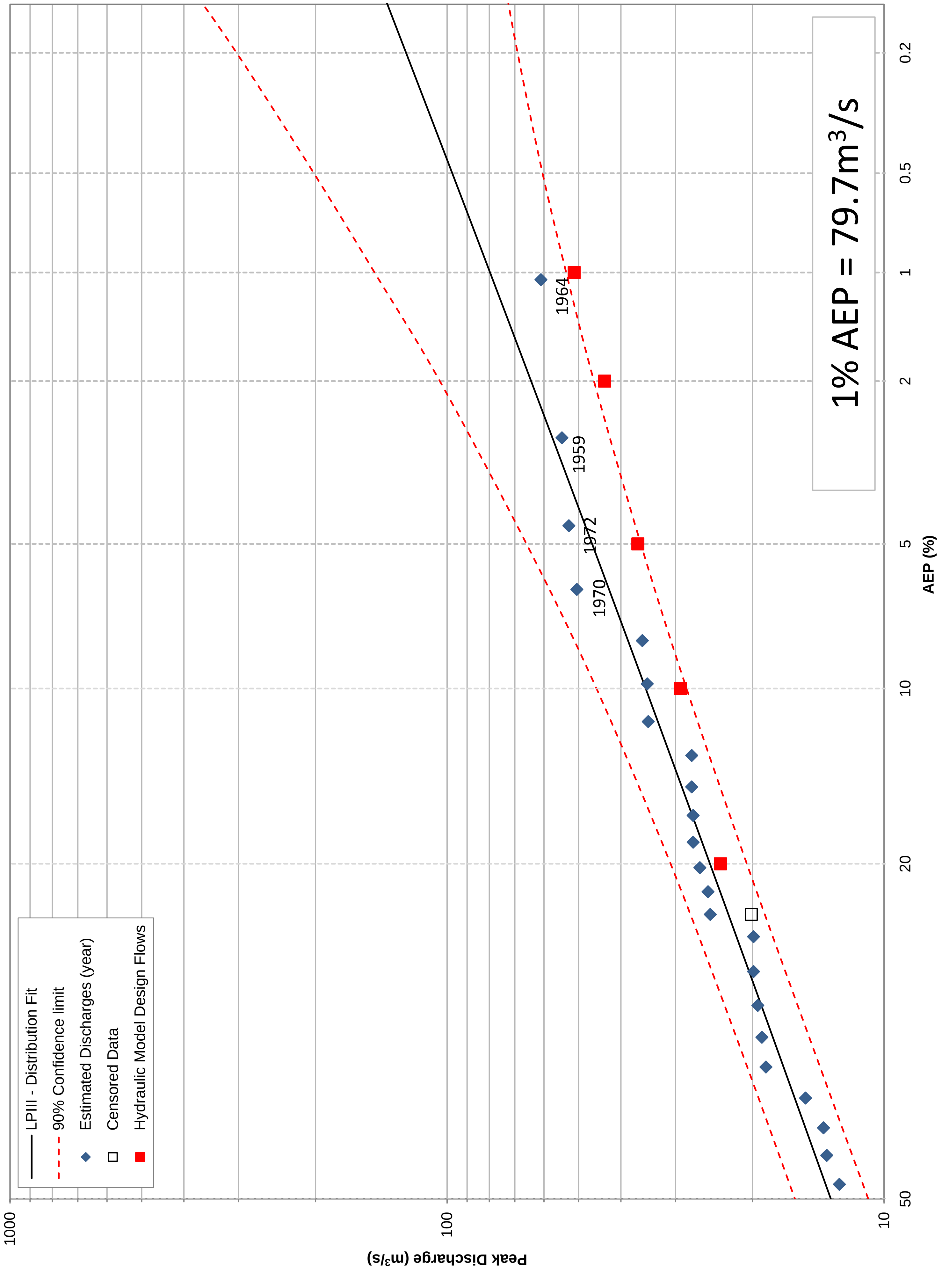


FIGURE B6

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

DATA SET #6

LP3 ANALYSIS - BAYESIAN

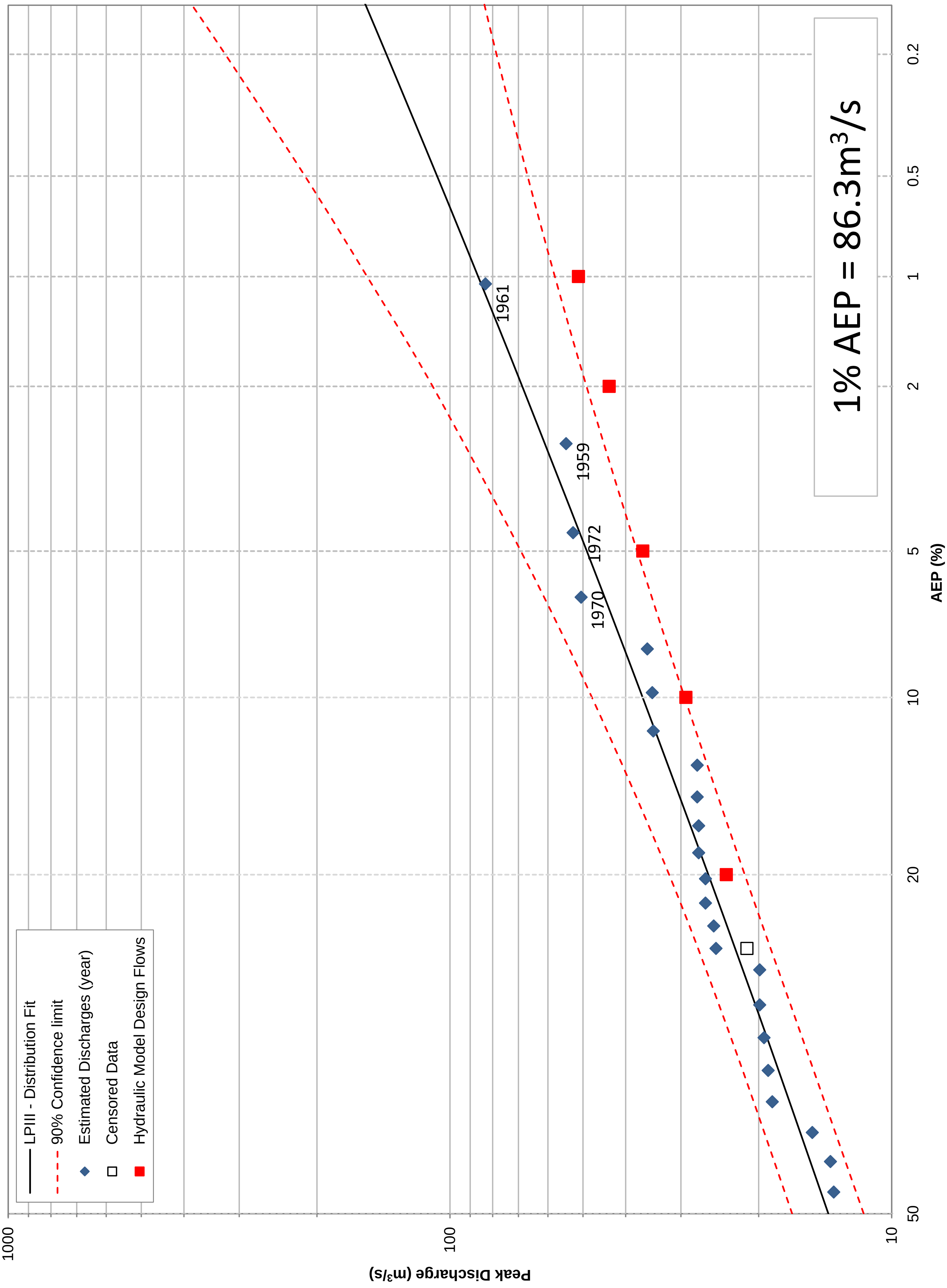


FIGURE B7

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

DATA SET #7

LP3 ANALYSIS - BAYESIAN

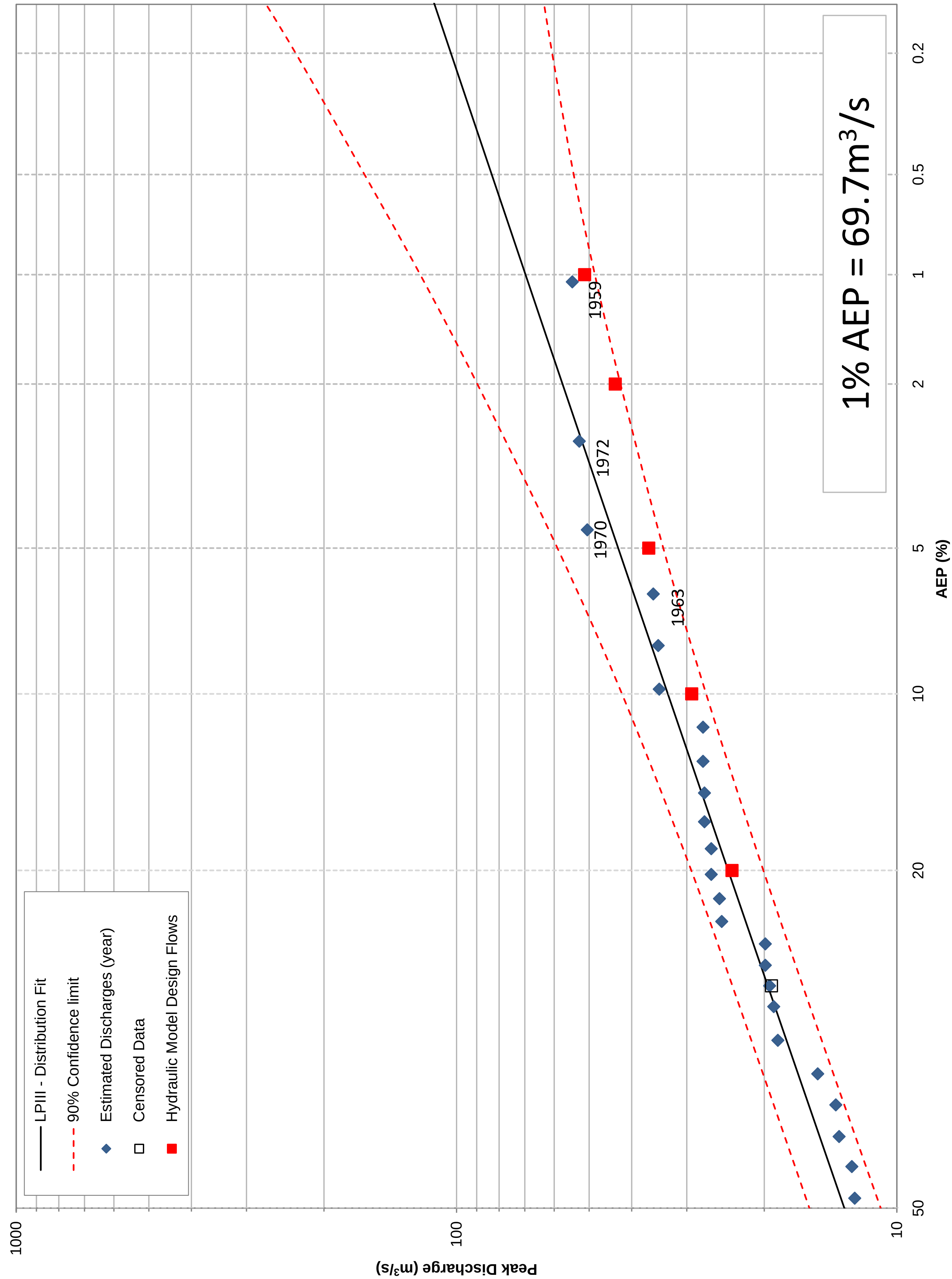
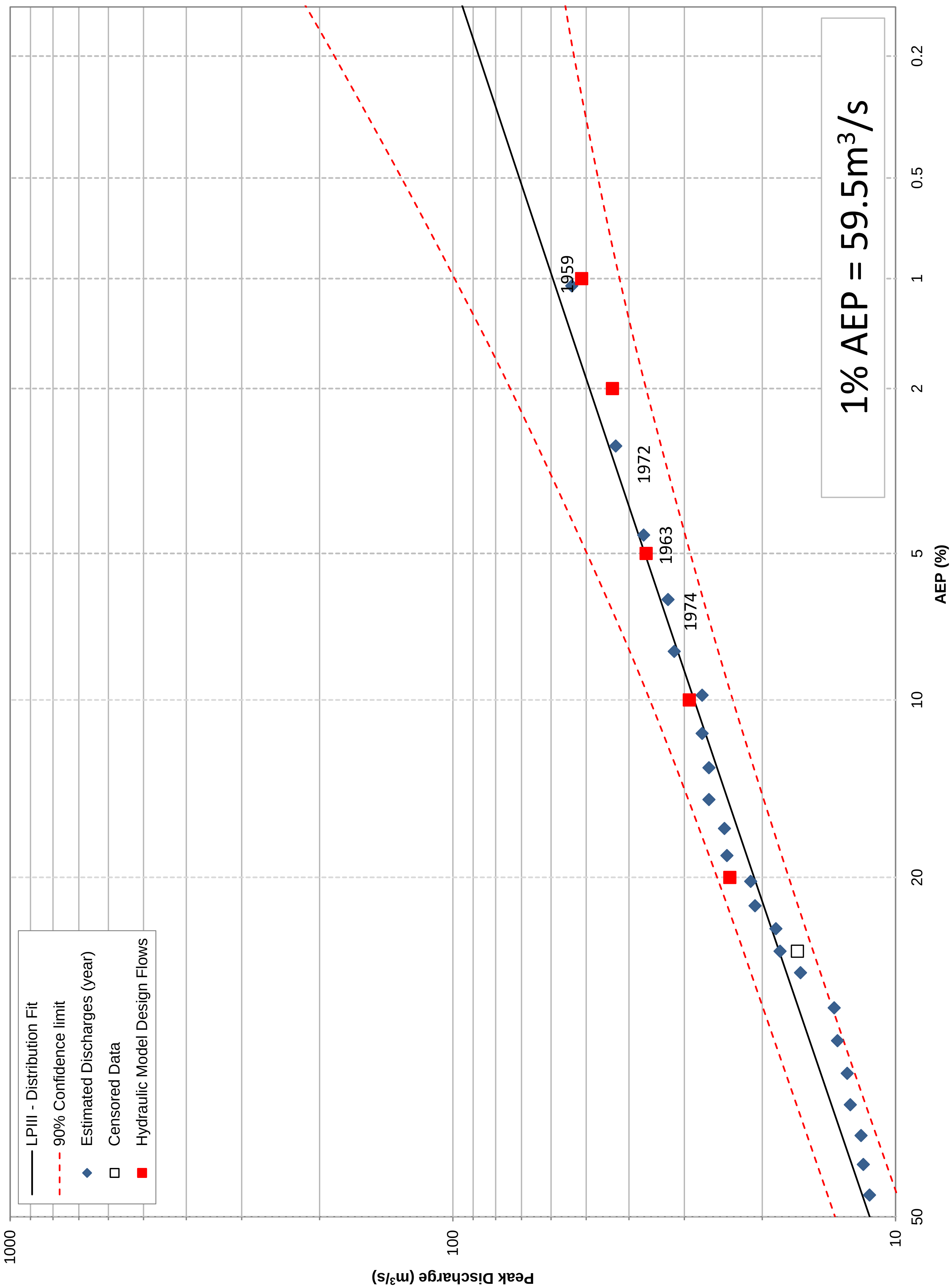


FIGURE B8
POWELLS CREEK - FLOOD FREQUENCY ANALYSIS
DATA SET #8
LP3 ANALYSIS - BAYESIAN



Appendix C

FIGURE C1

5% AEP EVENT PEAK FLOOD DEPTHS
MINNA STREET TO NORWOOD STREET

J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure_C01_Depths_020y_Minna.mxd

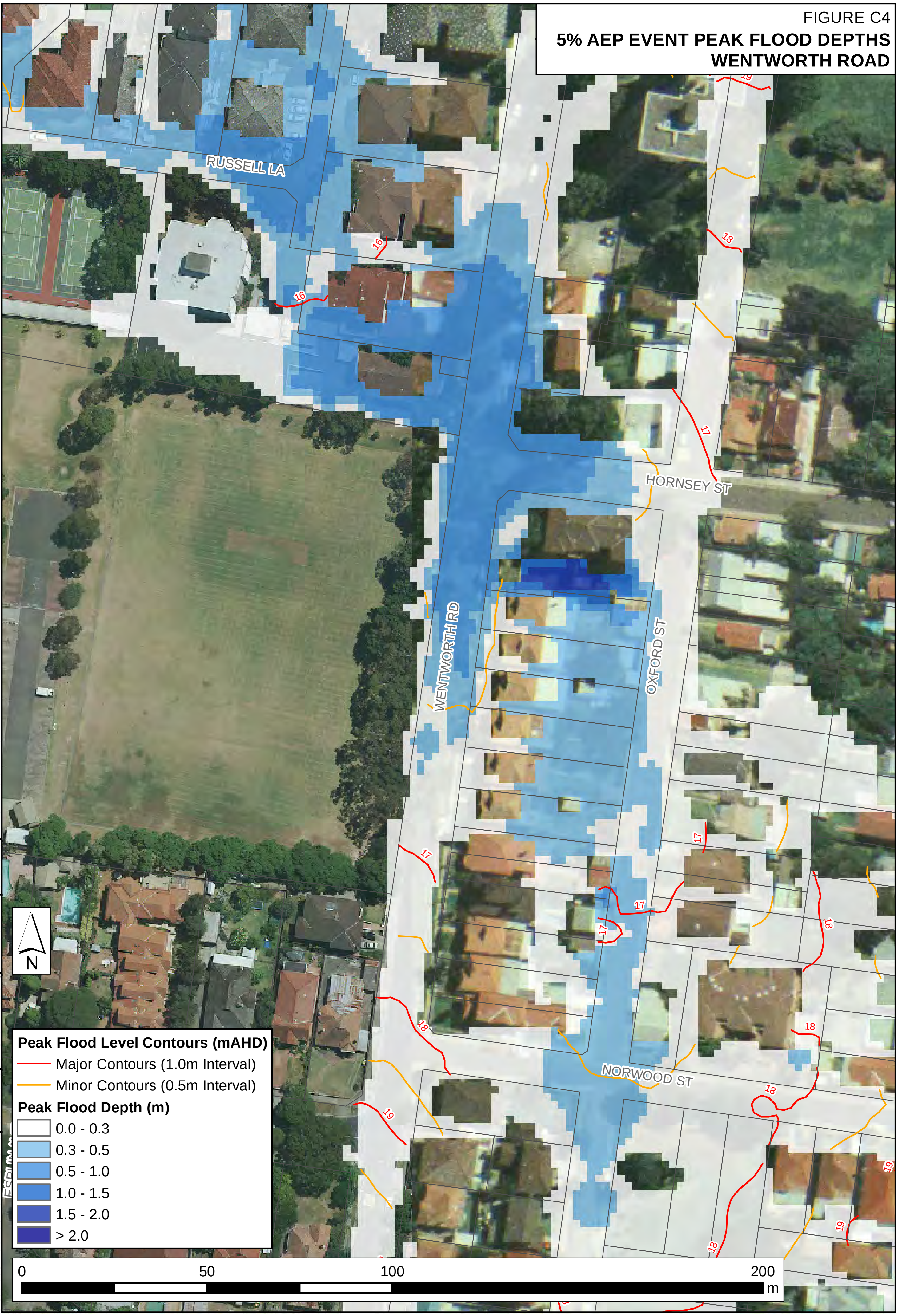
FIGURE C2

1% AEP EVENT PEAK FLOOD DEPTHS MINNA STREET TO NORWOOD STREET

J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure_C02_Depths_100y_Minna.mxd

FIGURE C4

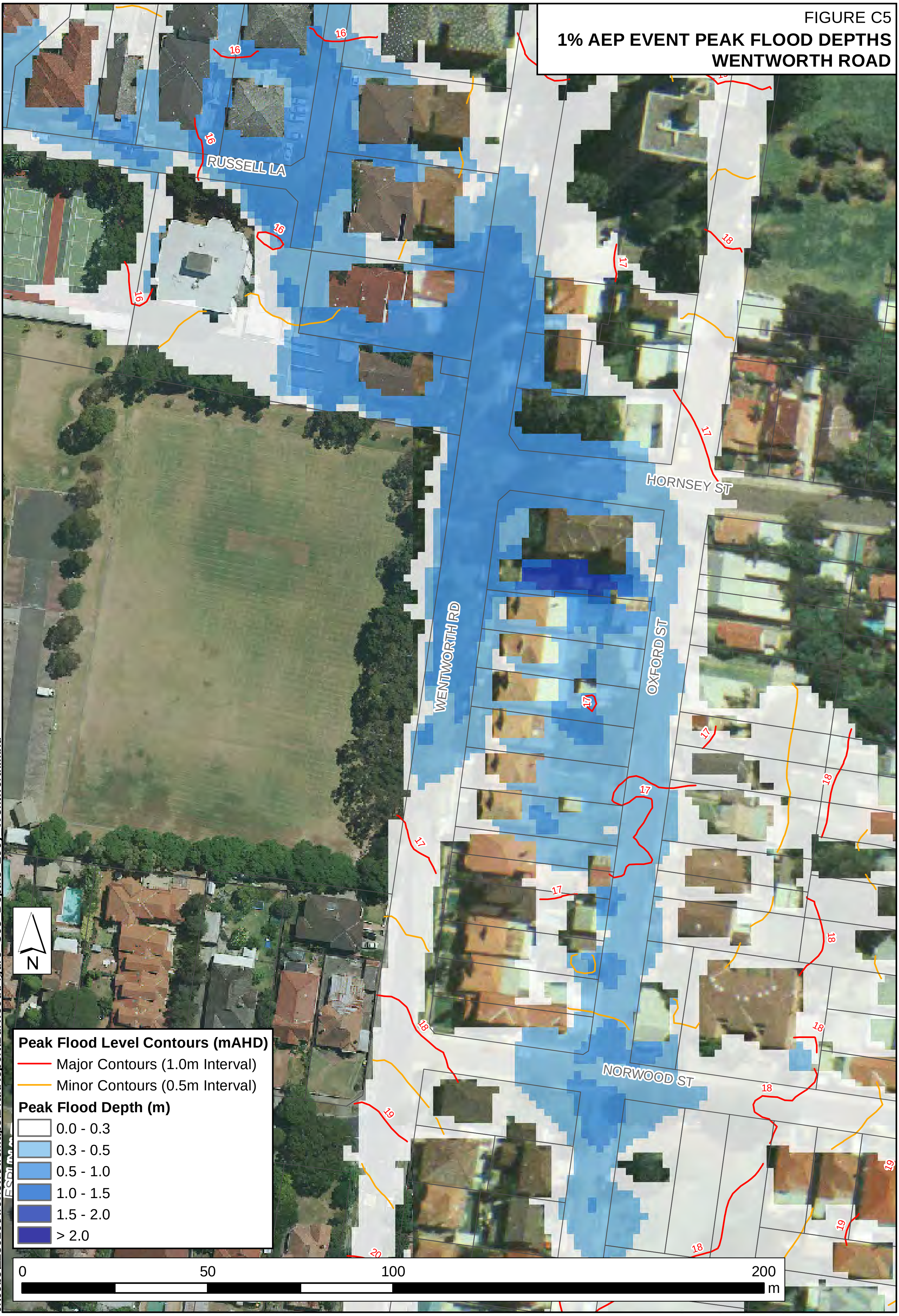
5% AEP EVENT PEAK FLOOD DEPTHS
WENTWORTH ROAD



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure C04 Depths 020y Wentworth.mxd

FIGURE C5

1% AEP EVENT PEAK FLOOD DEPTHS WENTWORTH ROAD



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure_C05_Depths_100y_Wentworth.mxd

FIGURE C7
5% AEP EVENT PEAK FLOOD DEPTHS
RUSSELL STREET

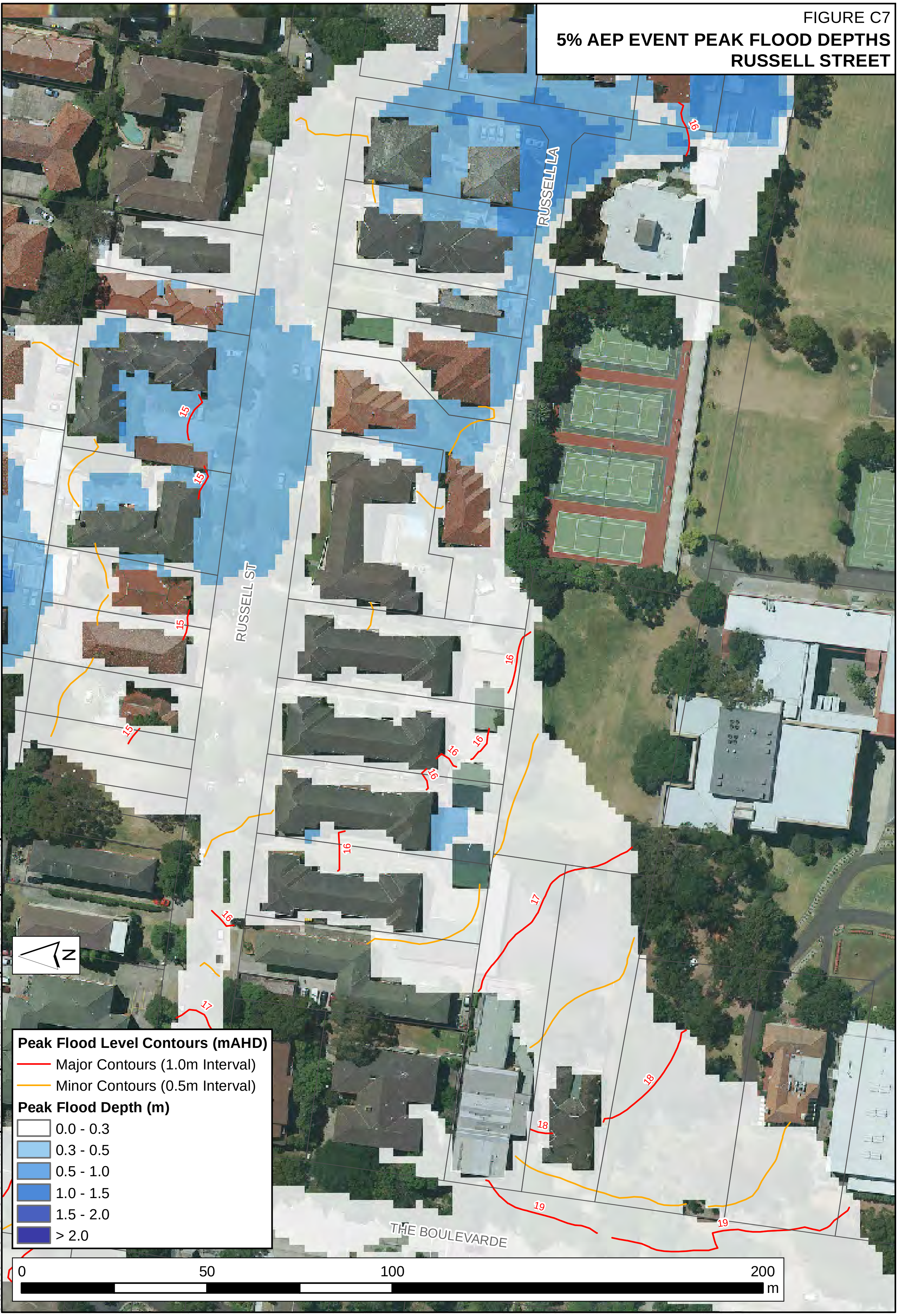


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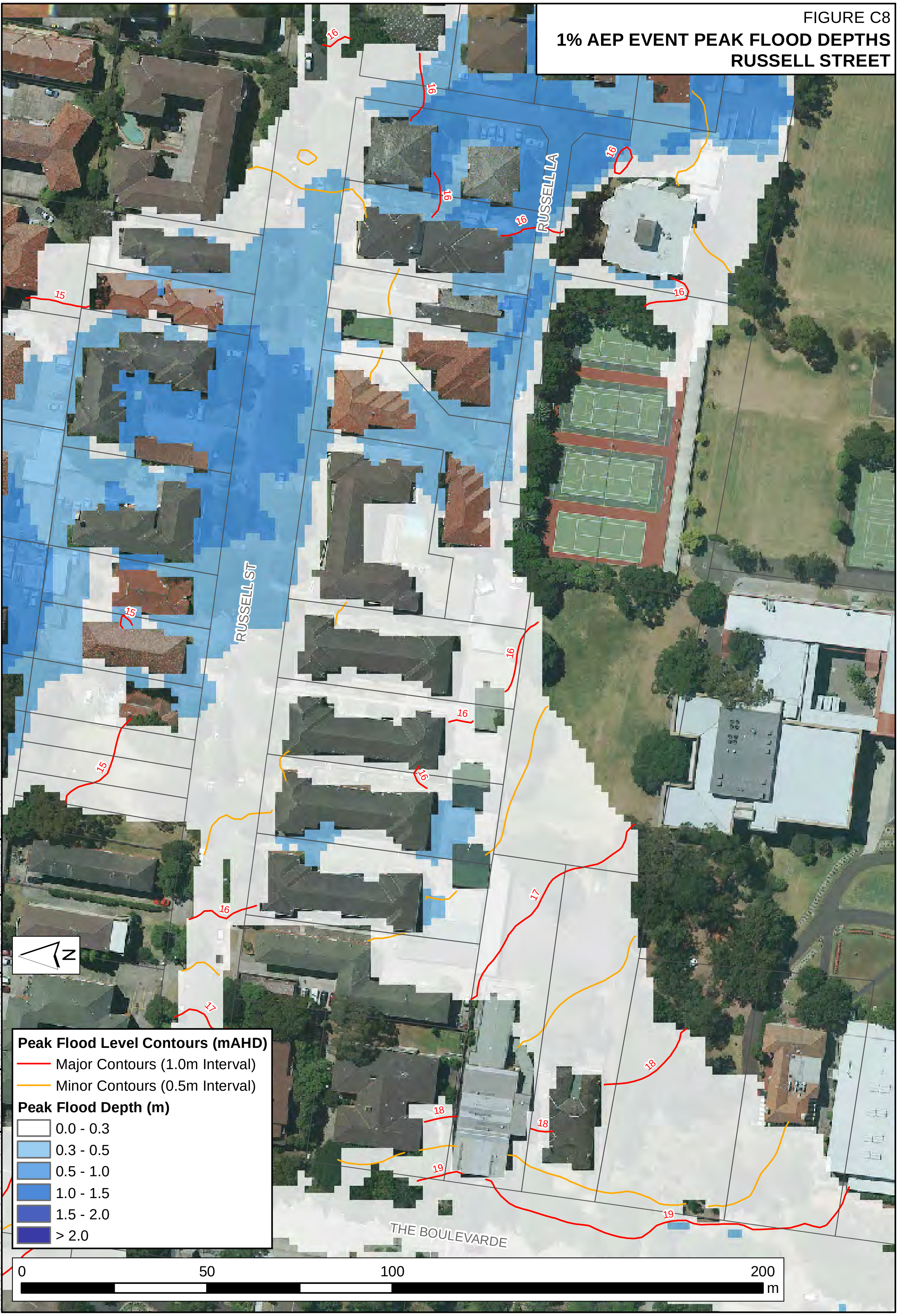
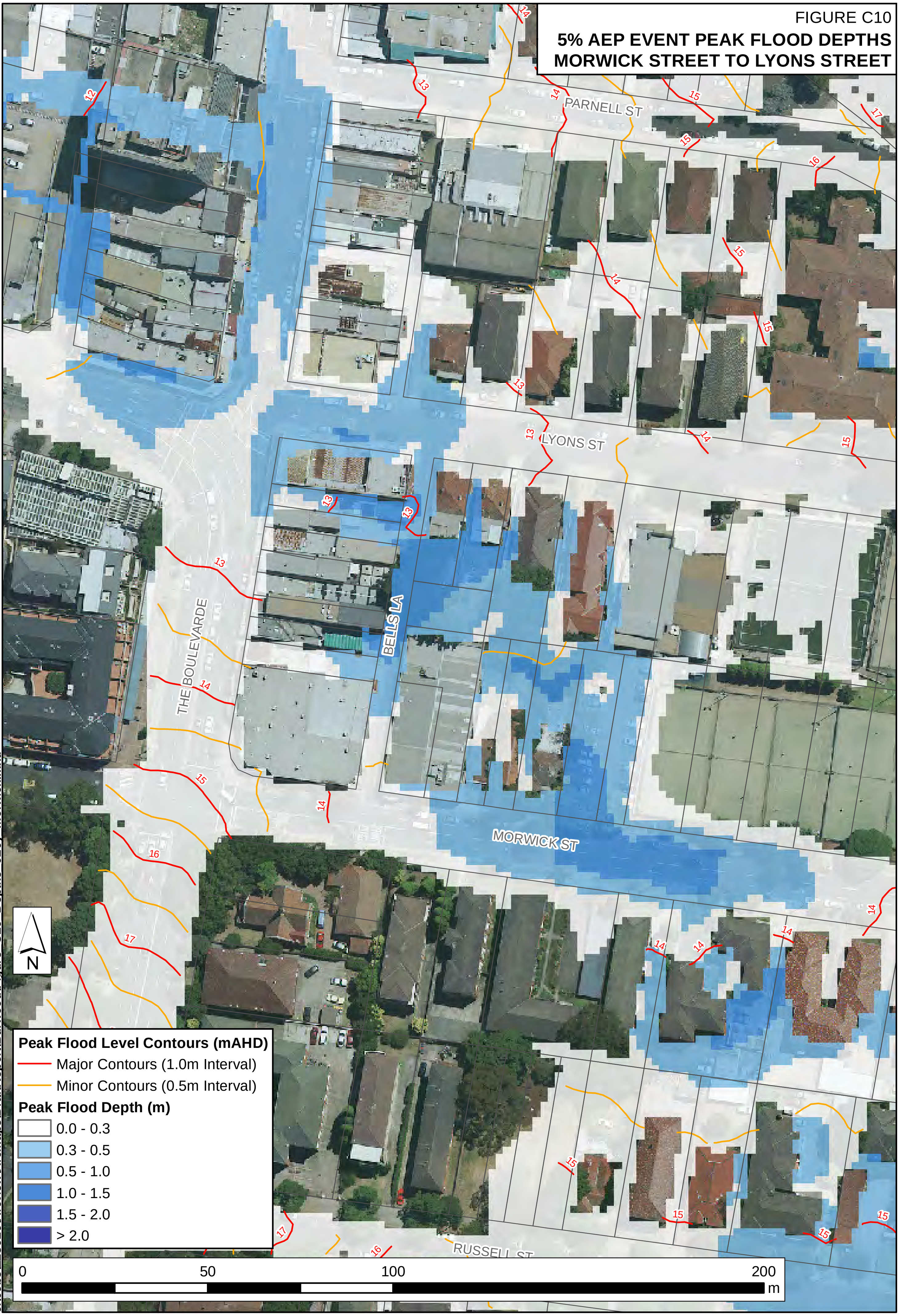
FIGURE C8
1% AEP EVENT PEAK FLOOD DEPTHS
RUSSELL STREET



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure C08 Depths 100y Russell.mxd

FIGURE C10

5% AEP EVENT PEAK FLOOD DEPTHS MORWICK STREET TO LYONS STREET



J:\Jobs\115010\Arcview\ArcMaps\DraftReport\Burwood\Figure C10 Depths 020y Morwick.mxd

FIGURE C11

1% AEP EVENT PEAK FLOOD DEPTHS MORWICK STREET TO LYONS STREET

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Burwood
heritage ▪ progress ▪ pride

EXILE BAY, ST LUKES AND WILLIAM STREET FLOOD STUDY

DRAFT REPORT 3

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MARCH 2017

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EXILE BAY, ST LUKES AND WILLIAM STREET FLOOD STUDY

DRAFT REPORT 3

MARCH 2017

Project Exile Bay, St Lukes and William Street Flood Study	**Project Number** 115036
Client Burwood Council	**Client's Representative** Kundan Pokharel
Authors Erika Taylor Stephen Gray	**Prepared by** TO BE SIGNED FOR FINAL REPORT
Date 1 March 2017	**Verified by** TO BE SIGNED FOR FINAL REPORT

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EXILE BAY, ST LUKES AND WILLIAM STREET FLOOD STUDY

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LIST OF ABBREVIATIONS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
ALS	Airborne Laser Scanning sometimes known as LiDAR
BCC	Burwood City Council
BoM	Bureau of Meteorology
CBD	Central Business District
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CFERP	Community Flood Emergency Response Plan
DEM	Digital Elevation Model
DRAINS	Hydrologic computer model developed from ILSAX
EPR	Entire Period of Record (of gauge data at Elva Street gauge)
EY	Exceedances per Year
FFA	Flood Frequency Analysis
GEV	Generalised Extreme Value probability distribution
GIS	Geographic Information System
GSDM	Generalised Short Duration Method
HEC-RAS	1D hydraulic computer model
HGL	Hydraulic Grade Line
ILSAX	Hydrologic model - a precursor to DRAINS
IFD	Intensity, Frequency and Duration of Rainfall
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
LiDAR	Light Detection and Radar
LPI	Land and Property Information
LP3	Log Pearson III probability distribution
m	metre
MHL	Manly Hydraulics Laboratory
m^3/s	cubic metres per second (flow measurement)
m/s	metres per second (velocity measurement)
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SEPP	State Environmental Planning Policy
SMC	Strathfield Municipal Council
SWC	Sydney Water Corporation
TIN	Triangular Irregular Network
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

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

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

1. Flood Study

- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management

- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan

- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan

- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Exile Bay, St Lukes and William Street Flood Study constitutes the first stage of the management process.

EXECUTIVE SUMMARY

BACKGROUND

The Exile Bay, St Lukes and William Street Catchments are adjacent catchments (listed west to east) that drain north into Iron Cove on the Parramatta River, shown in Figure 1. The upstream catchment area is within Burwood Council LGA and the downstream catchment area is within the Canada Bay LGA; with Parramatta Road as the boundary between the two LGA's. The study area comprises of the three aforementioned catchments up to Parramatta Road, with the area downstream of Parramatta Road outside the area of interest of this study.

OBJECTIVES

The primary objective of this Flood Study is to develop computational hydrologic and hydraulic models that define design flood behaviour for the 0.2 EY, 10% AEP, 5% AEP, 2% AEP and 1% AEP design storms and the Probable Maximum Flood (PMF) in the Exile Bay, St Lukes and William Street catchments and to:

- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study;
- provide results for flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area;
- prepare maps of provisional hydraulic categories and provisional hazard categories;
- prepare preliminary emergency response classifications for communities;
- determine provisional residential flood planning levels and flood planning area;
- assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise

FLOODING HISTORY

In examining the flooding history, it must be noted that the drainage characteristics of this catchment have been significantly altered as a result of urbanisation in the area and as such older flood extents and depths for a given storm may not apply to present day conditions. There have been a number of instances of flooding in the past including the 19 May 1946, 24 November 1961 and the 2 January 1996.

HYDROLOGIC AND HYDRAULIC MODELLING PROCESS

The hydrologic modelling was undertaken using DRAINS and the hydraulic model was established using TUFLOW.

These models were verified by comparison to specific yield rates for similar areas in the Sydney Metropolitan region and comparison to previous studies undertaken in the Exile Bay, St Lukes and William Street catchments.

The design rainfall events that were modelled were the 0.2 EY, 10% AEP, 5% AEP, 2% AEP and 1% AEP design storms and the Probable Maximum Precipitation (PMP). The temporal patterns for the design events were sourced from Australian Rainfall and Runoff (AR&R) (Pilgrim, 1987) and the Intensity-Frequency-Duration (IFD) data was obtained from the Bureau of Meteorology's (BoM) internet-based tool. The PMP estimates were derived according to the BoM guidelines, the *Generalised Short Duration Method* (BoM, 2003).

OUTCOMES

The design flood modelling indicates that notable flooding may occur in a number of locations including the intersection of Short Street and Parramatta Road; Parramatta Road and Shaftesbury Road; the intersection of Philip Street and Parramatta Road; Milton Street; New Street; and Railway Parade.

A preliminary investigation into properties subject to flood related development controls shows that approximately 278 lots (of the approximately 1,951 lots within the study area and accounting for around 14%) are liable to be identified under the criteria adopted for the study.

1. INTRODUCTION

1.1. Background

The study was commissioned by Burwood City Council (BCC), with the assistance of the NSW Government (Office of Environment and Heritage). Additional information has been provided by Sydney Water Corporation (SWC).

1.2. Description of the Catchments

The Exile Bay, St Lukes and William Street Catchments are adjacent catchments (listed west to east) that drain north into Iron Cove on the Parramatta River, shown in Figure 1. The upstream catchment area is within Burwood Council LGA and the downstream catchment area is within the Canada Bay LGA; with Parramatta Road as the boundary between the two LGA's. The study area comprises of the three aforementioned catchments up to Parramatta Road, with the area downstream of Parramatta Road outside the area of interest of this study.

The study area includes the suburbs of Strathfield, Burwood and Croydon. The area is fully urbanised, with 64% of the catchment zoned residential, 16% mixed use, 10% enterprise corridor (adjacent to Parramatta Road) and 10% for public recreation.

Elevations in the upper part of the catchment reach approximately 35 m AHD near Livingston Street and moderate grades of 3%. In the lower parts of the catchment, slopes are relatively shallow, in the order of 0.5%. The St Lukes and William Street catchments are tidal up to Queens Road.

1.3. Objectives

The primary objective of this Flood Study is to develop computational hydrologic and hydraulic models that define design flood behaviour for the 0.2 EY, 10% AEP, 5% AEP, 2% AEP and 1% AEP design storms and the Probable Maximum Flood (PMF) in the Exile Bay, St Lukes and William Street catchments and to:

- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study;
- provide results for flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area;
- prepare maps of provisional hydraulic categories and provisional hazard categories;
- prepare preliminary emergency response classifications for communities;
- determine provisional residential flood planning levels and flood planning area;
- assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.

A glossary of flood related terms is provided in Appendix A.

2. AVAILABLE DATA

2.1. Overview

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On large river systems such as the Hawkesbury River there are generally stream height and historical records dating back to the early 1900's, or in some cases even further. However, in small urban catchments such as that of Exile Bay, St Lukes and William Street Catchments there are no stream gauges or official historical records available. A picture of flooding must therefore be obtained from an examination of Council records, previous reports, rainfall records and local knowledge.

2.2. Topographic Data

Airborne Light Detection and Ranging (LiDAR) survey of the catchment and its immediate surroundings was obtained from Land and Property Information (LPI), which is a division of the Department of Finance, Services and Innovation (NSW Government). It was indicated that the data were collected in 2013. These data typically have accuracy in the order of:

- +/- 0.15m (for 70% of points) in the vertical direction on clear, hard ground; and
- +/- 0.75m in the horizontal direction.

The accuracy of the LiDAR data can be influenced by the presence of open water or vegetation (tree or shrub canopy) at the time of the survey.

The 1 m by 1 m Digital Elevation Model (DEM) generated from the LiDAR, which formed the basis of the two-dimensional hydraulic modelling for the study, is shown in Figure 2.

2.3. Pit and Pipe Data

The SWC capacity assessment reports provided dimensions for SWC owned underground pipes, in addition to the open channel cross-sections within the catchment area downstream of the Burwood LGA boundary. Appended to this SWC drainage network are underground pipes owned by BCC. BCC provided pipe dimensions, as well as pit inverts and dimensions.

2.4. Historical Flood Level Data

2.4.1. SWC Historic Flood Database

An historic flood database was supplied by SWC and provided information on flooding within the two catchments that SWC maintains assets within (the St Lukes and William Street Catchment) from 1946 to 1996. A summary of available historic flood levels is provided in Table 1.

Table 1: Summary of Historical Flood Data – SWC Database

Flood Events	Total Records	Number of Observed Flood Levels
19 May 1946	1	0
24 November 1961	1	0
2 January 1996	3	1

2.4.2. BCC Historic Flood Database

An historic flood database was supplied by BCC and provided information on flooding within the catchments from 2003 to 2015. Many of these reports were concerned with stormwater and drainage issues.

A summary of available historic flood locations is provided in Table 2.

Table 2: Summary of Historical Flood Data – BCC Database

Location	Catchment	Total Records
Cooper Lane	Exile Bay	1
Cooper Street	Exile Bay	5
Corner of Cooper Street and Wentworth Road	Exile Bay	3
Wentworth Road	Exile Bay	2
Mt Pleasant Avenue	Exile Bay	3
Roberts Street	Exile Bay	1
White Street	Exile Bay	1
Belmore Street	St Lukes	4
Belmore Street (Corner Wynne Ave)	St Lukes	2
Burwood Road	St Lukes	13
Burwood Road (Nr Station)	St Lukes	1
Cheltenham Road	St Lukes	7
Clarendon Place	St Lukes	3
Comer Street	St Lukes	2
Conder Street	St Lukes	1
Conder Street (Corner Hornsey St)	St Lukes	2
Elsie Street	St Lukes	1
Gladstone Street	St Lukes	1
Ilfracombe Avenue	St Lukes	1
John Street	St Lukes	1
King Edward Street	St Lukes	1
Lucas Road	St Lukes	13
Luke Avenue	St Lukes	11
Luke Street (Corner Bennett St)	St Lukes	1
Marmaduke Street	St Lukes	1
Meryla Street	St Lukes	9
Neich Parade	St Lukes	4
Park Road	St Lukes	3
Parramatta Road	St Lukes	1
Railway Crescent	St Lukes	1
Railway Parade	St Lukes	3
Rostherne Avenue	St Lukes	1
Royce Avenue	St Lukes	3

Royce Avenue (Corner Monash Pde)	St Lukes	2
Shaftesbury Road	St Lukes	4
Shaftesbury Road (Corner Wilga Street)	St Lukes	1
Simpson Avenue	St Lukes	2
Sym Avenue	St Lukes	4
Victoria Street	St Lukes	5
Wilga Street	St Lukes	2
Wynne Avenue	St Lukes	7
Youth Lane	St Lukes	1
Acton Street	William Street	11
Bay Street	William Street	3
Dawson Street	William Street	1
Grogan Street	William Street	1
Monash Parade	William Street	1
Short Street	William Street	2
Wychbury Avenue	William Street	8
Wychbury Lane	William Street	1
Corner of King Edward Street and Parramatta Road	William Street	1

2.4.3. Community Consultation

A community consultation process was undertaken in collaboration with BCC. This included distribution of an information sheet and a questionnaire to gather information pertaining to the community's experience of flooding within the catchments. BCC undertook this distribution to properties affected by a preliminary 1% AEP extent.

The response rate was on average 4% across the study area. This is similar to the response rate from community consultation carried out for Flood Studies in adjacent catchment areas and/or adjacent Council areas. This is considered to be influenced by the proportion of rental dwellings within the area (the Australian Bureau of Statistics recorded 37% of the Burwood population as residing in rental dwellings).

Two reports of flooding within the house were reported; with indications that at these locations the floor level is elevated and flood waters enter the cavity beneath the floor. The flood water reported beneath the houses were said to drain slowly and result in rising damp within the walls of the house. In both instances, no date was given and the flooding experienced was described as occurring any time there is heavy rainfall.

2.5. Historical Rainfall Data

Rainfall data is recorded either daily (24hr rainfall totals to 9:00 am) or continuously (pluviometers measuring rainfall in small increments – less than 1 mm). Daily rainfall data have been recorded for over 100 years at many locations within the Sydney basin. In general, pluviometers have only been installed since the 1970's. Together these records provide a picture of when and how often large rainfall events have occurred in the past.

However, care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past events due to a combination of factors including local site conditions, human error or limitations inherent to the type of recording instrument used. Examples of limitations that may impact the quality of data used for the present study are highlighted in the following:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall and records of large events are often lost or misrepresented.
- Daily read information is usually obtained at 9:00 am in the morning. Thus if a single storm is experienced both before and after 9:00 am, then the rainfall is "split" between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00 am reading.
- The duration of intense rainfall required to produce overland flooding in the study area is typically less than 6 hours (though this rainfall may be contained within a longer period of rainfall). This is termed the "critical storm duration". For a larger catchment (such as the Parramatta River) the critical storm duration may be greater (say 9 hours). For the study area a short intense period of rainfall can produce flooding but if the rain stops quickly, the daily rainfall total may not necessarily reflect the magnitude of the intensity and subsequent flooding. Alternatively the rainfall may be relatively consistent throughout the day, producing a large total but only minor flooding.
- Rainfall records can frequently have "gaps" ranging from a few days to several weeks or even years.
- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs. time) of rainfall events and have the advantage that the data can generally be analysed electronically. This data has much fewer limitations than daily read data. Pluviometers can also fail during storm events due to the extreme weather conditions.

Rainfall events which cause overland flooding (as opposed to mainstream flooding) in the study area are usually localised and as such are only accurately represented by a nearby gauge. Gauges sited even only a kilometre away can show very different intensities and total rainfall depths.

2.5.1. Rainfall Stations

Table 3 presents a summary of the official rainfall gauges (sourced from the Bureau of Meteorology) located close to or within the catchment and Figure 5 shows the location of these rainfall gauges. This includes daily read stations, continuous pluviometer stations, operational stations and synoptic stations. These gauges are operated either by Sydney Water Corporation (SWC) or the Bureau of Meteorology (BOM).

Table 3: Rainfall stations within 7km of the centroid of the study areas

Station Number	Station Name	Operating Authority	Distance from centre of the catchment (km)	Elevation (m AHD)	Date Opened	Date Closed	Type
66017	Barnwell Park Golf Course	BOM	1.11	4	29/11/1929	28/11/2003	Daily
66150	Canterbury Heights	BOM	1.29	61	30/08/1906	29/12/1916	Daily
566064	Concord Greenlees BC (formerly Wests Rugby Club)	SWB	2.05		1/06/1988		Continuous
66091	Burwood 2 Public School	BOM	2.49		29/09/1911	29/12/1923	Daily
66165	Ashfield Prospect Rd	BOM	2.49	43	01/01/1894	1/01/1904	Daily
66013	Concord Golf Club	BOM	2.56	15	1/01/1930		Daily
66113	Burwood 1	BOM	2.61		01/01/1884	1/01/1922	Daily
66026	Homebush	BOM	2.61		30/10/1924	29/12/1952	Daily
66000	Ashfield Bowling Club	BOM	2.67	25	30/03/1896		Daily
566112	Ashfield (Ashfield Park Bowling Club)	SWB	2.70		2/12/1993		Continuous
66111	Craydon	BOM	2.72		30/01/1879	29/12/1921	Daily
566022	Homebush SPS041 (formerly Homebush BC)	SWB	3.16		9/05/1969		Continuous
66034	Abbotsford (Blackwall Point Rd)	BOM	3.17	15	1/01/2004		Daily
566020	Enfield (composite site)	SWB	3.57		18/06/1983		Continuous
66194	Canterbury Racecourse AWS	BOM	3.58	3	2/10/1995		Synop
566113	Canterbury Racecourse	SWB	3.78		9/12/1993		Continuous
566066	Five Dock SPS065	SWB	3.80		19/10/1989		Continuous
66071	Gladesville Champion Rd	BOM	3.99	10	27/02/1997	29/09/2000	Daily
66070	Strathfield Golf Club	BOM	4.31	21	1/01/1952		Daily
66070	Strathfield Golf Club	BOMNS	4.31	21	11/06/1997		Operational
66164	Rookwood (Hawthorne Ave)	BOM	4.73	41	1/01/1945		Daily
66164	Rookwood (Hawthorne Ave)	BOM	4.73	41	29/11/1973	29/01/1985	Continuous
566065	Lilyfield Bowling Club	SWB	4.88		12/01/1989		Continuous
66108	Hunters Hill St Josephs Colleg	BOM	5.01		1/01/1916	1/01/1923	Daily
66064	Concord Walker Hospital	BOM	5.06	7.6	30/10/1894	29/12/1972	Daily
66082	Concord West Plaster Mills	BOM	5.06	5	1/01/1961	1/01/1982	Daily
66135	Ranad Newington	BOM	5.94	8	1/01/1967	1/01/1973	Daily
66135	Ranad Newington	BOM	5.94	8	27/05/1967	29/12/1973	Continuous

66175	Schnapper Island	BOM	5.95	5	28/02/1932	29/12/1939	Daily
66036	Marrickville Golf Club	BOM	6.05	6	29/04/1904	29/12/1970	Daily
66036	Marrickville Golf Club	BOMNS	6.05	6	6/04/2001		Operational
66102	Meadow Bank	BOM	6.35		1/01/1903	1/01/1916	Daily
566026	Marrickville Bowling Club	SWB	6.50		31/12/1979		Continuous
566064	Lidcombe (Carnarvon Golf Club)	BOMNS	6.53		5/08/1999		Operational
66018	Earlwood Bowling Club	BOM	6.66	31.1	30/07/1914	29/12/1975	Daily
66057	Ryde Pumping Stn	BOM	6.74	24.4	01/01/1894	1/01/1978	Daily
66131	Riverview Observatory	BOM	6.84	40	1/01/1905		Daily
66131	Riverview Observatory	BOM	6.84	40	1/01/1905		Synop
566036	Potts Hill Reservoir	SWB	6.91		29/12/1981		Continuous
66149	Glebe Point Syd. Water Supply	BOM	6.92	15.2	30/05/1907	29/12/1914	Daily
66015	Crown St. Reservoir	BOM	6.96		30/01/1882	29/12/1960	Daily
66097	Ranwick Bunnerong Rd	BOM	6.96		1/01/1904	1/01/1924	Daily

2.5.2. Analysis of Daily Read Data

An analysis of the records for the nearest daily rainfall stations, namely Barnwell Park Golf Course (66017) and Concord Golf Club (66013) was undertaken. The Barnwell Park and Concord Golf Club gauges are located within the Canada Bay Council LGA; with the former located in the William Street Catchment and the latter located on the north-western border of the Exile Bay Catchment.

Table 4: Daily rainfalls greater than 150mm at Barnwell Park Golf Club and Concord Golf Club

Barnwell Park Golf Course (66017)		
Nov 1929 – Nov 2003		
Rank	**Date**	**Rainfall (mm)**
1	30/03/1942	315
2	11/06/1991	253 (5 day total)
3	6/08/1986	250
4	5/02/1990	245 (3 day total)
5	11/02/1992	238 (3 day total)
6	30/04/1988	228
7	10/02/1956	201
8	9/04/1973	197
9	16/02/1988	164 (4 day total)
10	19/11/1961	163
11	10/01/1949	156
12	1/05/1955	156
13	27/11/1955	155
14	8/08/1998	152
15	15/06/1952	151

Concord Golf Club (66013)		
Jan 1930 – to date		
Rank	**Date**	**Rainfall (mm)**
1	28/03/1942	295
2	6/08/1986	249
3	3/02/1990	234
4	20/03/1978	222 (2 day total)
5	10/02/1956	221
6	11/06/1991	220 (2 day total)
7	10/01/1949	208
8	16/06/1952	208 (2 day total)
9	27/11/1955	206
10	22/02/1954	198
11	16/04/1946	187
12	26/07/1952	176
13	19/11/1961	154
14	11/03/1958	153
15	16/06/1950	151

The results indicate that the 1942, 1986 and 1990 events were the largest daily rainfall events since records began in 1930. The 1986 event was reported (via the community consultation) as resulting in flooding within the William Street Catchment and SWC records reported flooding to have occurred in the adjacent Dobroyd Canal Catchment during this period.

However, high daily rainfall totals will not necessarily result in widespread flooding of the catchments, particularly if the rainfall was fairly evenly distributed throughout the day. This can be attributed to flooding within the catchments typically resulting from intense rainfall over sub-daily durations.

2.5.3. Analysis of Pluviometer Data

Continuous pluviometer records provide a more detailed description of temporal variations in rainfall. As such, the Concord Greenlees BC, Ashfield Park Bowling Club, Homebush SPS041, Enfield and Canterbury Racecourse pluviometer stations were analysed.

These pluviometer stations are all operated by SWC. The Ashfield Park Bowling Club gauge had the shortest period of record; having been established in December 1993 and decommissioned in February 2001. The other gauges remain in operation. The Enfield gauge was established in 1959, with sub-daily records beginning in June 1983. The Concord gauge was established in June 1988; the Homebush gauge was established in May 1969; and the Canterbury gauge was established in December 1993.

Table 5: Approximate ARI Recorded at Pluviometer Stations

Station Name	Years of Record	Highest Approximate ARI (AR&R 1987)	
		30 minute storm burst	1 hour storm burst
Concord Greenlees BC (formerly Wests Rugby Club)	27	2 – 5 year ARI	2 – 5 year ARI
Ashfield Park Bowling Club (566112)	7	2 – 5 year ARI	1 – 2 year ARI
Homebush SPS041 (formerly Homebush BC)	46	20 – 50 year ARI	50 – 100 year ARI
Enfield (composite site)	32	20 – 50 year ARI	10 – 20 year ARI
Canterbury Racecourse	22	5 – 10 year ARI	2 – 5 year ARI

The period of record and highest approximate ARI's for short storm bursts at the closest pluviometer stations to the study area are shown in Table 5. From this, the Homebush pluviometer recorded the highest approximate ARI for the 30 minute and 1 hour storm burst. This occurred on the 20th June 1978 (for the 30 minute storm burst) and the 31st March 2015 (for the 1 hour storm burst).

From Table 6, the 1996 event was found to be a high intensity, short duration storm event; with relatively high approximate ARI's for the 30 minute duration at the Enfield gauge. The 1996 event also appears to have been highly localised as the other proximate gauges recorded low approximate ARI's across the 30 minute, 1 hour and 2 hour storm durations. Furthermore, the 1996 event resulted in 3 reports of flooding (1 of which was above floor flooding) within the

William Street Catchment according to SWC records, discussed in Section 2.4.1.

Table 6: Rainfall Intensities for the 2nd January 1996

	Duration (minutes)		
	30	**60**	**120**
Concord Greenlees BC (566064)			
Max Rainfall (mm)	30	34	50
Intensity (mm/hr)	59	34	25
Approximate ARI	2 – 5 year ARI	1 – 2 year ARI	2 – 5 year ARI
Rank comparative to gauge records for relevant duration	3	5	2
Ashfield Park Bowling Club (566112)			
Max Rainfall (mm)	25	28	32
Intensity (mm/hr)	50	28	16
Approximate ARI	1 – 2 year ARI	~ 1 year ARI	< 1 year ARI
Rank comparative to gauge records for relevant duration	4	6	9
Homebush SPS041 (566022)			
Max Rainfall (mm)	31	33	40
Intensity (mm/hr)	61	33	20
Approximate ARI	2 – 5 year ARI	1 – 2 year ARI	1 – 2 year ARI
Rank comparative to gauge records for relevant duration	6	9	13
Enfield (566020)			
Max Rainfall (mm)	49	49	50
Intensity (mm/hr)	97	49	25
Approximate ARI	20 – 50 year ARI	5 – 10 year ARI	2 – 5 year ARI
Rank comparative to gauge records for relevant duration	2	3	6
Canterbury Racecourse (566113)			
Max Rainfall (mm)	36	38	45
Intensity (mm/hr)	71	38	22
Approximate ARI	5 – 10 year ARI	2 – 5 year ARI	1 – 2 year ARI
Rank comparative to gauge records for relevant duration	2	4	7

2.6. Design Rainfall Data

The design rainfall intensity-frequency-duration (IFD) data (shown in Table 7) was obtained from the Bureau of Meteorology's online design rainfall tool. The input parameters for these calculations are sourced from AR&R (1987).

Table 7: Rainfall IFD data (mm/hr)

DURATION	Design Rainfall Intensity (mm/hr)						
	1 yr ARI	2 yr ARI	5 yr ARI	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI
5 minutes	92.2	118	150	168	192	224	248
6 minutes	86.4	111	141	158	181	210	233
10 minutes	70.7	90.7	116	130	149	174	193
20 minutes	51.7	66.5	85.6	96.7	111	130	145
30 minutes	42.1	54.2	70.1	79.3	91.4	107	119
1 hour	28.5	36.8	47.9	54.4	62.9	74.1	82.6
2 hours	18.6	24.1	31.5	35.8	41.5	49	54.7
3 hours	14.4	18.6	24.4	27.7	32.2	38	42.4
6 hours	9.18	11.9	15.6	17.8	20.7	24.5	27.4
12 hours	5.92	7.69	10.1	11.5	13.4	15.9	17.7
24 hours	3.88	5.04	6.61	7.55	8.77	10.4	11.6
48 hours	2.51	3.26	4.27	4.87	5.66	6.69	7.47
72 hours	1.88	2.44	3.2	3.65	4.23	5	5.59

The Probable Maximum Precipitation (PMP) estimates were derived according to Bureau of Meteorology guidelines, namely the *Generalised Short Duration Method* (BoM, 2003). The estimates obtained are summarised in Table 8.

Table 8: PMP Design Rainfall Intensity (mm/hr)

Duration	Design Rainfall Intensity (mm/hr)
15 minutes	649.6
30 minutes	470.4
1 hour	345.1
2 hours	219.8
3 hours	164.5
6 hours	102.55

2.7. Previous Studies

2.7.1. Hydraulic Study and On-Site Detention Modelling for Burwood Council Catchments (Robinson GRC Consulting, 2002)

Robinson GRC Consulting prepared this report on behalf of Burwood City Council from 2000 to 2002. The catchments were within the bounds of Burwood City Council's jurisdiction, and included the Dobroyd Canal, Cooks River, Powells Creek, Exile Bay, St Lukes and William Street catchments. The primary objective of this study was to develop a computer model to assess the 1% AEP event and from this determine insufficiencies in the drainage system, as well as identify overland flow paths that occurred to an unfavourable frequency. Once these "hotspots" were identified, possible mitigation measures were proposed with further modelling undertaken to assess these. Additional to this, the report modelled the 50%, 5% and 1% AEP event with the purpose to propose Permissible Site Discharge (PSD) and storage volumes for potential On-Site Detention (OSD) systems.

The data collected for the purpose of this study included:

- survey of pit levels;
- survey of levels of the kerb, gutter, road centrelines and driveways in locations that were deemed important;
- survey of property levels that may be subject to flooding;
- three laser-doppler flow gauges recorded over the period of the 8th May 2000 to the 31st August 2000. One was located in the Cooks River catchment and two were located in the Dobroyd Canal catchment; and
- two tipping-bucket rain gauges recorded over the period of the 3rd May 2000 to the 15th September 2000. These were located at the Woodstock Park Community Centre (on Church Street, Burwood) and in Council's Depot (near Tangarra Road, Croydon Park).

However, during the period in which the flow gauges and rain gauges were in operation, the rainfall experienced was not of a significant magnitude. The largest rainfall recorded over the period of record was 13 mm over a 24 hour period.

The hydraulic model established for this report was DRAINS. This model was calibrated to the flow gauge and rain gauge records that were collected for the purpose of this study. However, as these events were not of a significant magnitude, the calibration was determined to be inconclusive.

2.7.1.1. Exile Bay Catchment

The critical duration for the Exile Bay Catchment was found to be 25 minutes in the 1% AEP event and 15 minute in the PMF event.

The hotspots identified in this report for the Exile Bay Catchment were:

- Wentworth Road;
- Philip Street; and
- Parramatta Road.

The general assessment concerning hotspots in the Exile Bay Catchment was that the pipes were at full capacity in the 1 year ARI event. However pipe dimensions were limited by the 1050 mm diameter pipe (owned by the City of Canada Bay Council) at the downstream end of the Burwood portion of the Exile Bay Catchment.

2.7.1.2. St Lukes Catchment

The critical duration for the St Lukes Catchment was found to be 25 minutes in the 1% AEP event.

The hotspots identified in this report for the St Lukes Catchment were:

- Railway Parade;
- Elsie Street;
- John Street and Dunns Lane;

- New Street;
- Park Road;
- Britannia Avenue;
- Neich Parade;
- Milton Street;
- Royce Avenue;
- Cheltenham Road; and
- Parramatta Road and Lucas Road.

2.7.1.3. William Street Catchment

The critical duration for the William Street Catchment was found to be 25 minutes in the 1% AEP event.

The hotspots identified in this report for the William Street Catchment were:

- Bay Street;
- Wychbury Avenue and Wychbury Lane;
- Parramatta Road; and
- Acton Street.

2.7.2. Sydney Water Stormwater Capacity Assessment Reports

SWC have prepared various reports that investigated the capacity performance of the SWC owned infrastructure. The reports were:

- St Lukes Park (SWC 90) Capacity Assessment – June 1997; and
- William Street (SWC97) Capacity Assessment – June 1997.

The Exile Bay Catchment did not have a SWC report available as this catchment does not have SWC owned infrastructure within the catchment area.

The drainage data used for the SWC studies included the SWC trunk drainage system only and the analysis was undertaken using a spread sheet analysis based on:

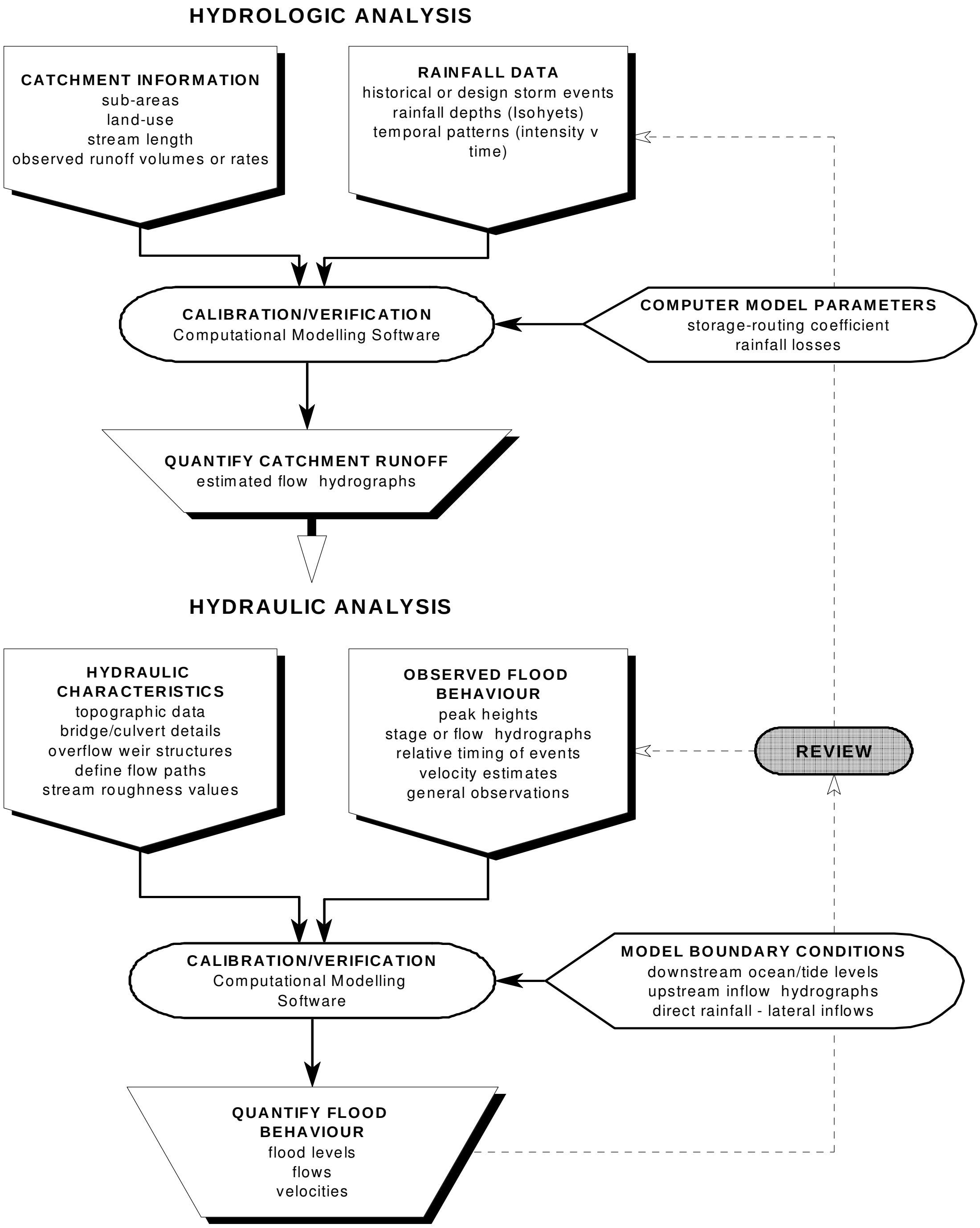
- Rational Method for inflows;
- Approximate capacities of pipes based on grade and area;
- Approximation of channel capacities using Manning's "n" formula; and the
- Hydraulic Grade Line method.

The SWC Capacity Assessment reports have been used in the present study for informing the SWC owned pit and pipe details (discussed in Section 2.3), as well as for model verification (to be completed).

3. STUDY METHODOLGOGY

A diagrammatic representation of the Flood Study process is shown in Diagram 1. The urbanised nature of the study area with its mix of pervious and impervious surfaces, and existing piped and overland flow drainage systems, has created a complex hydrologic and hydraulic flow regime.

Diagram 1: Flood Study Process



The estimation of flood behaviour in a catchment is undertaken as a two-stage process, consisting of:

1. hydrologic modelling to convert rainfall estimates to overland flow and stream runoff; and
2. hydraulic modelling to estimate overland flow distributions, flood levels and velocities.

As such, the hydrologic model, DRAINS, was built and used to create flow boundary conditions for input into a two-dimensional unsteady flow hydraulic model, i.e. TUFLOW.

Good historical flood data facilitates calibration of the models and increases confidence in the estimates. The calibration process involves modifying the initial model parameter values to produce modelled results that concur with observed data. Validation is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Recorded rainfall and stream-flow data are required for calibration of the hydrologic model, while historic records of flood levels, velocities and inundation extents can be used for the calibration of hydraulic model parameters. In the absence of such data, model verification is the only option and a detailed sensitivity analysis of the different model input parameters constitutes current best practice.

There are no stream-flow records in the catchment, so the use of a flood frequency approach for the estimation of design floods or independent calibration of the hydrologic model was not possible.

Flood estimation in urban catchments generally presents challenges for the integration of the hydrologic and hydraulic modelling approaches, which have been treated as two distinct tasks as part of traditional flood modelling methodologies. As the main output of a hydrologic model is the flow at the outlet of a catchment or sub-catchment, it is generally used to estimate inflows from catchment areas upstream of an area of interest, and the approach does not lend itself well to estimating flood inundation in mid- to upper-catchment areas, as required for this study. The aim of identifying the full extent of flood inundation can therefore be complicated by the separation of hydrologic and hydraulic processes into separate models, and these processes are increasingly being combined in a single modelling approach.

In view of the above, the broad approach adopted for this study was to use a widely utilised and well-regarded hydrologic model to conceptually model the rainfall concentration phase (including runoff from roof drainage systems, gutters, etc.). The hydrologic model used design rainfall patterns specified in AR&R (1987) and the runoff hydrographs were then used in a hydraulic model to estimate flood depths, velocities and hazard in the study area.

The sub-catchments in the hydrologic model were kept small (on average approximately 1.5 ha) such that the overland flow behaviour for the study was generally defined by the hydraulic model. This joint modelling approach was verified against previous studies and alternative methods.

3.1. Hydrologic Model

DRAINS is a hydrologic/hydraulic model that can simulate the full storm hydrograph and is capable of describing the flow behaviour of a catchment and pipe system for real storm events, as well as statistically based design storms. It is designed for analysing urban or partly urban catchments where artificial drainage elements have been installed.

The DRAINS model is broadly characterised by the following features

- the hydrological component is based on the theory applied in the ILSAX model which has seen wide usage and acceptance in Australia;
- its application of the hydraulic grade line method for hydraulic analysis throughout the drainage system; and
- the graphical display of network connections and results.

DRAINS generates a full hydrograph of surface flows arriving at each pit and routes these through the pipe network or overland, combining them where appropriate. Consequently, it avoids the "partial area" problems of the Rational Method and additionally it can model detention basins (unsteady flow rather than steady state).

Runoff hydrographs for each sub-catchment area are calculated using the time area method and the conveyance of flow through the drainage system is then modelled using the Hydraulic Grade Line method. Application of the Hydraulic Grade Line method is recommended for the design of pipe systems in AR&R (1987). The method allows pipes to operate under pressure or to "surcharge", meaning that water rises within pits, but does not necessarily overflow out onto streets. This provides improved prediction of hydraulic behaviour, consistency in design, and greater freedom in selecting pipe slopes. It requires more complicated design procedures, since pipe capacity is influenced by upstream and downstream conditions.

DRAINS cannot however adequately account for an elevated downstream tailwater level which would drown out the lower reaches of a drainage system (it can if the upstream pit is above the tailwater level but not if it is below). For this reason flooding within reaches affected by elevated water levels is more accurately assessed using the TUFLOW model.

It should be noted that DRAINS is not a true unsteady flow model and therefore does not account for the attenuation effects of routing through temporary floodplain storage (down streets or in yards). As such the use of DRAINS within the study is limited to some minor upstream routing and development of hydrological inputs into the downstream TUFLOW model.

3.2. Hydraulic Model

The availability of high quality LIDAR/ALS data means that the study area is suitable for two-dimensional (2D) hydraulic modelling. Various 2D software packages are available and the TUFLOW package was adopted as it is widely used in Australia and WMAwater have extensive experience with the model.

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions. The TUFLOW software is produced by BMT WBM and has been widely used for a range of similar projects. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short duration events and a combination of supercritical and subcritical flow behaviour.

The study area consists of a wide range of developments, with residential, commercial and open space areas. For this catchment, the study objectives require accurate representation of the overland flow system including kerbs and gutters and defined drainage controls.

For the hydraulic analysis of complex overland flow paths (such as the present study area where overland flow occurs between and around buildings), an integrated 1D/2D model such as TUFLOW provides several key advantages when compared to a 1D only model. For example, a 2D approach can:

- provide localised detail of any topographic and/or structural features that may influence flood behaviour,
- better facilitate the identification of the potential overland flow paths and flood problem areas,
- dynamically model the interaction between hydraulic structures such as culverts and complex overland flowpaths; and
- inherently represent the available floodplain storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into Council's planning activities. The model developed for the present study provides a flexible modelling platform to properly assess the impacts of any overland flow management strategies within the floodplain (as part of the ongoing floodplain management process.

In TUFLOW the ground topography is represented as a uniformly-spaced grid with a ground elevation and a Manning's "n" roughness value assigned to each grid cell. The grid cell size is determined as a balance between the model result definition required and the computer run time (which is largely determined by the total number of grid cells.

4. HYDROLOGIC MODEL

4.1. Sub-catchment Definition

The study area represented by the current DRAINS model is 1.8 km^2. This area has been represented by a total of 142 sub-catchments giving an average sub-catchment size of approximately 0.013 km^2. The sub-catchment delineation ensures that where hydraulic controls exist that these are accounted for and able to be appropriately incorporated into hydraulic routing. The sub-catchment layout is shown in Figure 6.

4.2. Impervious Surface Area

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occur significantly faster than from vegetated surfaces. This results in a faster concentration of flow within the downstream area of the catchment, and increased peak flow in some situations. It is therefore necessary to estimate the proportion of the catchment area that is covered by such surfaces.

DRAINS categorises these surface areas as either:

- paved areas (impervious areas directly connected to the drainage system),
- supplementary areas (impervious areas not directly connected to the drainage system, instead connected to the drainage system via the pervious areas), and
- grassed areas (pervious areas).

Within the study area, a uniform 5% was adopted as a supplementary area across the catchment. The remaining 95% was attributed to impervious (or paved areas) and pervious surface areas, as estimated for each individual sub-catchment. This was undertaken by determining the proportion of the sub-catchment area allocated to a land-use category and the estimated impervious percentage of each land-use category, summarised in Table 9.

Table 9: Impervious Percentage per Land-use

Land-use Category	Impervious Percentage
Property	50% Impervious
Vegetation (such as public parks)	0% Impervious
Roadway	100% Impervious

The proportion of each land-use category within a sub-catchment was determined based upon the hydraulic model roughness schematisation, shown in Figure 8. The impervious percentages attributed to each land-use category were estimated based on aerial observation of a representative area.

4.3. Rainfall Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in AR&R (1987). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed areas are comprised of an initial loss and a continuing loss. The continuing loss is calculated from an infiltration equation curve incorporated into the model and is based on the selected representative soil type and antecedent moisture condition. The catchment soil was assumed to have a slow infiltration rate and the antecedent moisture condition was considered to be rather wet.

The adopted parameters are summarised in Table 10. These are consistent with the parameters adopted in the adjacent catchments of Dobroyd Canal (WMAwater, 2013) and Powells Creek (WMAwater, 2015).

Table 10: Adopted DRAINS hydrologic model parameters

RAINFALL LOSSES	
Paved Area Depression Storage (Initial Loss)	1.0 mm
Grassed Area Depression Storage (Initial Loss)	5.0 mm
SOIL TYPE	**3**
Slow infiltration rates. This parameter, in conjunction with the AMC, determines the continuing loss	
ANTECEDENT MOISTURE CONDITONS (AMC)	**3**
Description	Rather wet
Total Rainfall in 5 Days Preceding the Storm	12.5 to 25 mm

5. HYDRAULIC MODEL

5.1. Digital Elevation Model

Given the objectives and requirements of the study and the availability of ALS data, a 2D overland flow hydraulic model is the most suitable model to effectively assess flood behaviour.

The model uses a regularly spaced computational grid, with a cell size of 3 m by 3 m. This resolution was adopted as it provides an appropriate balance between providing sufficient detail for roads and overland flow paths, while still resulting in workable computational run-times. The model grid was established by sampling from a 1 m by 1 m DEM. This DEM was generated from a triangulation of filtered ground points from the LiDAR dataset, discussed in Section 2.2. This DEM is shown in Figure 2.

5.2. Boundary Locations

The hydraulic model boundary was Queens Road / Gipps Street, which is located downstream of Parramatta Road and the Burwood LGA boundary (which is the subject of this Flood Study). The St Lukes and William Street hydraulic boundaries are within tidally affected areas and have design tidal conditions applied to the 1D and 2D domains. The Exile Bay hydraulic boundary is not affected by tide levels and as such, the invert level of the stormwater pipe in the 1D domain and the ground level of the roadway in the 2D domain were applied to the boundary.

5.3. Roughness Co-efficient

The hydraulic efficiency of the flow paths within the TUFLOW model is represented in part by the hydraulic roughness or friction factor formulated as Manning's "n" values. This factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features which may affect the hydraulic performance of the particular flow path.

The spatial variation in Manning's "n" values is shown on Figure 8. The Manning's "n" values adopted for these areas, including flowpaths (overland, pipe and in-channel), are shown in Table 11. These values have been adopted based on site inspection and past experience in similar floodplain environments. The values are consistent with typical values in the literature (Chow, 1959 and Henderson, 1966).

Table 11: Manning's "n" values adopted in TUFLOW

Surface	Manning's "n" Adopted
Pipes	0.015
Roads and Footpaths	0.02
Light Vegetation	0.03
Properties	0.05

5.4. Hydraulic Structures

5.4.1. Buildings

Buildings and other significant features likely to act as flow obstructions were incorporated into the model network based on building footprints, defined using aerial photography. These types of features were modelled as impermeable obstructions to the floodwaters.

5.4.2. Fencing and Obstructions

Smaller localised obstructions within or bordering private property, such as fences, were not explicitly represented within the hydraulic model, due to the relative impermanence of these features. The cumulative effects of these features on flow behaviour were assumed to be addressed partially by the adopted roughness parameters.

5.4.3. Sub-surface Drainage Network

Figure 7 shows the location and extent of drainage lines within the study catchment that have been included in the TUFLOW model. The drainage system defined in the model comprises:

- 2514 pipes;
- 19 open channel segments; and
- 2556 pits and nodes.

5.5. Blockage Assumptions

Blockage of hydraulic structures can occur with the transportation of a number of materials by flood waters. This includes vegetation, garbage bins, building materials and cars, the latter of which has been seen post-flood in Newcastle. However, the disparity in materials that may be mobilised within a catchment can vary greatly.

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the average exceedance probability (AEP) of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration (Barthelmess and Rigby 2009, cited in Engineers Australia 2013).

The potential effects of blockage include:

- decreased conveyance of flood waters through the blocked hydraulic structure or drainage system;
- variation in peak flood levels;
- variation in flood extent due to flows diverting into adjoining flow paths; and
- overtopping of hydraulic structures.

Existing practices and guidance on the application of blockage can be found in:

- the Queensland Urban Drainage Manual (Department of Natural Resources and Water, 2008);
- AR&R Revision Project 11 Blockage of Hydraulic Structures (Engineers Australia, 2013); and
- the policies of various local authorities and infrastructure agencies.

The guidelines proposed by the AR&R Revision Project 11 utilise generic blockage factors presented in Table 12.

Table 12: Suggested 'Design' and 'Severe' Blockage Conditions for Various Structures (Engineers Australia, 2013)

<table>
<tr><th colspan="2" rowspan="2">Type of structure</th><th colspan="2">Blockage conditions</th></tr>
<tr><th>Design blockage</th><th>Severe blockage</th></tr>
<tr><td>Sag Kerb Inlet</td><td>Kerb slot inlet only
Grated inlet only
Combined inlets</td><td>0/20%
0/50%
[1]</td><td>100% (all cases)</td></tr>
<tr><td>On-grade kerb inlets</td><td>Kerb slot inlet only
Grated inlet only (longitudinal bars)
Grated inlet only (transverse bars)
Combined inlets</td><td>0/20%
0/40%
0/50%
[2]</td><td>100% (all cases)</td></tr>
<tr><td>Field (drop) inlets</td><td>Flush mounted
Elevated (pill box) horizontal grate
Dome screen</td><td>0/80%
0/50%
0/50%</td><td>100% (all cases)</td></tr>
<tr><td rowspan="4">Pipe inlets and waterway culverts</td><td>Inlet height < 3m and width < 5m
Inlet
Chamber</td><td>0/20%
[3]</td><td>100% [4]</td></tr>
<tr><td>Inlet height > 3m and width > 5m
Inlet
Chamber</td><td>0/10%
[3]</td><td>25%
[3]</td></tr>
<tr><td>Culverts and pipe inlets with effective debris control features</td><td>As above</td><td>As above</td></tr>
<tr><td>Screened pipe and culvert inlets</td><td>0/50%</td><td>100%</td></tr>
<tr><td>Bridges</td><td>Clear opening height < 3 m
Clear opening height > 3 m
Central piers</td><td>[5]
0%
[7]</td><td>100%
[6]
[7]</td></tr>
<tr><td colspan="2">Solid handrails and traffic barriers associated with bridges and culverts</td><td>100%</td><td>100%</td></tr>
<tr><td colspan="2">Fencing across overland flow paths</td><td>[8]</td><td>100%</td></tr>
<tr><td colspan="2">Screened stormwater outlets</td><td>100%</td><td>100%</td></tr>
</table>

Current modelling has been undertaken assuming no blockage of pipes, culverts and bridges greater than 300 mm in diameter. Pipes less than or equal to 300 mm in diameter were conservatively assumed to be completely blocked.

6. VERIFICATION MODELLING

6.1. Introduction

Prior to use for defining design flood behaviour it is important that the performance of the overall modelling system be substantiated. Calibration involves modifying the initial model parameter values to produce modelled results that concur with observed data. Validation is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Best practice is that the modelling system should be calibrated to one historical event and validated using multiple historical events. To facilitate this there needs to be adequate historical flood observations and sufficient pluviometer rainfall data.

Typically in urban areas such information is lacking. Issues which may prevent a thorough calibration of hydrologic and hydraulic models are:

- there is only a limited amount of historical flood information available for the study area. For example, in Sydney (east of Parramatta) there are only two water level recorders in urban catchments similar to that of the study area; and
- rainfall records for past floods are limited and there is a lack of temporal information describing historical rainfall patterns within the catchment.

In the event that a calibration and validation of the models is not possible or limited in scope, it is best practice to undertake a verification of the models and a detailed sensitivity analysis.

6.2. Correlating Data

The correlation between the historic flood level data (discussed in Section 2.4) and available pluviometer data (discussed in Section 2.5.3) is summarised in Table 13.

The approximate ARI for these storm events have been estimated based on the pluviometer rainfall gauge at Concord Greenlees BC (566064) for the 30 minute storm duration and the IFD data for the centre of the study area (discussed in Section 2.6).

For the storm events in which a pluviometer station was present, the ARI estimated was typically of a small magnitude (shown in Table 13). Engineers Australia (2012) advises that calibration events “span the magnitude range of the intended design events with a preference for the more important design floods (eg. 1% AEP event)”. For this reason, a verification of the models was undertaken instead of calibrating or validating the models.

Table 13: Data available for various storm events

Storm Events	Total Records	Indicative Depths Available	Approximate ARI	Pluviometer Stations in Operation
19 May 1946	1	0	N/A	
Nov 1961	1	0	N/A	
1986	1	0	N/A	Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020)
2 Jan 1996	3	1	2 – 5 year ARI	Concord Greenlees BC (566064) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
2009	1	1	< 1 year ARI *	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
2013	1	1	< 1 year ARI *	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
Mar 2014	1	1	1 – 2 year ARI *	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
8 Nov 2014	1	1	< 1 year ARI	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
Aug 2015	1	0	< 1 year ARI *	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)

* Note: Where the precise date was not specified, the largest approximate ARI event to occur within the date range provided is shown.

6.3. Hydrologic Model Verification

A comparison against previous studies of nearby catchments can be undertaken to verify the model. For this study, the hydrologic model from the Rose Bay catchment was compared to study area. DRAINS was the hydrologic model used in Rose Bay and the catchment is located approximately 12 km from the study area.

Comparison of specific yield was used for the model verification and is calculated by dividing the peak discharge by the area of the upstream catchment. This calculation removes the effects that variations in sub-catchment size have on peak discharge. Also, to remove the effects that differences in catchment delineation can have on peak discharge, the specific yield was calculated for multiple, randomly-selected, sub-catchments. The results are shown in Table 14 and the specific yields from the two different DRAINS models were found to be comparable.

Table 14: Comparable sub-catchment hydrologic model verification

Sub-catchment	Exile Bay, St Lukes and William Street			Rose Bay		
	Area (ha)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)	Area (ha)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)
1	0.4	0.3	0.6	1	0.6	0.7
2	2.8	1.5	0.5	0.4	0.2	0.6
3	13.8	6.4	0.5	0.6	0.4	0.6

6.4. Hydrologic and Hydraulic Model Verification

Verification of the hydraulic model was undertaken by:

- comparing the modelled design results against the results in the 1997 report by SWC;
- comparing the modelled design results against the hotspots identified in the 2002 report by Robinson GRC Consulting.

6.4.1. Comparison with the SWC (1997) report

Comparison was undertaken on the 20% AEP peak flows produced in the TUFLOW hydraulic model and those in the SWC report, summarised in Table 15.

Table 15: SWC (1997) results compared to the current study results – for the 20% AEP event

Pipe/Channel ID	Catchment	SWC Report (1998) (m^3/s)	Current Study (m^3/s)
C-D	St Lukes	24.3	17.2
D-E	St Lukes	15.2	8.8
E-K	St Lukes	10.2	4.8
K-F	St Lukes	5.5	3.1
G-H	St Lukes	4.8	3.2
H-HA	St Lukes	3.5	2.9
HA-HB	St Lukes	3.2	2.7
HB-J	St Lukes	2.6	2.7
D-D1	St Lukes	7.9	4.4
B-C	William Street	8.1	4.0
C-D	William Street	7.4	4.0
D-E	William Street	6.9	3.9
E-F	William Street	6.9	3.7
F-G	William Street	5.8	3.4
B-BA	William Street	3.1	0.6
BA-BB	William Street	2.1	0.1
BB-BC	William Street	2.1	0.1
BC-BD	William Street	1.5	0.0
BA-BAA	William Street	1.1	0.6
BAA-BAB	William Street	0.8	0.6

Peak flows in the current study were significantly less than those in the previous study. The peak flows produced in the previous study were obtained using the Manning's "n" formula and did not explicitly account for storage within the catchment. Within the study area, this has a significant influence due to parks that act as detention basins and obstructions such as buildings and the railway embankment impeding flow.

6.4.2. Comparison with the Robinson GRC Consulting (2002) report

Comparison was made between the 1% AEP flood extent obtained in the current study with the hotspots identified in the Robinson GRC Consulting (2002) report. It was found that the hotspots identified in the previous report coincided with the flow paths identified in the current study. This is summarised in Table 16.

Table 16: Robinson GRC Consulting (2002) hotspots compared to the 1% AEP peak flood depth

Location	Catchment	Flood Depth (m)
Wentworth Road	Exile Bay	0.31
Philip Street	Exile Bay	0.22
Parramatta Road	Exile Bay	0.49
Railway Parade	St Lukes	0.49
Elsie Street	St Lukes	0.52
John Street and Dunns Lane	St Lukes	0.54
New Street	St Lukes	0.56
Park Road	St Lukes	0.02
Britannia Avenue	St Lukes	0.15
Neich Parade	St Lukes	0.30
Milton Street	St Lukes	0.69
Royce Avenue	St Lukes	0.12
Cheltenham Road	St Lukes	0.27
Parramatta Road and Lucas Road	St Lukes	0.63
Bay Street	William Street	0.22
Wychbury Avenue and Wychbury Lane	William Street	0.59
Parramatta Road	William Street	0.55
Acton Street	William Street	0.03

7. DESIGN EVENT MODELLING

7.1. Overview

There are two basic approaches to determining design flood levels, namely:

- *flood frequency analysis* – based upon a statistical analysis of the flood events; and
- *rainfall and runoff routing* – design rainfalls are processed by hydrologic and hydraulic computer models to produce estimates of design flood behaviour.

The *flood frequency* approach requires a reasonably complete homogenous record of flood levels and flows over a number of decades to give satisfactory results. No such records were available within this catchment. For this reason a *rainfall and runoff routing* approach using DRAINS model results was adopted for this study to derive inflow hydrographs for input to the TUFLOW hydraulic model, which determines design flood levels, flows and velocities. This approach reflects current engineering practice outlined in the recent revisions to Australian Rainfall and Runoff (Engineers Australia, 2016) and is consistent with the quality and quantity of available data.

7.2. Critical Duration

To determine the critical duration for various parts of the catchments, modelling of the 1% AEP event was undertaken for a range of design storm durations from 15 minutes to 9 hours, using temporal patterns from AR&R (1987). An envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

It was found that a combination of the 25 minute and 1 hour design storm durations were critical across all the catchments for the 1% AEP event. The 1 hour storm duration was critical in the downstream areas; up to and including Parramatta Road within the Exile Bay and William Street Catchments; and up to Burwood Road (to the west), New Street (to the south) and Lucas Road (to the east) within the St Lukes Catchment. The 1 hour storm duration was also critical between George Street and Park Avenue to the west of the buildings on Burwood Road. The critical duration that was predominant across the remainder of the study area was the 25 minute storm burst. The difference between the peak flood levels for the 25 minute and 1 hour storm durations was within ± 0.15 m. Therefore it was determined appropriate to adopt an embedded design storm for the entire catchment, using the 25 minute design storm burst within the 1 hour design storm, adjusted to maintain the correct 1 hour total rainfall depth. This method is described in References 10, 11 and 12.

Additionally, the critical storm duration was determined for the PMF event for a range of storm durations, ranging from 15 minutes to 6 hours. Similarly, an envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

It was found that a combination of the 15 minute, 30 minute and 1 hour design storm durations were critical in the PMF event. The 1 hour storm duration was critical upstream of the railway embankment (along Railway Parade). The 30 minute storm duration was critical from Wangal Park to Cheltenham Road and in the downstream areas up to and including Parramatta Road within the St Lukes and William Street Catchments. The critical duration that was predominant across the remainder of the study area was the 15 minute storm burst. The difference between the peak flood levels for the 15 minute and 30 minute storm durations was within ± 0.10 m. Therefore, a peak envelope of the 15 minute and 30 minute storm durations was adopted.

7.3. Downstream Boundary Conditions

In addition to runoff from the catchment, downstream areas can also be influenced by high water levels within Iron Cove and the trunk drainage system. Consideration must therefore be given to accounting for the joint probability to coincident flooding from both catchment runoff and backwater effects.

The combined impact of these two sources on overall flood risk varies significantly with distance from the ocean and the degree of ocean influence, which is in turn affected by the entrance conditions. The *Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* guide (2015) presents a multivariate approach for hydraulic modelling purposes and was applied in this study.

Given the short duration of the critical storm burst, the simplistic approach using a steady state ocean boundary was considered sufficient. The catchment was defined as Entrance Type A (open oceanic embayment) and was located south of Crowdy Head; resulting in the 1% AEP and 5% AEP ocean levels as those shown in Table 17.

Table 17: Combinations of Catchment Flooding and Oceanic Inundation Scenarios

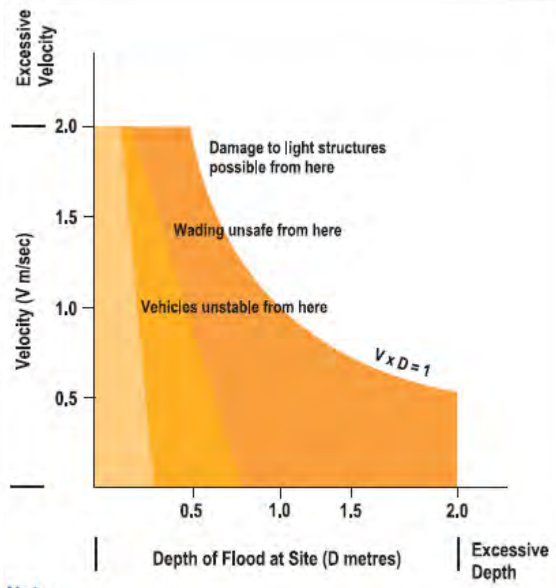
Design AEP for peak flood levels	Catchment Flood Scenario	Ocean Water Level Boundary
0.2 EY	0.2 EY Rainfall	HHWS Ocean Level 1.25 m AHD
10% AEP	10% AEP Rainfall	HHWS Ocean Level 1.25 m AHD
5% AEP	5% AEP Rainfall	HHWS Ocean Level 1.25 m AHD
2% AEP	2% AEP Rainfall	5% AEP Ocean Level 1.40 m AHD
1% AEP (Enveloped)	5% AEP Rainfall	1% AEP Ocean Level 1.45 m AHD
	1% AEP Rainfall	5% AEP Ocean Level 1.40 m AHD
PMF	PMF Rainfall	1% AEP Ocean Level 1.45 m AHD

7.4. Analysis

7.4.1. Provisional Hydraulic Hazard

Hazard categories were determined in accordance with Appendix L of the NSW Floodplain Development Manual, the relevant section of which is shown in Diagram 2. For the purposes of this report, the transition zone presented in Diagram 2 (L2) was considered to be high hazard.

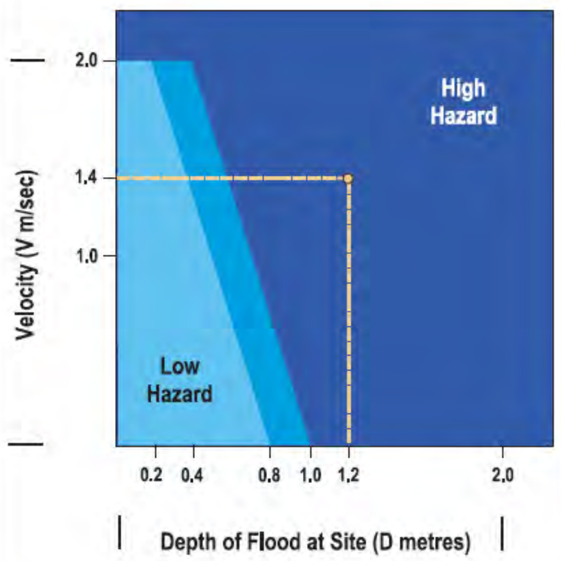
Diagram 2: (L1) Velocity and Depth Relationship; (L2) Provisional Hydraulic Hazard Categories (NSW State Government, 2005)



Notes

1. At velocities in excess of 2.0 m/s, the stability of foundations and poles can be affected by scour. Also, grass and earth surfaces begin to scour and can become rough and unstable
2. The velocity of floodwaters passing between buildings can produce a hazard, which may not be apparent if only the average velocity is considered. For instance, the velocity of floodwaters in a model test has risen from an average of 1 m/sec to 3 m/sec between houses.
3. Vehicle instability is initially by buoyancy.
4. At floodwater depths in excess of 2.0 meters and even at low velocities, there can be damage to light-framed buildings from water pressure, flotation and debris impact.

Derived from laboratory testing and flood conditions which caused damage.



Notes

The degree of hazard may be either -

- reduced by establishment of an effective flood evacuation procedure.
- increased if evacuation difficulties exist.

In the transition zone highlight by the median colour, the degree of hazard is dependant on site conditions and the nature of the proposed development.

Example:

If the depth of flood water is **1.2 m**
and the velocity of floodwater is **1.4 m/sec**
then the provisional hazard is **high**

7.4.2. Provisional Hydraulic Categorisation

The hydraulic categories, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (NSW State Government, 2005). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study area.

For this study, hydraulic categories were defined by the following criteria, which correspond in part with the criteria proposed by Howells et. al. (2003):

- Floodway is defined as areas where:
    - o the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s **AND** peak velocity > 0.25 m/s, **OR**
    - o peak velocity > 1.0 m/s **AND** peak depth > 0.15 m

The remainder of the floodplain is either Flood Storage or Flood Fringe:

- Flood Storage comprises areas outside the floodway where peak depth > 0.5 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 0.5 m

7.4.3. Preliminary Flood Emergency Response Classification of Communities

The Floodplain Development Manual, 2005 requires flood studies to address the management of continuing flood risk to both existing and future development areas. As continuing flood risk varies across the floodplain so does the type and scale of emergency response problem and therefore the information necessary for effective Emergency Response Planning (ERP). Classification provides an indication of the vulnerability of the community in flood emergency response and identifies the type and scale of information needed by the SES to assist in emergency response planning (ERP).

Criteria for determining flood ERP classifications and an indication of the emergency response required for these classifications are provided in the Floodplain Risk Management Guideline, 2007 (Flood Emergency Response Planning: Classification of Communities). Table 18 summarises the response required for areas of different classification. However, these may vary depending on local flood characteristics and resultant flood behaviour, i.e. in flash flooding or overland flood areas.

Table 18: Response Required for Different Flood ERP Classifications

Classification	**Response Required**		
	Resupply	**Rescue/Medivac**	**Evacuation**
High Flood Island	Yes	Possibly	Possibly
Low Flood Island	No	Yes	Yes
Area with Rising Road Access	No	Possibly	Yes
Area with Overland Escape Routes	No	Possibly	Yes
Low Trapped Perimeter	No	Yes	Yes
High Trapped Perimeter	Yes	Possibly	Possibly
Indirectly Affected Areas	Possibly	Possibly	Possibly

7.5. Results

The results from this study are presented as:

- Peak flood level profiles in Figure 10;
- Flow and level hydrographs in Figure 11;
- Peak flood depths and level contours in Figure 12 to Figure 17;
- Peak flood velocities in Figure 18 to Figure 20;
- Provisional hydraulic hazard in Figure 21 to Figure 23;
- Provisional hydraulic categorisation in Figure 24 to Figure 26;
- Preliminary flood emergency response classification of communities in Figure 27; and
- Preliminary flood planning areas in Figure 28.

7.5.1. Peak Flood Depths and Levels

The tabulated summary of peak flood depths is presented in Table 19.

Table 19: Peak Flood Depths (m) at Key Locations

ID	Location	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.32	0.37	0.42	0.45	0.49	0.93
H02	Cnr Wentworth Rd and White St	0.13	0.15	0.17	0.18	0.19	0.42
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.40	0.45	0.51	0.58	0.63	1.31
H04	Cnr Milton St and Archer St	0.44	0.50	0.57	0.64	0.69	1.62
H05	Meryla St	0.33	0.36	0.39	0.42	0.45	0.93
H06	Cnr Burwood Rd and Park Ave	0.29	0.32	0.36	0.39	0.43	1.18
H07	Elsie St	0.22	0.33	0.42	0.47	0.52	0.93
H08	Railway Parade near Wynne Ave	0.36	0.39	0.43	0.46	0.49	2.14
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.24	0.28	0.37	0.44	0.49	1.01
H10	Wangal Park	0.89	1.06	1.17	1.36	1.50	2.58
H11	Cnr Parramatta Rd and Short St	0.44	0.47	0.50	0.52	0.55	1.21
H12	Grogan St	0.38	0.40	0.44	0.46	0.48	0.92
H13	Wychbury La	0.40	0.45	0.50	0.54	0.59	1.26

The tabulated summary of peak flood levels is presented in Table 20.

Table 20: Peak Flood Levels (m AHD) at Key Locations

ID	Location	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Parramatta Rd – Between Philip St and Wentworth Rd	15.26	15.30	15.35	15.39	15.43	15.86
H02	Cnr Wentworth Rd and White St	18.55	18.57	18.59	18.60	18.61	18.84
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	4.17	4.22	4.29	4.35	4.40	5.08
H04	Cnr Milton St and Archer St	5.67	5.73	5.80	5.87	5.92	6.85
H05	Meryla St	9.25	9.27	9.31	9.33	9.36	9.85
H06	Cnr Burwood Rd and Park Ave	11.66	11.69	11.73	11.76	11.80	12.55
H07	Elsie St	14.36	14.47	14.56	14.61	14.65	15.07
H08	Railway Parade near Wynne Ave	19.20	19.24	19.27	19.30	19.33	20.99
H09	Lucas Rd – Between Parramatta Rd and Stuart St	5.89	5.94	6.03	6.10	6.14	6.66
H10	Wangal Park	13.89	14.06	14.17	14.36	14.50	15.58
H11	Cnr Parramatta Rd and Short St	3.91	3.94	3.97	3.99	4.02	4.68
H12	Grogan St	4.90	4.93	4.96	4.98	5.00	5.45
H13	Wychbury La	9.58	9.63	9.69	9.73	9.77	10.45

7.5.2. Peak Flow

The tabulated summary of peak flows within the stormwater pipes and overland is presented in Table 21.

Table 21: Peak Flow (m^3/s) at Key Locations

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	2.3	3.6	5.3	6.6	8.1	45.4
		Pipe	2.1	2.2	2.2	2.2	2.3	2.7
Q02	Cnr Wentworth Rd and Nixon La	Overland	0.5	0.7	1.0	1.2	1.5	9.6
		Pipe	0.8	0.9	1.0	1.1	1.1	1.6
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	4.6	6.8	10.4	15.1	19.2	141.6
		Pipe	13.1	13.9	15.0	15.5	16.3	17.8
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	4.5	6.2	8.9	12.0	15.0	95.8
		Pipe	8.8	9.0	9.9	9.7	9.9	10.2
Q05	New Street	Overland	6.0	7.6	9.9	12.1	14.4	79.7
		Pipe	5.3	5.2	5.6	5.7	5.8	7.0
Q06	Cnr Burwood Rd and Wilga St	Overland	3.7	4.6	5.8	6.5	7.9	46.5
		Pipe	2.9	3.0	3.1	3.1	3.1	4.1
Q07	Elsie St	Overland	0.2	0.6	1.1	1.5	1.9	9.8
		Pipe	2.5	2.5	2.6	2.6	2.6	3.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0	0.0	0.0	0.0
		Pipe	1.8	2.0	2.1	2.2	2.4	4.2
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	1.8	2.3	3.2	4.4	5.6	29.5
		Pipe	1.9	1.9	2.0	2.1	2.1	2.3
Q10	Wangal Park	Overland	0.0	0.0	0.0	0.0	0.0	5.1
		Pipe	0.2	0.2	0.2	0.2	0.2	0.3
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	3.5	5.3	7.5	9.3	11.1	60.8
		Pipe	3.4	3.4	3.5	3.5	3.5	3.6
Q12	Grogan St	Overland	4.6	5.6	7.0	8.1	9.4	47.1
		Pipe	0.8	0.8	0.8	0.9	0.9	0.9
Q13	Wychbury La	Overland	0.5	0.6	0.8	0.9	1.1	4.3
		Pipe	0.3	0.3	0.3	0.3	0.3	0.4

7.5.3. Provisional Hydraulic Hazard

The high hazard areas were predominantly located in the roadways in the 1% AEP event. The areas of high hazard were located at:

- Esher Street, south of New Street;
- Milton Street;
- Shaftesbury Road, north of Milton Street;
- Parramatta Road, between Shaftesbury Road and the open channel;
- St Lukes open channel and Concord Oval; and
- William Street, north of Parramatta Road.

7.5.4. Provisional Hydraulic Categorisation

In the 1% AEP event, the floodway areas were predominantly located in the roadways, located at:

- Wentworth Road, north of White Street;
- Burwood Road, between Victoria Street East and Meryla Street;
- Meryla Street, west of Esher Street;
- Esher Street, south of New Street;
- New Street;
- Archer Street, north of New Street;
- Milton Street, between Esher Street and Archer Street;
- Shaftesbury Road, north of Milton Street;
- Parramatta Road, between Shaftesbury Road and Lucas Road;
- Lucas Road, north of Stuart Street;
- St Lukes open channel;
- Short Street; and
- William Street.

The flood storage areas were predominantly located in parks, such as Wangal Park and Concord Oval.

7.5.5. Preliminary Flood Emergency Response Classification of Communities

ERP classifications for the study area are shown in Figure 27. Due to the railway embankment between Burwood Road and Park Road, the area immediately upstream of the embankment was classified as a Low Trapped Perimeter Area and the area immediately downstream was classified as a High Trapped Perimeter Area. Areas along Wentworth Road, Burwood Road, Milton Street and Parramatta Road were classified as Low Flood Island areas. The areas classified as Rising Road Access are likely to be inundated but have roads rising uphill and away from the rising floodwaters.

The criteria for classification of floodplain communities are generally more applicable to riverine flooding where significant flood warning time is available and emergency response action can be taken prior to the flood. In urban areas like Burwood, flash flooding from local catchment and overland flow will generally occur as a direct response to intense rainfall without significant warning. For most (if not all) flood affected properties in the catchment, remaining inside the building is likely to present less risk to life than attempting to drive or wade through floodwaters, as flow velocities and depths are likely to be greater in the roadway.

8. SENSITIVITY ANALYSIS

8.1. Overview

The following sensitivity analyses were undertaken to establish the variation in design flood levels and flow that may occur if different parameter assumptions were made:

- Routing Lag: The hydrologic routing length values were increased and decreased by 20% for all sub-catchments;
- Manning's "n": The hydraulic roughness values were increased and decreased by 20%;
- Blockage (pipes): Sensitivity to blockage of all pipes was assessed for 20% and 50% blockage;
- Climate Change (Rainfall Increase): Sensitivity to rainfall/runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30% as recommended under current guidelines;
- Climate Change (Sea Level Rise): Sea level rise scenarios of 0.4 m and 0.9 m were assessed.

These sensitivity scenarios were undertaken for the 1% AEP rainfall event with the 5% AEP ocean level.

8.2. Climate Change Background

Intensive scientific investigation is ongoing to estimate the effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) are having on the average earth surface temperature. Changes to surface and atmospheric temperatures may affect climate and sea levels. The extent of any permanent climatic or sea level change can only be established with certainty through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change, evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing greenhouse gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase;
- global sea level has risen about 0.1 m to 0.25 m in the past century;
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

8.2.1. Rainfall Increase

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however this information is not of sufficient accuracy for use as yet (NSW State Government, 2007).

Any increase in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation (IPO) index (Westra et al, 2009). Although mean daily rainfall intensity is not observed to differ significantly between IPO phases, runoff is significantly reduced during periods with fewer rain days.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the Dobroyd Canal catchment under warmer climate scenarios.

In light of this uncertainty, the NSW State Government (2007) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

8.2.2. Sea Level Rise

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009. This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (NSW State Government, 2009) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010.*

The Policy Statement says:

> *"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… However, the 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible"* (NSW State Government, 2009)

In light of this uncertainty, the NSW State Government's advice is subject to periodical review. As of 2012, the NSW State Government withdrew endorsement of sea level rise predictions but still require sea level rise to be considered. The current Flood Study assessed the sensitivity to a projected sea level rise of 0.4 m by 2050 and 0.9 m by 2100, corresponding to the sea level rise sensitivity analysis in the adjacent Dobroyd Canal Flood Study.

8.3. Results

The sensitivity scenario results were compared to the 1% AEP rainfall event with the 5% AEP ocean level. A summary of peak flood level and peak flow differences at various locations are provided in:

- Table 22 for variations in routing;
- Table 24 for variations in roughness;
- Table 26 for variations in blockage; and
- Table 28 for variations in climate conditions.

Comparison of peak flood levels have been highlighted such that yellow highlighting indicates that the magnitude of the change is greater than 0.1 m, while red highlighting indicates changes greater than 0.3 m in magnitude.

8.3.1. Roughness Variations

Overall peak flood level results were shown to be relatively insensitivity to variations in the roughness parameter. Generally, these results were found to be within ± 0.05 m.

Table 22: Results of Roughness Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Roughness Decreased by 20%	Roughness Increased by 20%
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.49	-0.01	0.00
H02	Cnr Wentworth Rd and White St	0.19	-0.01	0.01
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.63	0.00	0.00
H04	Cnr Milton St and Archer St	0.69	-0.01	0.01
H05	Meryla St	0.45	0.00	0.01
H06	Cnr Burwood Rd and Park Ave	0.43	-0.01	0.01
H07	Elsie St	0.52	-0.01	0.01
H08	Railway Parade near Wynne Ave	0.49	0.00	0.01
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.49	-0.02	0.01
H10	Wangal Park	1.50	-0.01	0.01
H11	Cnr Parramatta Rd and Short St	0.55	0.00	0.00
H12	Grogan St	0.48	-0.01	0.01
H13	Wychbury La	0.59	-0.01	0.02

Table 23: Results of Roughness Analysis – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
				Roughness Decreased by 20%	Roughness Increased by 20%
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	0.3	-0.3
		Pipe	2.3	0.0	0.0
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	0.0	-0.1
		Pipe	1.1	0.0	0.0
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	1.7	-1.3
		Pipe	16.3	-0.9	0.3
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	1.0	-1.0
		Pipe	9.9	-0.2	0.0
Q05	New Street	Overland	14.4	0.7	-0.6
		Pipe	5.8	-0.5	-0.1
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	0.2	-0.2
		Pipe	3.1	0.1	0.0
Q07	Elsie St	Overland	1.9	0.0	0.0
		Pipe	2.6	0.0	0.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0
		Pipe	2.4	-0.1	0.1
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	0.3	-0.3
		Pipe	2.1	0.0	0.0
Q10	Wangal Park	Overland	0.0	0.0	0.0
		Pipe	0.2	0.0	0.0
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	0.6	-0.5
		Pipe	3.5	0.0	0.0
Q12	Grogan St	Overland	9.4	0.2	-0.2
		Pipe	0.9	0.0	0.0
Q13	Wychbury La	Overland	1.1	0.0	0.0
		Pipe	0.3	0.0	0.0

8.3.2. Routing Variations

Overall peak flood level results were shown to be relatively insensitivity to variations in the routing parameter. Generally, these results were found to be within ± 0.05 m.

Table 24: Results of Routing Analysis – Change in Levels

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Routing Decreased by 20%	Routing Increased by 20%
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.49	0.00	0.00
H02	Cnr Wentworth Rd and White St	0.19	0.00	0.00
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.63	0.00	0.00
H04	Cnr Milton St and Archer St	0.69	0.00	0.00
H05	Meryla St	0.45	0.00	0.00
H06	Cnr Burwood Rd and Park Ave	0.43	0.00	0.00
H07	Elsie St	0.52	0.00	0.00
H08	Railway Parade near Wynne Ave	0.49	0.00	0.00
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.49	0.00	0.00
H10	Wangal Park	1.50	0.00	0.00
H11	Cnr Parramatta Rd and Short St	0.55	0.00	-0.01
H12	Grogan St	0.48	0.00	0.00
H13	Wychbury La	0.59	0.01	-0.01

Table 25: Results of Routing Analysis – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
				Routing Decreased by 20%	Routing Increased by 20%
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	-0.3	0.2
		Pipe	2.3	0.0	0.0
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	-0.1	0.1
		Pipe	1.1	0.0	0.0
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	-1.3	0.1
		Pipe	16.3	0.3	-0.4
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	-1.0	0.1
		Pipe	9.9	0.0	0.1
Q05	New Street	Overland	14.4	-0.6	0.2
		Pipe	5.8	-0.1	-0.1
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	-0.2	0.2
		Pipe	3.1	0.0	0.0
Q07	Elsie St	Overland	1.9	0.0	0.0
		Pipe	2.6	0.0	0.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0
		Pipe	2.4	0.1	0.1
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	-0.3	0.1
		Pipe	2.1	0.0	0.0
Q10	Wangal Park	Overland	0.0	0.0	0.0
		Pipe	0.2	0.0	0.0
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	-0.5	0.3
		Pipe	3.5	0.0	0.0
Q12	Grogan St	Overland	9.4	-0.2	0.2
		Pipe	0.9	0.0	0.0
Q13	Wychbury La	Overland	1.1	0.0	0.0
		Pipe	0.3	0.0	0.0

8.3.3. Blockage Variations

Peak flood level results were found to be relatively insensitive to blockage of pipes, with the exclusion of Railway Parade and Wangal Park.

Railway Parade is a trapped low point and the pits and pipes are the sole means of discharge from this area (as discussed in Section 10.5), therefore blockage of pipes resulted in increased peak flood levels.

In the case of Wangal Park, the area was designed to function as a detention basin; with inflows from pits and pipes diverting flow into this location as well as local runoff. Outflows from Wangal Park occur predominantly via pipes, with the exclusion of the PMF event in which the detention basin is overtopped and overland flow occurs (as shown in Table 21). Therefore, in the pipe blockage scenario the decrease in outflows exceeds the decrease in inflows and resulted in increased peak flood levels.

Table 26: Results of Blockage Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Blockage (Pipes) by 20%	Blockage (Pipes) by 50%
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.49	0.01	0.03
H02	Cnr Wentworth Rd and White St	0.19	0.00	0.01
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.63	0.02	0.06
H04	Cnr Milton St and Archer St	0.69	0.02	0.05
H05	Meryla St	0.45	0.01	0.02
H06	Cnr Burwood Rd and Park Ave	0.43	0.02	0.06
H07	Elsie St	0.52	0.03	0.06
H08	Railway Parade near Wynne Ave	0.49	0.03	0.12
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.49	0.02	0.04
H10	Wangal Park	1.50	0.08	0.20
H11	Cnr Parramatta Rd and Short St	0.55	0.01	0.03
H12	Grogan St	0.48	0.00	0.01
H13	Wychbury La	0.59	0.02	0.04

Table 27: Results of Blockage Analysis – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
				Blockage (Pipes) by 20%	Blockage (Pipes) by 50%
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	0.5	1.4
		Pipe	2.3	-0.4	-1.2
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	0.2	0.5
		Pipe	1.1	-0.2	-0.5
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	1.9	5.6
		Pipe	16.3	-3.5	-8.1
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	1.3	3.7
		Pipe	9.9	-2.0	-5.0
Q05	New Street	Overland	14.4	0.4	1.3
		Pipe	5.8	-1.3	-2.8
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	0.5	1.7
		Pipe	3.1	-0.6	-1.5
Q07	Elsie St	Overland	1.9	0.3	0.6
		Pipe	2.6	-0.5	-1.3
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0
		Pipe	2.4	-0.2	-0.6
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	0.4	1.2
		Pipe	2.1	-0.4	-1.1
Q10	Wangal Park	Overland	0.0	0.0	0.0
		Pipe	0.2	-0.1	-0.1
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	0.6	1.7
		Pipe	3.5	-0.7	-1.8
Q12	Grogan St	Overland	9.4	0.1	0.4
		Pipe	0.9	-0.2	-0.5
Q13	Wychbury La	Overland	1.1	0.1	0.2
		Pipe	0.3	-0.1	-0.2

8.3.4. Climate Variations

The effect of increasing the design rainfalls by 10%, 20% and 30% has been evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the study area; with the greatest increases occurring in flood storage areas such as Wangal Park, Concord Oval and Spencer Avenue Five Dock. Generally speaking, each incremental 10% increase in rainfall results in an approximately 0.1 m increase in peak flood levels at the more sensitive locations analysed. The 1% AEP event with a rainfall increase of 30% is approximately equivalent to a 0.2% AEP event in present day conditions and an impact on flood levels is not unexpected.

The sea level rise scenarios were found not to have a significant effect on peak flood levels upstream of Parramatta Road. Downstream of Parramatta Road, areas found to be sensitive to sea level rise were the St Lukes open channel, William Street, Spencer Street and Queens Road Five Dock.

Table 28: Results of Climate Change Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)				
			Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	2050 Sea Level Rise + 0.4 m	2100 Sea Level Rise + 0.9 m
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.49	0.03	0.05	0.08	0.00	0.00
H02	Cnr Wentworth Rd and White St	0.19	0.01	0.03	0.03	0.00	0.00
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.63	0.05	0.09	0.13	0.00	0.00
H04	Cnr Milton St and Archer St	0.69	0.05	0.10	0.14	0.00	0.00
H05	Meryla St	0.45	0.03	0.06	0.08	0.00	0.00
H06	Cnr Burwood Rd and Park Ave	0.43	0.04	0.08	0.12	0.00	0.00
H07	Elsie St	0.52	0.03	0.06	0.08	0.00	0.00
H08	Railway Parade near Wynne Ave	0.49	0.07	0.14	0.21	0.00	0.00
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.49	0.04	0.07	0.10	0.00	0.00
H10	Wangal Park	1.50	0.13	0.26	0.37	0.00	0.00
H11	Cnr Parramatta Rd and Short St	0.55	0.03	0.06	0.09	0.00	0.01
H12	Grogan St	0.48	0.02	0.04	0.06	0.00	0.00
H13	Wychbury La	0.59	0.04	0.08	0.12	0.00	0.00

Table 29: Results of Climate Change Analysis (Rainfall Increase) – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)		
				Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	1.4	2.8	4.1
		Pipe	2.3	0.0	0.0	0.1
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	0.3	0.5	0.8
		Pipe	1.1	0.0	0.1	0.1
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	4.3	8.3	12.5
		Pipe	16.3	-0.7	-0.4	-0.2
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	3.0	6.2	9.5
		Pipe	9.9	0.0	0.0	0.1
Q05	New Street	Overland	14.4	2.4	5.0	7.4
		Pipe	5.8	-0.1	-0.1	0.0
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	1.4	2.8	4.3
		Pipe	3.1	0.1	0.1	0.2
Q07	Elsie St	Overland	1.9	0.3	0.7	1.0
		Pipe	2.6	0.0	0.0	0.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0	0.0
		Pipe	2.4	0.2	0.3	0.4
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	1.1	2.1	3.1
		Pipe	2.1	0.0	0.0	0.1
Q10	Wangal Park	Overland	0.0	0.0	0.0	0.0
		Pipe	0.2	0.0	0.0	0.0
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	1.8	3.6	5.4
		Pipe	3.5	0.0	0.0	0.0
Q12	Grogan St	Overland	9.4	1.1	2.3	3.6
		Pipe	0.9	0.0	0.0	0.0
Q13	Wychbury La	Overland	1.1	0.2	0.3	0.5
		Pipe	0.3	0.0	0.0	0.0

Table 30: Results of Climate Change Analysis (Sea Level Rise) – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
				2050 Sea Level Rise + 0.4 m	2100 Sea Level Rise + 0.9 m
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	0.0	0.0
		Pipe	2.3	0.0	0.0
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	0.0	0.0
		Pipe	1.1	0.0	0.0
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	-0.1	0.0
		Pipe	16.3	-1.2	-1.1
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	-0.1	-0.1
		Pipe	9.9	0.0	-0.1
Q05	New Street	Overland	14.4	0.0	0.0
		Pipe	5.8	-0.1	-0.4
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	0.0	0.0
		Pipe	3.1	0.0	0.0
Q07	Elsie St	Overland	1.9	0.0	0.0
		Pipe	2.6	0.0	0.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0
		Pipe	2.4	0.0	0.0
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	0.0	0.0
		Pipe	2.1	0.0	0.0
Q10	Wangal Park	Overland	0.0	0.0	0.0
		Pipe	0.2	0.0	0.0
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	0.2	0.5
		Pipe	3.5	-0.1	-0.5
Q12	Grogan St	Overland	9.4	0.0	0.0
		Pipe	0.9	0.0	-0.1
Q13	Wychbury La	Overland	1.1	0.0	0.0
		Pipe	0.3	0.0	0.0

9. PRELIMINARY FLOOD PLANNING AREAS

9.1. Background

Land use planning is considered to be one of the most effective means of minimising flood risk and damages from flooding. The Flood Planning Area (FPA) identifies land that is subject to flood related development controls via Section 149(2) notifications under the 1979 EP&A Act. The Flood Planning Level (FPL) is the minimum floor level applied to new developments within the FPA.

The process of defining FPA's and FPL's is somewhat complicated by the variability of flow conditions between mainstream and local overland flow, particularly in urban areas. The more traditional approaches typically having been developed for riverine environments and mainstream flow.

Defining the area of flood affectation due to overland flow (which by its nature includes shallow flow) often involves determining at which point it becomes significant enough to classify as "flooding". The difference in peak flood level between events of varying magnitude may be minor in areas of overland flow, such that applying the typical freeboard can result in a FPL greater than the Probable Maximum Flood (PMF) level.

The FPA should include properties where future development would result in impacts on flood behaviour in the surrounding area and areas of high hazard that pose a risk to safety or life. Further to this, the FPL is determined with the purpose to decrease the likelihood of over-floor flooding of buildings and the associated damages.

The Floodplain Development Manual suggests that the FPL generally be based on the 1% AEP event plus an appropriate freeboard. The typical freeboard cited in the manual is that of 0.5 m; however it also recognises that different freeboards may be deemed more appropriate due to local conditions. In these circumstances, some justification is called for where a lower value is adopted.

The FPA is classified as 'provisional' as it is based on results from the current study, and may be re-assessed as part of a floodplain risk management study for the catchment. Such a study would review the area's existing planning policies with respect to floodplain management, and then make recommendations (including adoption of a Flood Planning Area and Flood Planning Level) via a floodplain risk management plan. It may also be that the same assessment for the LGA's other catchments be undertaken so that a single LGA-wide FPA/FPL can be adopted.

9.2. Methodology and Criteria

The methodology used in this report is consistent with that adopted in a number of previous studies. It divides flooding between Mainstream flooding and Overland flooding using the following criteria:

- Mainstream flooding: Any percentage of the cadastral area is affected by mainstream flooding in the 1% AEP event. This has been defined as the peak flood level within the open channel section of Dobroyd Canal plus a 0.5 m freeboard, with the level extended perpendicular to the flow direction.
- Overland flooding: Greater than or equal to 10% of the “active” cadastral area is affected by the 1% AEP peak flood depth of greater than 0.15 m. The “active” cadastral area was considered to be the cadastral area excluding the building area that was modelled as impermeable

In situations where a cadastral lot is subject to both mainstream flooding and overland flooding, the mechanism that produces the highest Flood Planning Level is given precedence, although both levels have been provided.

Furthermore, a “ground truthing” exercise was undertaken to ensure that the properties identified as subject to flood related development controls were located within a continuous flow path area.

9.3. Results

The provisional FPA is shown on Figure 28. The mainstream flood affectation was limited to the Canada Bay LGA (not reported herein); with only overland flood affectation within the Burwood LGA portion of the study area.

A total of 278 properties were tagged for flood related development controls in the study area. This results in total averages of 1.7 properties per hectare for the study area. This value was consistent with those obtained in adjacent urban catchments.

Properties that are not tagged as part of this process may not be excluded from development controls. It is advisable that new developments (regardless of whether they are tagged as flood liable or not) have habitable floor levels a minimum of 300 mm above the surrounding ground level to minimise affectation due to local overland flow

10. DISCUSSION

Various locations were identified as “hotspots” or “areas of interest” with the study area. These locations were identified based upon flood behaviour occurring at ground level. The above floor liability of these locations has not yet been determined due to a lack of surveyed floor levels at this stage. However, some over floor liability is likely at some of these locations.

10.1. Parramatta Road / Short Street, Croydon

The intersection of Parramatta Road and Short Street is located on the boundary between the Burwood LGA and the City of Canada Bay LGA. The area is a topographical low point exacerbated with buildings obstructing flow and tidally affected areas in close proximity, immediately downstream. The contributing catchment area is approximately 30 ha.

Two trapezoidal pipes, each with a cross-sectional area of approximately 1.1 m^2, convey flow across Parramatta Road. The capacity of these pipes and the surrounding pipes in this location was found to be less than a 5 year ARI event. The peak flows within the pipe and the overland flow path across Parramatta Road are provided in Table 31.

Table 31: Parramatta Road/Short Street – Peak Flow (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	3.5	5.3	7.5	9.3	11.1	60.8
		Pipe	3.4	3.4	3.5	3.5	3.5	3.6

The peak flood depths and levels at this location are shown in Table 32.

Table 32: Parramatta Road/Short Street – Peak Flood Depths (m) and Levels (m AHD)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H11	Cnr Parramatta Rd and Short St	Depth	0.44	0.47	0.50	0.52	0.55	1.21
		Level	3.91	3.94	3.97	3.99	4.02	4.68

10.2. Parramatta Road / Concord Oval

Parramatta Road, between Shaftesbury Road and Bennett Street, is a topographic low point at the confluence of two flow paths. The upstream flow paths originate from the south-east and south-west; with a contributing catchment area of approximately 31 ha and 88 ha respectively. Downstream of Parramatta Road, the flow is conveyed north primarily via the open channel.

The Hockey Complex to the east of the open channel has a ridge parallel to Parramatta Road; in some locations 2.4 m higher than the road elevation. Concord Oval to the west of the open channel has a similar ridge; in some locations 1.5 m higher than the road elevation. The combined effect of these ridges is to constrict flow exiting Parramatta Road to the open channel and to a small gully into Concord Oval (located at the south-east corner of the Oval). Flow that enters Concord Oval is retained there, as the Oval acts as a detention basin. In extreme events, such as the PMF event, alternative flow paths form along the eastern boundary of the Hockey Complex and along the western boundary of Concord Oval.

The peak flood depths and levels at this location are shown in Table 33.

Table 33: Parramatta Road / Concord Oval – Peak Flood Depths (m) and Levels (m AHD)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	Depth	0.40	0.45	0.51	0.58	0.63	1.31
		Level	4.17	4.22	4.29	4.35	4.40	5.08

Two Sydney Water stormwater pipes convey flow across Parramatta Road. The pipe adjacent to Luke Avenue was U-shaped with a height of 1.37 m and a maximum width of 2.67 m. The pipe located between Shaftesbury Road and Loftus was mostly rectangular shaped with a maximum height of 1.37 m and a maximum width of 3.35 m. The peak flows within the pipes and the overland flow path across Parramatta Road are provided in Table 34.

Table 34: Parramatta Road / Concord Oval – Peak Flows (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	4.6	6.8	10.4	15.1	19.2	141.6
		Pipe	13.1	13.9	15.0	15.5	16.3	17.8

10.3. Parramatta Road / Wentworth Road

Parramatta Road between Wentworth Road and Philip Street is located in a topographic low point. The contributing catchment area is approximately 24 ha.

One 1.05 m diameter pipe conveys flow across Parramatta Road. The capacity of this pipe and the surrounding pipes in this location was found to be less than a 5 year ARI event. The peak flows within the pipe and the overland flow path across Parramatta Road are provided in Table 35.

Table 35: Parramatta Road / Wentworth Road – Peak Flows (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	2.3	3.6	5.3	6.6	8.1	45.4
		Pipe	2.1	2.2	2.2	2.2	2.3	2.7

The peak flood depths and levels at this location are shown in Table 36.

Table 36: Parramatta Road/Wentworth Road – Peak Flood Depths (m) and Levels (m AHD)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Parramatta Rd – Between Philip St and Wentworth Rd	Depth	0.32	0.37	0.42	0.45	0.49	0.93
		Level	15.26	15.30	15.35	15.39	15.43	15.86

10.4. Shaftesbury Road / Burwood Road

From the Burwood Road – Meryla Street intersection to the Shaftesbury Road – Parramatta Road intersection, flow occurs in a north-east direction and often through private property. Where buildings intersect the flow path, flood water accumulates on the upstream side.

The pipe sizes vary across this area and include divergent amplification within the roadway area. Some sections of this drainage network are operating at capacity in events up to and including the 5 year ARI event. During the PMF event, all pipes within this area were operating at capacity. The peak flows within select pipes and overland flow paths in this area are provided in Table 37.

Table 37: Shaftesbury Road / Burwood Road – Peak Flows (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	4.5	6.2	8.9	12.0	15.0	95.8
		Pipe	8.8	9.0	9.9	9.7	9.9	10.2
Q05	New Street	Overland	6.0	7.6	9.9	12.1	14.4	79.7
		Pipe	5.3	5.2	5.6	5.7	5.8	7.0
Q06	Cnr Burwood Rd and Wilga St	Overland	3.7	4.6	5.8	6.5	7.9	46.5
		Pipe	2.9	3.0	3.1	3.1	3.1	4.1

The peak flood depths at select locations are shown in Table 38.

Table 38: Shaftesbury Road / Burwood Road – Peak Flood Depths (m)

ID	Location	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H04	Cnr Milton St and Archer St	0.44	0.50	0.57	0.64	0.69	1.62
H05	Meryla St	0.33	0.36	0.39	0.42	0.45	0.93
H06	Cnr Burwood Rd and Park Ave	0.29	0.32	0.36	0.39	0.43	1.18

10.5. Railway Parade

Railway Parade (near the junction with Wynne Avenue) is a trapped low point. The railway embankment located to the north and downstream of Railway Parade prevents flow from discharging overland from this location. The BCC-owned stormwater pipes through the railway embankment are the primary means of drainage.

The railway embankment is approximately 5.5 m higher than the roadway at the lowest point. Alternate overland flow paths to the east (where Burwood Road cuts into the embankment) and to the west (where the road becomes level with the railway tracks), are 3.8 m and 2.3 m higher than the lowest point on Railway Parade.

The contributing catchment area is approximately 8 ha. A stormwater pipe with a diameter of 1.35 m conveys flow through the railway embankment, as shown in Table 39. This pipe is not directly connected to an inlet pit, but accepts flow from four pipes with inlet pits along Railway Parade. These feeder pipes include a 1.35 m diameter pipe, a 600 mm diameter pipe and two 450 mm diameter pipes.

Table 39: Railway Parade – Peak Flows (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0	0.0	0.0	0.0
		Pipe	1.8	2.0	2.1	2.2	2.4	4.2

The peak flood depths and levels at this location are shown in Table 40. In the PMF event, the peak flood depth is less than the elevation difference that would allow alternative overland flow paths to be activated.

Table 40: Railway Parade – Peak Flood Depths (m) and Levels (m AHD)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H08	Railway Parade near Wynne Ave	Depth	0.36	0.39	0.43	0.46	0.49	2.14
		Level	19.20	19.24	19.27	19.30	19.33	20.99

11. ACKNOWLEDGEMENTS

WMAwater wish to acknowledge the assistance of Burwood City Council staff in carrying out this study, the NSW Government (Office of Environment and Heritage) and the residents of the Exile Bay, St Lukes and William Street Catchments. This study was jointly funded by Burwood Council and the NSW Government.

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Figures

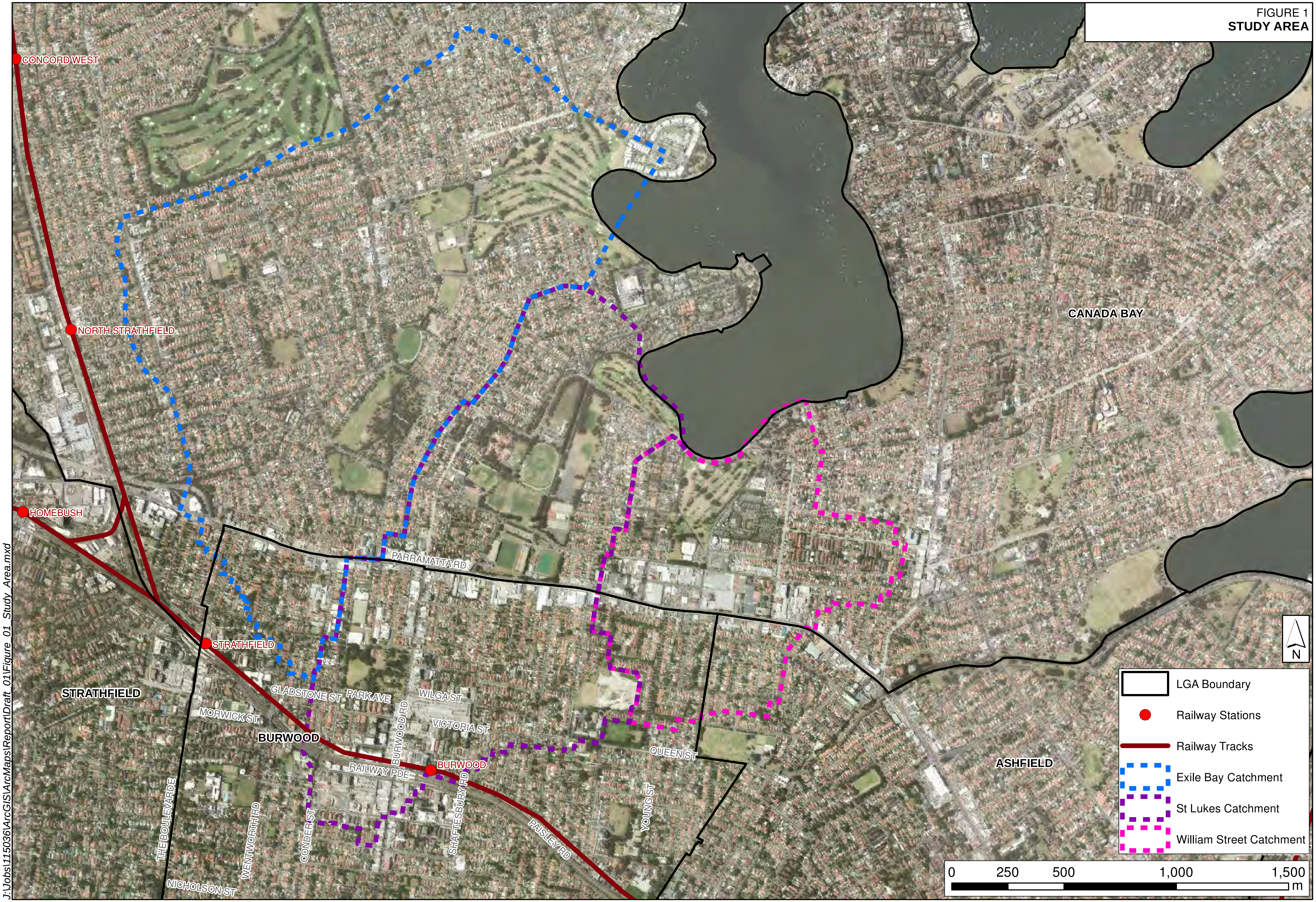

FIGURE 1
STUDY AREA

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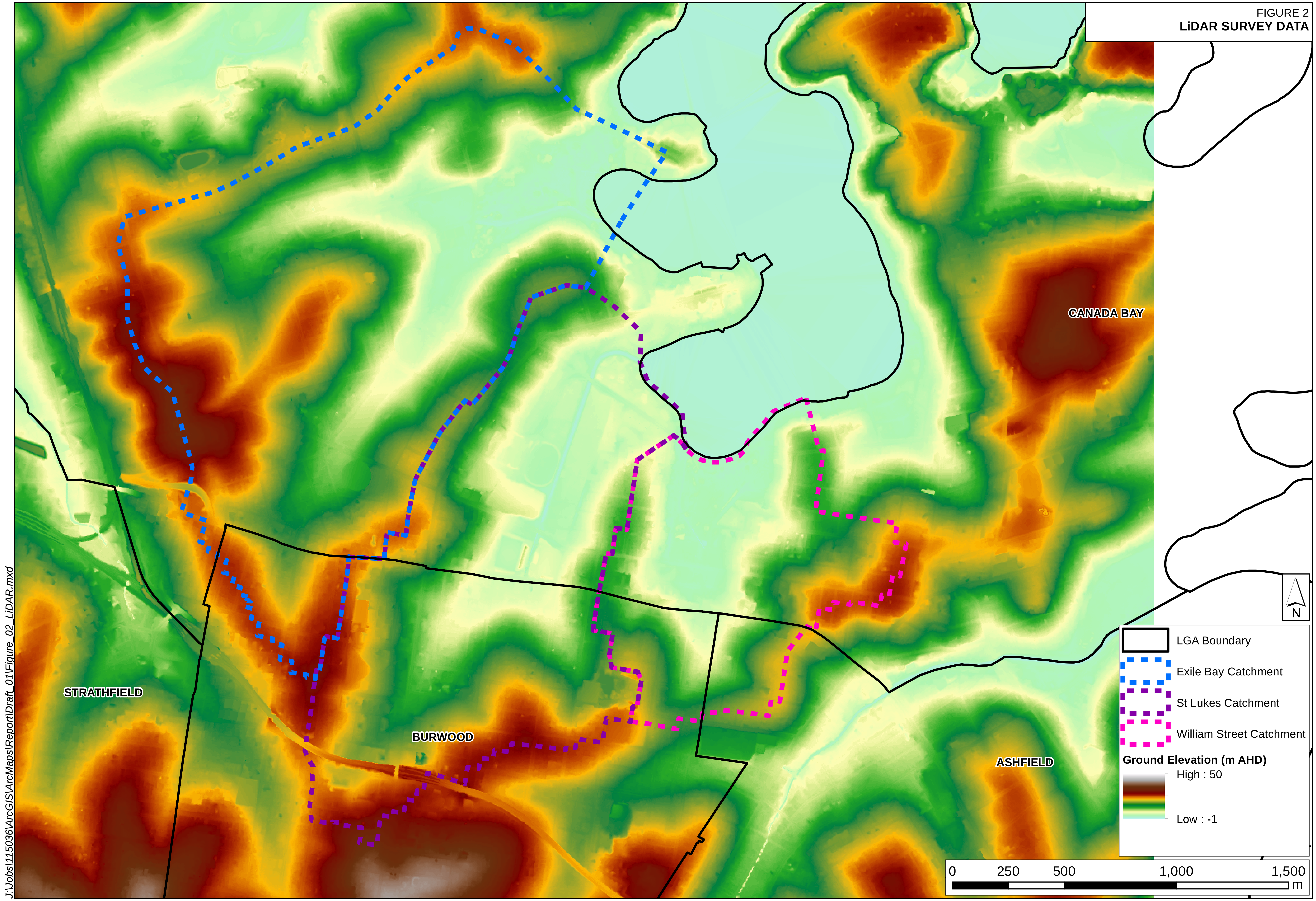
FIGURE 2
LiDAR SURVEY DATA
CANADA BAY
STRATHFIELD
BURWOOD
ASHFIELD
N
LGA Boundary
Exile Bay Catchment
St Lukes Catchment
William Street Catchment
Ground Elevation (m AHD)
High : 50
Low : -1
0
250
500
1,000
1,500
m
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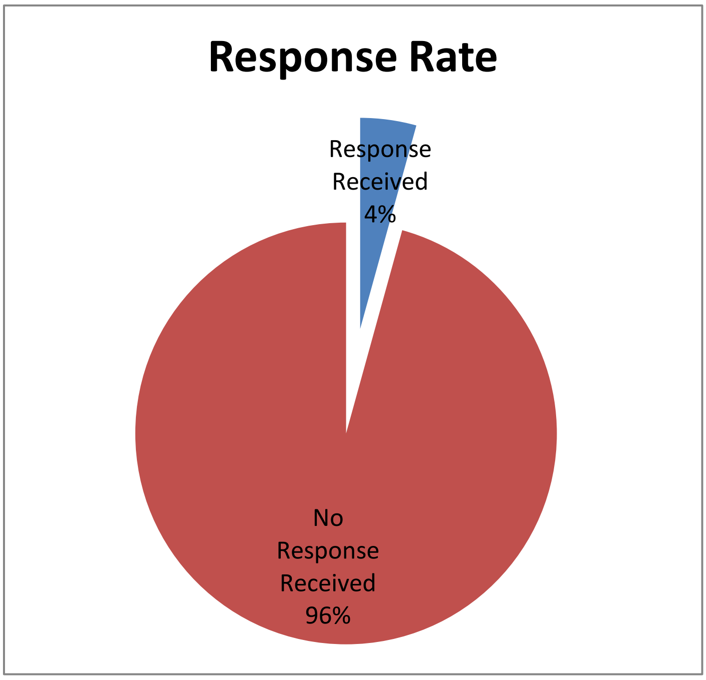
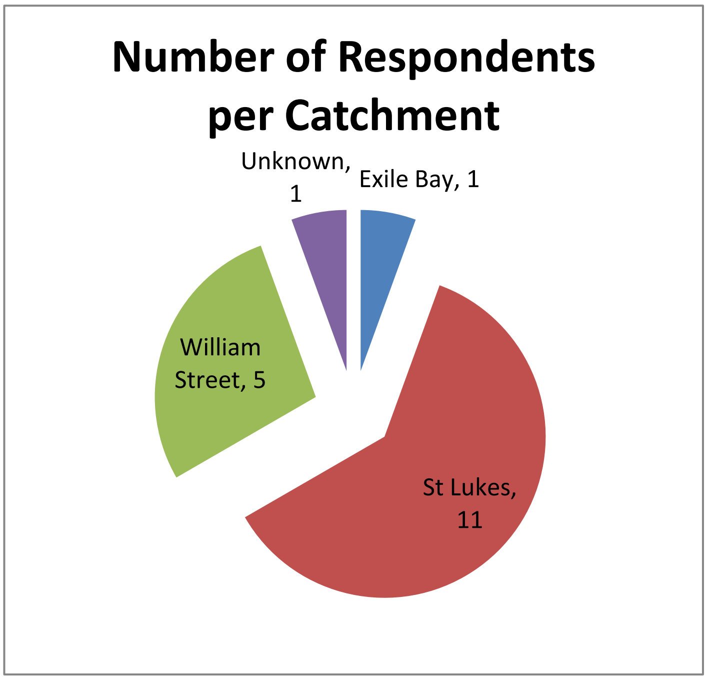
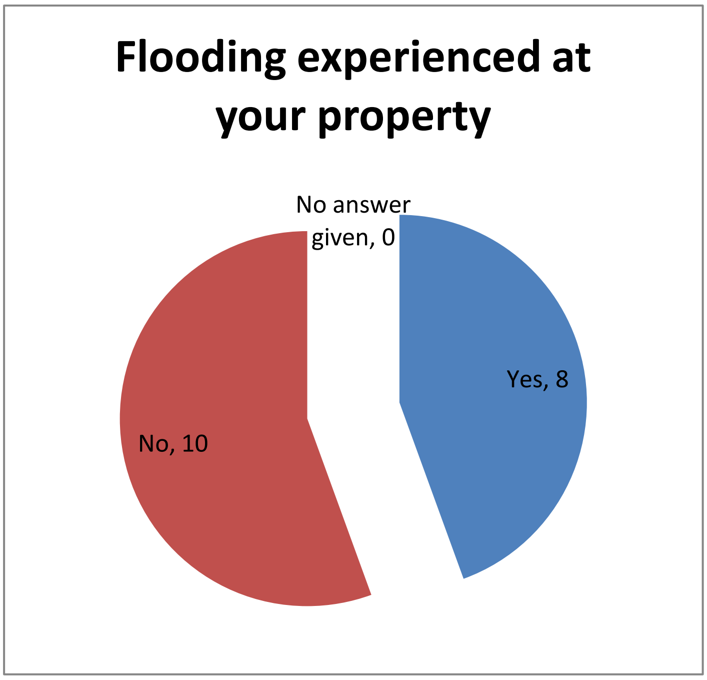
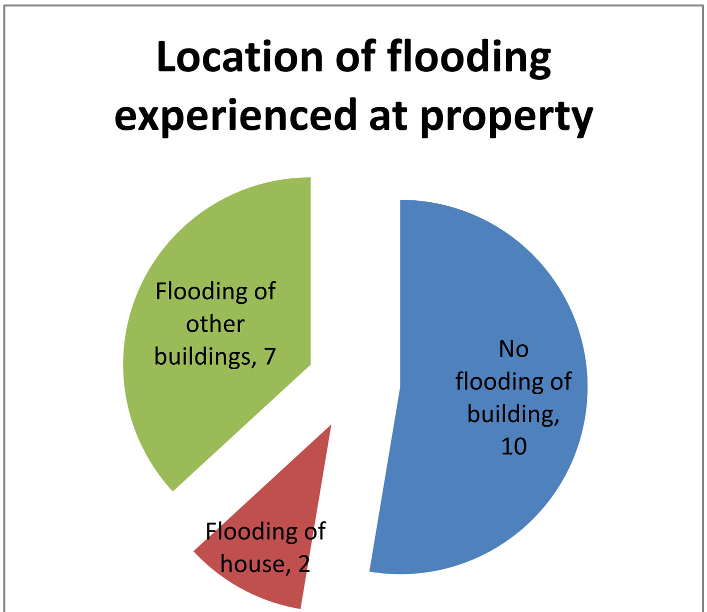
SUMMARY OF COMMUNITY CONSULTATION STATISTICAL ANAYLSIS









Note: Responses may have experienced both flooding of other buildings and flooding of house

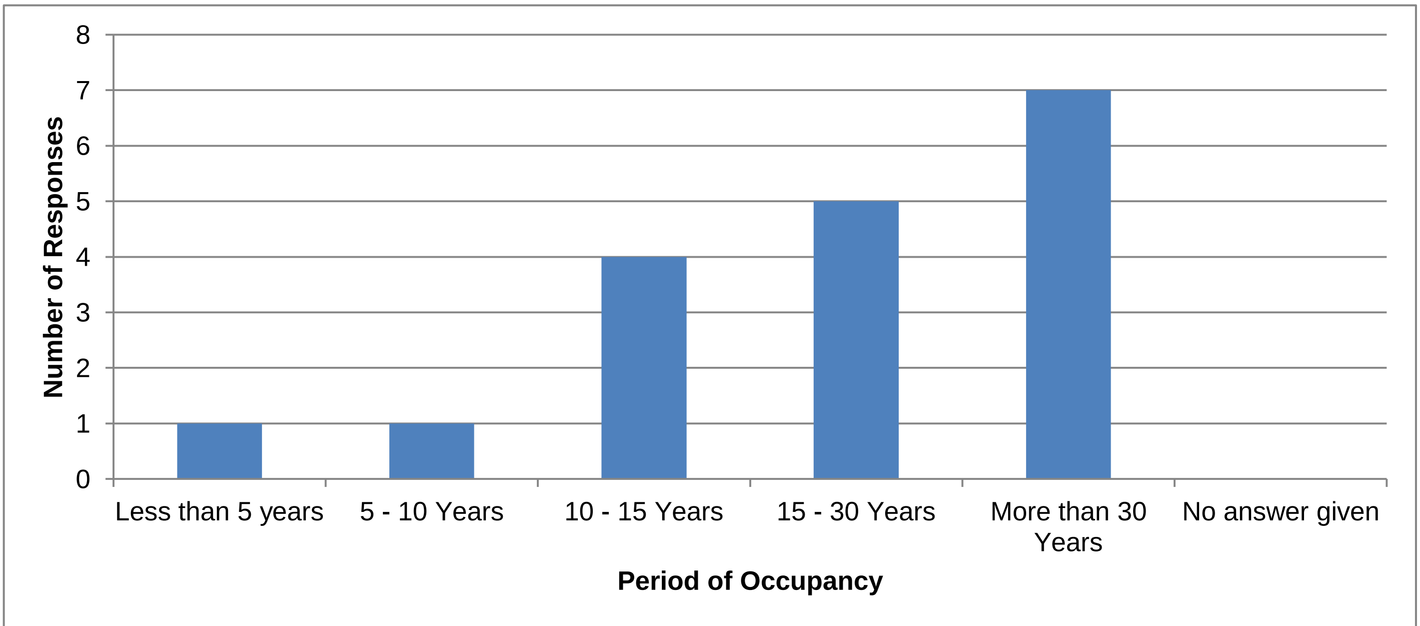


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FIGURE 5
RAINFALL GAUGE LOCATIONS

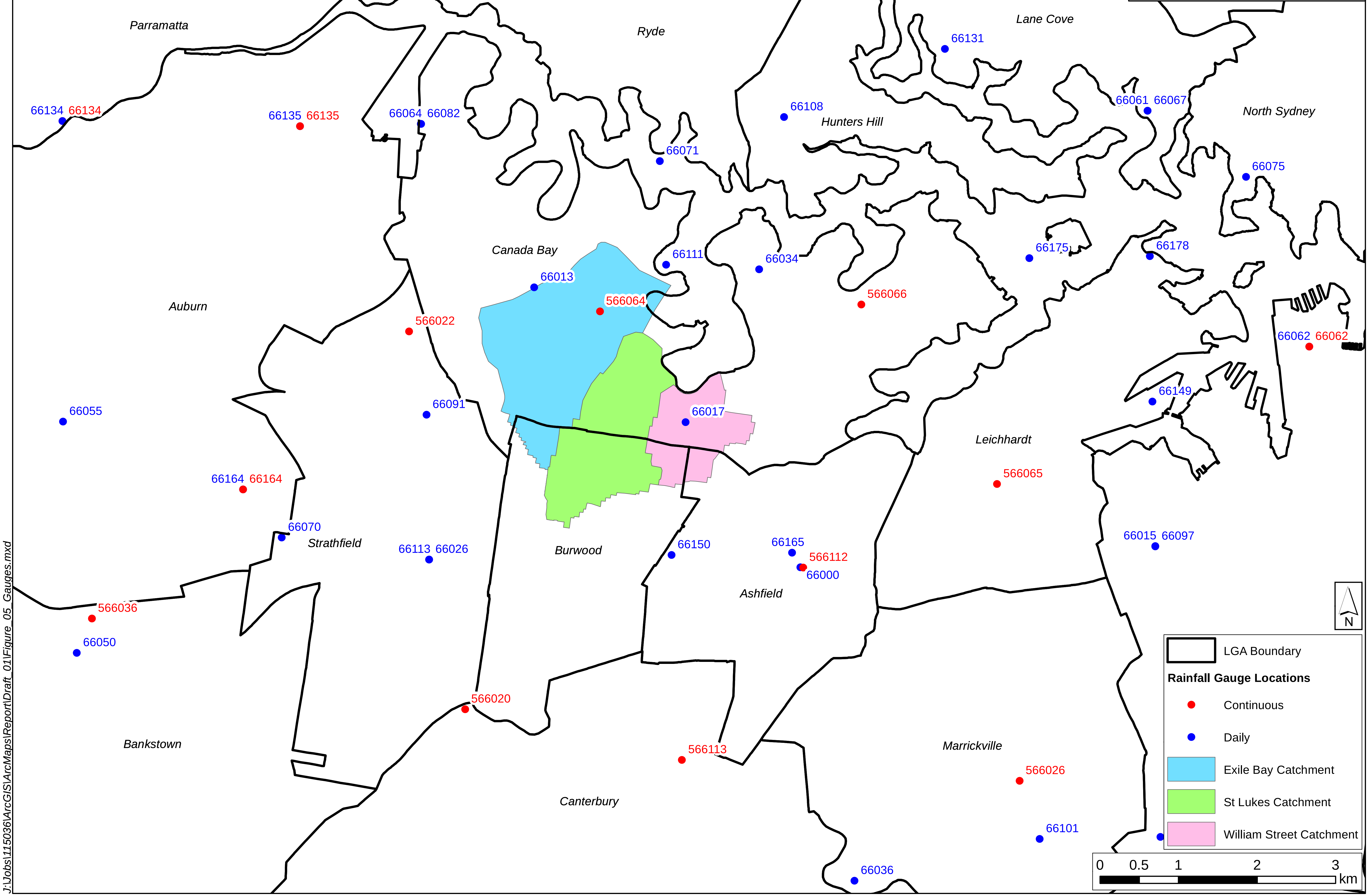

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FIGURE 6
HYDROLOGIC MODEL SCHEMATISATION

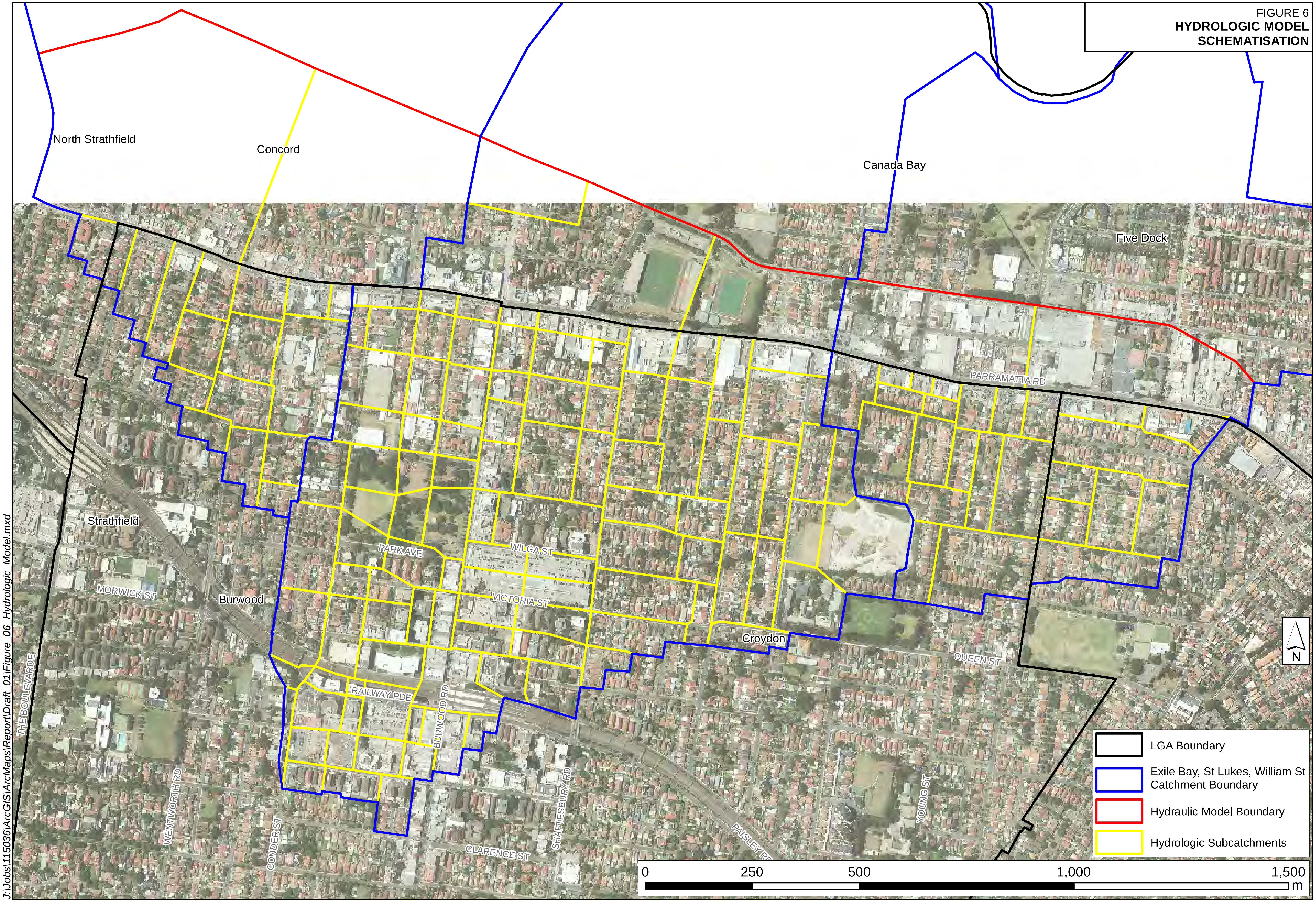

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FIGURE 7
HYDRAULIC MODEL SCHEMATISATION

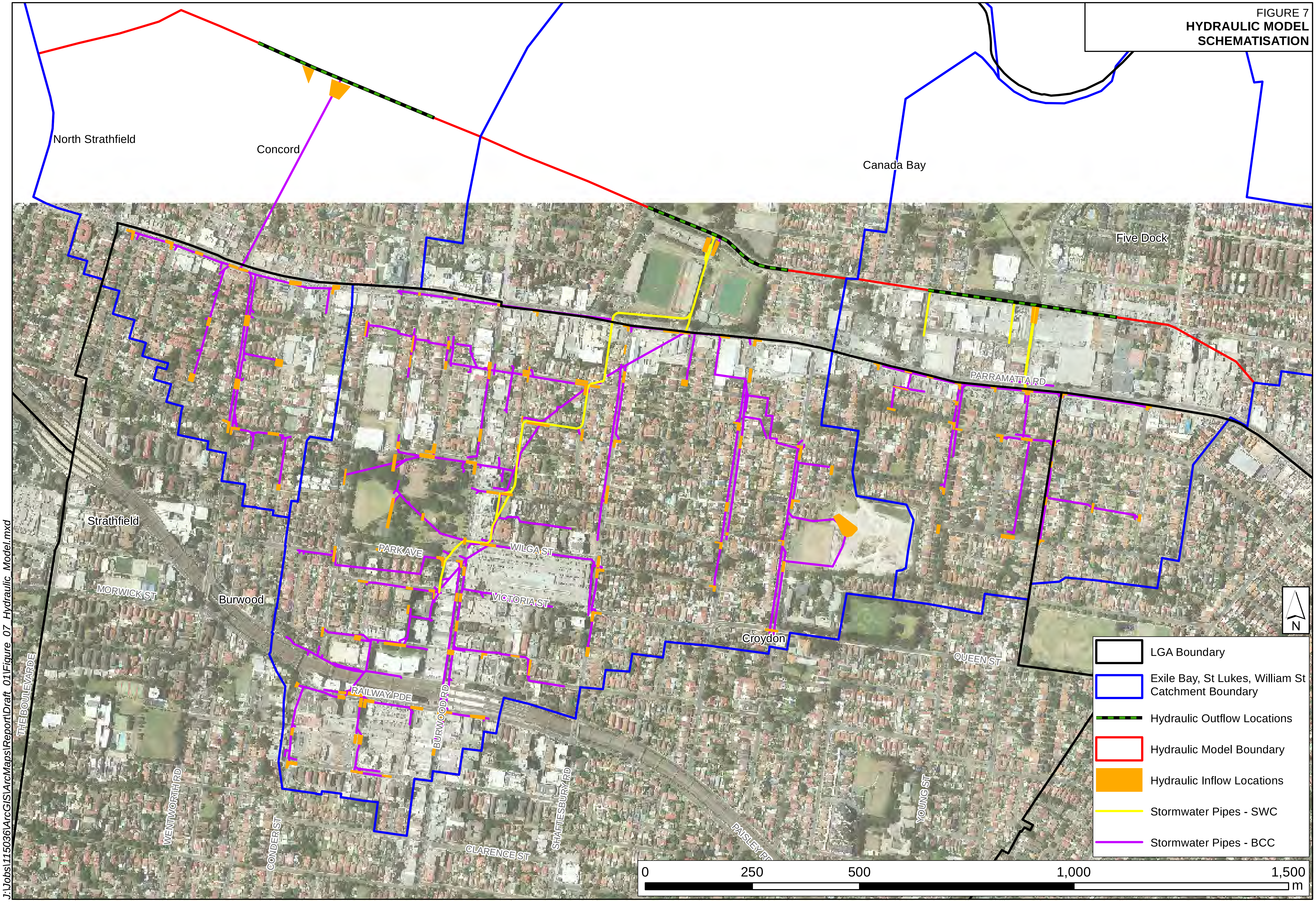

FIGURE 8
HYDRAULIC MODEL ROUGHNESS VALUES

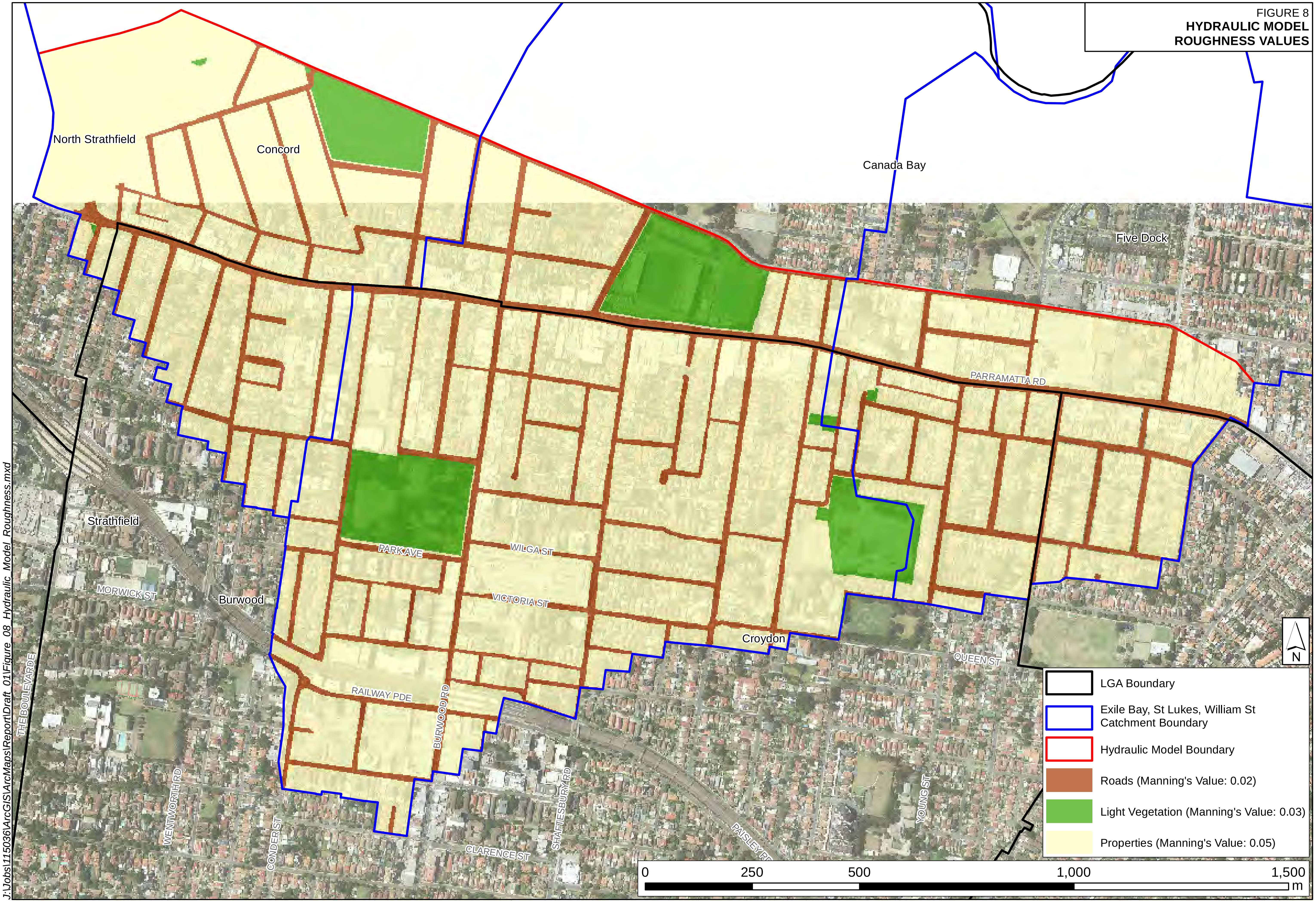

FIGURE 9
RESULTS LAYOUT

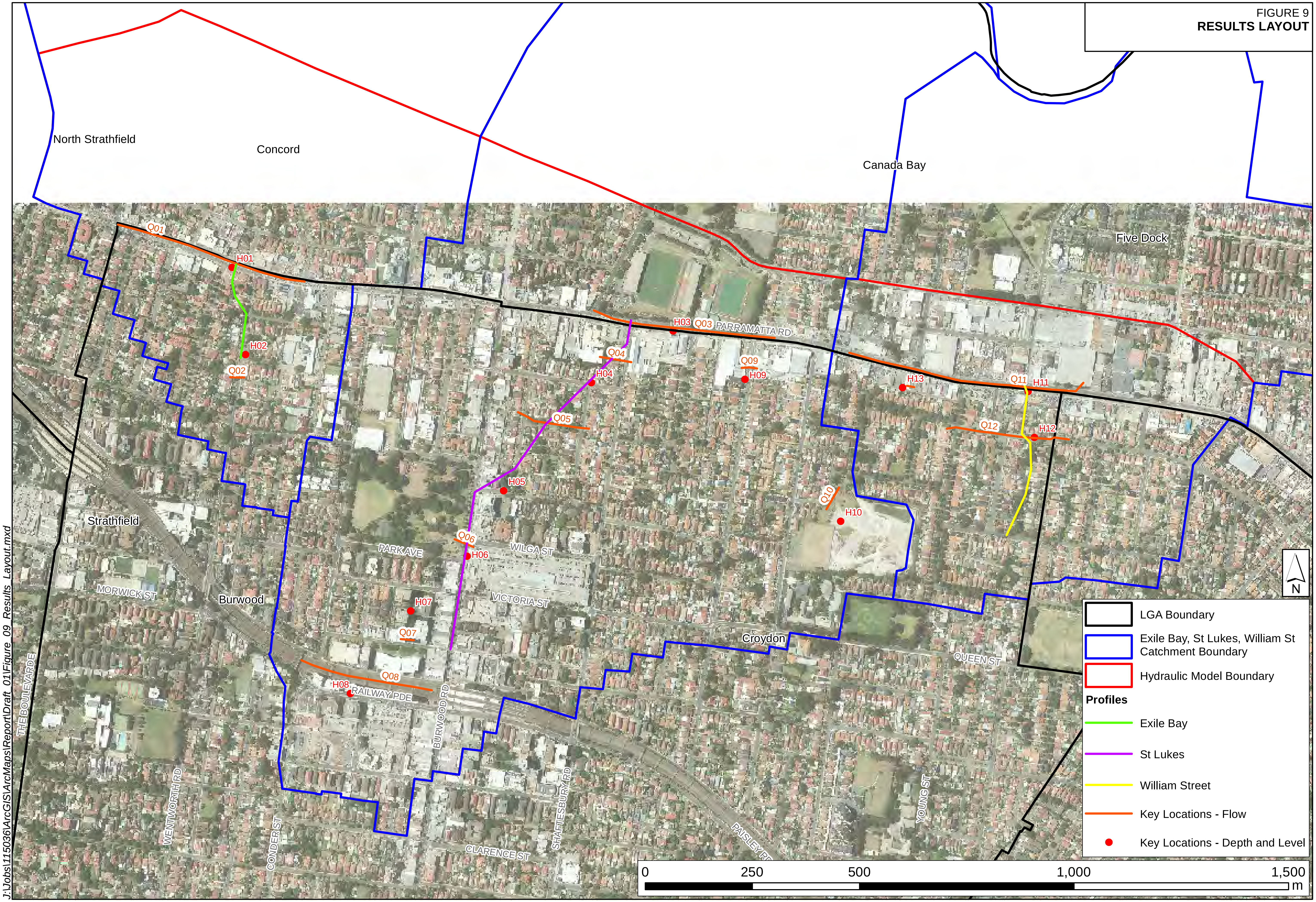

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FIGURE 10A
PEAK FLOOD LEVEL PROFILE
EXILE BAY

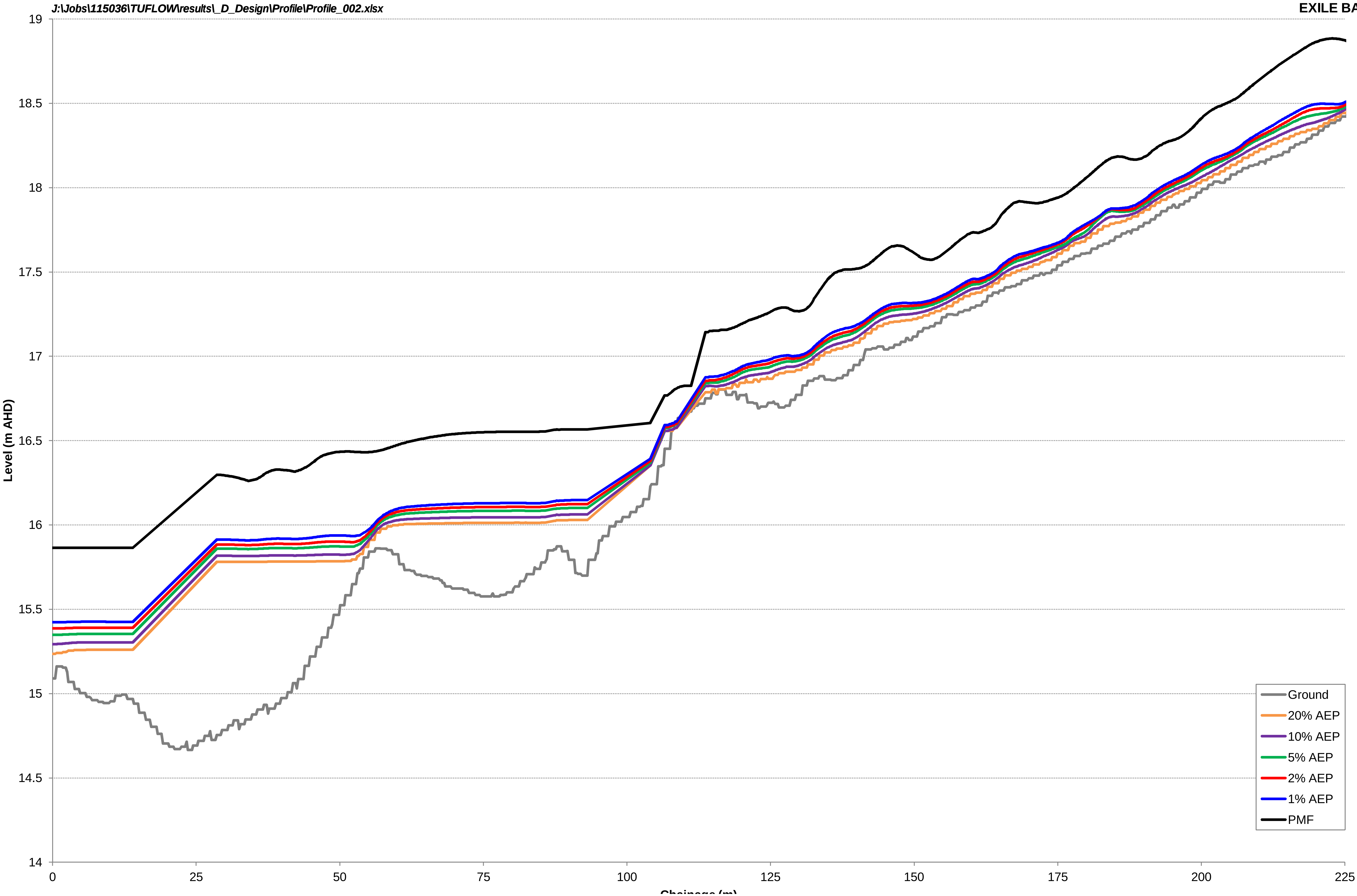

FIGURE 10B
PEAK FLOOD LEVEL PROFILE
ST LUKES

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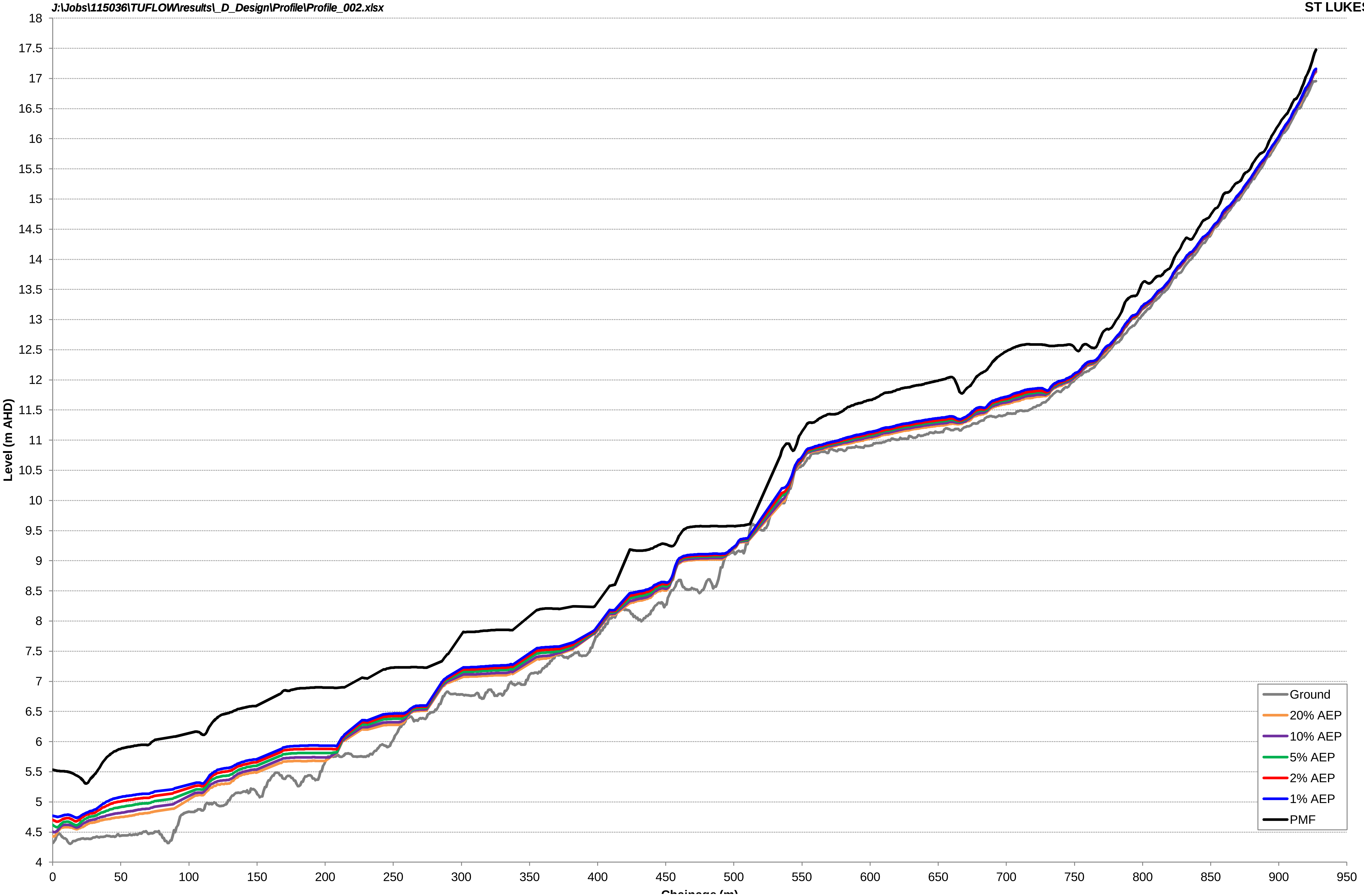

FIGURE 10C
PEAK FLOOD LEVEL PROFILE
WILLIAM STREET

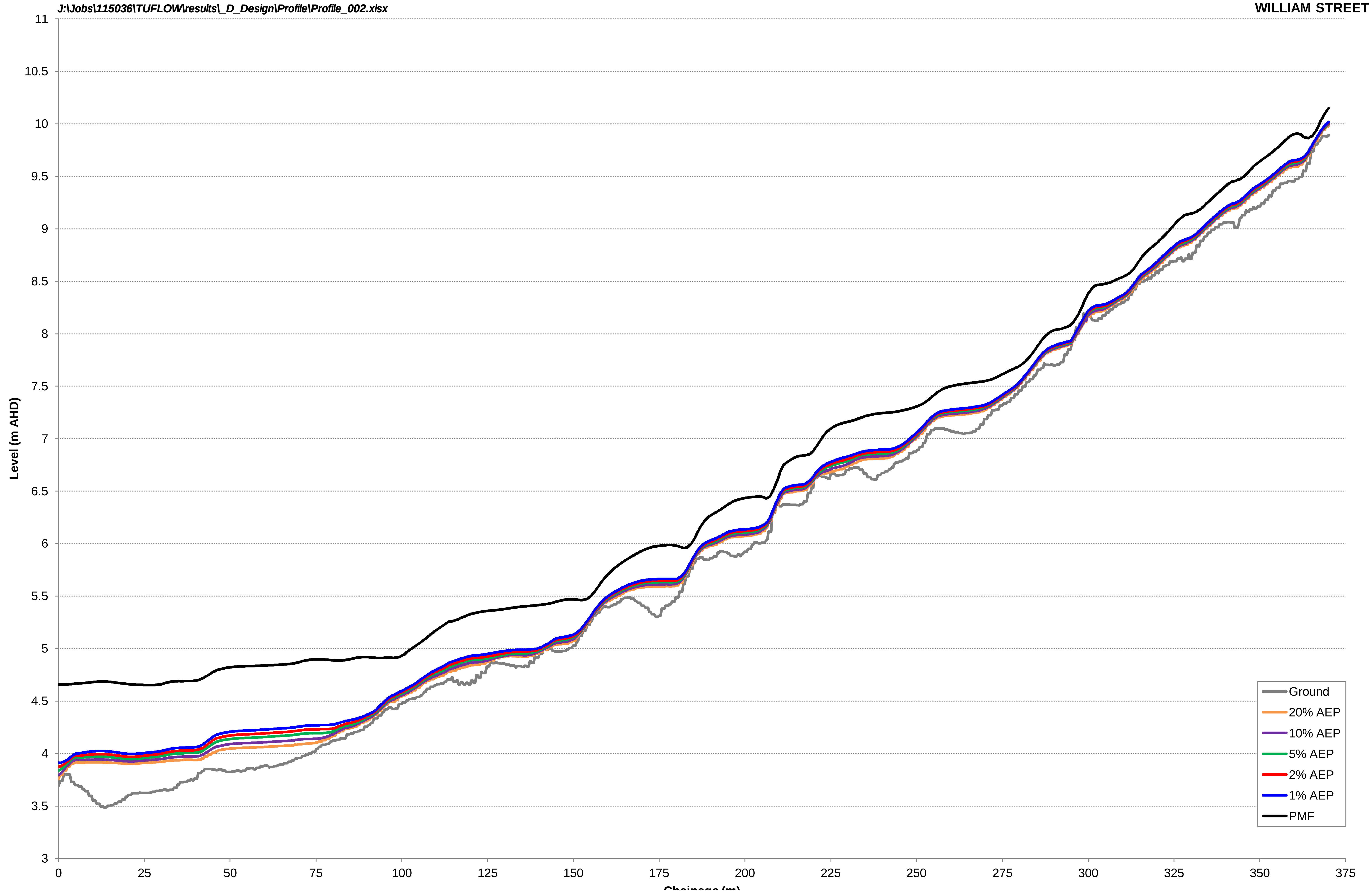

FIGURE 11A

DESIGN HYDROGRAPHS

Q01 - PARRAMATTA ROAD

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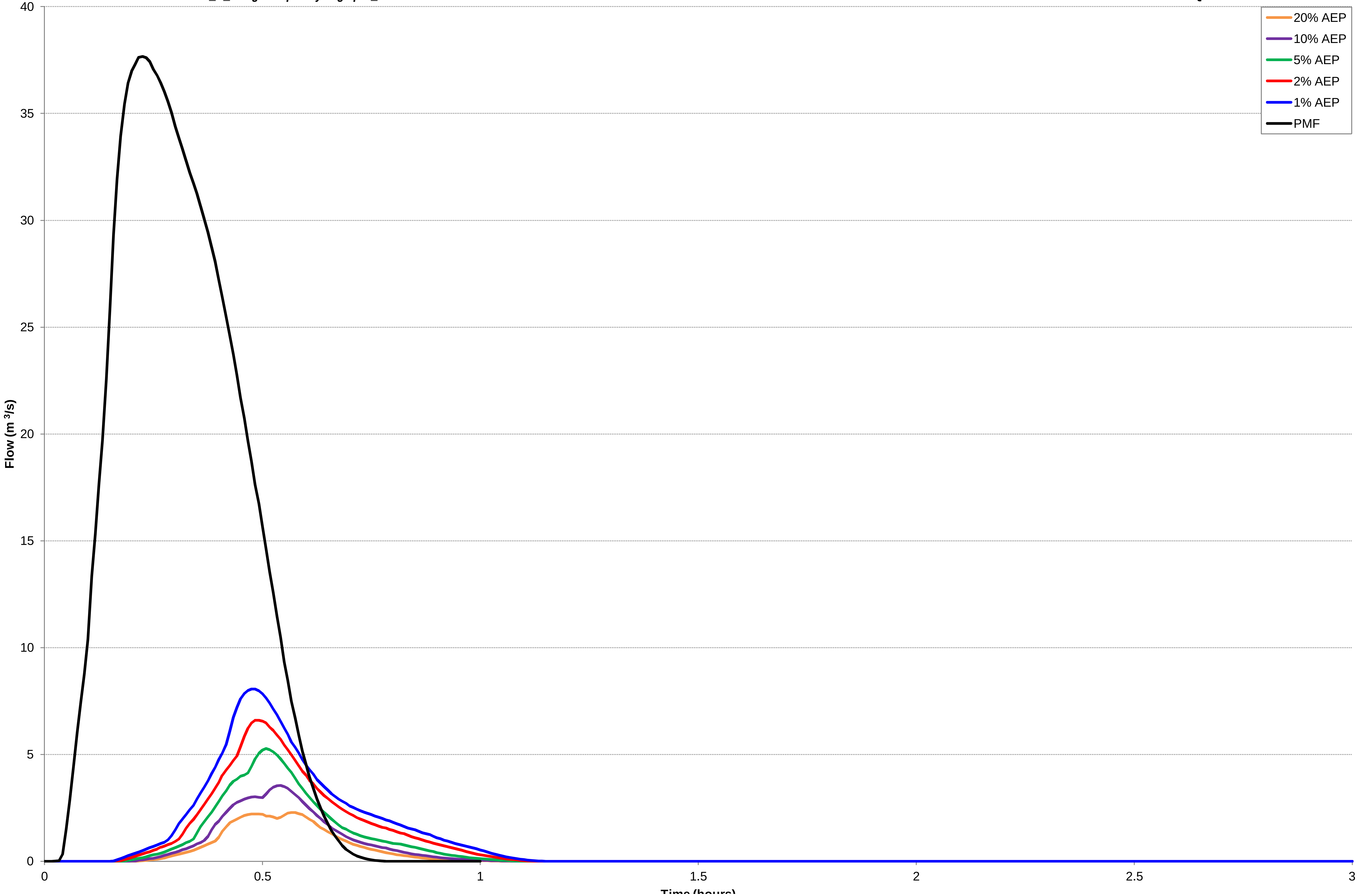

FIGURE 11B
DESIGN HYDROGRAPHS
Q03 - PARRAMATTA ROAD

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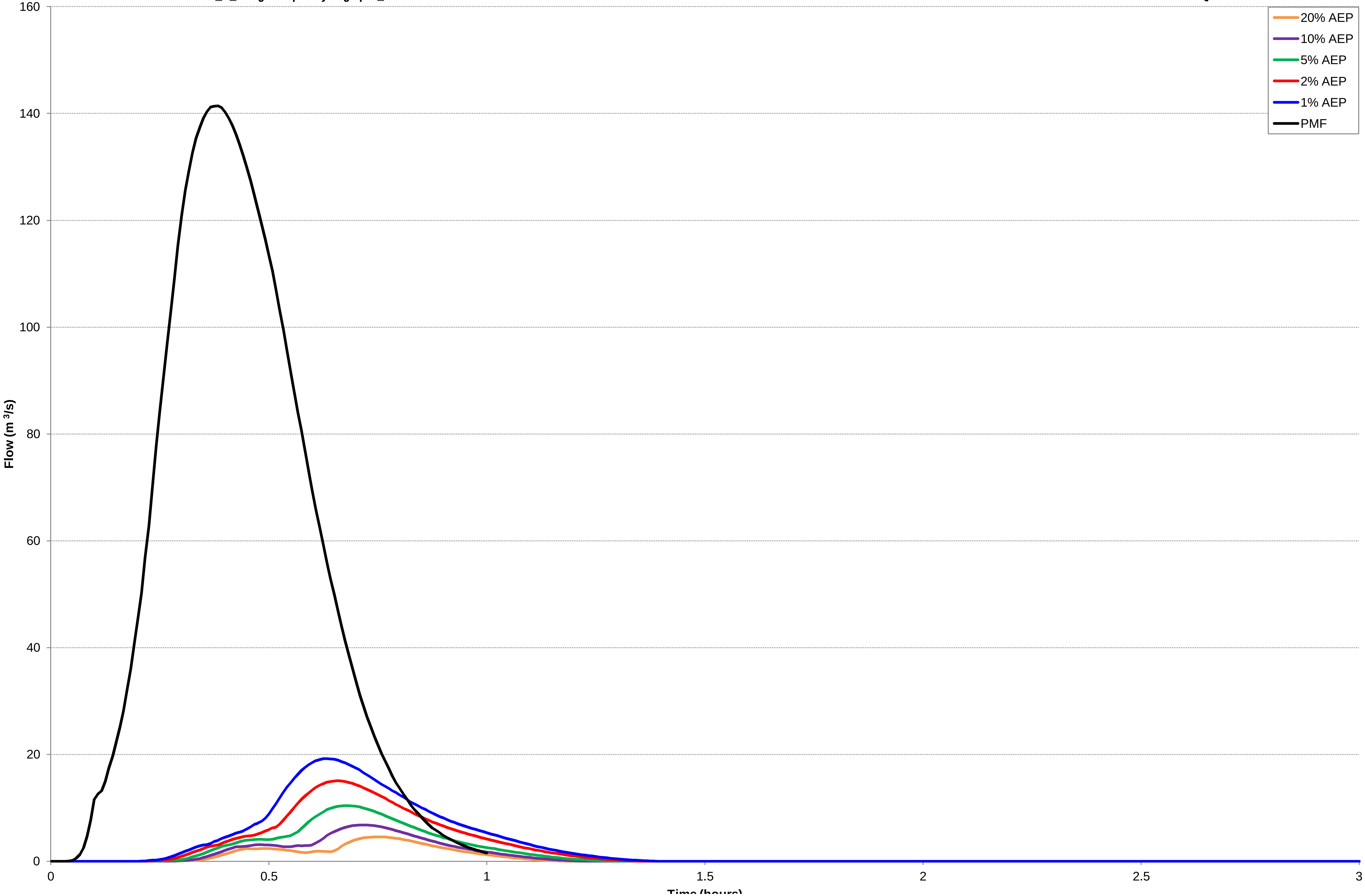

FIGURE 11C
DESIGN HYDROGRAPHS
Q11 - PARRAMATTA ROAD

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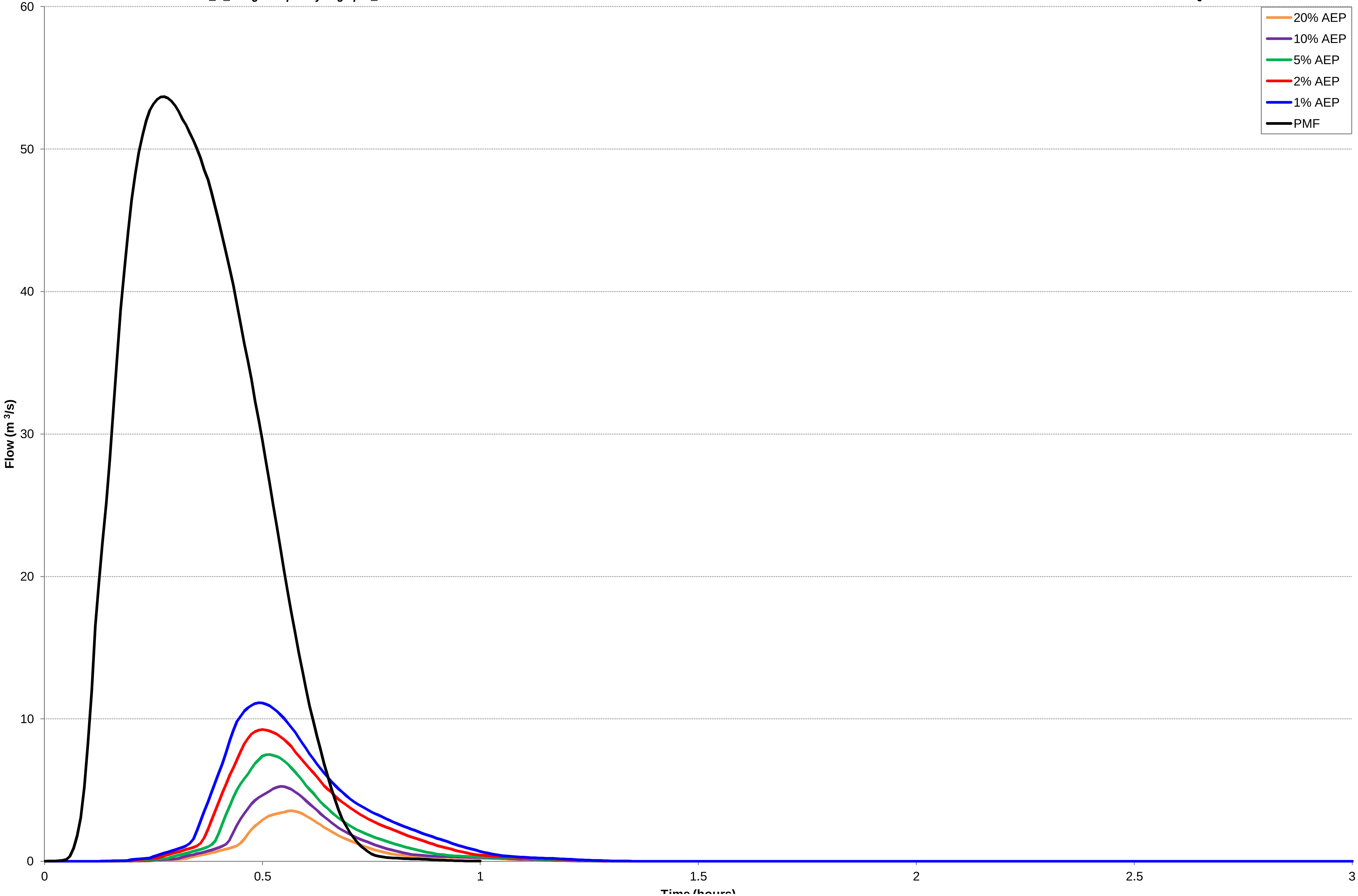

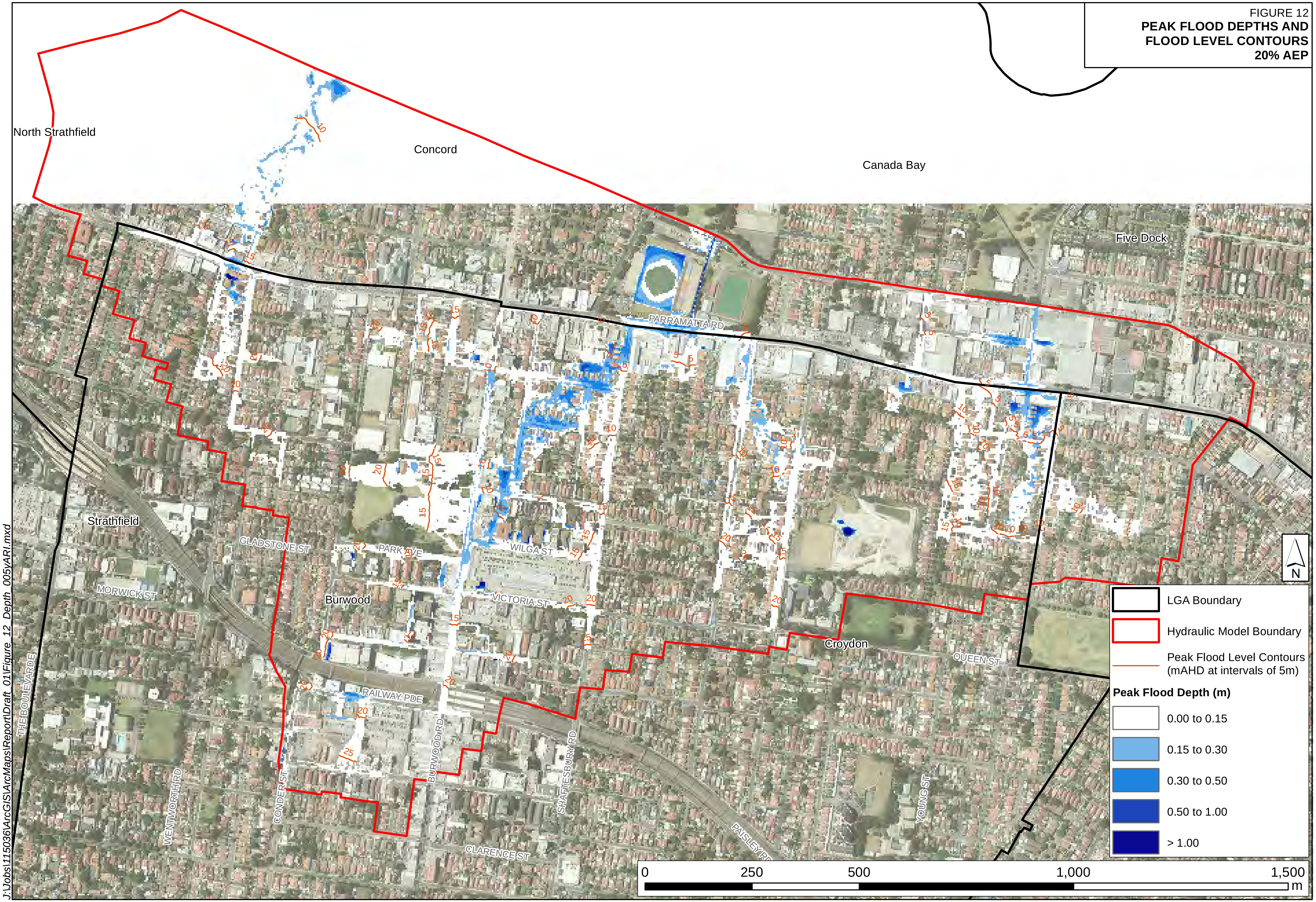

FIGURE 12
PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
20% AEP
North Strathfield
Concord
Canada Bay
Five Dock
Strathfield
Burwood
Croydon
PARRAMATTA RD
GLADSTONE ST
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
RAILWAY PDE
QUEEN ST
THE BOULEVARDE
WENTWORTH RD
CONDER ST
BURWOOD RD
SHAFTESBURY RD
CLARENCE ST
PAISLEY RD
YOUNG ST
N
LGA Boundary
Hydraulic Model Boundary
Peak Flood Level Contours (mAHD at intervals of 5m)
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
0
250
500
1,000
1,500
m
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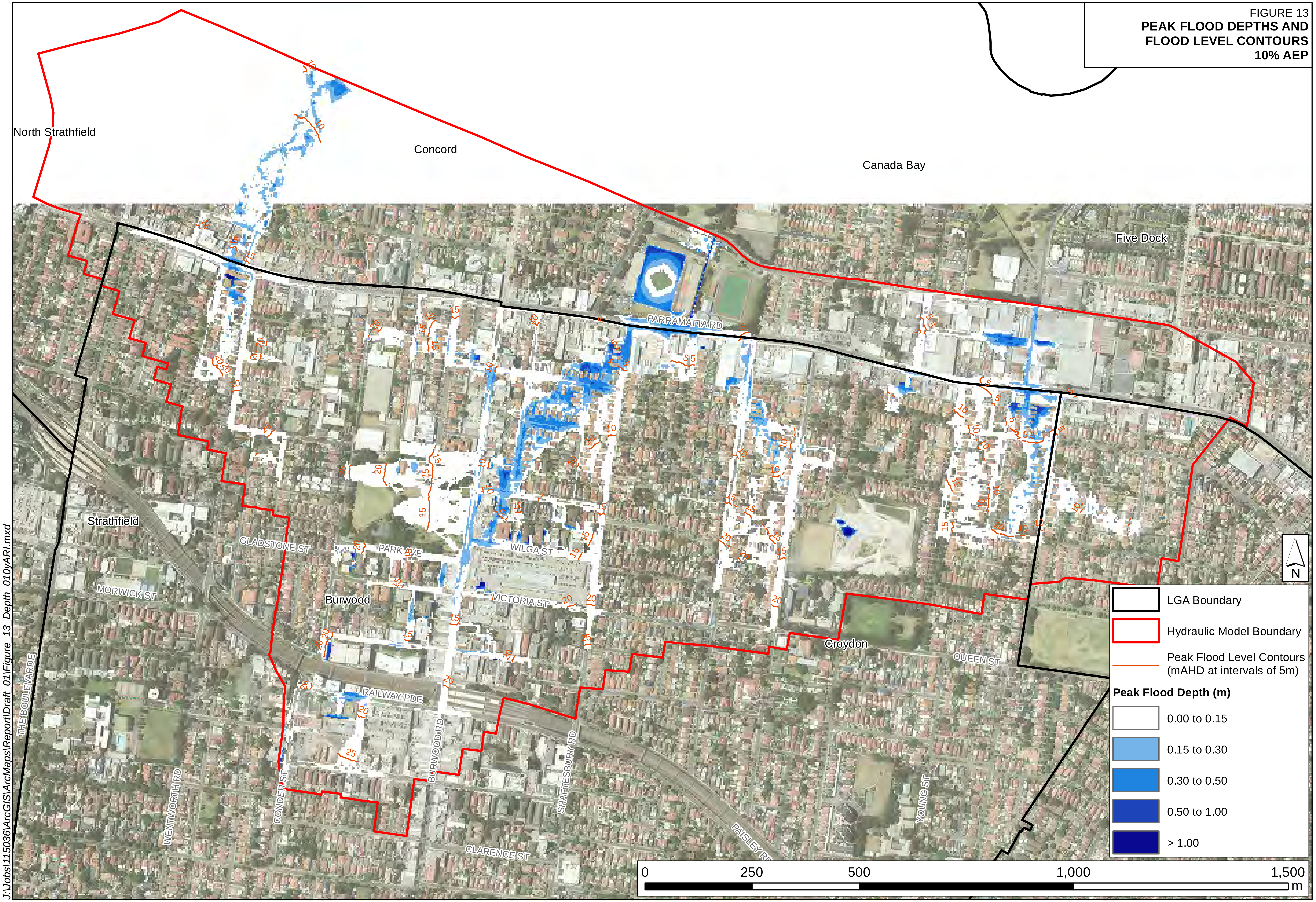
FIGURE 13
PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
10% AEP
North Strathfield
Concord
Canada Bay
Five Dock
Strathfield
Burwood
Croydon
PARRAMATTA RD
GLADSTONE ST
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
RAILWAY PDE
QUEEN ST
THE BOULEVARDE
WENTWORTH RD
CONDER ST
BURWOOD RD
SHAFTESBURY RD
YOUNG ST
PAISLEY RD
CLARENCE ST
LGA Boundary
Hydraulic Model Boundary
Peak Flood Level Contours
(mAHD at intervals of 5m)
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
N
0
250
500
1,000
1,500
m
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FIGURE 14
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 5% AEP

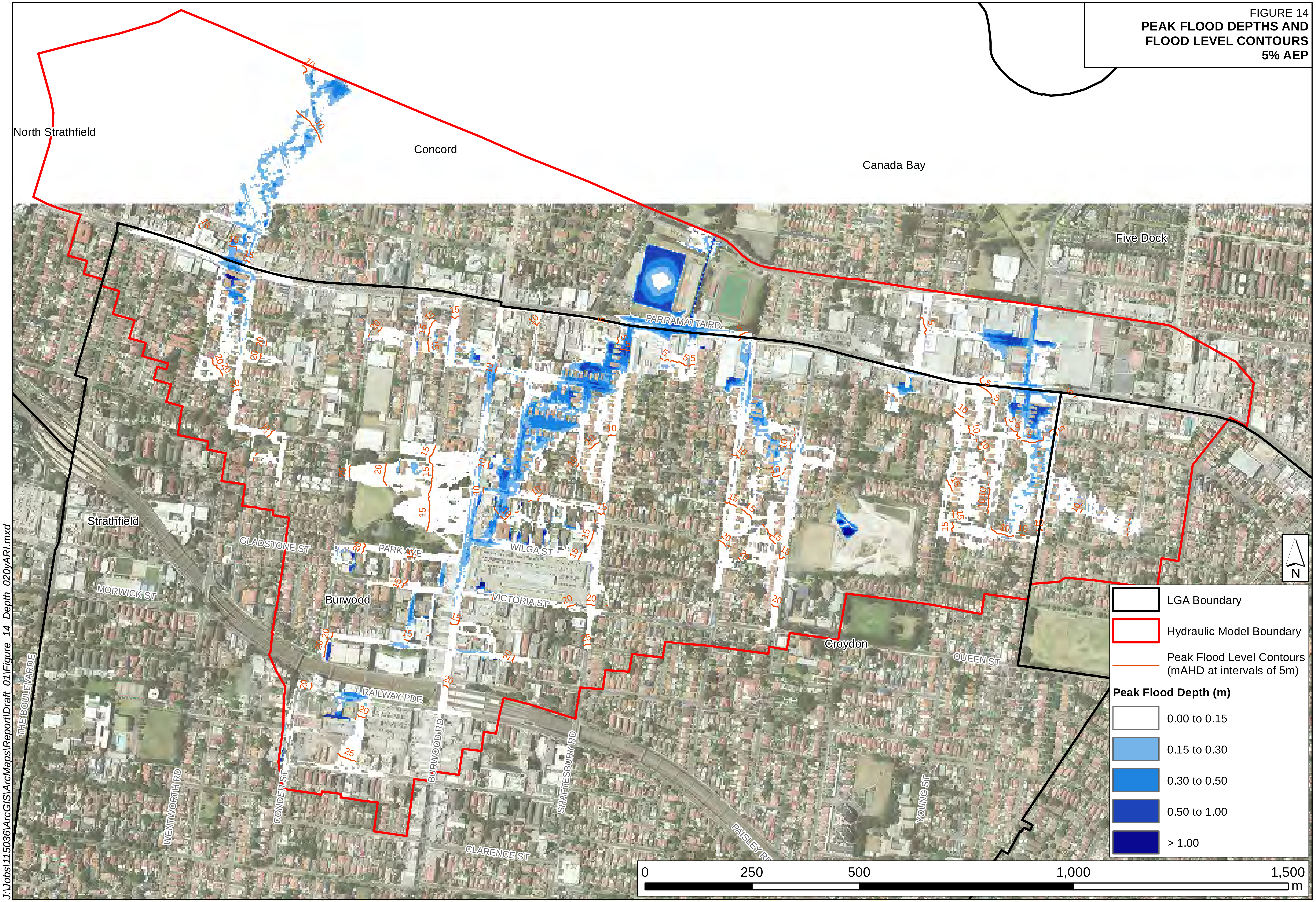

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FIGURE 15
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 2% AEP

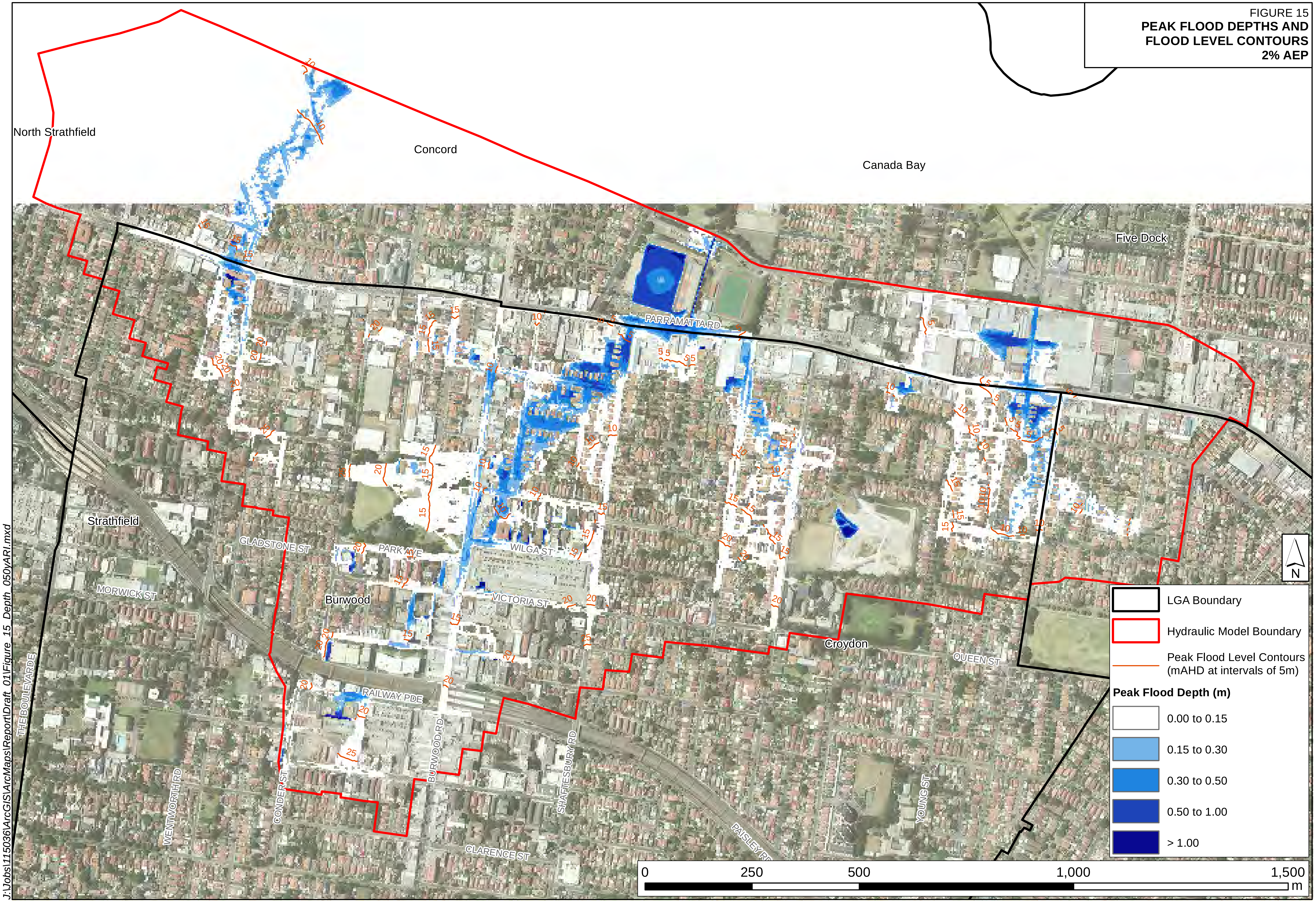

FIGURE 16
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 1% AEP

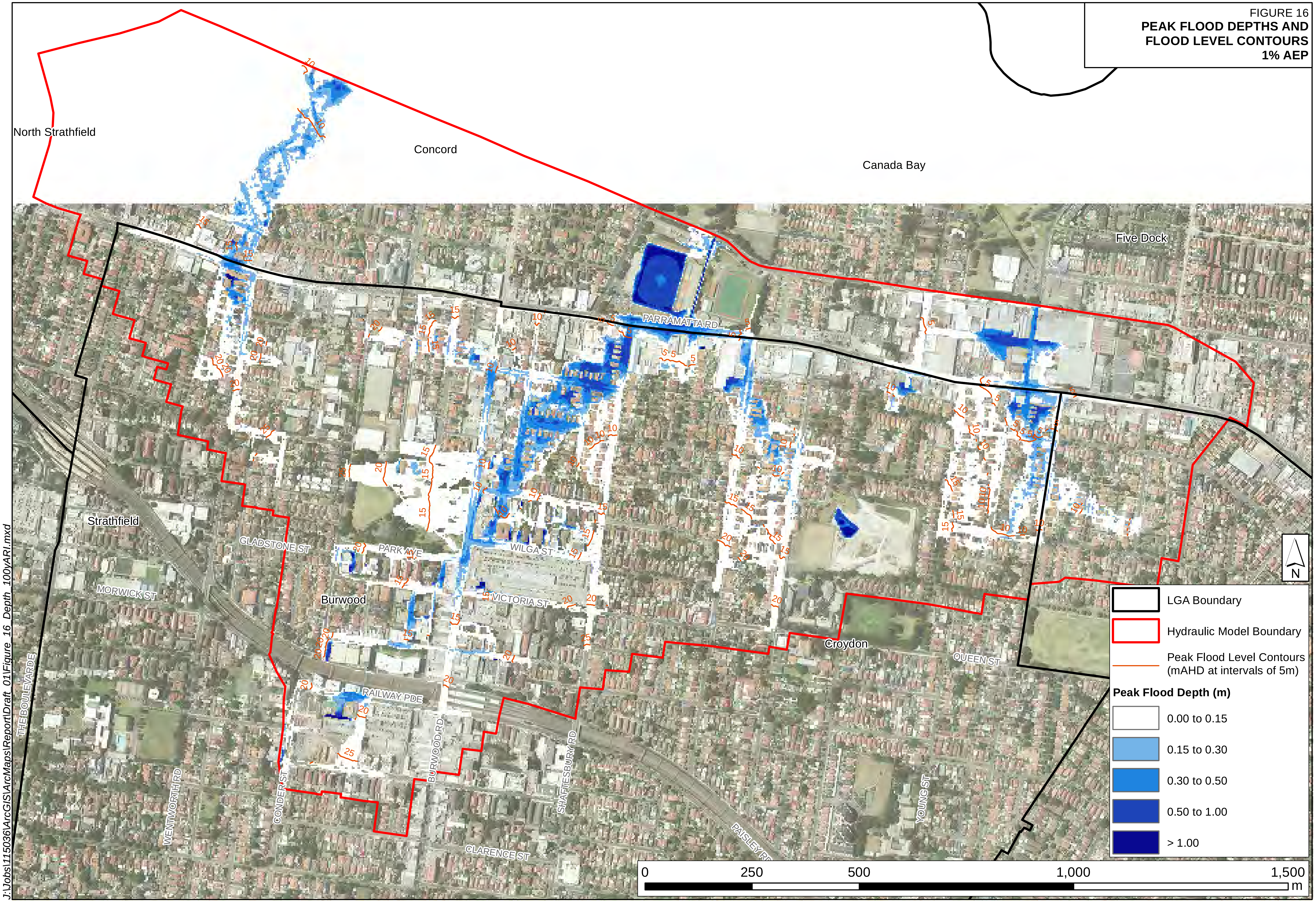

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FIGURE 17
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PMF

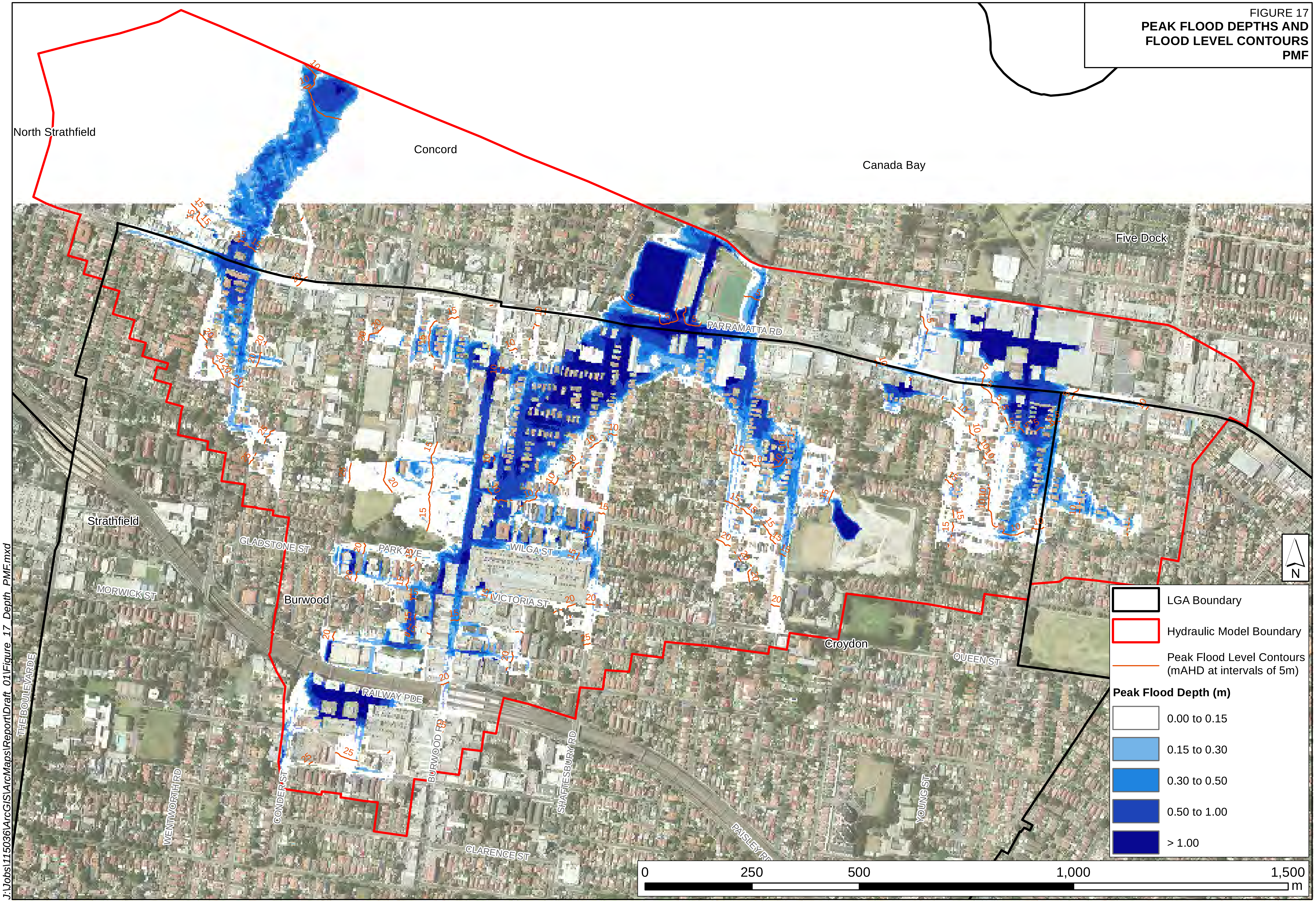

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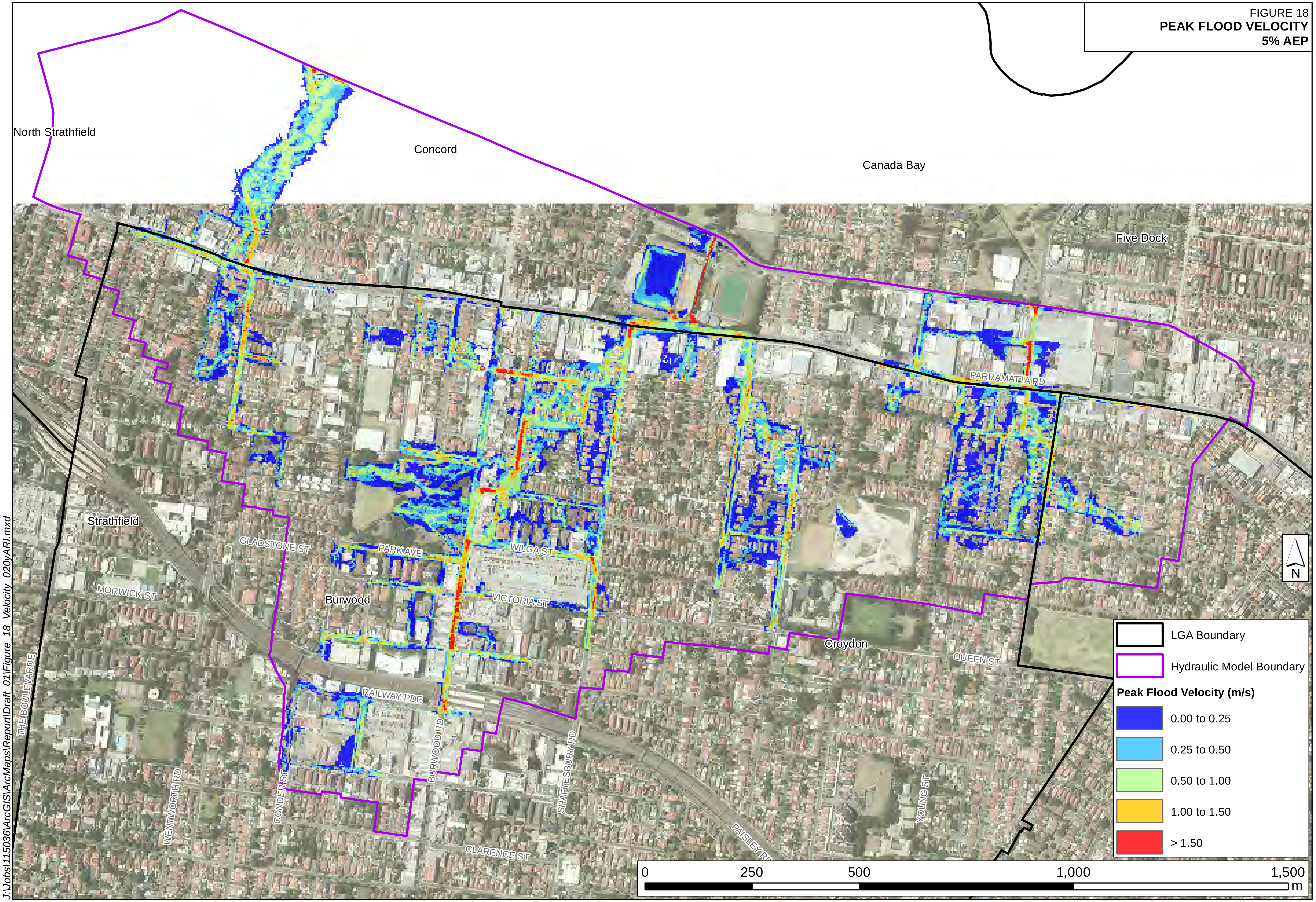
FIGURE 18
PEAK FLOOD VELOCITY
5% AEP



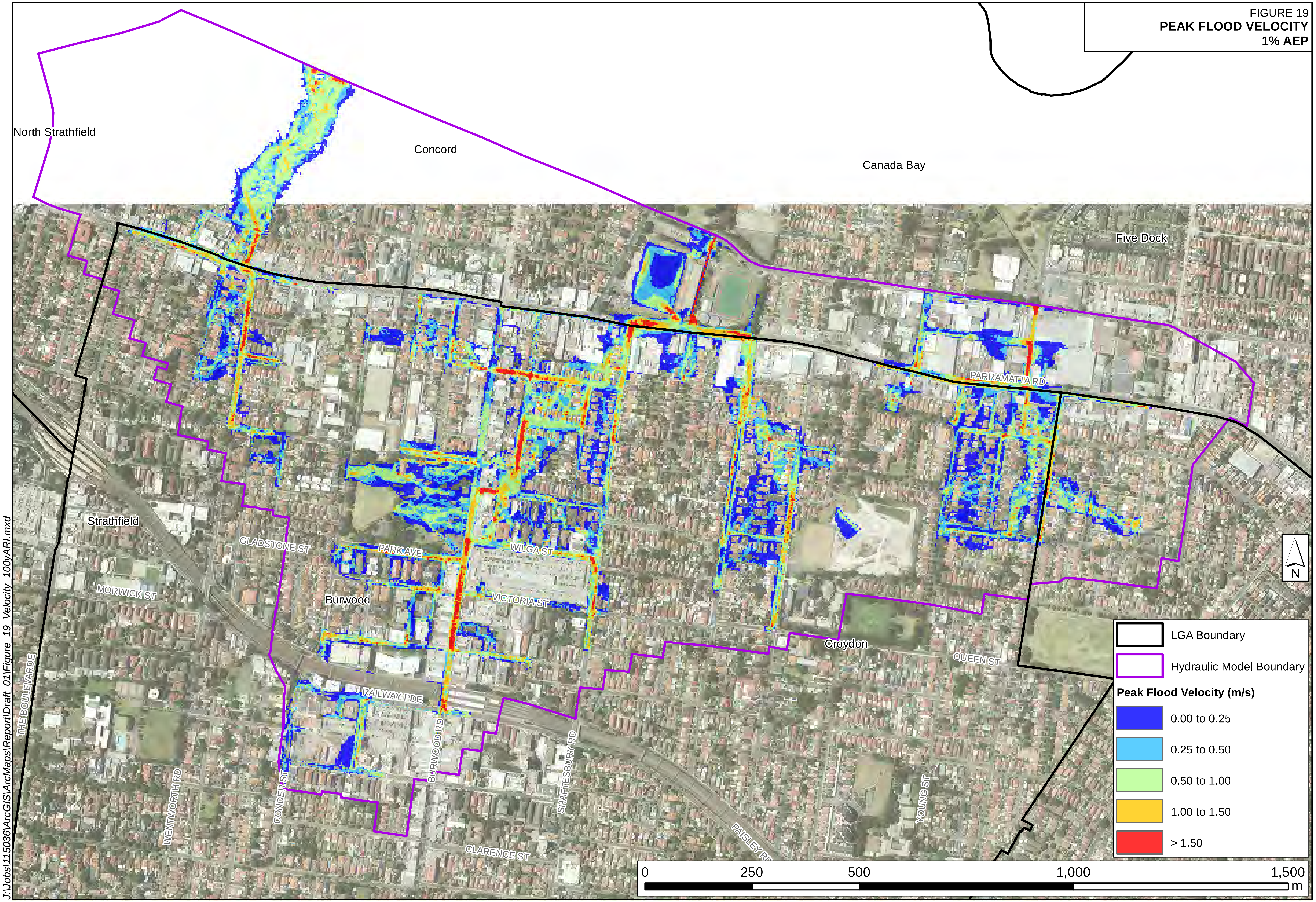


FIGURE 19
PEAK FLOOD VELOCITY
1% AEP
North Strathfield
Concord
Canada Bay
Five Dock
Strathfield
Burwood
Croydon
PARRAMATTA RD
GLADSTONE ST
PARK AVE
WILGA ST
MORWICK ST
VICTORIA ST
RAILWAY PDE
BURWOOD RD
SHAFTESBURY RD
CONDER ST
WENTWORTH RD
THE BOULEVARDE
QUEEN ST
YOUNG ST
CLARENCE ST
N
LGA Boundary
Hydraulic Model Boundary
Peak Flood Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0
250
500
1,000
1,500
m
J:\Jobs\115036\ArcGIS\ArcMaps\Report\Draft_01\Figure_19_Velocity_100yARI.mxd

FIGURE 20
PEAK FLOOD VELOCITY
PMF

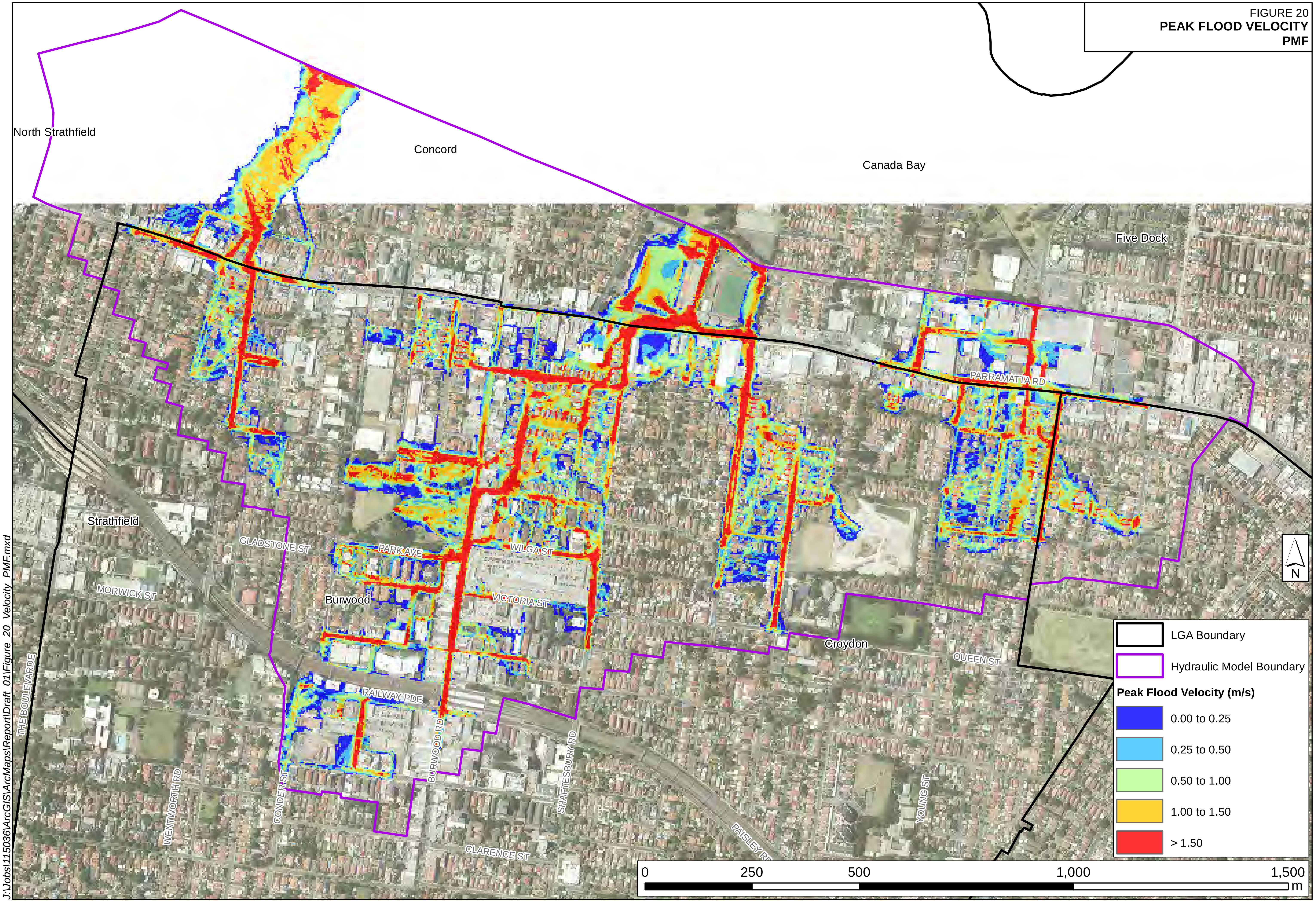


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FIGURE 21
PROVISIONAL HYDRAULIC HAZARD
5% AEP

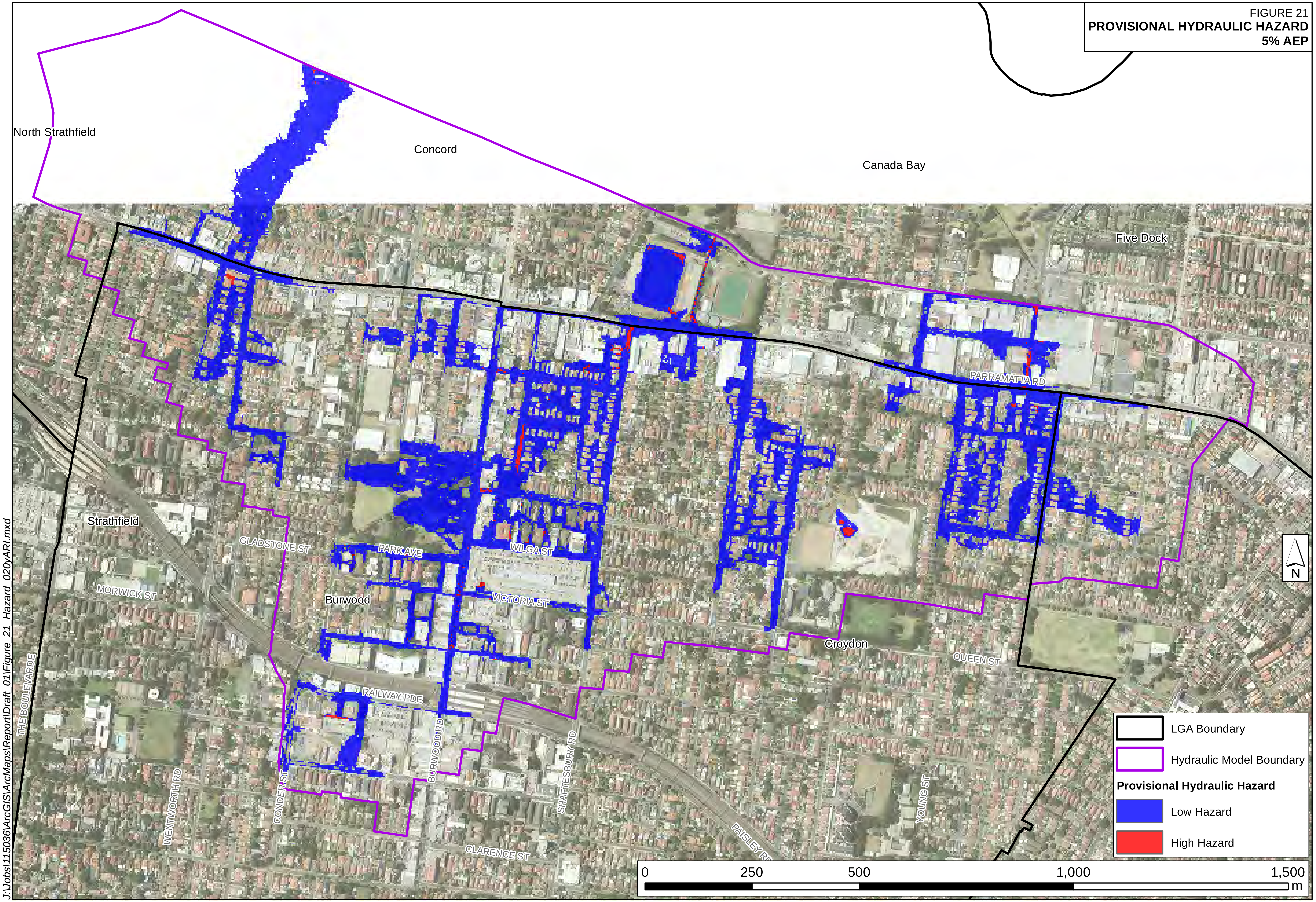

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FIGURE 22
PROVISIONAL HYDRAULIC HAZARD
1% AEP

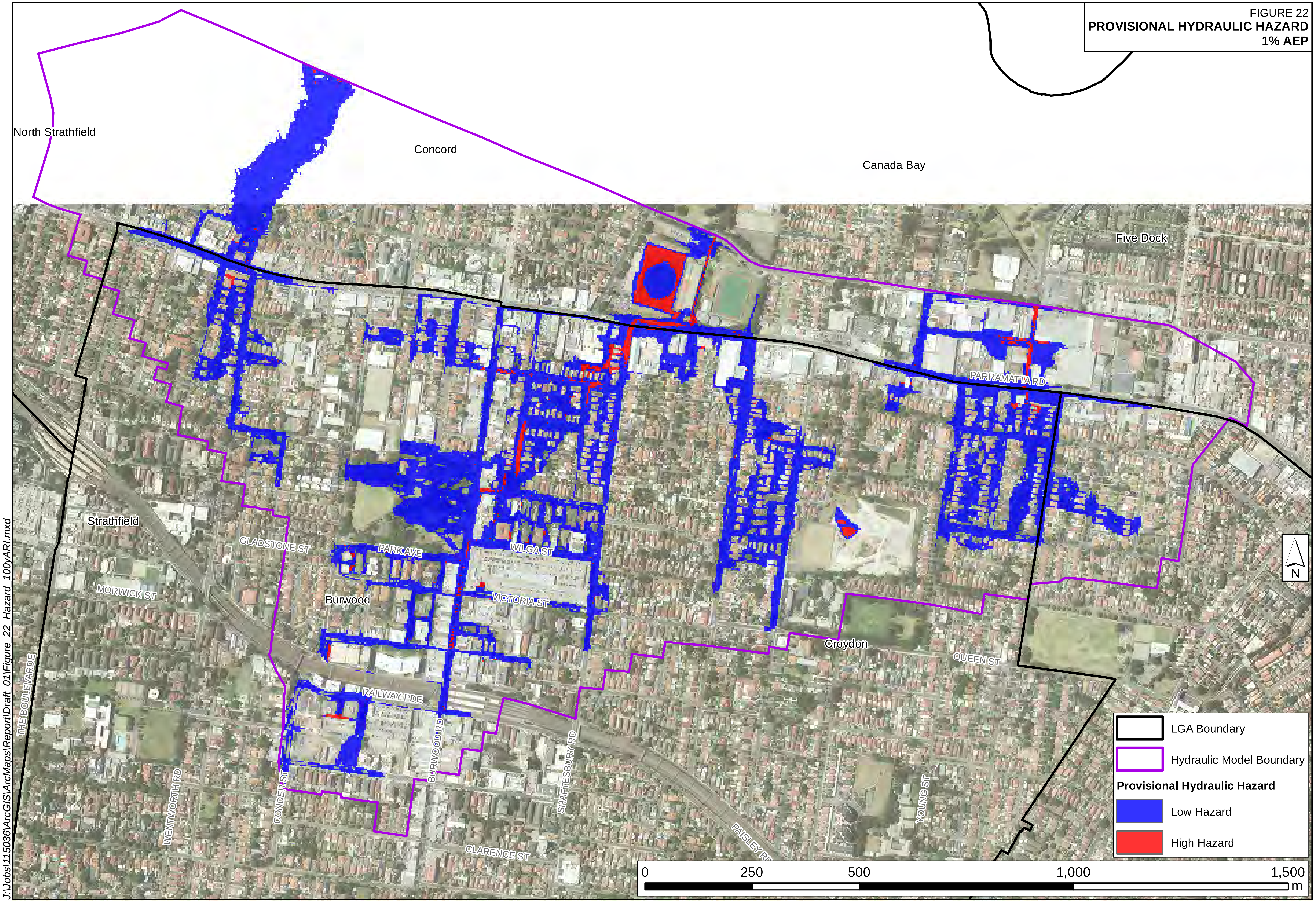

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FIGURE 23
PROVISIONAL HYDRAULIC HAZARD
PMF

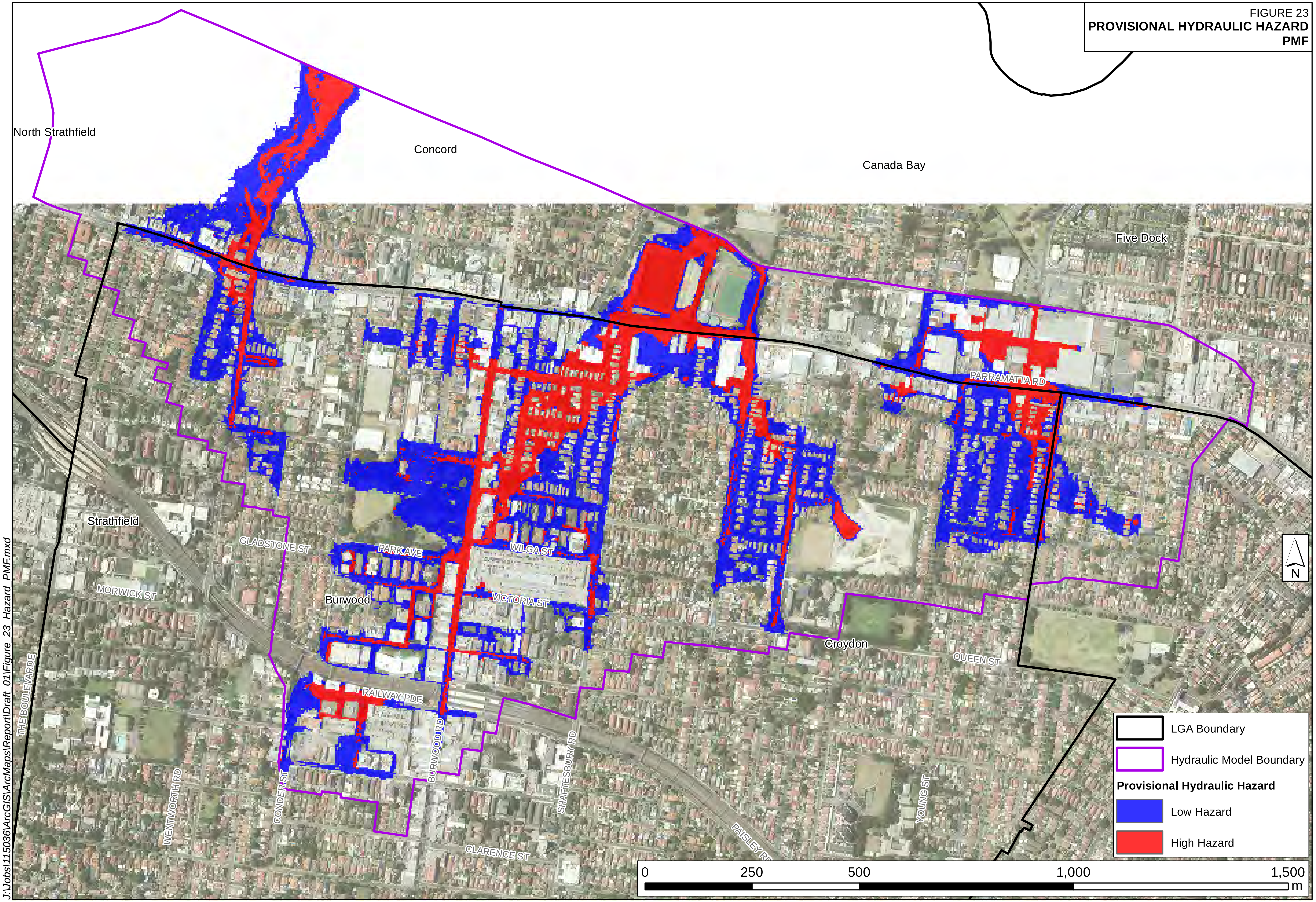
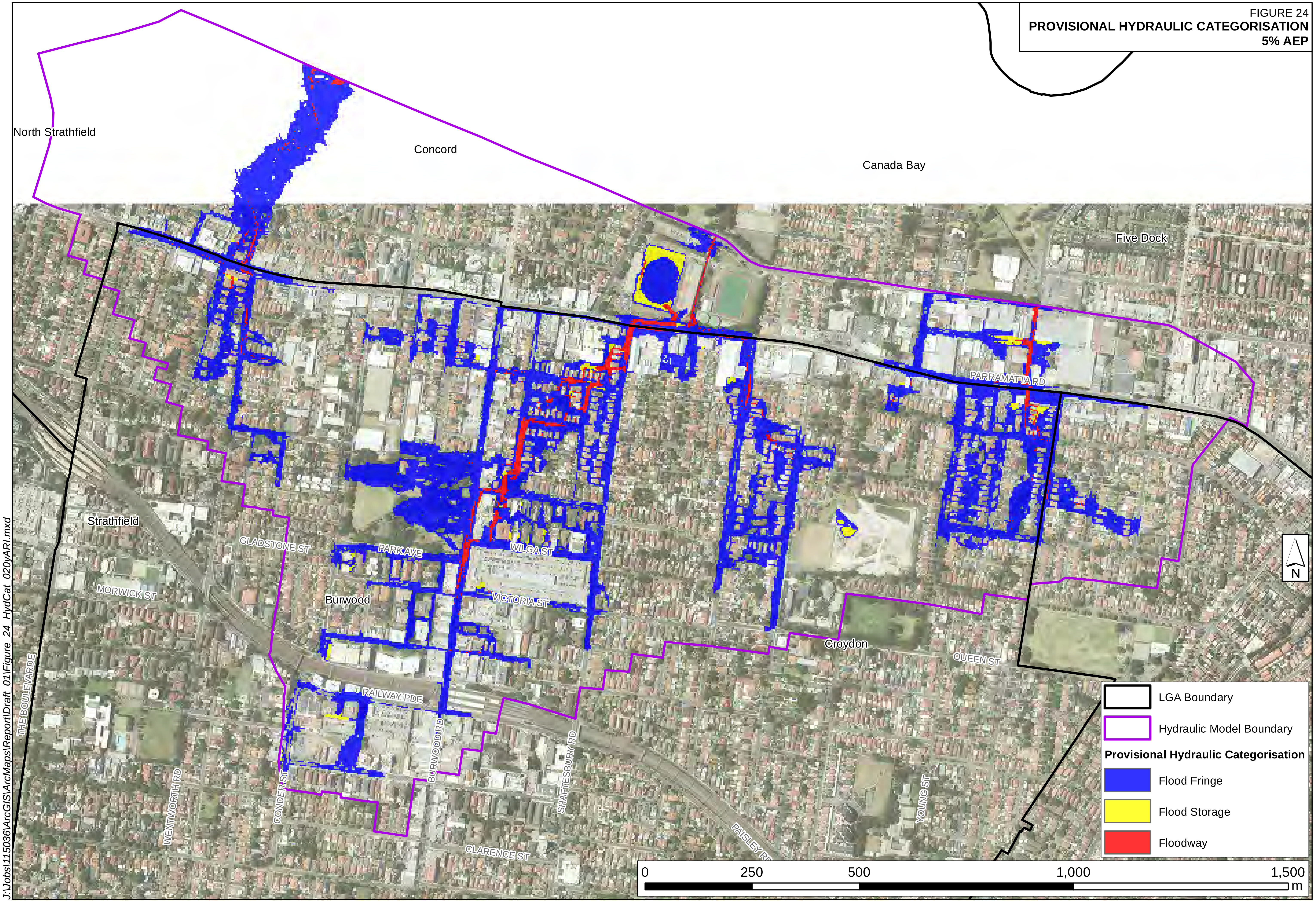


FIGURE 24
PROVISIONAL HYDRAULIC CATEGORISATION
5% AEP



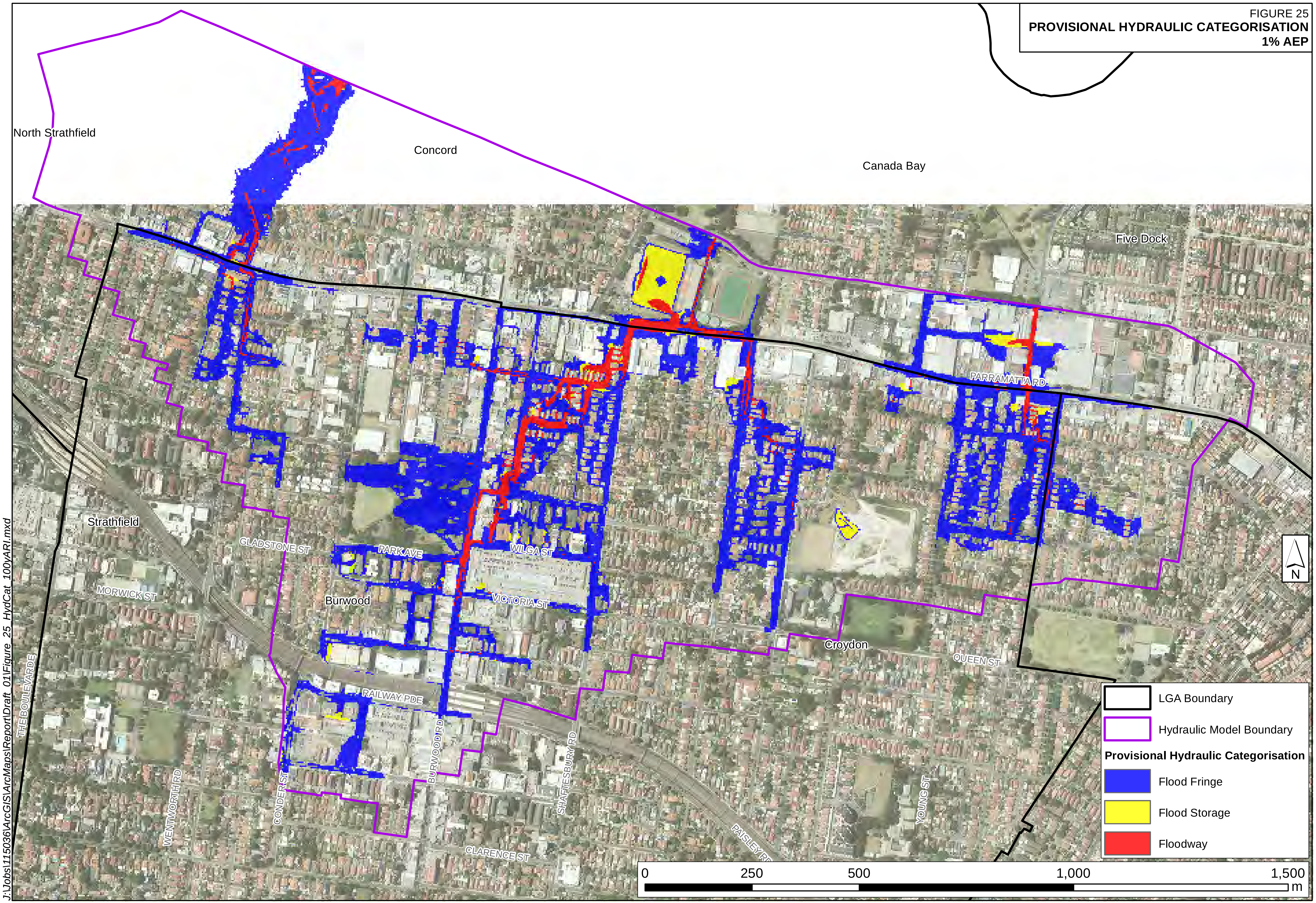


FIGURE 25
PROVISIONAL HYDRAULIC CATEGORISATION
1% AEP
North Strathfield
Concord
Canada Bay
Five Dock
Strathfield
Burwood
Croydon
PARRAMATTA RD
GLADSTONE ST
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
RAILWAY PDE
QUEEN ST
THE BOULEVARDE
WENTWORTH RD
CONDER ST
BURWOOD RD
SHAFTESBURY RD
YOUNG ST
CLARENCE ST
LGA Boundary
Hydraulic Model Boundary
Provisional Hydraulic Categorisation
Flood Fringe
Flood Storage
Floodway
0
250
500
1,000
1,500
m
N
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FIGURE 26
PROVISIONAL HYDRAULIC CATEGORISATION PMF

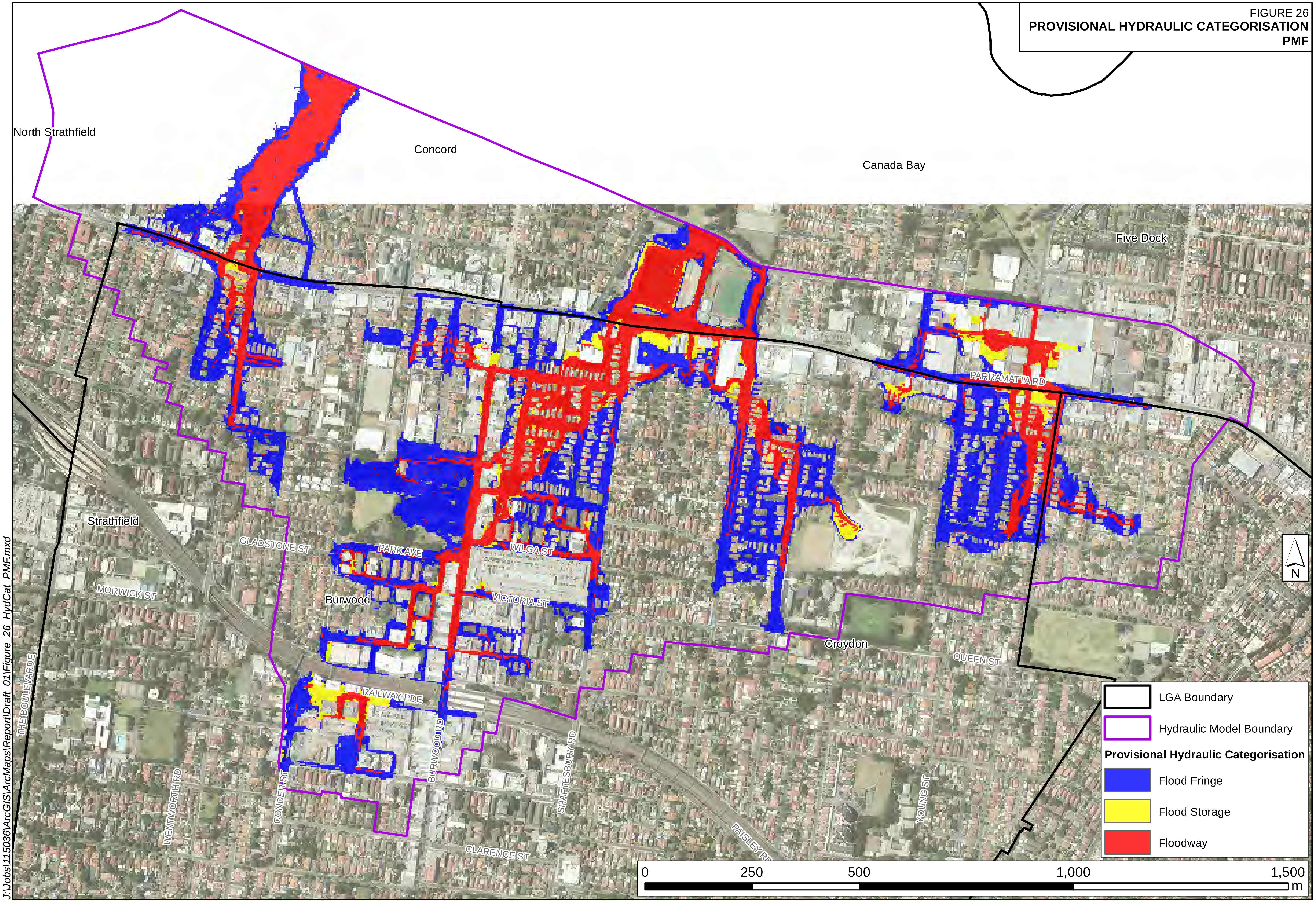

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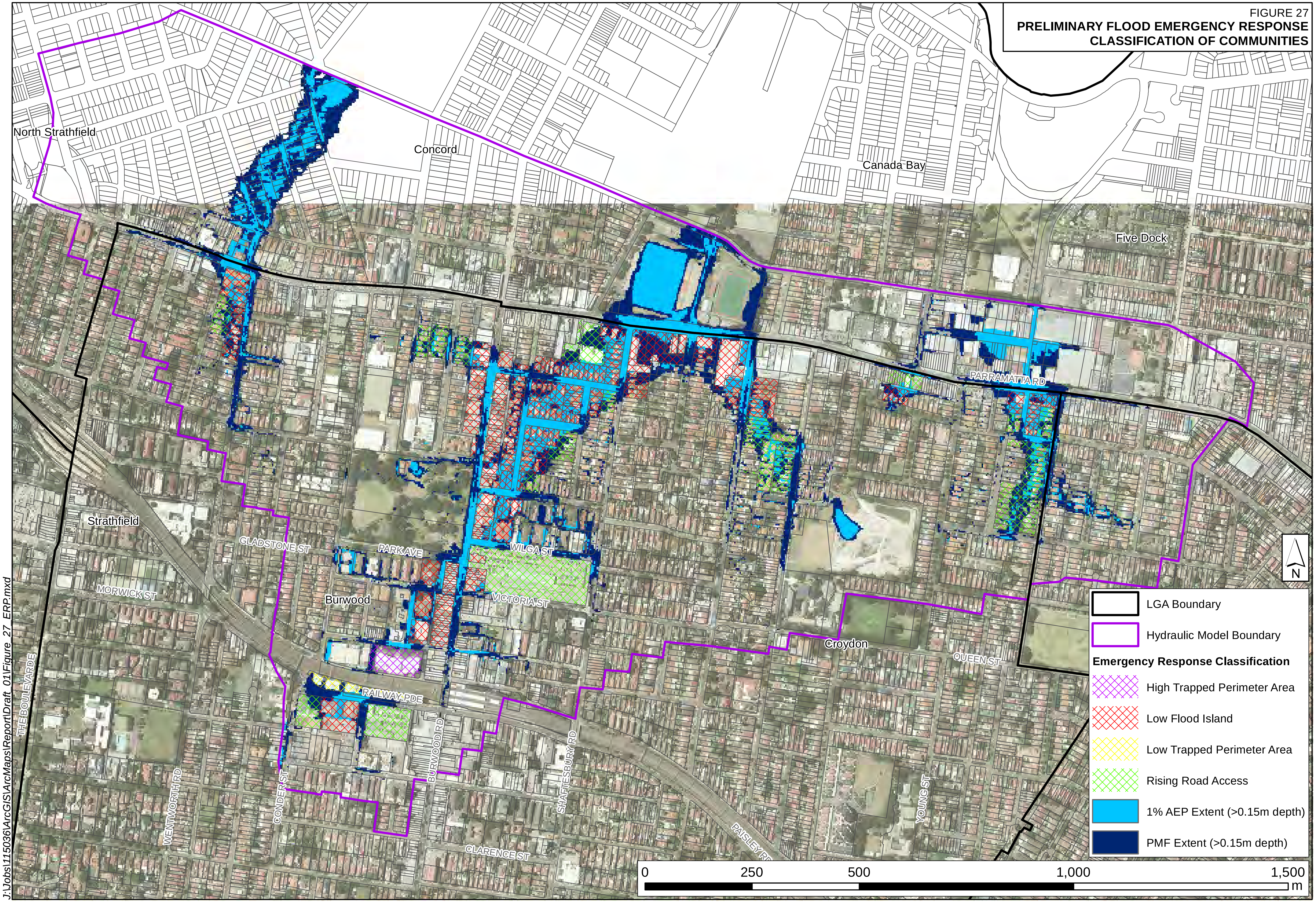
FIGURE 27
PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION OF COMMUNITIES



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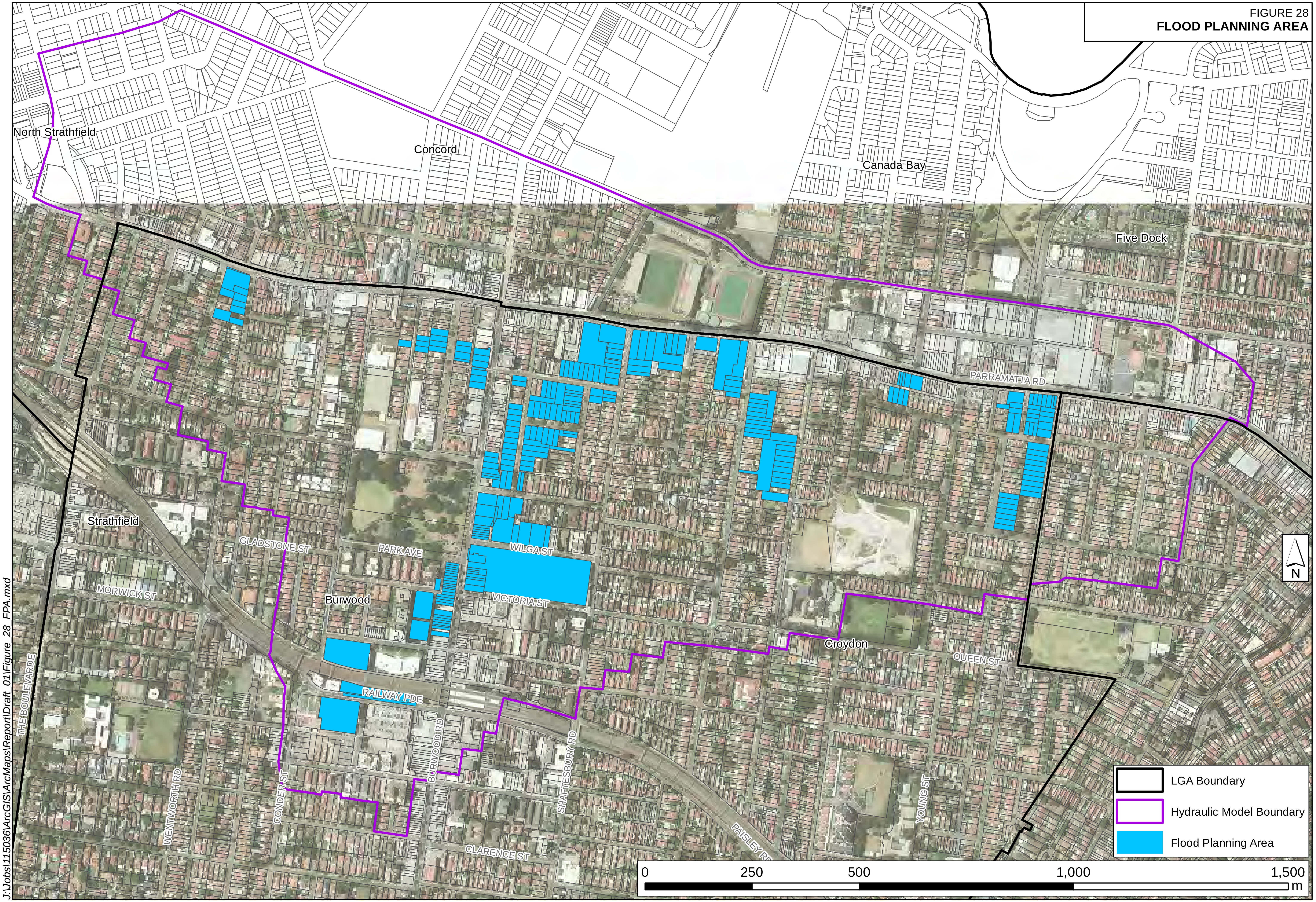

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Appendix A

APPENDIX A. GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate 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. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
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 LG 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 DIPNR, 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 the 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).
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 the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).

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 diagrammetic 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 State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL=s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the Astandard flood event@ in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of

	floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
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	Are 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. For the purpose of this manual 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 0.3 m (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 flow paths 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 floodplain risk management policy and EPIs.

minor, moderate and major flooding Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.

peak discharge The maximum discharge occurring during a flood event.

Probable Maximum Flood (PMF) The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to Awater level@. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
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.

Appendix B

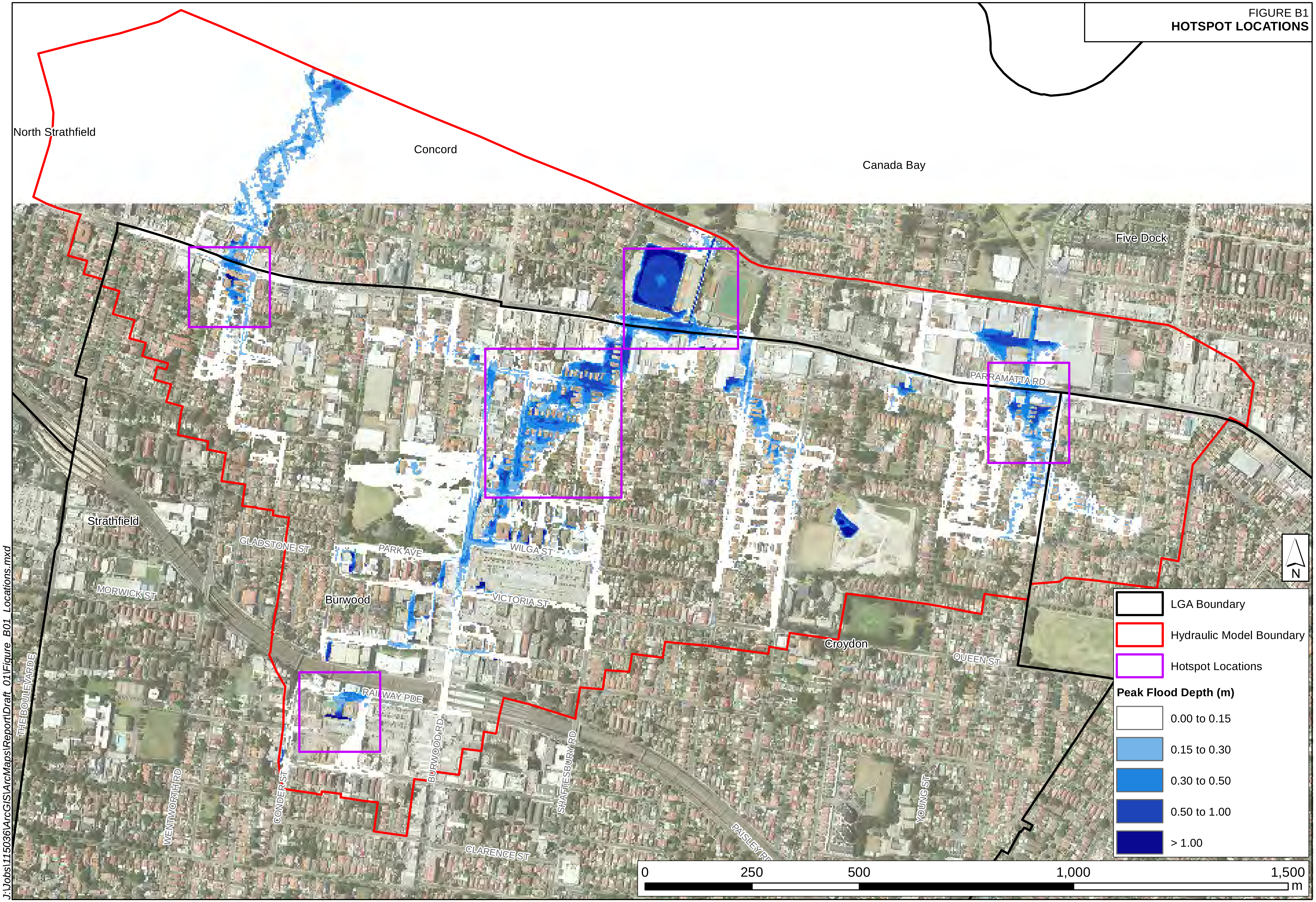

FIGURE B1
HOTSPOT LOCATIONS
North Strathfield
Concord
Canada Bay
Five Dock
PARRAMATTA RD
Strathfield
GLADSTONE ST
PARK AVE
WILGA ST
MORWICK ST
Burwood
VICTORIA ST
Croydon
QUEEN ST
RAILWAY PDE
THE BOULEVARDE
WENTWORTH RD
CONDER ST
BURWOOD RD
SHAFTESBURY RD
YOUNG ST
PAISLEY RD
CLARENCE ST
N
LGA Boundary
Hydraulic Model Boundary
Hotspot Locations
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
0
250
500
1,000
1,500
m
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FIGURE B2
5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / SHORT ST

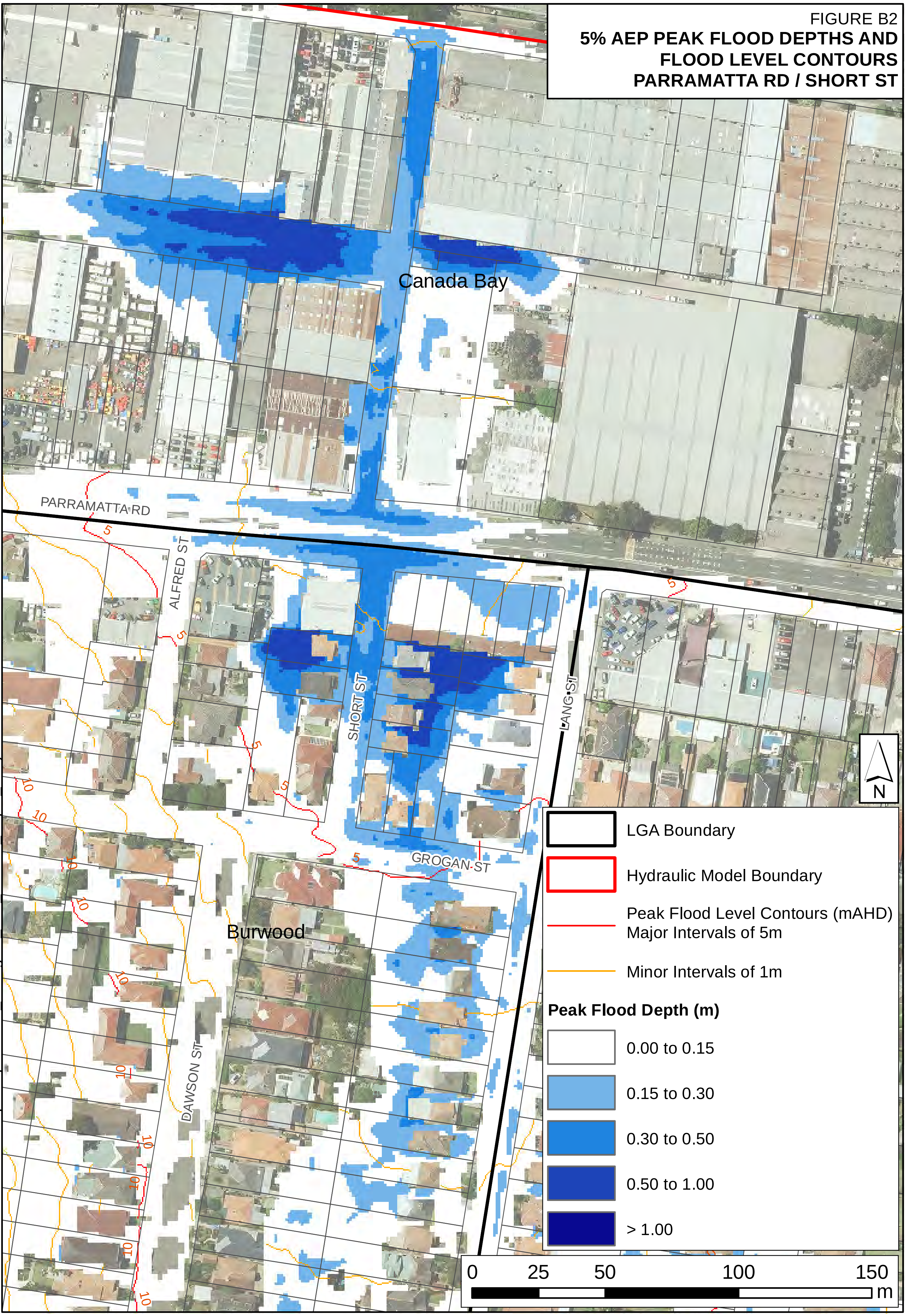

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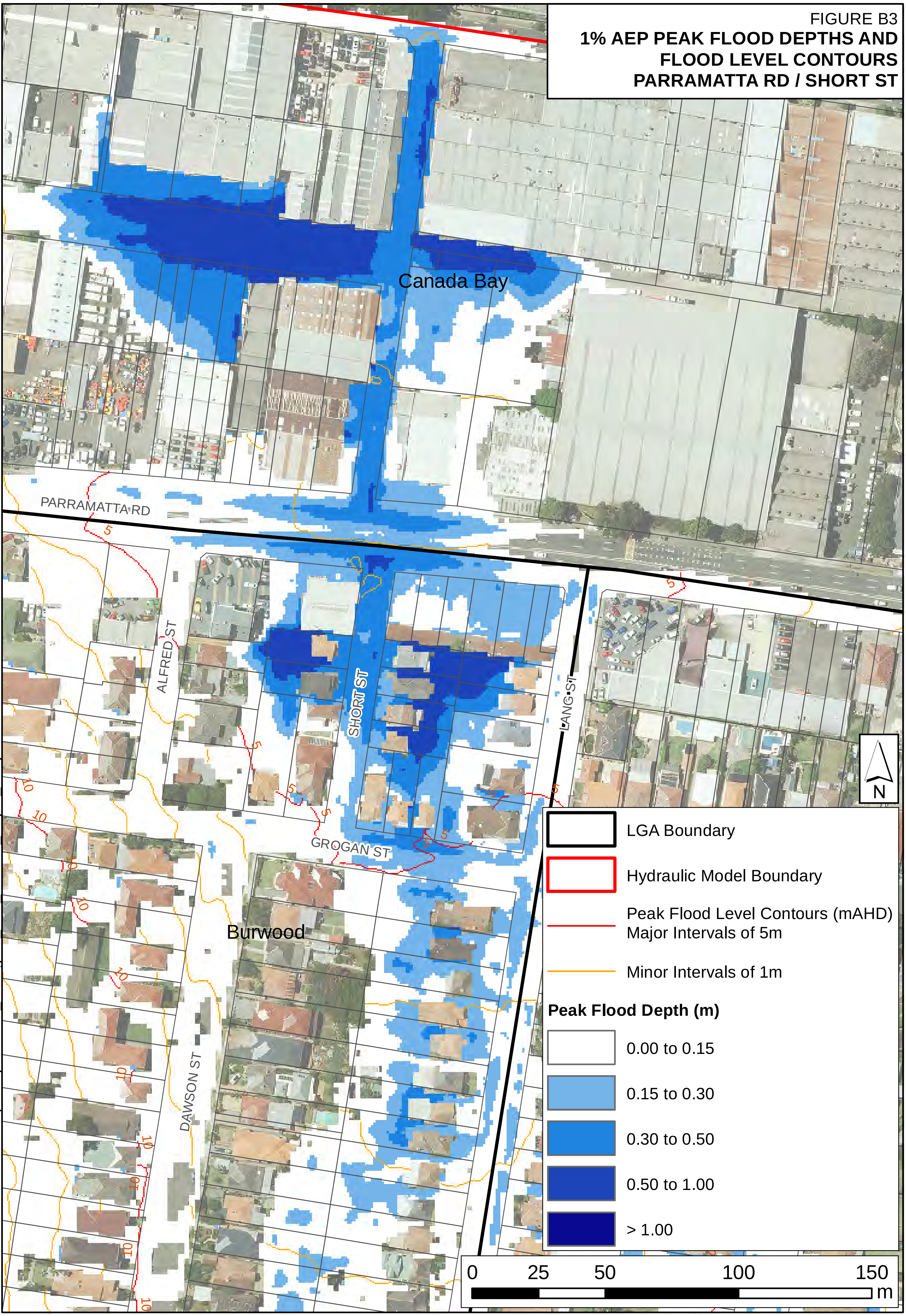
FIGURE B3

1% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / SHORT ST



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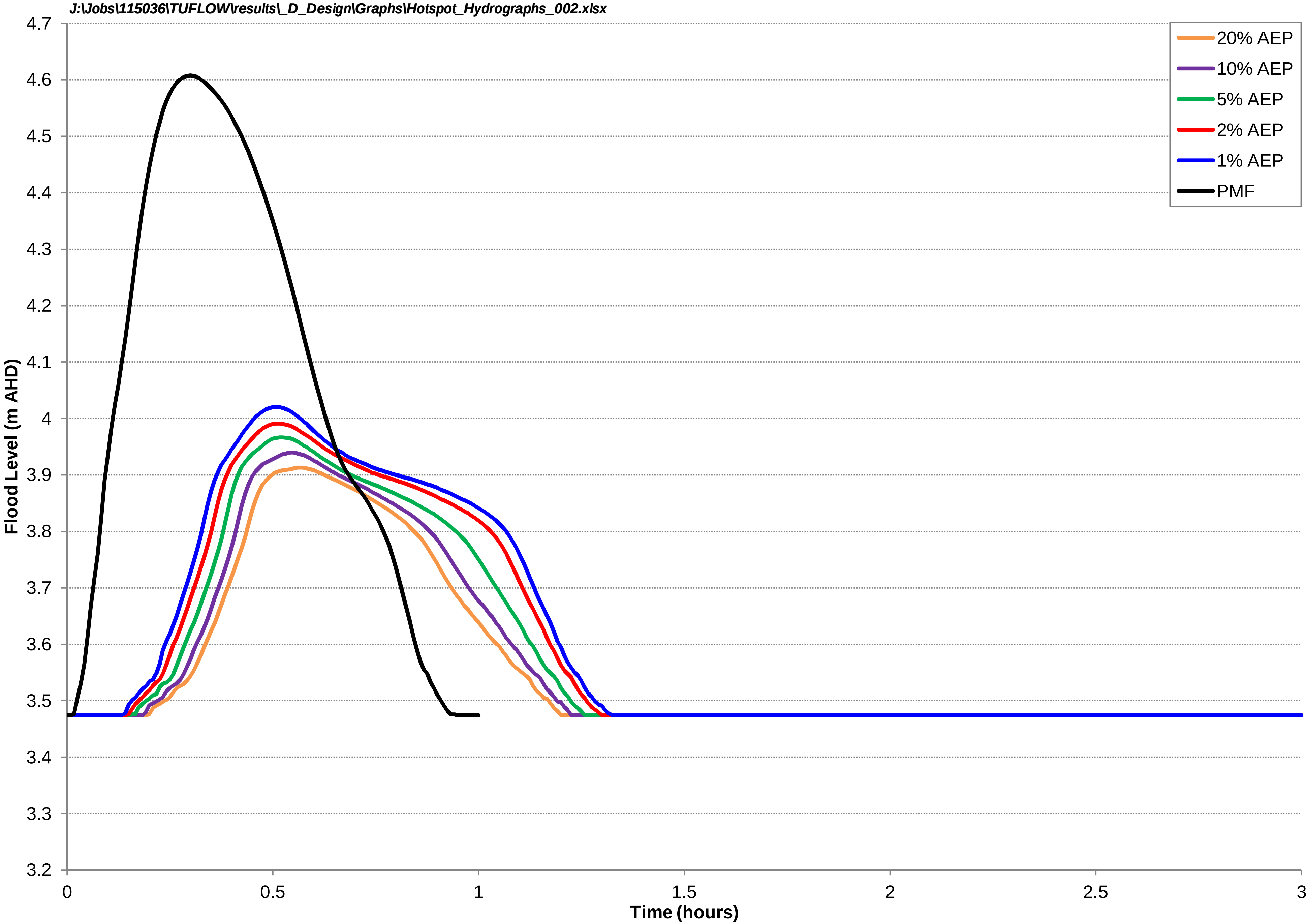

FIGURE B4
DESIGN HYDROGRAPHS
H1 - PARRAMATTA ROAD - SHORT STREET

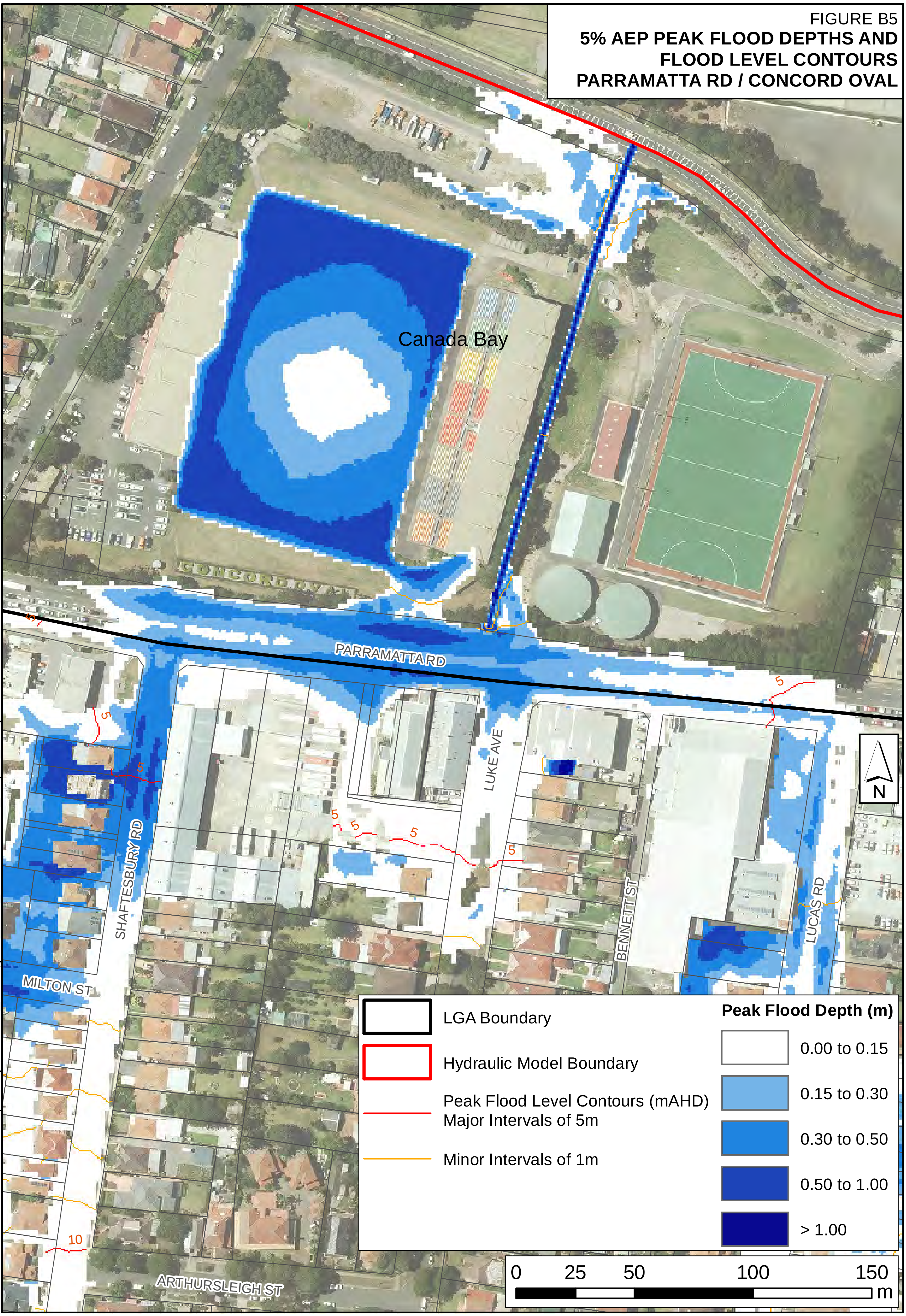
FIGURE B5
5% AEP PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
PARRAMATTA RD / CONCORD OVAL
Canada Bay
PARRAMATTA RD
LUKE AVE
SHAFTESBURY RD
BENNETT ST
LUCAS RD
MILTON ST
ARTHURSLEIGH ST
N
LGA Boundary
Hydraulic Model Boundary
Peak Flood Level Contours (mAHD)
Major Intervals of 5m
Minor Intervals of 1m
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
0 25 50 100 150
m
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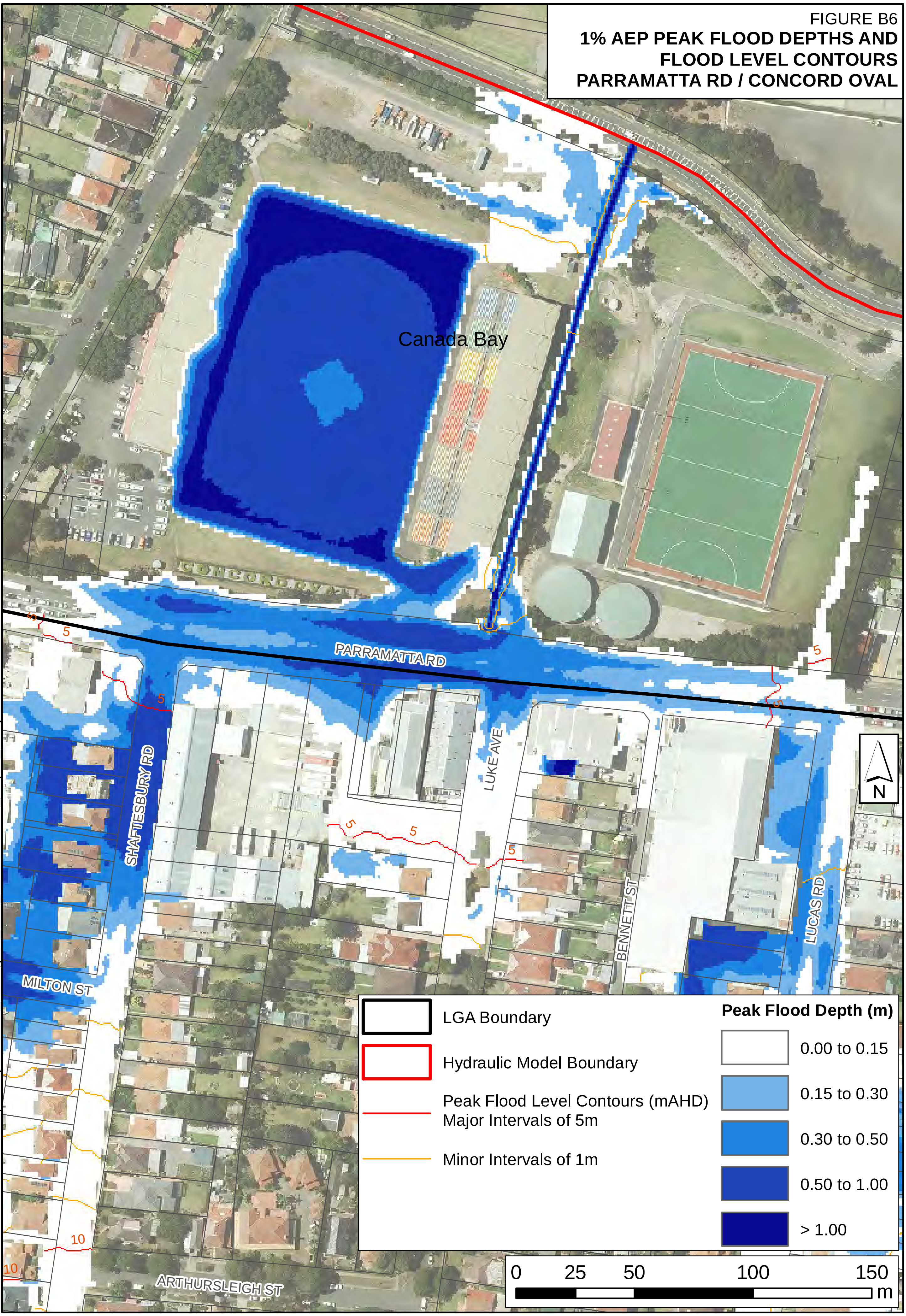
FIGURE B6
1% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / CONCORD OVAL



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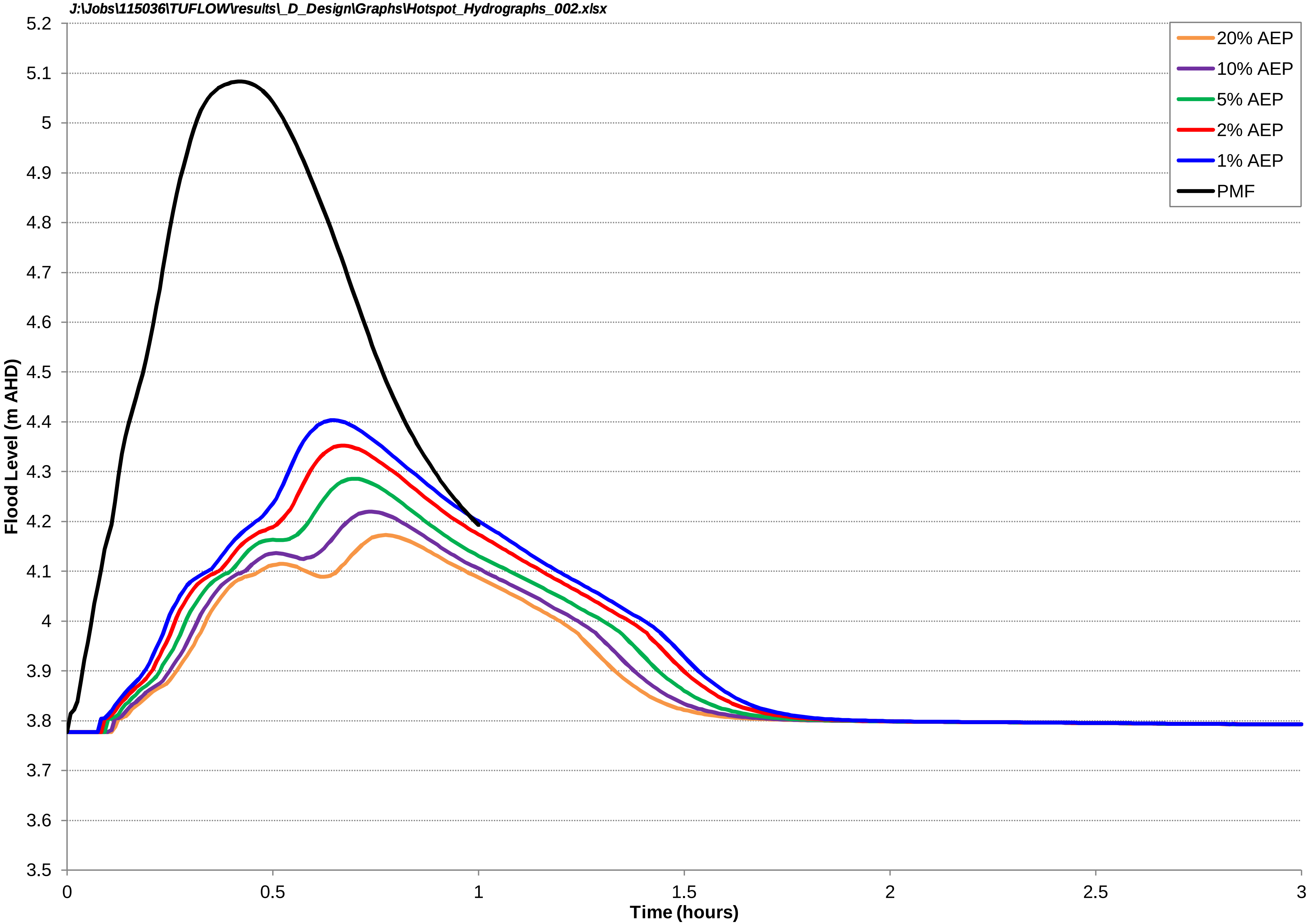

FIGURE B7
DESIGN HYDROGRAPHS
H03 - PARRAMATTA ROAD - CONCORD OVAL

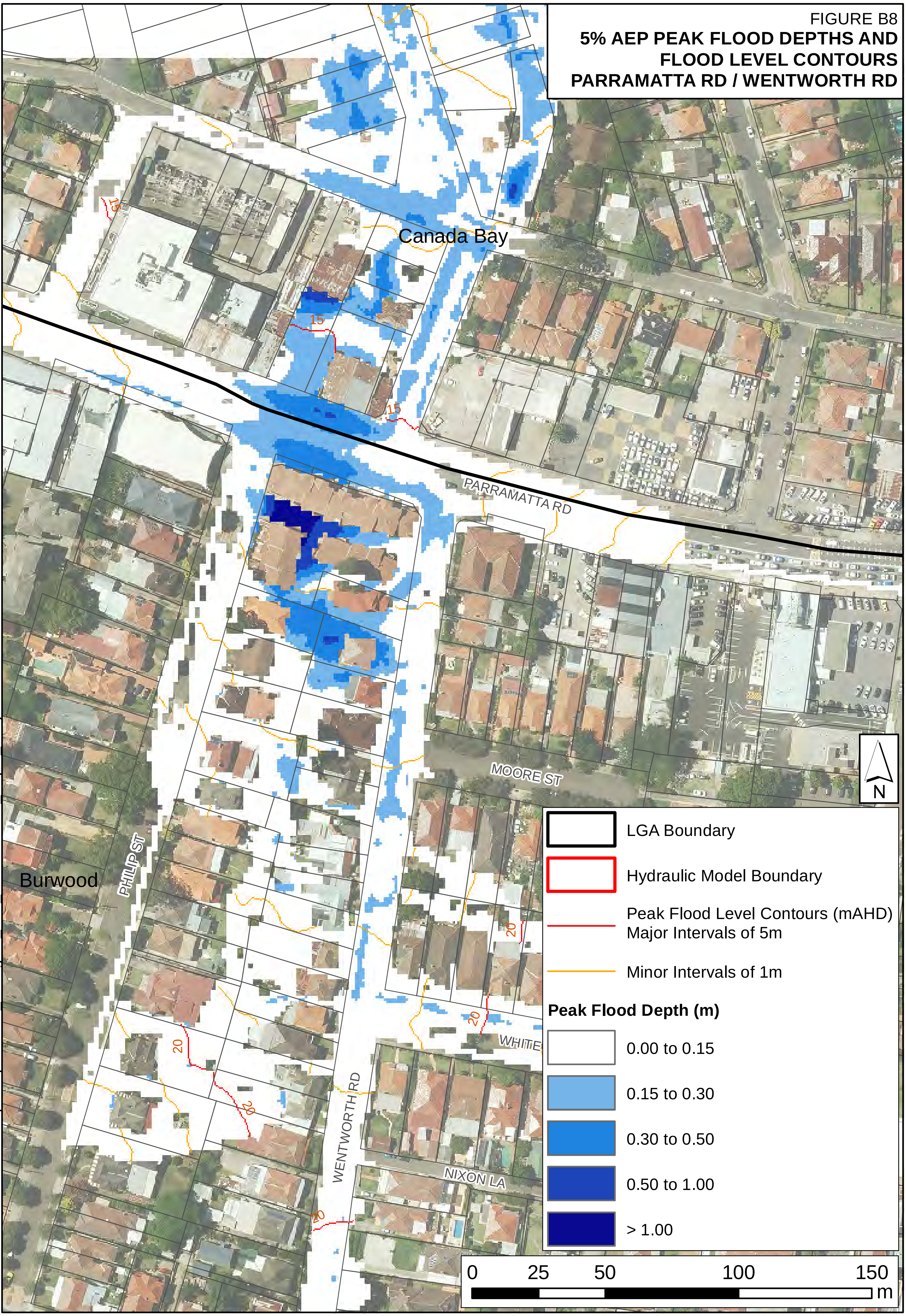

FIGURE B8
5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / WENTWORTH RD

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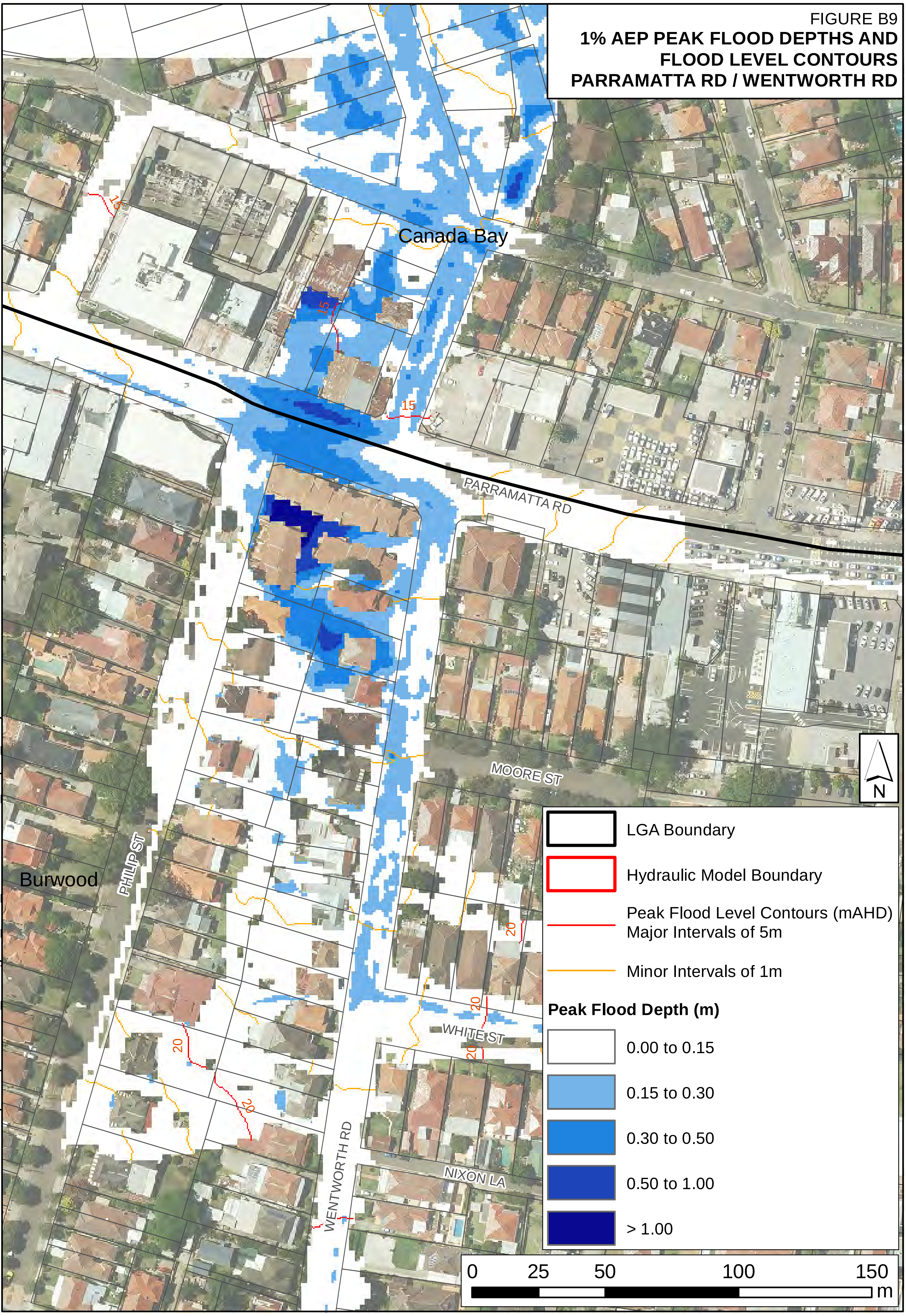

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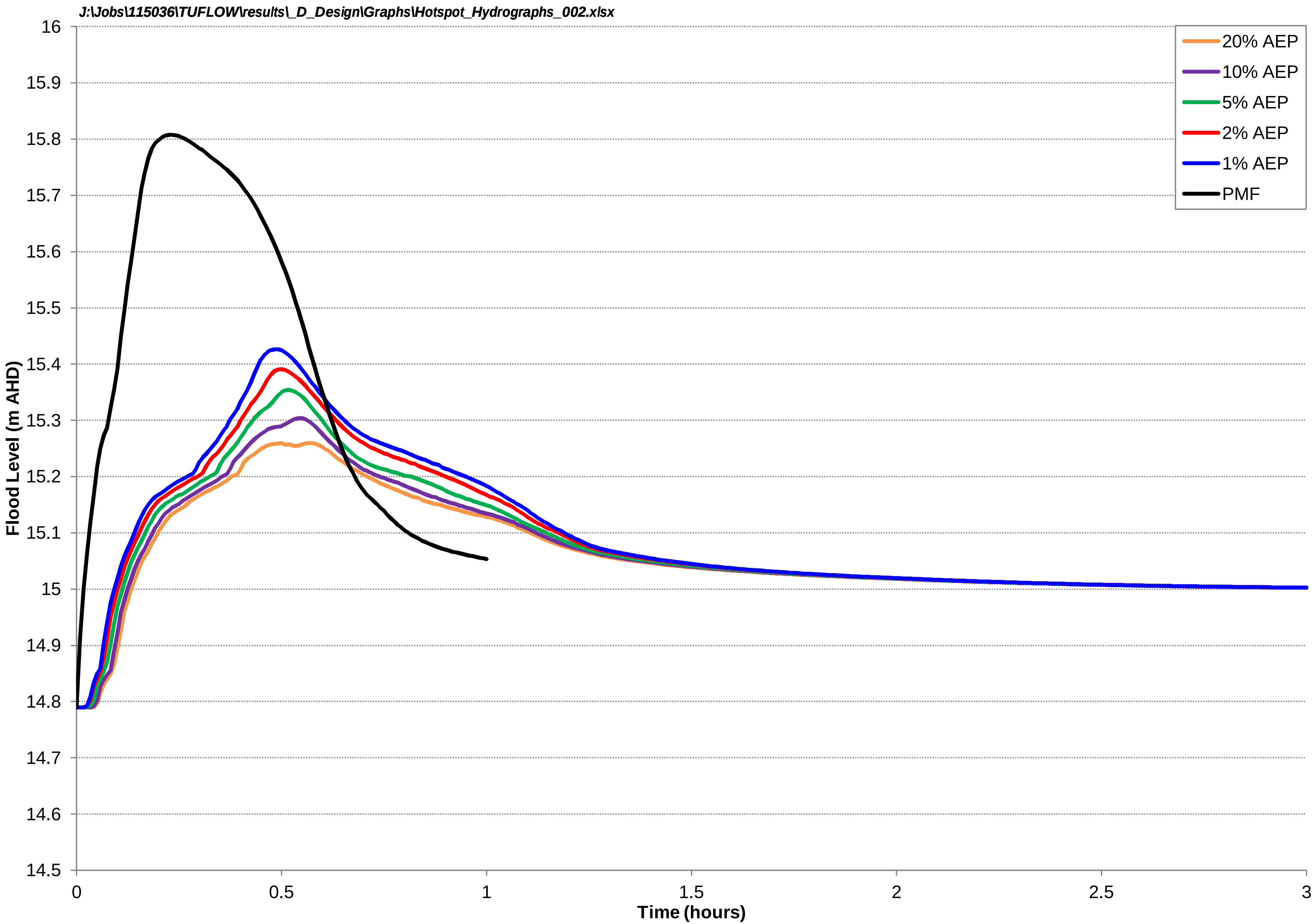

H01 - PARRAMATTA ROAD - WENTWORTH ROAD

DESIGN HYDROGRAPHS

FIGURE B10

FIGURE B11
5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS SHAFTESBURY RD / BURWOOD RD

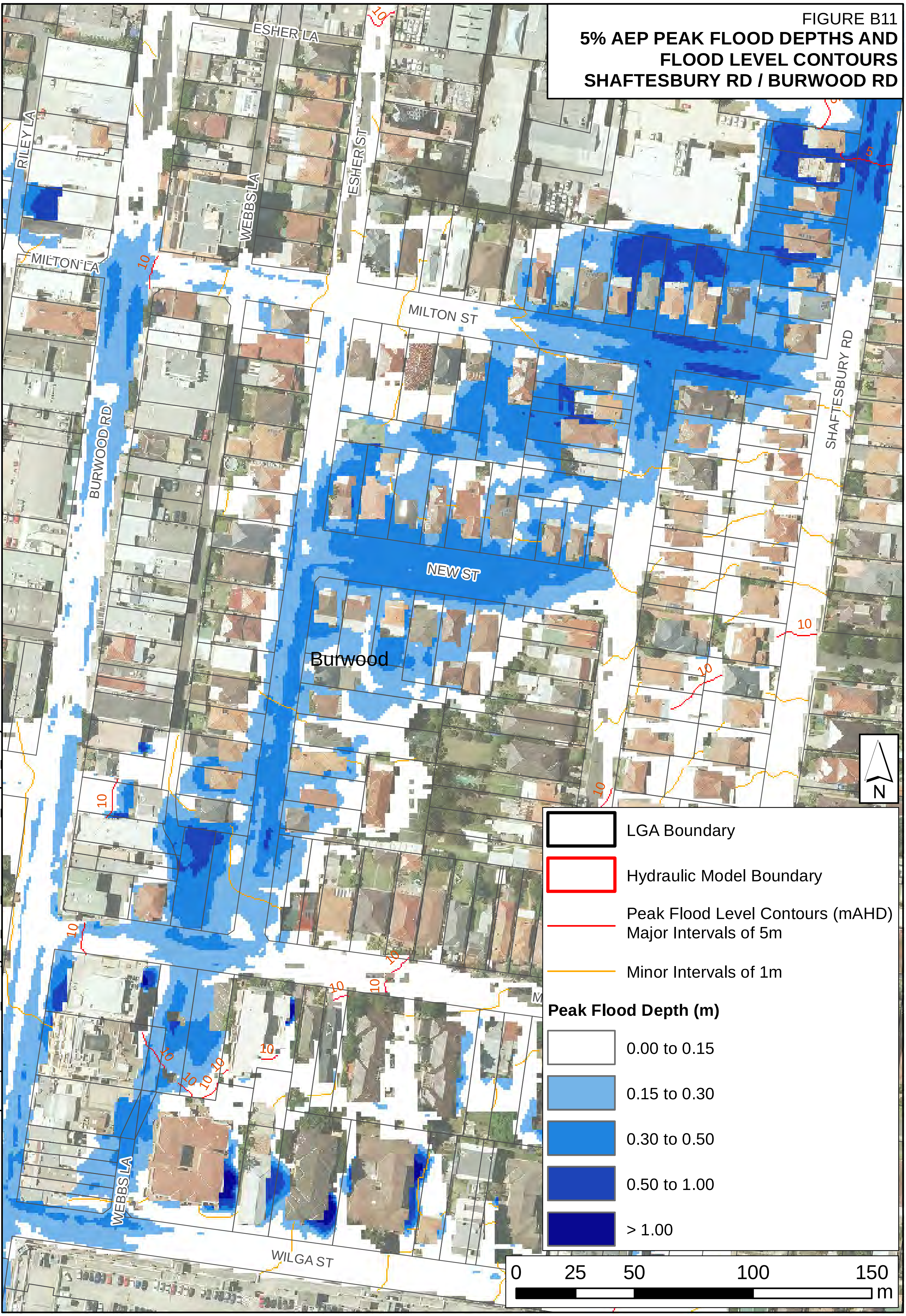

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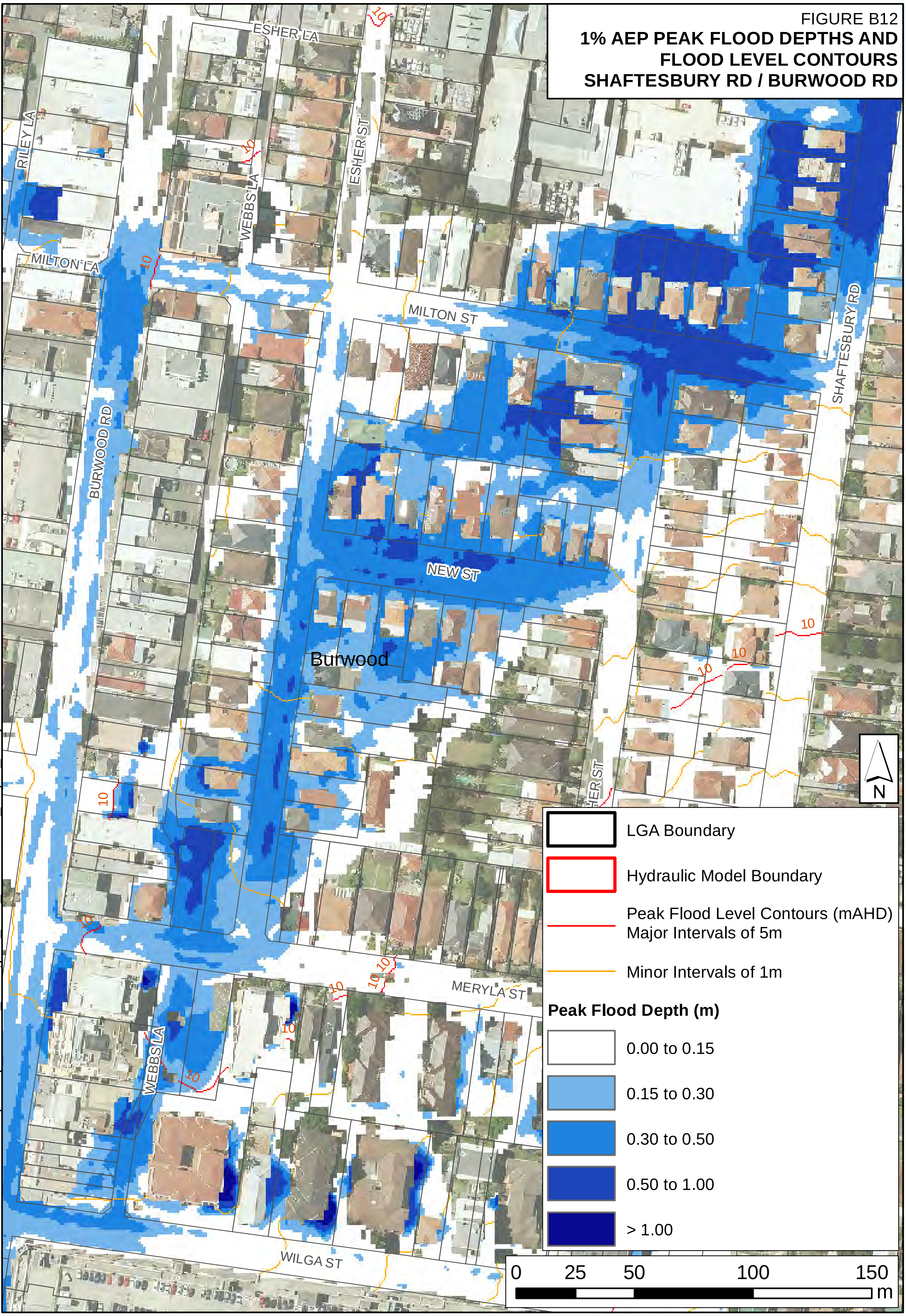
FIGURE B12

1% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS SHAFTESBURY RD / BURWOOD RD



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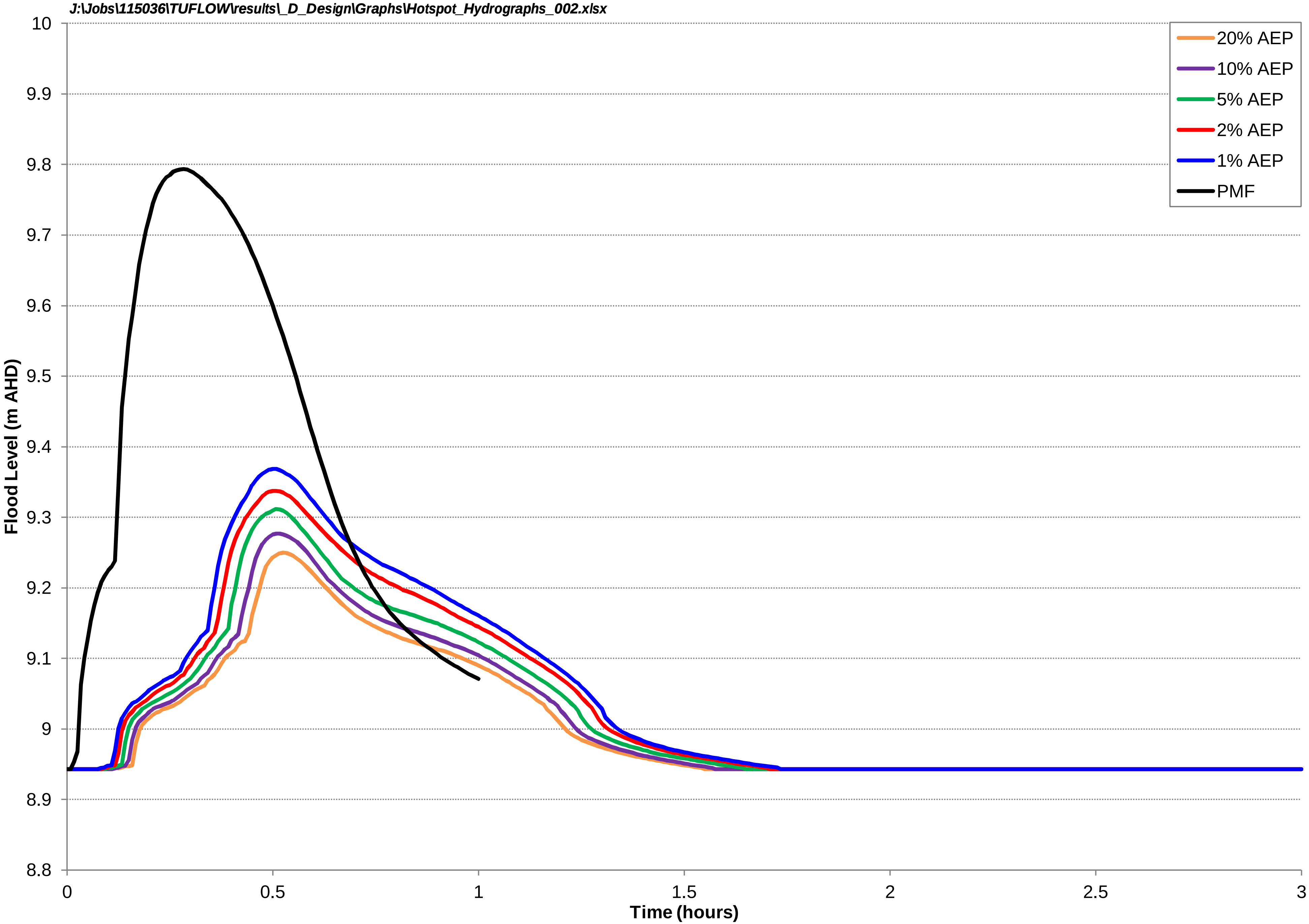
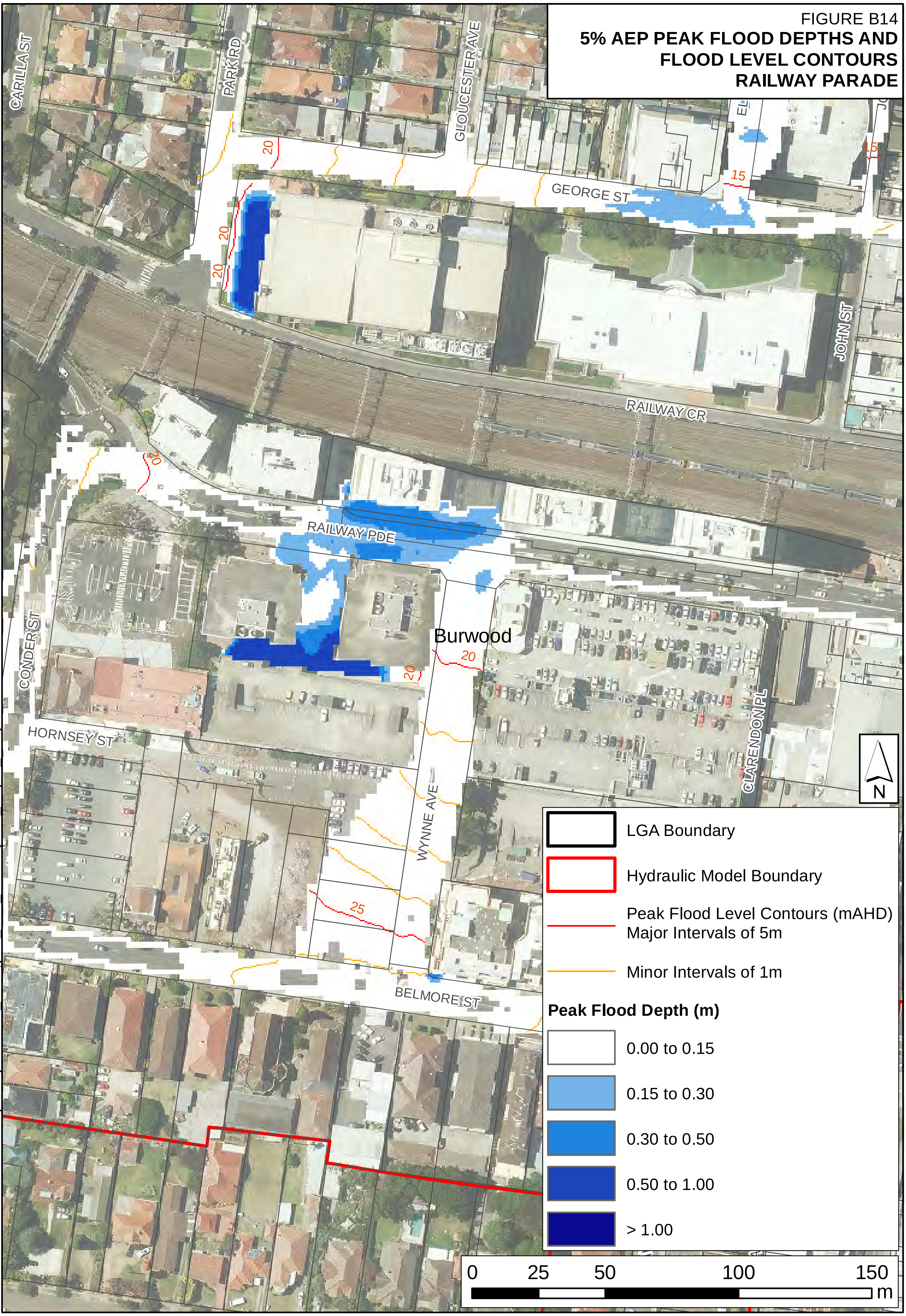


FIGURE B13
DESIGN HYDROGRAPHS
H05 - MERYLA STREET

FIGURE B14
5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS RAILWAY PARADE



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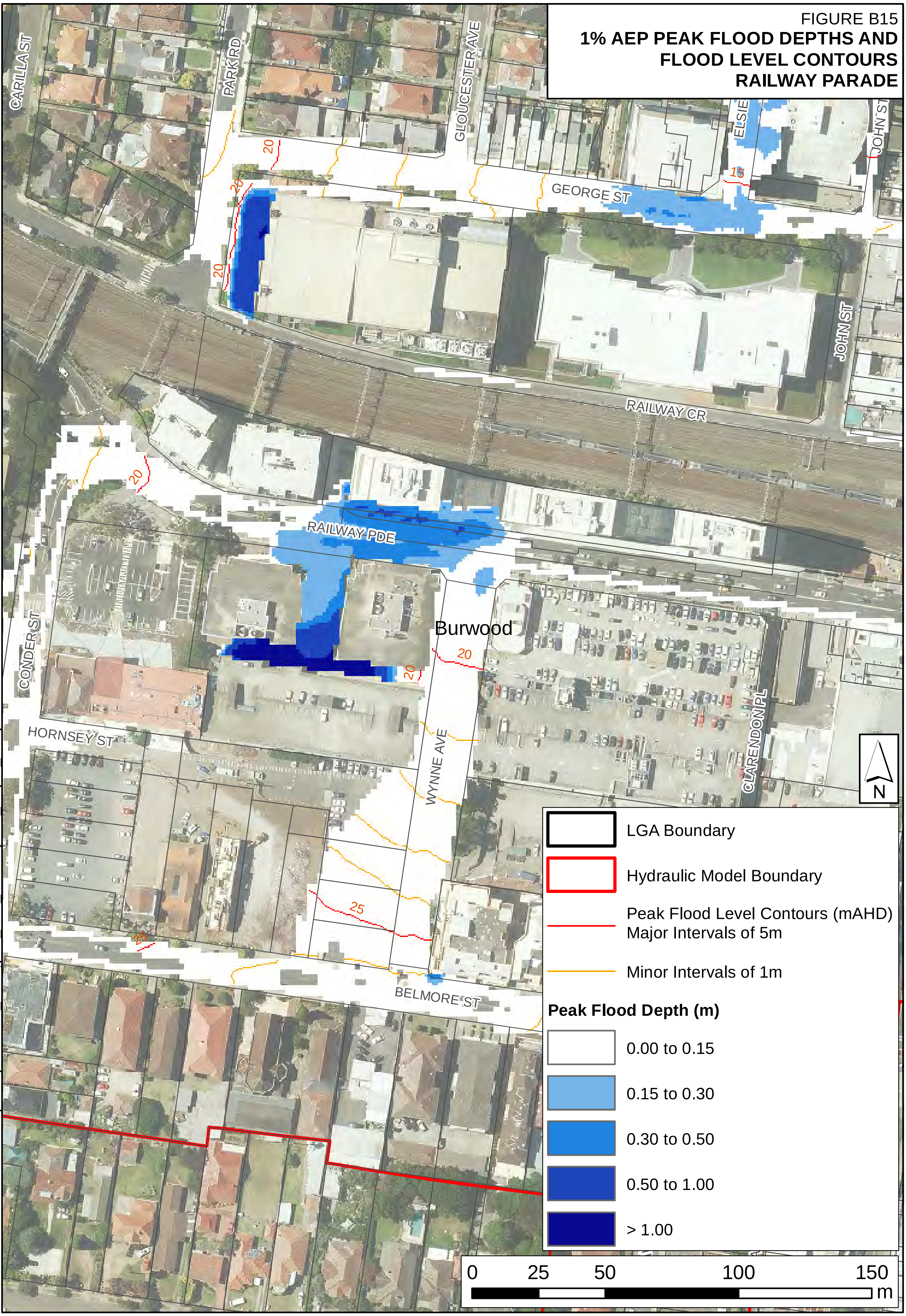

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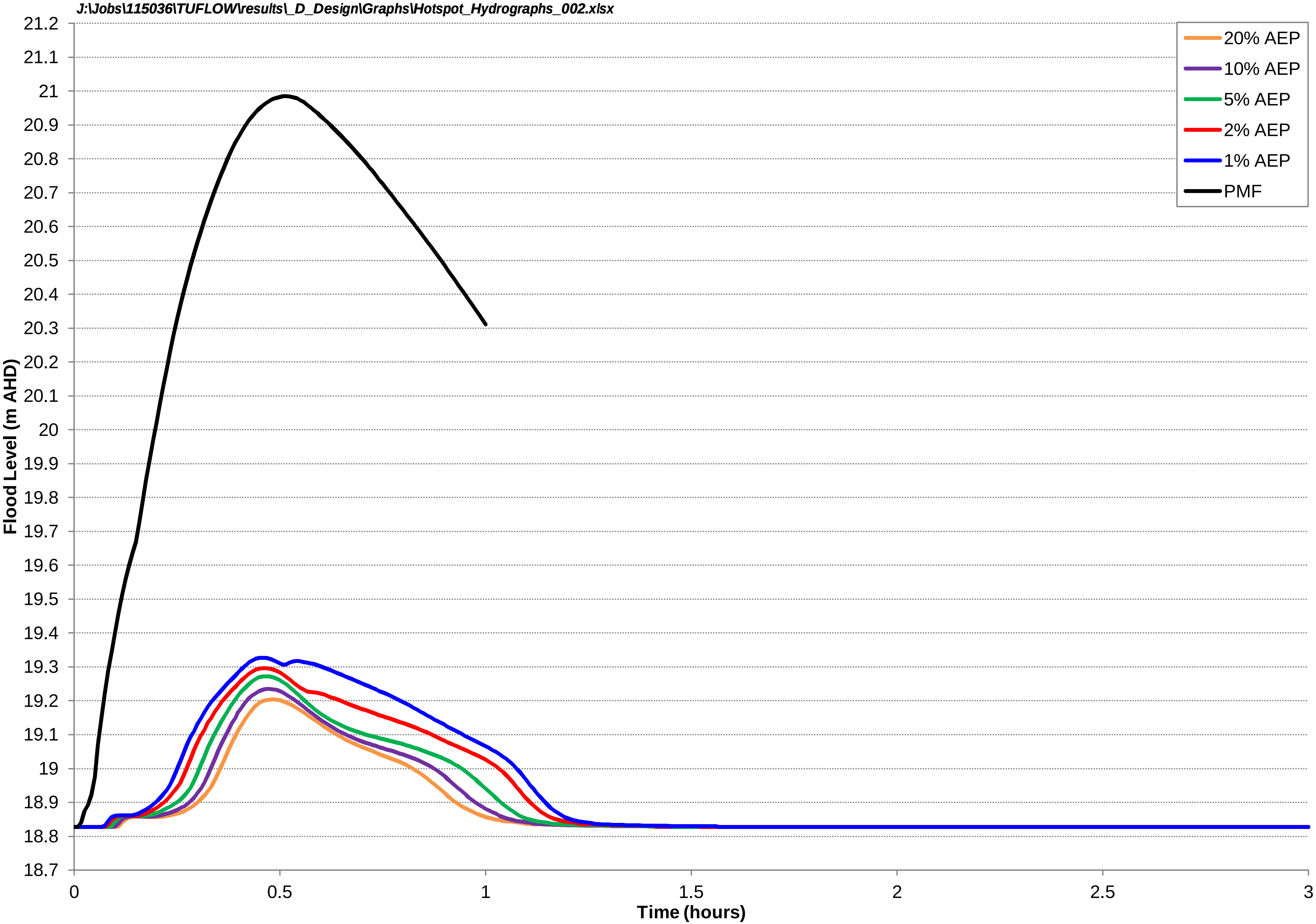

FIGURE B16
DESIGN HYDROGRAPHS
H08 - RAILWAY PARADE

Burwood
heritage • progress • pride

Ashfield Council

DOBROYD CANAL FLOOD STUDY

FINAL DRAFT REPORT

wma water

OCTOBER 2013

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Sydney, NSW, 2000

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Web: www.wmawater.com.au

DOBROYD CANAL FLOOD STUDY

FINAL DRAFT REPORT

OCTOBER 2013

Project Dobroyd Canal Flood Study	**Project Number** 111053
Client Ashfield Council Burwood Council Sydney Water Corporation	**Client's Representative** Peter O'Sullivan – Ashfield Council Bill Adamopoulos – Burwood Council Matthew Lewis – Sydney Water
Authors Erika Taylor Stephen Gray	**Prepared by** TO BE SIGNED FOR FINAL REPORT
Date 30 October 2013	**Verified by** TO BE SIGNED FOR FINAL REPORT

Revision	Description	Date
4	Final Draft Report	30 October 2013
3	Draft Report	6 September 2013
2	Preliminary Draft Report	14 June 2013
1	Progress Report	20 April 2012

Ashfield City Council and Burwood City Council have prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

DOBROYD CANAL FLOOD STUDY

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LIST OF ABBREVIATIONS

1D	One (1) Dimensional
2D	Two (2) Dimensional
ACC	Ashfield City Council
ALS	Airborne Laser Scanning
BCC	Burwood City Council
DEM	Digital Elevation Model
IFD	Intensity-Frequency-Duration
LiDAR	Airborne Light Detection and Ranging Survey
SWC	Sydney Water Corporation
TIN	Triangular Irregular Network

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government provides funding for flood studies, floodplain risk management plans and works to alleviate existing problems, to undertake the necessary technical studies to identify and address the problem and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities. The Federal Government may also provide funding in some circumstances.

In order to implement the Policy within its Local Government Area (LGA), Ashfield City Council (ACC) and Burwood City Council (BCC) have embarked on a program of studies and actions as set out in the NSW Floodplain Development Manual with the assistance of Sydney Water Corporation (SWC).

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

1. ***Flood Study***
   - Determine the nature and extent of the flood problem for the full range of flood events up to the Probable Maximum Flood (PMF).
2. ***Floodplain Risk Management***
   - Evaluates management options for the floodplain in respect of both existing and proposed development taking into consideration social, ecological and environmental factors related to flood risk.
3. ***Floodplain Risk Management Plan***
   - Involves formal adoption by Council of a plan of management for the floodplain after consultation with the public.
4. ***Implementation of the Plan***
   - Involves construction of flood mitigation works to protect existing development, implementation of community awareness programs to heighten flood awareness, improved evacuation arrangements to minimise flood damages and the risk to life, and the introduction of development control polices at various levels within the planning framework to ensure new development is constructed in a manner compatible with the flood hazard.

The Dobroyd Canal Flood Study constitutes the first stage of the management process for the Dobroyd Canal Catchment.

EXECUTIVE SUMMARY

BACKGROUND

The Dobroyd Canal catchment is located in Sydney's Inner West region, approximately 10 km from the CBD. The catchment includes the suburbs of Ashbury, Ashfield, Burwood, Burwood Heights, Croydon, Croydon Park, Haberfield and Summer Hill. Approximately 62% of the catchment is within Ashfield Council, 28% is within Burwood Council and the remaining 10% is within the City of Canterbury and Canada Bay Councils.

The Dobroyd Canal catchment drains to Iron Cove on the Parramatta River via an open channel and a series of inlet pits and pipes. Sydney Water Corporation (SWC) owns the larger "trunk" drainage assets including the open channel and the smaller pit and pipe networks are owned by the various councils. Open channel sections extend from Iron Cove up to the intersection of Carshalton and Norton Street.

OBJECTIVES

The purpose of this Flood Study is to identify local overland flow as well as mainstream flow and define existing flood liability. This objective is achieved through the development of a suitable model that can also be used as the basis for a future Floodplain Risk Management Study and Plan for the study area, and to assist Ashfield Council and Burwood Council when undertaking flood-related planning decisions for existing and future developments.

The primary objectives of the study are to:

- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study;
- provide results for flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area;
- prepare maps of provisional hydraulic categories and provisional hazard categories;
- determine provisional residential flood planning levels and flood planning area;
- prepare preliminary emergency response classifications for communities; and
- assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.

FLOODING HISTORY

In examining the flooding history it must be noted that the drainage characteristics of this catchment have been significantly altered as a result of urbanisation in the area and as such older flood extents and depths for a given storm may not apply to present day conditions. There have been many instances of flooding in the past with November 1961, March 1975 and March 1983 having the greatest number of records.

HYDROLOGIC AND HYDRAULIC MODELLING PROCESS

The hydrologic modelling was undertaken using DRAINS and the hydraulic model was established using TUFLOW.

These models were verified by comparison to specific yield rates for similar areas in the Sydney Metropolitan region, similarity to the adjacent Hawthorne Canal Flood Study and comparison to previous studies undertaken in the Dobroyd Canal catchment.

The design rainfall events that were modelled were the 50%, 20%, 10%, 5% and 1% AEP design events and the Probable Maximum Precipitation (PMP). The temporal patterns for the design events were sourced from Australian Rainfall and Runoff (AR&R) (Pilgrim, 1987) and the Intensity-Frequency-Duration (IFD) data was obtained from the Bureau of Meteorology's (BoM) internet-based tool. The PMP estimates were derived according to the BoM guidelines, the *Generalised Short Duration Method* (BoM, 2003).

OUTCOMES

The design flood modelling indicates that significant flood depths may occur in a number of locations including in the vicinity of Heighway Avenue (Ashfield), in the vicinity of Paisley Road (Burwood), on Queen Street (Burwood) and at the junction of Brown Street and Bland Street (Ashfield). A detailed examination of existing flood behaviour at these "hotspots" has been undertaken. The study shows that the railway line restricts flows and exacerbates the flooding problem. The former two "hotspots" are a result of this behaviour and extends floodwaters to surrounding streets. Major road routes such as the Dobroyd Parade (that leads onto the City West Link), the Hume Highway and Frederick Street (adjacent to the junction with Parramatta Road) are shown to experience significant flooding during many AEP design events. Inundation of these roads is likely to result in severe traffic disruption that would extend outside the Dobroyd Canal catchment.

A preliminary investigation into properties subject to flood related development controls shows that approximately 2,200 lots (of the approximately 9,900 lots within the catchment and accounting for around 22%) are liable to be tagged under the criteria adopted for the study.

1. INTRODUCTION

1.1. Background

The study was initially commissioned by Sydney Water Corporation (SWC) with the intent of modelling trunk drainage assets owned by SWC only. Subsequently, Ashfield City Council (ACC) and Burwood City Council (BCC) were invited to participate in the flood study. Both Councils accepted the opportunity and the scope of work was expanded to include modelling of Council's drainage infrastructure and local overland flow.

1.2. General

The Dobroyd Canal catchment drains to Iron Cove on the Parramatta River. Dobroyd Canal is also known as "Iron Cove Creek". The catchment includes the suburbs of Ashbury, Ashfield, Burwood, Burwood Heights, Croydon, Croydon Park, Haberfield and Summer Hill (shown in Figure 1). Approximately 62% of the catchment is within Ashfield Council, 28% is within Burwood Council and the remaining 10% is within the City of Canterbury and Canada Bay Councils.

Drainage elements in the catchment include kerbs and gutters, pits and pipes, and a network of trunk drainage elements including culverts and open channels. Ownership of the assets is split between SWC and Council, with SWC owning the trunk elements. Amongst the drainage assets is a length of brickwork drain that was one of the first nine purpose-built stormwater drains to be constructed in Sydney in the 1890's. Open channel sections extend from Iron Cove up to the intersection of Carshalton and Norton Street.

1.3. Description of Study Area

The study area's catchment is fully urbanised, with approximately 79% of the catchment zoned for residential developments, 9% for special purpose, 6% for open space areas (parks and recreation areas), and the remaining 7% for business/commercial and industrial areas.

Elevations in the upper part of the catchment reach approximately 55 m AHD near Arthur Street and some reaches are relative steep with 2% to 4% grades. Overall catchment slope averages 0.8% along the main flow-path from headwaters to outlet. The main channel is tidal to upstream of Parramatta Road and channel width varies from ~ 2 m in upper areas to ~ 22 m at its confluence with Iron Cove.

1.4. Objectives

The primary objective of this Flood Study is to develop computational hydrologic and hydraulic models that define design flood behaviour for the 50%, 20%, 10%, 5% and 1% AEP design storms and the Probable Maximum Flood (PMF) in the Dobroyd Canal catchment and to:

- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study;
- provide results for flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area;
- prepare maps of provisional hydraulic categories and provisional hazard categories;
- determine provisional residential flood planning levels and flood planning area;
- prepare preliminary emergency response classifications for communities; and
- assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.

A glossary of flood related terms is provided in Appendix A.

1.5. Multiple Stakeholders

This Flood Study is a collaborative project with multiple stakeholders, namely Sydney Water Corporation (SWC), Ashfield City Council (ACC) and Burwood City Council (BCC). These three stakeholders were provided with this report and attached appendices, which are inclusive of the other stakeholders' areas of interest. However, the information provided to stakeholders specific to their area of interest, such as electronic spreadsheets of properties flood planning levels, were filtered to their relevant areas.

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2. AVAILABLE DATA

2.1. Overview

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On large river systems such as the Hawkesbury River there are generally stream height and historical records dating back to the early 1900's, or in some cases even further. However, in small urban catchments such as that of Dobroyd Canal there are no stream gauges or official historical records available. A picture of flooding must therefore be obtained from an examination of Council records (if any), previous reports, rainfall records and local knowledge.

2.2. Data Sources

Data utilised in the study has been sourced from a variety of organisations. The table below lists the type of data sourced and from where it has been extracted.

Table 1: Data Sources

Type of Data	Format Provided (Source)	Format Stored
Location, description and invert depths of pits, pipes and trunk drainage network	GIS (SWC)	DRAINS and TUFLOW models
Ground levels from ALS data	GIS (SWC)	GIS and TUFLOW model
Detailed survey data	GIS (SWC)	GIS and TUFLOW model
GIS information (cadastre, drainage pipe layout)	GIS (SWC)	GIS and TUFLOW model
Design rainfall	AR&R (1987)	DRAINS
Recorded flood data	Observation by Sydney Water	Report
Hydrology	ASCII text (Bureau of Meteorology, Sydney Water)	DRAINS

2.3. Topographic Data

Airborne Light Detection and Ranging (LiDAR) survey of the catchment and its immediate surroundings was provided for the study by SWC. It was indicated that the data were collected in 2007 by AAMHatch. These data typically have accuracy in the order of:

- +/- 0.15m (for 70% of points) in the vertical direction on clear, hard ground; and
- +/- 0.75m in the horizontal direction.

The accuracy of the ALS data can be influenced by the presence of open water or vegetation (tree or shrub canopy) at the time of the survey.

From this data, a Triangular Irregular Network (TIN) was generated by WMAwater. This TIN was sampled at a regular spacing of 1 m by 1 m to create a Digital Elevation Model (DEM), which formed the basis of the two-dimensional hydraulic modelling for the study (shown in

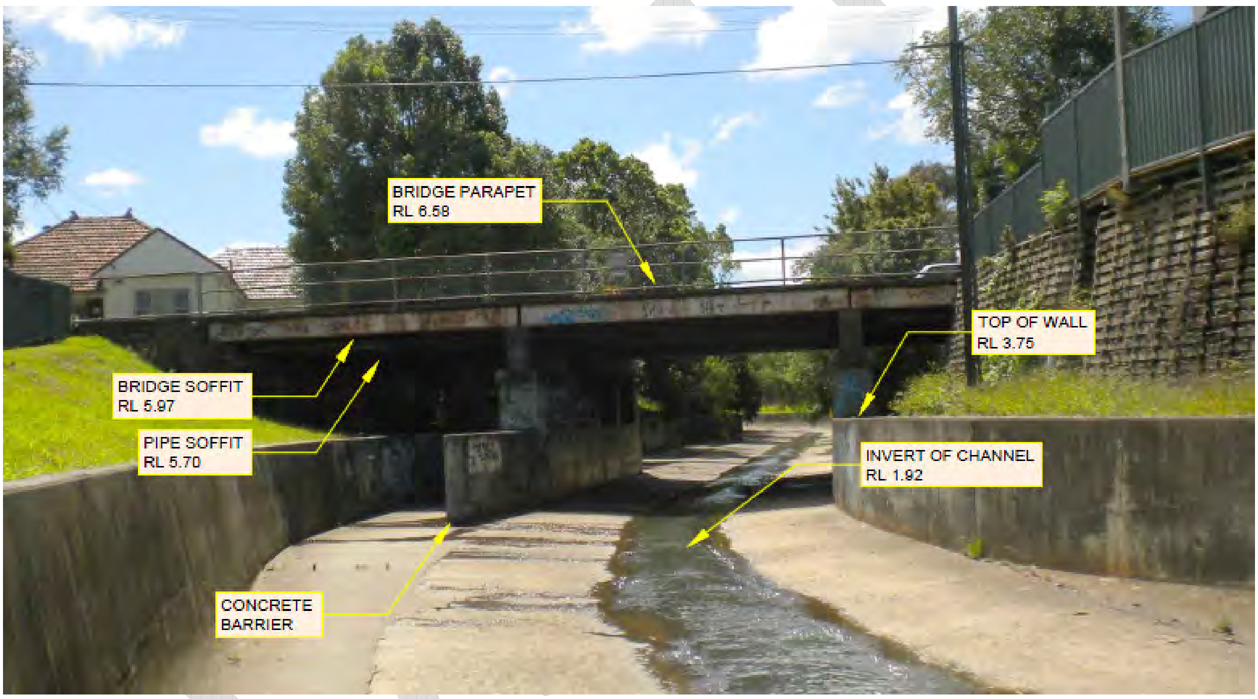
Figure 2).

2.4. Cross-section Data

Within the Dobroyd Canal catchment the main drainage network includes regular open channel sections. For these areas, the definition to the top of the concrete-lined channel was based on cross-sections provide by the SWC capacity assessment document (SWC, 1998).

In locations where bridges traverse the open channel, additional survey was performed by Chase Burke & Harvey (CBH) Surveyors. From this, definition of the cross-sectional area was obtained, particularly where the bridge soffit was not the same height as the top of the concrete-lined channel, as shown in Photo 1.

Photo 1: Church Street bridge traversing open channel (provided by CBH Surveyors)



2.5. Pit and Pipe Data

The SWC capacity assessment document (SWC, 1998) provided dimensions for SWC owned underground pipes, in addition to the open channel cross-sections discussed above. Appended to this SWC drainage network are underground pipes owned by the various Council jurisdictions within the Dobroyd Canal catchment.

Ashfield City Council and Burwood City Council provided pit location and pipe dimensions for the infrastructure within the respective council area, where feasible. However, some pipe dimensions within the Ashfield LGA were not available due to the inaccessibility of the location, notably those pipes located along the busy thorough-fare of Parramatta Road. Lack of this data will only impact results to a very small degree and impacts will be less significant for larger events such as the 1% AEP.

The pit and pipe details used have not been verified as part of the study, although details provided by the respective parties have been merged together and shown to demonstrate basic agreement.

2.6. Historical Flood Level Data

2.6.1. SWC Historic Flood Database

An historic flood database, provided by SWC, provided information of flooding within the catchment from 1951 to 1988 (SWC, 2011). A summary of available historical flood levels is provided in Table 2 and Figure 5.

Table 2: Summary of Historical Flood Levels

Flood Events	Total Records	Number of Observed Flood Levels
September 1951	1	1
February 1959	3	3
November 1961	52	51
November 1969	2	1
October 1972	2	0
February 1973	5	1
April 1973	2	1
March 1975	14	10
March 1977	5	1
February 1980	1	0
March 1983	10	8
August 1986	5	4
November 1988	1	0

2.6.2. Community Consultation

A community consultation process was undertaken in collaboration with Ashfield City Council and Burwood City Council. This included distribution of an information sheet and a questionnaire to gather information pertaining to the community's experience of flooding within the catchment. BCC undertook this distribution to properties affected by preliminary 1% AEP extents. As ACC undertook the Dobroyd Canal Flood Study in conjunction with the Hawthorne Canal Flood Study, this information was distributed to the entire LGA.

The response rate was on average 6% across the two catchments. The responses received from the Ashfield Council area dominated the response rate with a ratio of 44:1. Given that the Ashfield LGA accounts for a larger portion of the overall catchment as well as the downstream and more flood affected regions, it is reasonable that the Ashfield residents would be more aware of flooding.

It was found that a quarter of the respondents had lived in the area for less than 5 years. This relatively high proportion can be accounted for by the proportion of rental dwellings within the respective LGA's (the Australian Bureau of Statistics recorded 40% of the Ashfield population and 37% of the Burwood population as residing in rental dwellings). As such, many would not have been present during less recent flood events and so were unable to provide information on these.

Table 3: Summary of Reported Incidences of flooding

Flood Event	Total Responses	House Flooded (above floor)	Other Buildings Flooded (above floor)	Other Descriptions of Flooding
1982	1	0	1	Depth of 0.3m reported
1984	1	0	1	Depth of 0.3m reported
1985	1	0	1	Depth of 0.3m reported
1980s	1	0	0	
1994-1995	1	0	0	
1998	1	0	1	Depth of 0.25m reported
2008	1	0	1	
2010	2	0	0	
2011	4	1	0	Depth of 0.5m reported
March 2012	6	0	1	
April 2012	2	0	1	
May 2012	1	2	1	
No Date Given	38	3	11	

2.7. Historical Rainfall Data

2.7.1. Overview

Rainfall data is recorded either daily (24hr rainfall totals to 9:00 am) or continuously (pluviometers measuring rainfall in small increments – less than 1 mm). Daily rainfall data have been recorded for over 100 years at many locations within the Sydney basin. In general, pluviometers have only been installed since the 1970's. Together these records provide a picture of when and how often large rainfall events have occurred in the past.

However, care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past events due to a combination of factors including local site conditions, human error or limitations inherent to the type of recording instrument used. Examples of limitations that may impact the quality of data used for the present study are highlighted in the following:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall and records of large events are often lost or misrepresented.

- Daily read information is usually obtained at 9:00 am in the morning. Thus if a single storm is experienced both before and after 9:00 am, then the rainfall is “split” between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00 am reading.
- The duration of intense rainfall required to produce overland flooding in the study area is typically less than 6 hours (though this rainfall may be contained within a longer period of rainfall). This is termed the “critical storm duration”. For a larger catchment (such as the Parramatta River) the critical storm duration may be greater (say 9 hours). For the study area a short intense period of rainfall can produce flooding but if the rain stops quickly, the daily rainfall total may not necessarily reflect the magnitude of the intensity and subsequent flooding. Alternatively the rainfall may be relatively consistent throughout the day, producing a large total but only minor flooding.
- Rainfall records can frequently have “gaps” ranging from a few days to several weeks or even years.
- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs. time) of rainfall events and have the advantage that the data can generally be analysed electronically. This data has much fewer limitations than daily read data. Pluviometers can also fail during storm events due to the extreme weather conditions.

Rainfall events which cause overland flooding (as opposed to mainstream flooding) in the Dobroyd Canal catchment are usually localised and as such are only accurately represented by a nearby gauge. Gauges sited even only a kilometre away can show very different intensities and total rainfall depths.

2.7.2. Rainfall Stations

Table 4 presents a summary of the official rainfall gauges (sourced from the Bureau of Meteorology) located close to or within the catchment. This includes daily read stations, continuous pluviometer stations, operational stations and synoptic stations. These gauges are operated either by Sydney Water Corporation (SWC) or the Bureau of Meteorology (BOM).

Table 4: Rainfall stations within 6km of the centre of the Dobroyd Canal catchment.

Station Number	Station Name	Operating Authority	Distance from centre of the catchment (km)	Elevation (m AHD)	Date Opened	Date Closed	Type
66000	Ashfield Bowling Club	BOM	1.16	25	30/03/1896		Daily
566112	Ashfield (Ashfield Park Bowling Club)	SWC	1.20	20	2/12/1993	1/02/2001	Continuous
66017	Barnwell Park Golf Course	BOM	1.52	4	29/11/1929	28/11/2003	Daily
66150	Canterbury Heights	BOM	1.83	61	30/08/1906	29/12/1916	Daily
66165	Ashfield Prospect Rd	BOM	2.00	43	01/01/1894	1/01/1904	Daily
66194	Canterbury Racecourse AWS	BOM	2.48	3	2/10/1995		Synop
66091	Burwood 2 Public School	BOM	2.81		29/09/1911	29/12/1923	Daily
66113	Burwood 1	BOM	2.87		01/01/1884	1/01/1922	Daily
66026	Homebush	BOM	2.87		30/10/1924	29/12/1952	Daily
66034	Abbotsford (Blackwall Point Rd)	BOM	3.28	15	1/01/2004		Daily
66111	Croydon	BOM	3.34		30/01/1879	29/12/1921	Daily
66013	Concord Golf Club	BOM	3.91	15	1/01/1930		Daily
566020	Enfield (Composite Site)	SWC	3.93	10	14/04/1959		Continuous
566020	Enfield (Composite Site)	SWC	3.93	10	14/04/1959		Daily
566065	Lilyfield Bowling Club	SWC	3.94	20	21/12/1988		Continuous
66036	Marrickville Golf Club	BOM	4.24	6	29/04/1904	29/12/1970	Daily
66036	Marrickville Golf Club	BOM	4.24	6	6/04/2001		Operational
66071	Gladesville Champion Rd	BOM	4.52	10	27/02/1997	29/09/2000	Daily
566026	Marrickville Sps	SWC	4.92	5	1/05/1904		Continuous
566026	Marrickville Sps	SWC	4.92	5	1/05/1904		Daily
66108	Hunters Hill St Josephs College	BOM	5.06		1/01/1916	1/01/1923	Daily
66018	Earlwood Bowling Club	BOM	5.09	31.1	30/07/1914	29/12/1975	Daily
66064	Concord Walker Hospital	BOM	5.46	7.6	30/10/1894	29/12/1972	Daily
66175	Schnapper Island	BOM	5.46	5	28/02/1932	29/12/1939	Daily
66101	Fernbank	BOM	5.53		01/01/1889	1/01/1913	Daily
566078	South Cronulla	SWC	5.64	20	9/02/1990		Continuous
66070	Strathfield Golf Club	BOM	5.99	21	11/06/1997		Operational
66070	Strathfield Golf Club	BOM	5.99	21	1/01/1952		Daily

2.7.3. Analysis of Daily Read Data

An analysis of the records for the nearest daily rainfall stations, namely Ashfield Bowling Club (66000) and Barnwell Park Golf Course (66017), was undertaken. The Ashfield gauge is located within the Dobroyd Canal Catchment (adjacent to the eastern catchment border) and the Barnwell Park gauge is located to the north of the catchment, both of which are shown on Figure 6. Additional daily rainfall stations surrounding the catchment are shown within Figure 9 however these were of insufficient record length and had been decommissioned prior to 1952. The Ashfield Bowling Club station was established in March 1896 and is still active. The Barnwell Park Golf Course station was established in November 1929 and decommissioned in November 2003.

The results indicate that the 1986 and 1990 events were the largest daily rainfall events in recent times. The 1986 event is known to have caused flooding in the Dobroyd Canal Catchment based upon SWC records (see Section 2.6). Although there is no evidence to suggest that the 1990 storm event resulted in flooding within the catchment, based upon either SWC records or community consultation. However, this can be attributed to flooding within the catchment typically resulting from intense rainfall over sub-daily durations. High daily rainfall totals will not necessarily result in widespread flooding of the catchment, particularly if the rainfall is fairly evenly distributed throughout the day.

Table 5: Daily rainfalls greater than 150mm at Ashfield Bowling Club and Barnwell Park Golf Course

Ashfield Bowling Club (66000)		
Mar 1896 – to date		
Rank	**Date**	**Rainfall (mm)**
1	6/08/1986	245
2	9/03/1913	210
3	28/03/1942	206
4	3/02/1990	206
5	10/02/1956	194
6	17/06/1950	182
7	13/02/1911	175
8	27/11/1955	167
9	22/02/1954	160
10	26/03/1984	158
11	24/01/1955	157
12	11/03/1958	154
13	19/02/1959	152
14	10/01/1949	151

Barnwell Park Golf Course (66017)		
Nov 1929 – Nov 2003		
Rank	**Date**	**Rainfall (mm)**
1	30/03/1942	315
2	11/06/1991	253
3	6/08/1986	250
4	5/02/1990	245
5	11/02/1992	238
6	30/04/1988	228
7	10/02/1956	201
8	9/04/1973	197
9	16/02/1988	164
10	19/11/1961	163
11	10/01/1949	156
12	1/05/1955	156
13	27/11/1955	155
14	8/08/1998	152
15	15/06/1952	151

2.7.4. Analysis of Pluviometer Data

Continuous pluviometer records provide a more detailed description of temporal variations in rainfall. As such, the Ashfield Park Bowling Club, Enfield, Lilyfield Bowling Club and Marrickville Bowling Club pluviometer stations were analysed.

These pluviometer stations are all operated by SWC, with Marrickville and Enfield having the longest records. The Marrickville gauge was established in 1904 with sub-daily records available from December 1979. The Enfield gauge was established in 1959 with sub-daily records beginning in June 1983. The Ashfield gauge was established in December 1993 and the Lilyfield gauge was established in December 1988. However, the Ashfield gauge has since been decommissioned, as of February 2001.

Rainfall intensities at the gauges were assessed for the 1 hour and 2 hour storm burst durations and compared to frequencies derived from AR&R 1987 in Table 6 These durations were selected for analysis based upon the critical duration analysis (discussed in Section 7.2.), which found these storm durations to produce the highest flood levels within the Dobroyd Canal Catchment. From Table 6 it can be seen that a large magnitude rainfall event has not occurred within the operational period of any of these gauges.

Table 6: Approximate ARI Recorded at Pluviometer Stations

Station Name	Years of Record	Highest Approximate ARI (AR&R 1987)	
		1 hour storm burst	2 hour storm burst
Ashfield Park Bowling Club (566112)	7	1 – 2 year ARI	2 – 5 year ARI
Enfield (566020)	30	10 – 20 year ARI	2 – 5 year ARI
Lilyfield Bowling Club (566065)	24	10 – 20 year ARI	10 – 20 year ARI
Marrickville Bowling Club (566026)	34	10 – 20 year ARI	10 – 20 year ARI

The 10th April 1998 event produced the highest intensity 2 hour storm burst at the pluviometer stations analysed. A comparison of significant rainfall events and their respective ranking is shown in Table 7 (1 being the highest ranked storm burst at the pluviometer gauge).

The Ashfield pluviometer is the only gauge located within the catchment however it also has the shortest operational period. As a result, the 1998 storm event was the only significant event recorded at the gauge with corresponding reports of flooding. Despite the 1998 event recording the highest intensity 2 hour storm burst, there were insufficient records of resulting flooding to calibrate to this event with only a single indicative depth reported.

Table 7: Rainfall Intensities for the 10th April 1998

	Duration (minutes)		
	30	**60**	**120**
Ashfield Park Bowling Club (566112)			
Max Rainfall (mm)	26	33	57
Intensity (mm/hr)	52	33	28
Approximate ARI	1 – 2 year ARI	1 – 2 year ARI	2 – 5 year ARI
Rank comparative to gauge records for relevant duration	3	1	1
Enfield (566020)			
Max Rainfall (mm)	24	42	64
Intensity (mm/hr)	48	42	32
Approximate ARI	1 – 2 year ARI	2 – 5 year ARI	2 – 5 year ARI
Rank comparative to gauge records for relevant duration	20	4	1 (equal rank as 5/8/1986)
Lilyfield Bowling Club (566065)			
Max Rainfall (mm)	41	47	59
Intensity (mm/hr)	82	47	30
Approximate ARI	5 – 10 year ARI	2 – 5 year ARI	2 – 5 year ARI
Rank comparative to gauge records for relevant duration	3	2	2
Marrickville Bowling Club (566026)			
Max Rainfall (mm)	39	51	76
Intensity (mm/hr)	78	51	38
Approximate ARI	5 – 10 year ARI	5 – 10 year ARI	10 – 20 year ARI
Rank comparative to gauge records for relevant duration	3	4	2

2.8. Design Rainfall Data

The design rainfall intensity-frequency-duration (IFD) data was obtained from the Bureau of Meteorology's online design rainfall tool. The input parameters for these calculations are sourced from AR&R (1987).

Table 8: Rainfall IFD data at the centre of the Dobroyd Canal catchment

DURATION	Design Rainfall Intensity (mm/hr)						
	1 yr ARI	2 yr ARI	5 yr ARI	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI
5 minutes	94.5	121	154	173	198	230	255
6 minutes	88.4	113	144	162	186	216	239
10 minutes	72.4	93	119	134	154	180	199
20 minutes	53	68.3	88.4	100	115	135	151
30 minutes	43.1	55.7	72.5	82.3	95.2	112	125
1 hour	29.2	37.9	49.6	56.5	65.6	77.5	86.6
2 hours	19.1	24.8	32.5	37.1	43.1	51	57.1
3 hours	14.7	19.1	25.1	28.7	33.3	39.4	44.1
6 hours	9.44	12.2	16.1	18.3	21.2	25.1	28.1
12 hours	6.09	7.89	10.3	11.8	13.7	16.2	18.1
24 hours	3.97	5.15	6.74	7.69	8.92	10.5	11.8
48 hours	2.55	3.31	4.33	4.94	5.74	6.79	7.58
72 hours	1.91	2.47	3.24	3.69	4.28	5.06	5.65

The Probable Maximum Precipitation (PMP) estimates were derived according to Bureau of Meteorology guidelines, namely the *Generalised Short Duration Method* (BoM, 2003). The estimates obtained are summarised in Table 9.

Table 9: PMP Design Rainfall Intensity (mm/hr)

Duration	Design Rainfall Intensity (mm/hr)
30 minutes	470.4
1 hour	345.1
2 hours	219.8
3 hours	164.5
6 hours	102.6

2.9. Previous Studies

2.9.1. Dobroyd SWC 53 Capacity Assessment (SWC, 1998)

This report was prepared by Sydney Water and investigated the current performance of Sydney Water Corporation's Dobroyd SWC 53 and gives an estimate of the impact of simulated urban consolidation on that performance.

The drainage data used for the study included the Sydney Water trunk drainage system only and the analysis was undertaken using a spread sheet analysis based on:

- Rational Method for inflows;
- Approximate capacities of pipes based on grade and area;
- Approximation of channel capacities using Manning's "n" formula; and the
- Hydraulic Grade Line method.

Local catchment pit and pipe details were unavailable and therefore not modelled. The report notes that this results in an overestimation of flows and ponding depths in the smaller design events modelled.

The hydraulic capacity in the main stormwater channel discharging into Iron Cove was found to be 183 m^3/s with a 5 year ARI peak flow of 105 m^3/s. The capacity of the main channel was found to be in the range of 25 – 50 year ARI with 51% of the current trunk drainage system able to contain flows from a 5 year ARI storm event. Note that given suitably conservative tail water levels it is likely that all of these estimates would be revised downwards.

2.9.2. Hydraulic Study and On-Site Detention Modelling for Burwood Council Catchments (Robinson GRC Consulting, 2002)

Robinson GRC Consulting prepared this report on behalf of Burwood City Council from 2000 to 2002. The catchments within the bounds of Burwood City Council's jurisdiction, and hence included in the study, included the Dobroyd Canal catchment, Cooks River catchment, Powells Creek catchment, Exile Bay catchment, St Lukes catchment and William Street catchment. The primary objective of this study was to develop a computer model to assess the 1% AEP event and from this determine insufficiencies in the drainage system, as well as identify overland flow paths that occurred to an unfavourable frequency. Once these "hotspots" were identified, possible mitigation measures were proposed with further modelling undertaken to assess these. Additional to this, the report modelled the 50%, 5% and 1% AEP event with the purpose to propose Permissible Site Discharge (PSD) and storage volumes for potential On-Site Detention (OSD) systems.

The data collected for the purpose of this study included:

- survey of pit levels;
- survey of levels of the kerb, gutter, road centrelines and driveways in locations that were deemed important;
- survey of property levels that may be subject to flooding;
- three laser-doppler flow gauges recorded over the period of the 8th May 2000 to the 31st August 2000. One was located in the Cooks River catchment and two were located in the Dobroyd Canal catchment; and
- two tipping-bucket rain gauges recorded over the period of the 3rd May 2000 to the 15th September 2000. These were located at the Woodstock Park Community Centre (on Church Street, Burwood) and in Council's Depot (near Tangarra Road, Croydon Park).

However, during the period in which the flow gauges and rain gauges were in operation, the rainfall experienced was not of a significant magnitude. The largest rainfall recorded over the period of record was 13 mm over a 24 hour period.

The hydraulic model established for this report was DRAINS. This model was calibrated to the flow gauge and rain gauge records that were collected for the purpose of this study. However, as these events were not of a significant magnitude, the calibration was determined to be inconclusive.

The hotspots identified in this report were:

(Croydon Branch)

- Appian Way;
- Wyatt Avenue and Weldon Street;
- Tahlee Street;
- Devonshire Street;
- Murray Street;
- Brady Street;
- Fitzroy Street;
- Rosa Street;
- Paisley Road;
- Church Street;
- Elizabeth Street;
- Shaftesbury Road and Paisley Road
- Albert Crescent (West);
- Lucas Road;
- Albert Crescent (East);
- Webb Street;
- Irrara Street;
- Young Street (South);
- Young Street (North);
- Wright Street;
- Robinson Street;
- Queen Street;

(Main Dobroyd Branch (South))

- Culdees Road;
- Ardgryffe Street;
- Waratah Street;
- Boyle Street;
- Beaufort Street;
- Seymour Street;
- Beresford Avenue;
- Brighton Street (South);
- Croydon Avenue South;
- Greenhills Street;

(Badminton Street Branch)

- Claremont Road;
- Badminton Road (North);
- Badminton Road (South);
- Austin Avenue;
- Gala Avenue;
- Brighton Street (North);
- Croydon Avenue (North);
- Greenhills Street (North).

The general assessment concerning hotspots in the Dobroyd Canal catchment was that the drainage network followed previously existing creek lines that have since been built over. With the urbanisation of the catchment a road network was established that appears to disregard the topography such as creeks.

The report found that the potential for remedial work was limited and “the provision of overland flow paths through properties … appears to be the most effective type of remedy” (Robinson GRC Consulting, 2002).

2.9.3. Stormwater Drainage Infrastructure Review for Burwood Council (Brown Consulting (NSW), 2004)

Brown Consulting carried out this study on behalf of Burwood Council in 2004. The study investigated overland flow that resulted from the drainage system’s inability to convey runoff under current conditions, the impact of increased development, the effectiveness of OSD, and the re-assessment of the proposed remedial works identified by Robinson GRC Consulting. From this, recommendations were made as to what provisions Burwood Council may have to establish developer contributions under Section 94 due to increased development within the Town Centre area. The Town Centre area was identified as being the area surrounding Burwood Train Station, which includes the Dobroyd Canal, St. Lukes and Powells Creek catchments.

This study used the DRAINS model that had been established for the catchments by Robinson GRC Consulting (although it was noted that in 2003, Robinson GRC Consulting merged with WP Brown and Partners, now Brown Consulting (NSW)). However the version of DRAINS utilised was updated to the latest version available at the time the study was being undertaken.

Increased development was assessed as an increase in modelled impervious percentage. In the Town Centre area the impervious percentage was increased from 70% impervious in the current conditions to 90% impervious. Elsewhere in the catchments the impervious area was increased by 6%. This scenario was modelled for all the catchments identified in the Robinson GRC Consulting report.

OSD was modelled for three different scenarios. The first scenario applied OSD to 30% of the Town Centre area without applying OSD outside this area. The second scenario applied OSD to 30% of the Town Centre area and 10% of the area outside this area. The third scenario applied OSD to 50% of the Town Centre area and 10% of the area outside this area.

2.9.4. Flood Study for Proposed New Residence: No. 7 Alexandra Street, Ashfield NSW (ACOR Consultants, 2007)

This report was undertaken by ACOR Consultants on behalf of the property owner. The flood study was prompted by a request from Ashfield Council upon receipt of a Development Application (DA) proposal for the site.

The hydrologic model used for the study was DRAINS. The flow rates produced by DRAINS were applied to the HEC-RAS hydraulic model for the 100 year ARI and the 20 year ARI. The hydraulic model extended from the Ramsey Street Bridge up to the John Street Bridge and Croydon Road.

The peak flood rates produced by DRAINS are summarised in Table 10 and compared to the current study in Section 6.4.4.

Table 10: ACOR Consultants – DRAINS peak flow rates

Sub Catchment	20 year ARI		100 year ARI	
	Q_{20} (m^3/s) from DRAINS for catchment	Q_{20} (m^3/s) from Cumulative in Channel	Q_{100} (m^3/s) from DRAINS for catchment	Q_{100} (m^3/s) from Cumulative in Channel
Arthur St – 1	33.7	33.7	55.4	55.4
Thomas St – 1	27.9	61.5	45.9	101
Elizabeth St – 3	12.3	73.7	20.2	121
John St – 4	9.5	82.9	15.6	136
Burwood – 5	22.2	104	36.6	172
Alexandra St – 6	4.63	107	7.09	176
Parramatta Rd – 7	27.5	133	45.1	220
Henley Marine Dr – 8	15.5	142	23.6	235
Iron Cove – 9	28.7	170	47.4	279

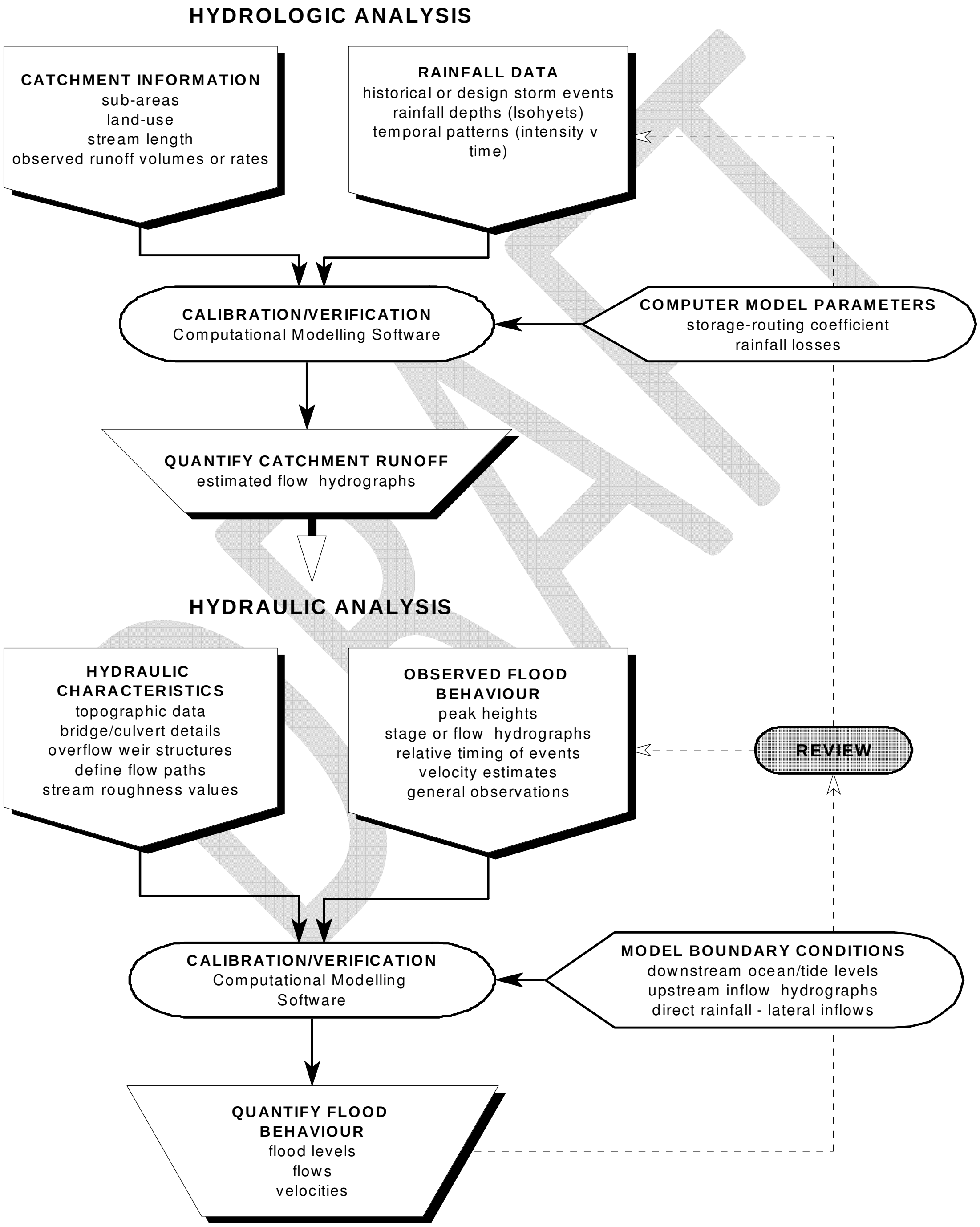
The hydraulic model determined the peak flood level in the open channel adjacent to No. 7 Alexandra Street to be 6.36 m AHD in the 100 year ARI event.

The report concluded that the minimum floor level at No. 7 Alexandra Street be 6.87 m AHD (or above), thereby complying with the council's specification that new floor levels be 0.5m above the 100 year ARI peak flood level.

3. STUDY METHODOLOGY

A diagrammatic representation of the Flood Study process is shown in Diagram 1. The urbanised nature of the study area with its mix of pervious and impervious surfaces, and existing piped and overland flow drainage systems, has created a complex hydrologic and hydraulic flow regime.

Diagram 1: Flood Study Process



The estimation of flood behaviour in a catchment is undertaken as a two-stage process, consisting of:

1. hydrologic modelling to convert rainfall estimates to overland flow and stream runoff; and
2. hydraulic modelling to estimate overland flow distributions, flood levels and velocities.

As such, the hydrologic model, DRAINS, was built and used to create flow boundary conditions for input into a two-dimensional unsteady flow hydraulic model, i.e. TUFLOW.

Good historical flood data facilitates calibration of the models and increases confidence in the estimates. The calibration process involves modifying the initial model parameter values to produce modelled results that concur with observed data. Validation is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Recorded rainfall and stream-flow data are required for calibration of the hydrologic model, while historic records of flood levels, velocities and inundation extents can be used for the calibration of hydraulic model parameters. In the absence of such data, model verification is the only option and a detailed sensitivity analysis of the different model input parameters constitutes current best practice.

There are no stream-flow records in the catchment, so the use of a flood frequency approach for the estimation of design floods or independent calibration of the hydrologic model was not possible.

Flood estimation in urban catchments generally presents challenges for the integration of the hydrologic and hydraulic modelling approaches, which have been treated as two distinct tasks as part of traditional flood modelling methodologies. As the main output of a hydrologic model is the flow at the outlet of a catchment or sub-catchment, it is generally used to estimate inflows from catchment areas upstream of an area of interest, and the approach does not lend itself well to estimating flood inundation in mid- to upper-catchment areas, as required for this study. The aim of identifying the full extent of flood inundation can therefore be complicated by the separation of hydrologic and hydraulic processes into separate models, and these processes are increasingly being combined in a single modelling approach.

In view of the above, the broad approach adopted for this study was to use a widely utilised and well-regarded hydrologic model to conceptually model the rainfall concentration phase (including runoff from roof drainage systems, gutters, etc.). The hydrologic model used design rainfall patterns specified in AR&R (1987) and the runoff hydrographs were then used in a hydraulic model to estimate flood depths, velocities and hazard in the study area.

The sub-catchments in the hydrologic model were kept small (on average approximately 1.5 ha) such that the overland flow behaviour for the study was generally defined by the hydraulic model. This joint modelling approach was verified against previous studies and alternative methods.

3.1. Hydrologic Model

DRAINS is a hydrologic/hydraulic model that can simulate the full storm hydrograph and is capable of describing the flow behaviour of a catchment and pipe system for real storm events, as well as statistically based design storms. It is designed for analysing urban or partly urban catchments where artificial drainage elements have been installed.

The DRAINS model is broadly characterised by the following features:

- the hydrological component is based on the theory applied in the ILSAX model which has seen wide usage and acceptance in Australia;
- its application of the hydraulic grade line method for hydraulic analysis throughout the drainage system; and
- the graphical display of network connections and results.

DRAINS generates a full hydrograph of surface flows arriving at each pit and routes these through the pipe network or overland, combining them where appropriate. Consequently, it avoids the "partial area" problems of the Rational Method and additionally it can model detention basins (unsteady flow rather than steady state).

Runoff hydrographs for each sub-catchment area are calculated using the time area method and the conveyance of flow through the drainage system is then modelled using the Hydraulic Grade Line method. Application of the Hydraulic Grade Line method is recommended for the design of pipe systems in AR&R (1987). The method allows pipes to operate under pressure or to "surcharge", meaning that water rises within pits, but does not necessarily overflow out onto streets. This provides improved prediction of hydraulic behaviour, consistency in design, and greater freedom in selecting pipe slopes. It requires more complicated design procedures, since pipe capacity is influenced by upstream and downstream conditions.

DRAINS cannot however adequately account for an elevated downstream tailwater level which would drown out the lower reaches of a drainage system (it can if the upstream pit is above the tailwater level but not if it is below). For this reason flooding within reaches affected by elevated water levels is more accurately assessed using the TUFLOW model.

It should be noted that DRAINS is not a true unsteady flow model and therefore does not account for the attenuation effects of routing through temporary floodplain storage (down streets or in yards). As such the use of DRAINS within the study is limited to some minor upstream routing and development of hydrological inputs into the downstream TUFLOW model.

3.2. Hydraulic Model

The availability of high quality LIDAR/ALS data means that the study area is suitable for two-dimensional (2D) hydraulic modelling. Various 2D software packages are available and the TUFLOW package was adopted as it is widely used in Australia and WMAwater have extensive experience with the model.

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions. The TUFLOW software is produced by BMT WBM and has been widely used for a range of similar projects. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short duration events and a combination of supercritical and subcritical flow behaviour

The Dobroyd Canal study area consists of a wide range of developments, with residential, commercial and open space areas. For this catchment, the study objectives require accurate representation of the overland flow system including kerbs and gutters and defined drainage controls.

For the hydraulic analysis of complex overland flow paths (such as the present study area where overland flow occurs between and around buildings), an integrated 1D/2D model such as TUFLOW provides several key advantages when compared to a 1D only model. For example, a 2D approach can:

- provide localised detail of any topographic and/or structural features that may influence flood behaviour,
- better facilitate the identification of the potential overland flow paths and flood problem areas,
- dynamically model the interaction between hydraulic structures such as culverts and complex overland flowpaths; and
- inherently represent the available floodplain storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into Council's planning activities. The model developed for the present study provides a flexible modelling platform to properly assess the impacts of any overland flow management strategies within the floodplain (as part of the ongoing floodplain management process.

In TUFLOW the ground topography is represented as a uniformly-spaced grid with a ground elevation and a Manning's "n" roughness value assigned to each grid cell. The grid cell size is determined as a balance between the model result definition required and the computer run time (which is largely determined by the total number of grid cells.

3.3. Design Flood Modelling

Following validation of the hydrologic model against previous studies with similar catchment characteristics and alternative calculation methods, the following steps were undertaken:

- some calibration was undertaken after the community consultation;
- design outflows for localised sub-catchments were obtained from the DRAINS hydrologic model and applied as inflows to the TUFLOW model;
- sensitivity analysis was undertaken to assess the relative effect of changing various TUFLOW modelling parameters.

4. HYDROLOGIC MODEL

4.1. Sub-catchment Definition

The total catchment represented by the current DRAINS model is 8.3 km^2. This area has been represented by a total of 551 sub-catchments giving an average sub-catchment size of approximately 0.015 km^2. The sub-catchment delineation ensures that where hydraulic controls exist that these are accounted for and able to be appropriately incorporated into hydraulic routing. The sub-catchment layout is shown in Figure 7.

4.2. Impervious Surface Area

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occur significantly faster than from vegetated surfaces. This results in a faster concentration of flow within the downstream area of the catchment, and increased peak flow in some situations. It is therefore necessary to estimate the proportion of the catchment area that is covered by such surfaces.

DRAINS categorises these surface areas as either:

- paved areas (impervious areas directly connected to the drainage system),
- supplementary areas (impervious areas not directly connected to the drainage system, instead connected to the drainage system via the pervious areas), and
- grassed areas (pervious areas).

Within the Dobroyd Canal Catchment, a uniform 5% was adopted as a supplementary area across the catchment. The remaining 95% was attributed to impervious (or paved areas) and pervious surface areas, as estimated for each individual sub-catchment. This was undertaken by determining the proportion of the sub-catchment area allocated to a land-use category and the estimated impervious percentage of each land-use category, summarised in Table 11.

Table 11: Impervious Percentage per Land-use

Land-use Category	**Impervious Percentage**
Residential Property	50% Impervious
Commercial Property	95% Impervious
Vacant Land	0% Impervious
Vegetation (such as public parks)	0% Impervious
Roadway	100% Impervious

The proportion of each land-use category within a sub-catchment was determined based upon the hydraulic model roughness schematisation, shown in Figure 9. Although, further categorisation was undertaken on the property areas to specify residential, commercial or vacant land for each property lot based upon the cadastre provided by SWC.

The impervious percentages attributed to each land-use category were estimated based on aerial observation of a representative area, examples of which are shown in Photo 2 and Photo 3.

Photo 2: Impervious area (shaded in red) within a representative residential area (outlined in blue)

Photo 3: Impervious area (shaded in red) within a representative commercial area (outlined in blue)

4.3. Rainfall Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in AR&R (1987). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed areas are comprised of an initial loss and a continuing loss. The continuing loss is calculated from an infiltration equation curve incorporated into the model and is based on the selected representative soil type and antecedent moisture condition. The catchment soil was assumed to have a slow infiltration rate and the antecedent moisture condition was considered to be rather wet.

The adopted parameters are summarised in Table 12. These are consistent with the parameters adopted in previous studies within the Dobroyd Canal catchment undertaken by Robinson GRC Consulting (2002) and ACOR Consultants (2007) and the adjacent catchment of Hawthorne Canal (WMAwater, 2013).

Table 12: Adopted DRAINS hydrologic model parameters

RAINFALL LOSSES	
Paved Area Depression Storage (Initial Loss)	1.0 mm
Grassed Area Depression Storage (Initial Loss)	5.0 mm
SOIL TYPE	**3**
Slow infiltration rates. This parameter, in conjunction with the AMC, determines the continuing loss	
ANTECEDENT MOISTURE CONDITONS (AMC)	**3**
Description	Rather wet
Total Rainfall in 5 Days Preceding the Storm	12.5 to 25 mm

5. HYDRAULIC MODEL

5.1. Digital Elevation Model

Given the objectives and requirements of the study and the availability of ALS data, a 2D overland flow hydraulic model is the most suitable model to effectively assess flood behaviour.

The model uses a regularly spaced computational grid, with a cell size of 3 m by 3 m. This resolution was adopted as it provides an appropriate balance between providing sufficient detail for roads and overland flow paths, while still resulting in workable computational run-times. The model grid was established by sampling from a 1 m by 1 m DEM. This DEM was generated from a triangulation of filtered ground points from the LiDAR dataset, discussed in Section 2.3. This DEM is shown in Figure 2.

The TUFLOW hydraulic model includes the Dobroyd Canal catchment drainage down to Iron Cove. The 2D model extends from WH Wagener Oval in Ashbury to the south, down to Iron Cove. The total area included in the 2D model is 8.3 km^2. The extents of the TUFLOW model are shown in Figure 1.

5.2. Boundary Locations

5.2.1. Inflows

For local sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the DRAINS model (see Section 4). These were applied to the downstream end of the sub-catchments within the 2D domain of the hydraulic model. The inflow locations typically corresponded with inlet pits on the roadway as this is where most rainfall is directed.

5.2.2. Downstream Boundary

The downstream boundary was located at the confluence of the trunk drainage system with Iron Cove, as shown in Figure 8. At this location, the 1D and the 2D domain are operating and the boundary was applied to both domains within the hydraulic model.

5.2.3. Outflows into Adjacent Catchments

In events of a relatively small magnitude, runoff produced within the Dobroyd Canal Catchment discharge into Iron Cove. However, in larger events some flood waters are restricted in their capacity to flow downstream and instead drain out of the catchment they originated in.

The hydraulic model was schematised so as not to restrict flow from crossing the watershed boundary. As such, the hydraulic model extent was expanded to include small portions of the adjoining catchments. Where the watershed boundary was crossed, the flow was removed from the hydraulic model with localised hydraulic boundaries.

The two locations where the watershed boundary was crossed were:

- within the Burwood Town Centre; and
- within the vicinity of Beaufort Street, Burwood.

Flow from the Burwood Town Centre that was impeded from crossing Shaftsbury Road and the railway embankment accumulated in these areas. When the height of this accumulated flood water exceeded the watershed boundary height, flow crossed into the St. Lukes Catchment. Within this adjacent catchment, the topography conveyed flow west along Railway Parade and then along Burwood Road underneath the railway embankment, where a localised hydraulic boundary was schematised.

Flow through properties on Boyle Street, Beaufort Street and Seymour Street occurred parallel to the watershed boundary. The height of the boundary above the ground level being traversed by the flow was not significant. As such, a portion of the flow has the potential to cross the watershed boundary into the Cooks River Catchment, located south of the Dobroyd Canal Catchment. Within this adjoining catchment, the flow is conveyed perpendicular to the flow within the study area catchment from which it originated. This flow travelled along the aforementioned roadways (and the properties adjacent to) before crossing Georges River Road, where a localised hydraulic boundary was schematised.

The discharge into adjoining catchments was quantified, the summary of which is provided in Table 13. Comparative to the flow discharged into Iron Cove, the amount crossing the watershed boundary into adjacent catchments was relatively insignificant.

Table 13: Discharge into adjacent catchments

Location	5% AEP	2% AEP	1% AEP	PMF
Burwood Town Centre				
Volume (m^3)	0	3.8	259.1	5,581
Peak Flow (m^3/s)	0	0.01	0.20	2.49
Beaufort Street, Burwood				
Volume (m^3)	11.0	83.6	290.0	17,974
Peak Flow (m^3/s)	0.06	0.15	0.48	9.56

5.3. Roughness Co-efficient

The hydraulic efficiency of the flow paths within the TUFLOW model is represented in part by the hydraulic roughness or friction factor formulated as Manning's "n" values. This factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features which may affect the hydraulic performance of the particular flow path.

The spatial variation in Manning's "n" values is shown on Figure 9. The Manning's "n" values adopted for these areas, including flowpaths (overland, pipe and in-channel), are shown in Table 14. These values have been adopted based on site inspection and past experience in similar floodplain environments. The values are consistent with typical values in the literature (Chow, 1959 and Henderson, 1966).

Table 14: Manning's "n" values adopted in TUFLOW

Surface	Manning's "n" Adopted
Pipes	0.015
Roads and Footpaths	0.02
Light Vegetation	0.03
General Overland Areas	0.04
Properties	0.05

5.4. Hydraulic Structures

5.4.1. Buildings

Buildings and other significant features likely to act as flow obstructions were incorporated into the model network based on building footprints, defined using aerial photography. These types of features were modelled as impermeable obstructions to the floodwaters.

5.4.2. Fencing and Obstructions

Smaller localised obstructions within or bordering private property, such as fences, were not explicitly represented within the hydraulic model, due to the relative impermanence of these features. The cumulative effects of these features on flow behaviour were assumed to be addressed partially by the adopted roughness parameters.

5.4.3. Bridges

Key hydraulic structures were included in the hydraulic model, as shown in Figure 3. Culverts and bridges were modelled as 1D features within the 1D channels, with the purpose of maintaining continuity within the model. Roadways underneath the railway embankment that contribute to the conveyance of flow were modelled in the 2D domain using a TUFLOW feature specifically designed for this purpose, whereby the energy losses and blockage caused by any piers and the deck can be applied directly to the grid cells.

The modelling parameter values for the culverts and bridges were based on the geometrical properties of the structures, which were obtained from detailed survey, photographs taken during site inspections, and previous experience modelling similar structures.

5.4.4. Sub-surface Drainage Network

Figure 8 shows the location and extent of drainage lines within the study catchment that have been included in the TUFLOW model. The drainage system defined in the model comprises:

- 1043 pipes;
- 214 open channel segments; and

- 1243 pits and nodes.

5.5. Blockage Assumptions

Blockage of hydraulic structures can occur with the transportation of a number of materials by flood waters. This includes vegetation, garbage bins, building materials and cars, the latter of which has been seen post-flood in Newcastle. However, the disparity in materials that may be mobilised within a catchment can vary greatly.

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the average exceedance probability (AEP) of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration (Barthelmess and Rigby 2009, cited in Engineers Australia 2013).

The potential effects of blockage include:

- decreased conveyance of flood waters through the blocked hydraulic structure or drainage system;
- variation in peak flood levels;
- variation in flood extent due to flows diverting into adjoining flow paths; and
- overtopping of hydraulic structures.

Existing practices and guidance on the application of blockage can be found in:

- the Queensland Urban Drainage Manual (Department of Natural Resources and Water, 2008);
- AR&R Revision Project 11 Blockage of Hydraulic Structures (Engineers Australia, 2013); and
- the policies of various local authorities and infrastructure agencies.

The guidelines proposed by the AR&R Revision Project 11 utilise generic blockage factors presented in Table 15.

Table 15: Suggested 'Design' and 'Severe' Blockage Conditions for Various Structures (Engineers Australia, 2013)

Type of structure		Blockage conditions	
		Design blockage	Severe blockage
Sag Kerb Inlet	Kerb slot inlet only Grated inlet only Combined inlets	0/20% 0/50% [1]	100% (all cases)
On-grade kerb inlets	Kerb slot inlet only Grated inlet only (longitudinal bars) Grated inlet only (transverse bars) Combined inlets	0/20% 0/40% 0/50% [2]	100% (all cases)
Field (drop) inlets	Flush mounted Elevated (pill box) horizontal grate Dome screen	0/80% 0/50% 0/50%	100% (all cases)
Pipe inlets and waterway culverts	*Inlet height < 3m and width < 5m* Inlet Chamber	0/20% [3]	100% [4]
	Inlet height > 3m and width > 5m Inlet Chamber	0/10% [3]	25% [3]
	Culverts and pipe inlets with effective debris control features	As above	As above
	Screened pipe and culvert inlets	0/50%	100%
Bridges	Clear opening height < 3 m Clear opening height > 3 m Central piers	[5] 0% [7]	100% [6] [7]
Solid handrails and traffic barriers associated with bridges and culverts		100%	100%
Fencing across overland flow paths		[8]	100%
Screened stormwater outlets		100%	100%

Current modelling has been undertaken assuming no blockage of pipes, culverts and bridges greater than 450 mm in diameter. Pipes less than 450 mm in diameter were conservatively assumed to be completely blocked.

Various scenarios have been investigated to assess the catchment's sensitivity to 20% and 50% blockage and the results of this are discussed in Section 8.3.2. These scenarios included blockage of all pipes, blockage of all bridges and culverts over the open channel, and blockage of the drainage infrastructure (such as pipes and culverts, but excluding roadways that convey flow) underneath the railway embankment. Blockage was assumed to occur laterally across the cross-section. This is particularly relevant for structures that contain piers around which debris may become entangled. Alternative applications of blockage include reducing the cross-sectional area upwards from the invert. This is perhaps more relevant to vegetated open channels that are subject to sedimentation rather than the concrete lined open channels present in the Dobroyd Canal Catchment.

6. MODEL CALIBRATION AND VERIFICATION

6.1. Introduction

Prior to use for defining design flood behaviour it is important that the performance of the overall modelling system be substantiated. Calibration involves modifying the initial model parameter values to produce modelled results that concur with observed data. Validation is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Best practice is that the modelling system should be calibrated to one historical event and validated using multiple historical events. To facilitate this there needs to be adequate historical flood observations and sufficient pluviometer rainfall data.

Typically in urban areas such information is lacking. Issues which may prevent a thorough calibration of hydrologic and hydraulic models are:

- there is only a limited amount of historical flood information available for the study area. For example, in Sydney (east of Parramatta) there are only two water level recorders in urban catchments similar to that of the study area; and
- rainfall records for past floods are limited and there is a lack of temporal information describing historical rainfall patterns within the catchment.

In the event that a calibration and validation of the models is not possible or limited in scope, it is best practice to undertake a verification of the models and a detailed sensitivity analysis.

6.2. Correlating Data

The correlation between the historic flood level data (discussed in Section 2.6) and available pluviometer data (discussed in Section 2.7.4) is summarised in Table 16.

The approximate ARI for these storm events have been estimated based on the daily read rainfall station located at Ashfield Bowling Club (discussed in Section 2.7.4) and the IFD data for the centre of the Dobroyd Canal catchment (discussed in Section 2.8). However, this estimation considers the daily rainfall to have occurred at a constant intensity over the 24 hour period of record. As such it is possible that the rainfall intensity was greater over a shorter duration, and hence the approximate ARI's are likely to be an under estimation. Sufficiently located pluviometer stations provide a closer approximation of the storm intensity and ARI event. However, as can be seen in Table 16, many of the storm events occurred prior to the establishment of pluviometer stations.

For the storm events in which a pluviometer station was present, the number of corresponding recorded flood levels were found to be of an insufficient quantity or spatial distribution. The pluviometer stations were located outside the catchment and the ARI estimated for the rainfall recorded was typical of a small magnitude (shown in Table 19). Engineers Australia (2012) advises that calibration events "span the magnitude range of the intended design events with a preference for the more important design floods (eg. 1% AEP event)"

For this reason, a verification of the models was undertaken instead of calibrating or validating the models.

Table 16: Data available for various storm events

Storm Events	Total Records	Indicative Depths Available	Approximate ARI	Pluviometer Stations in Operation
September 1951	1	1	< 1 year ARI	N/A
February 1959	3	1	2 – 5 year ARI	N/A
November 1961	52	44	2 – 5 year ARI	N/A
November 1969	2	1	1 – 2 year ARI	N/A
October 1972	2	0	< 1 year ARI	N/A
February 1973	5	1	< 1 year ARI	N/A
April 1973	2	1	< 1 year ARI	N/A
March 1975	14	12	1 – 2 year ARI	N/A
March 1977	5	0	1 – 2 year ARI	N/A
February 1980	1	0	< 1 year ARI	566026 – Marrickville Bowling Club
March 1983	10	7	1 – 2 year ARI	566026 – Marrickville Bowling Club
August 1986	5	3	20 – 50 year ARI	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club
November 1988	1	0	< 1 year ARI	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club
1998	1	1	N/A *	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club 566065 - Lilyfield Bowling Club 566112 – Ashfield Bowling Club
2008	1	0	N/A *	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club 566065 - Lilyfield Bowling Club
2010	2	0	N/A *	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club 566065 - Lilyfield Bowling Club
2011	4	1	N/A *	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club 566065 - Lilyfield Bowling Club
8 March 2012	6	3	1 – 2 year ARI	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club 566065 - Lilyfield Bowling Club
April 2012	2	0	N/A *	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club 566065 - Lilyfield Bowling Club
May 2012	1	0	N/A *	566020 - Enfield (Composite Site) 566026 – Marrickville Bowling Club 566065 - Lilyfield Bowling Club

* Incomplete daily rainfall records during these periods

6.3. Hydrologic Model Verification

A comparison against previous studies of nearby catchments can be undertaken to verify the model. For this study, the hydrologic model from the Rose Bay catchment was compared to Dobroyd Canal catchment. DRAINS was the hydrologic model used in Rose Bay and the catchment is located approximately 12 km from the Dobroyd Canal Catchment.

Comparison of specific yield was used for the model verification and is calculated by dividing the peak discharge by the area of the upstream catchment. This calculation removes the effects that variations in sub-catchment size have on peak discharge. Also, to remove the effects that differences in catchment delineation can have on peak discharge, the specific yield was calculated for multiple, randomly-selected, sub-catchments. The results are shown in Table 17.

Table 17: Comparable Sub-catchment Hydrologic Model Check

Sub-catchment	Dobroyd Canal			Rose Bay		
	Area (ha)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)	Area (ha)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)
1	1.7	1.0	0.6	1	0.6	0.7
2	10.1	5.3	0.5	0.4	0.2	0.6
3	20.7	10.3	0.5	0.6	0.4	0.6

The specific yields from the two different DRAINS models were found to be comparable.

6.4. Hydrologic and Hydraulic Model Verification

Verification of the hydraulic model was undertaken by:

- comparing the flood levels collated from all the observed historic storm events to modelled design flood levels;
- comparing the modelled design results against the results in the 1998 report by SWC;
- comparing the modelled design results against the results in the 2004 report by Brown Consulting (NSW); and
- comparing the modelled design results against the results in the 2007 report by ACOR Consultants.

6.4.1. Comparison with observed historic flood levels

The number of properties for which flooding is reported to have occurred, including those with no date or no depth specified, affected by various magnitudes of design storm events are shown in Table 18. It is noted that there are some properties that are not affected in the 1% AEP event for which flooding has been reported. However, the flooding reported for these properties include those with ponding of water on the property, sewage backing up within the property, localised or private drainage issues, or no information given. Furthermore, no flood depths, against which verification could be undertaken, were specified for the properties not affected by the 1% AEP event.

Table 18: Comparison of properties with reported flooding and results from design storm events

	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Number of properties with any reported flooding – Not affected by flooding in hydraulic model	25	20	17	17	16	15
Number of properties with any reported flooding – Affected by flooding in hydraulic model	122	127	130	130	131	132

Indicative depths provided by the community and SWC for events occurring subsequent to 1980 have been compared against the current model results for design event rainfall, shown in Table 19. Even across this time span (1980 to date); it is possible that the catchment conditions have changed, such as increased impervious area or altered land use zoning etc. However, no information is available that would allow these changes to be quantified or incorporated into the model.

Table 19: Peak Flood Depths (m) – Indicative results (events with pluviometer stations) compared to the design events in the current study results

Storm Events	Approximate ARI (Storm Duration 60 min)	Pluviometer Stations in Operation	Indicative Depth	2 yr ARI	5 yr ARI	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI
February 1980	1 – 2 year ARI	566026	N/A						
March 1983	1 – 2 year ARI	566026	0.08	0.14	0.23	0.25	0.28	0.31	0.34
			0.10	0.00	0.02	0.29	0.62	0.94	1.22
			0.10	0.03	0.13	0.19	0.25	0.30	0.35
			0.10	0.05	0.11	0.32	0.64	0.96	1.25
			0.10	0.05	0.14	0.28	0.45	0.64	0.85
			0.30	0.02	0.24	0.38	0.48	0.54	0.59
			0.50	0.24	0.37	0.44	0.50	0.56	0.62
August 1986	2 – 5 year ARI < 1 year ARI	566020 566026	0.10	0.21	0.33	0.39	0.46	0.53	0.59
			0.50	0.05	0.14	0.28	0.45	0.64	0.85
			0.90	0.00	0.06	0.26	0.58	0.91	1.19
November 1988	1 – 2 year ARI < 1 year ARI	566020 566026	N/A						
1998	2 – 5 year ARI 5 – 10 year ARI 2 – 5 year ARI 1 – 2 year ARI	566020 566026 566065 566112	0.25	0.07	0.15	0.20	0.27	0.34	0.64
2008	1 – 2 year ARI < 1 year ARI < 1 year ARI	566020 566026 566065	N/A						
2010	< 1 year ARI < 1 year ARI 2 – 5 year ARI	566020 566026 566065	N/A						
2011	< 1 year ARI 2 – 5 year ARI < 1 year ARI	566020 566026 566065	0.40	0.14	0.17	0.19	0.21	0.22	0.24
8 March 2012	< 1 year ARI < 1 year ARI < 1 year ARI	566020 566026 566065	0.17	0.17	0.25	0.28	0.31	0.34	0.38
			0.30	0.22	0.26	0.28	0.30	0.32	0.35
			0.42	0.14	0.17	0.19	0.21	0.22	0.24
April 2012	< 1 year ARI < 1 year ARI < 1 year ARI	566020 566026 566065	N/A						
May 2012	< 1 year ARI < 1 year ARI < 1 year ARI	566020 566026 566065	N/A						

6.4.2. Comparison with the SWC (1998) report

Comparison was undertaken on the 20% AEP peak flows produced in the TUFLOW hydraulic model and those in the SWC report, summarised in Table 20.

Table 20: SWC (1998) results compared to the current study results – for the 20% AEP event

Pipe/Channel ID	Branch	Land Feature	SWC Report (1998) (m^3/s)	Current Study (m^3/s)
A-B	Main Branch	Open Channel	105.0	77.2
B-C	Main Branch	Open Channel	105.1	73.3
D-E	Main Branch	Culvert under Ramsay St	98.3	62.2
HA-HB	Main Branch	Open Channel	84.0	51.8
J-K	Main Branch	Culvert under Church St	82.8	49.1
L-M	Main Branch	Open Channel	58.6	43.9
N-O	Main Branch	Culvert under John St	58.9	39.2
RC-RD	Main Branch	Culvert under Banks St	52.9	34.8
T-U	Main Branch	Culvert under Elizabeth St	46.5	30.3
W-X	Main Branch	Culvert under Railway	31.1	20.2
VA1-VA2	Main Branch	Culvert under Railway	14.3	11.6
ZBB-ZC	Main Branch	Open Channel	24.4	20.8
ZC1-ZD	Main Branch	Culvert under Hume Hwy	15.0	11.4
ZE-ZF	Main Branch	Culvert under Norton St	14.1	11.1
C4-C5	Chidgeys Branch	Pipe under corner of Alt St and Martin St	6.5	2.8
H13-H14	Alt St Branch	Pipe under Alt St (adjacent to Parramatta Road)	9.9	5.0
L34-L35	Croydon Branch	Pipe under Railway (near Reed St)	10.8	5.9
L46-L46A	Croydon Branch	Pipe under Railway (near Burwood Town Centre)	4.2	1.5

Peak flows in the current study were consistently less than the previous study. These differences were greater in the downstream sections of the main channel.

6.4.3. Comparison with the Brown Consulting (2004) report

Peak flood depths and peak flows detailed in the Brown Consulting report were compared to those produced by the current study in the TUFLOW hydraulic model, summarised in Table 21.

Table 21: Brown Consulting (2004) results compared to current study results

Location	10% AEP		1% AEP	
	Brown Consulting Q (m^3/s)	Current Study Q (m^3/s)	Brown Consulting Q (m^3/s)	Current Study Q (m^3/s)
Dobroyd Centre-North Catchment				
Overflow from Appian Way through properties into Wyatt St	2.0	2.2	3.0	3.6
Overflow from Weldon St to Tahlee St	6.9	4.7	11.1	8.5
Ponding depth at Paisley Rd	1.1 (m)	1.3 (m)	2.1 (m)	2.0 (m)
Ponding depth within the Christadelphian Bible Studies Centre grounds at 72/74 Paisley St	1.4 (m)	1.1 (m)	1.5 (m)	1.2 (m)
Overflow from 3 Albert Cres into Brand St	1.8	1.7	2.9	2.7
Overflow from vicinity of Brand St into Webb St	3.8	2.5	5.7	5.7
Overflow from Irrara St into Young St through houses	4.4	2.2	11.3	6.6
Overflow from Young St, north through properties into Wright St	4.9	2.9	11.9	7.5
Overflow from Wright St to Robinson St	5.5	3.3	12.2	8.1
Overflow from Robinson St to Ivanhoe Rd	5.6	3.4	12.1	8.6
Ponding depth within Queen St at the low point near No. 2	1.2 (m)	1.5 (m)	1.6 (m)	1.7 (m)
Peak catchment overland outflow at No. 2 Queen Street (the boundary with Ashfield LGA)	5.2	3.4	11.7	9.6
Peak catchment pipe outflow at No. 2 Queen Street (the boundary with Ashfield LGA)	8.7	8.5	8.8	7.9
Dobroyd South Catchment (Badminton Branch)				
Overflow from Badminton Road (North) to Austin Avenue (through properties)	0.3	0.6	0.5	0.9
Overflow from Badminton Road (South) to Austin Avenue (through properties)	3.5	2.8	5.6	4.5
Overflow from Austin Avenue to Brighton Street (through properties)	4.9	4.2	8.1	7.4
Overflow from Brighton Street to Croydon Avenue (through properties)	5.4	5.6	9.4	10.2
Overflow out of Gala Avenue cul-de-sac	0.2	0.2	0.4	0.3
Overflow from Croydon Avenue to Greenhills Street (through properties)	6.3	6.3	11.9	11.6

Overflow across Greenhills Street	6.3	6.8	12.0	12.6
Dobroyd South Catchment (Main Branch)				
Overflow from Ardgryffe Street to Waratah Street (through property)	1.2	2.3	1.9	3.6
Overflow from Boyle Street to Beaufort Street (through property)	3.1	2.9	5.9	5.3
Overflow from Seymour Street to Beresford Avenue (through School)	4.5	3.3	8.3	6.2
Overflow from Beresford Avenue to Brighton Street (through properties)	5.3	2.7	9.4	6.6
Overflow from Croydon Avenue to Greenhills Street (through property)	6.9	4.1	11.8	9.1

The current results compared variably to the Brown Consulting (2004) results, however given the differences in methodology this is not unreasonable.

Additionally, comparison was made between the 1% AEP flood extent obtained in the current study with the hotspots identified in the preceding Robinson GRC Consulting (2002) report, shown on Figure 5B. It was found that the hotspots identified in the previous report coincided with the flow paths identified in the current study.

6.4.4. Comparison with the ACOR Consultants (2007) report

Comparison was undertaken on the peak flows produced in the TUFLOW hydraulic model and those in the ACOR Consultants report, summarised in Table 22.

Table 22: Peak flow comparison between hydraulic model and ACOR Consultants report

Sub Catchment	5% AEP		1% AEP	
	ACOR Consultants Q (m^3/s)	Current Study Q (m^3/s)	ACOR Consultants Q (m^3/s)	Current Study Q (m^3/s)
Elizabeth St – 3	74	45	121	56
John St – 4	83	51	136	66
Burwood – 5 (Croydon Road)	22	12	37	15
Alexandra St – 6	107	63	176	84
Parramatta Rd – 7	133	82	220	110
Iron Cove – 9	170	101	279	139

Peak flows in the current study were significantly less than those in the previous study. The peak flows produced in the previous study were obtained using the DRAINS hydrologic model and did not explicitly account for storage within the catchment. Within the Dobroyd Canal catchment, this has a significant influence due to parks that act as detention basins and obstructions such as the railway embankment impeding flow.

The Heighway Avenue and Paisley Road "hotspots" (discussed in Section 9) are the most significant examples of impeded flow and are caused by the limited conveyance capacity through the railway embankment. These hotspots are located upstream of the ACOR hydraulic study area, within the Burwood sub-catchment (in the case of the Paisley Road Hotspot) and upstream of the Elizabeth Street sub-catchment (in the case of the Heighway Avenue Hotspot).

The ACOR study assumed that all overland flow occurred along roadways and discharges into the open channel. This contrasts to results within the current study, which shows significant flow through private property, perpendicular to the roadway. As such, the attenuation of flow that occurs due to the combination of these factors is significant and their exclusion from the ACOR hydrologic model accounts for differences in peak flow results.

The highest 1% AEP flood level across the cadastral lot was also compared to the previous study. Modelled results in the current study produce a peak flood level of 5.5 m AHD compared to 6.4 m AHD in the previous study. Given that peak flows vary significantly between the two studies, it is unsurprising that the peak flood levels within the property are significantly lower in the current study.

6.5. Discussion

Although the available data within the Dobroyd Canal catchment was insufficient to undertake a comprehensive calibration of the models, a comprehensive verification of the models has been carried out. Furthermore, the Dobroyd Canal catchment has strong similarities to the adjacent Hawthorne Canal catchment, which was calibrated. These similarities include catchment conditions, parameter adoption and methodology.

In totality, the comparison to specific yield rates for similar areas in the Sydney Metropolitan region, similarity to the Hawthorne Canal Flood Study (which was calibrated), the comparison with previous studies, and sensitivity analysis provide a strong confidence in the model and the model results (within reasonable tolerance).

7. DESIGN EVENT MODELLING

7.1. Overview

There are two basic approaches to determining design flood levels, namely:

- *flood frequency analysis* – based upon a statistical analysis of the flood events, and
- *rainfall and runoff routing* – design rainfalls are processed by hydrologic and hydraulic computer models to produce estimates of design flood behaviour.

The *flood frequency* approach requires a reasonably complete homogenous record of flood levels and flows over a number of decades to give satisfactory results. No such records were available within this catchment. For this reason a *rainfall and runoff routing* approach using DRAINS model results was adopted for this study to derive inflow hydrographs for input to the TUFLOW hydraulic model, which determines design flood levels, flows and velocities. This approach reflects current engineering practice and is consistent with the quality and quantity of available data.

7.2. Critical Duration

To determine the critical storm duration for various parts of the catchment, modelling of the 1% AEP event was undertaken for a range of design storm durations from 15 minutes to 9 hours, using temporal patterns from AR&R (1987). An envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

It was found that a combination of the 25 minute, 1 hour and 2 hour design storm durations were critical across the whole catchment for the 1% AEP event. The 25 minute design storm duration was mostly critical in areas of shallow overland flow, with 92% of the area considered critical in this storm duration having a peak flood depth no greater than 0.3 m. As such, the 25 minute storm burst was disregarded as a critical storm burst. The 1 hour storm duration was critical over a greater area than the 2 hour storm duration, both of which occur along the main drainage lines. However, the height difference between the two durations was within ± 0.025 m across 90% of the area affected by these two durations. Furthermore, the 1 hour design storm duration was mostly critical in the area upstream of the railway embankment on Heighway Avenue, which has been classified a “hotspot” (discussed in Section 10.1.1)

Additionally, the critical storm duration was determined for the PMF event for a range of storm durations, ranging from 30 minutes to 6 hours. Similarly, an envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

It was found that a combination of the 30 minute and 1 hour storm duration was critical in the PMF event. The 1 hour storm duration was generally critical in the open channel sections and the trunk drainage system that extends from Croydon Road up to and including the Paisley

Road “hotspot” (discussed in Section 10.1.2). Between the two durations, the locations with the largest height difference were Timbrell Park, the junction of two open channel branches between Church Street and John Street, and the Heighway Avenue “hotspot”. In these locations the 1 hour storm duration was greater than the 30 minute storm duration by 0.3 m to 1 m and accounted for 15% of the total area affected by these two durations.

Based on this outcome, it was considered appropriate to adopt the 1 hour storm burst for all events.

7.3. Downstream Boundary Conditions

In addition to runoff from the catchment, downstream areas can also be influenced by high water levels at the confluence of Iron Cove and the trunk drainage system. Consideration must therefore also be given to accounting for the joint probability to coincident flooding from both catchment runoff and backwater effects.

A full joint probability analysis to consider the interaction of these two mechanisms is beyond the scope of the present study. It is accepted practice to estimate design flood levels in these situations using a ‘peak envelope’ approach that adopts the highest of the predicted levels from the two mechanisms. The constant water level applied to the downstream boundary for each design rainfall event is summarised in Table 23.

For the 2050 and 2100 sea level rise scenarios, a constant water level of 1.78 m AHD and 2.28 m AHD were specified respectively, in accordance with guidelines from the NSW State Government (2010).

Table 23: Design Rainfall Event and Downstream Boundary Conditions

Design Event (AEP)	Rainfall Event	Ocean Level
50% AEP	50% AEP Rainfall	50% AEP Ocean Level 1.28 m AHD
20% AEP	20% AEP Rainfall	20% AEP Ocean Level 1.32 m AHD
10% AEP	10% AEP Rainfall	10% AEP Ocean Level 1.35 m AHD
5% AEP	5% AEP Rainfall	5% AEP Ocean Level 1.38 m AHD
2% AEP	2% AEP Rainfall	5% AEP Ocean Level 1.38 m AHD
1% AEP (Enveloped)	1% AEP Rainfall	5% AEP Ocean Level 1.38 m AHD
	5% AEP Rainfall	1% AEP Ocean Level 1.44 m AHD
PMF	Probable Maximum Precipitation	1% AEP Ocean Level 1.44 m AHD

7.4. Design Results

The results from this study are presented as:

- Peak flood level profiles in Figure 11;
- Flow and level hydrographs in Figure 12;
- Peak flood depths and level contours in Figure 13 to Figure 19;
- Peak flood velocities in Figure 20;
- Provisional hydraulic hazard in Figure 21 to Figure 24;
- Provisional hydraulic categorisation in Figure 25 to Figure 28;
- Preliminary flood emergency response classification of communities in Figure 30; and
- Preliminary flood planning areas in Figure 31.

The definition and methodology used to derive these categorisations from the results are discussed below.

The results have been provided to Ashfield City Council and Burwood City Council in digital format compatible with council's Geographic Information System (GIS).

7.4.1. Summary of Results

Peak flood levels, depths and flows at key locations within the catchment are summarised below. These key locations coincide with the key locations used for the sensitivity analysis discussed in Section 8. The placement of the key locations is shown in Figure 10.

A tabulated summary of peak flood depth and level results at key locations are detailed in Table 24.

Table 24: Peak Flood Levels (m AHD) and Depths (m) at Key Locations

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Open Channel – Upstream of Timbrell Dr	Level	1.33	1.39	1.45	1.55	1.63	1.77	2.89
		Depth	2.37	2.43	2.48	2.57	2.65	2.78	3.83
H02	Timbrell Drive	Level	N/A	N/A	N/A	N/A	N/A	N/A	2.72
		Depth	N/A	N/A	N/A	N/A	N/A	N/A	1.23
H03	Dobroyd Parade	Level	2.10	2.16	2.18	2.21	2.22	2.23	2.99
		Depth	0.82	0.88	0.90	0.93	0.94	0.95	1.71
H04	Open Channel – Downstream of Parramatta Rd	Level	2.13	2.34	2.49	2.72	2.96	3.19	5.50
		Depth	1.51	1.70	1.84	2.06	2.28	2.49	4.71
H05	Open Channel – Upstream of Church St	Level	4.41	4.53	4.70	4.93	5.17	5.38	8.43
		Depth	2.38	2.50	2.66	2.90	3.14	3.35	6.40
H06	Open Channel – Upstream of Banks St	Level	9.17	9.74	10.02	10.14	10.23	10.30	11.29
		Depth	2.38	2.88	3.17	3.29	3.38	3.44	4.44
H07	Heighway Avenue	Level	13.26	13.30	13.57	13.89	14.21	14.50	17.48
		Depth	0.37	0.41	0.68	1.00	1.32	1.61	4.59
H08	Norton Street	Level	16.50	16.67	16.77	16.88	16.98	17.07	17.93
		Depth	0.45	0.62	0.72	0.84	0.94	1.03	1.89
H09	Hume Highway	Level	17.05	17.30	17.41	17.53	17.64	17.73	18.64
		Depth	0.26	0.51	0.62	0.74	0.84	0.94	1.85
H10	Brown Street	Level	21.89	22.12	22.22	22.33	22.42	22.52	23.23
		Depth	2.09	2.31	2.41	2.52	2.62	2.71	3.43
H11	Frederick Street	Level	9.02	9.12	9.21	9.29	9.35	9.41	9.92
		Depth	0.13	0.23	0.32	0.40	0.46	0.52	1.03
H12	Queen Street	Level	7.58	8.49	8.78	8.88	8.97	9.03	10.02
		Depth	0.27	1.18	1.46	1.56	1.65	1.72	2.70
H13	Webb Street	Level	15.28	15.40	15.45	15.51	15.57	15.63	16.58
		Depth	0.61	0.72	0.77	0.83	0.89	0.95	1.91
H14	Paisley Road	Level	18.51	18.92	19.13	19.38	19.64	19.87	21.85
		Depth	0.65	1.06	1.28	1.53	1.79	2.02	4.00

The tabulated summary of peak flows at key locations is presented in Table 25.

Table 25: Peak Flows (m^3/s) at Key Locations

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q01	Open Channel – Upstream of Timbrell Dr	Overland	0.0	0.1	0.1	0.1	0.1	0.4	369.2
		Pipe/Channel	62.3	77.2	87.1	100.5	110.4	139.1	252.2
Q02	Open Channel – Downstream of Parramatta Rd	Overland	0.7	1.6	3.9	7.2	9.6	12.3	234.3
		Pipe/Channel	51.0	59.2	65.5	74.7	86.9	98.0	251.0
Q03	Open Channel – Upstream of Banks St	Overland	0.0	0.0	0.7	2.0	3.8	5.4	88.1
		Pipe/Channel	26.4	34.8	41.8	46.6	51.9	56.6	147.6
Q04	Under Railway Embankment – Heighway Ave	Overland	0.0	0.0	0.0	0.0	0.1	0.6	93.0
		Pipe/Channel	13.0	20.3	27.1	31.6	36.6	40.3	78.8
Q05	Open Channel – Downstream of Hume Hwy	Overland	1.4	2.1	2.4	2.8	5.3	8.4	79.8
		Pipe/Channel	13.8	22.7	23.7	27.7	32.0	35.8	79.4
Q06	Hume Highway	Overland	3.1	8.9	12.9	17.8	22.8	28.0	112.0
		Pipe/Channel	5.3	5.2	5.2	5.2	5.2	5.2	4.7
Q07	Bland Street	Overland	0.3	1.4	2.2	3.2	4.2	5.3	23.0
		Pipe/Channel	0.6	0.7	0.7	0.7	0.7	0.7	0.7
Q08	Frederick Street	Overland	1.5	3.2	6.1	9.6	13.2	16.6	78.3
		Pipe/Channel	3.7	3.8	3.7	3.9	3.8	3.9	4.2
Q09	Queen Street	Overland	0.0	0.0	1.6	3.5	5.9	8.0	108.9
		Pipe/Channel	8.0	8.6	8.5	8.5	7.9	8.5	8.1
Q10	Webb Street	Overland	1.2	3.0	4.2	5.6	7.1	8.7	62.9
		Pipe/Channel	6.4	6.4	6.5	6.5	6.5	6.6	6.7
Q11	Under Railway Embankment – Paisley Rd	Overland	0.0	0.0	0.0	0.0	0.0	0.0	14.9
		Pipe/Channel	5.2	5.9	6.3	6.6	7.0	7.2	8.7

The tabulated summary of peak velocities within the open channel and overtopping structures traversing the open channel is presented in Table 26.

Table 26: Peak Velocities (m/s) in Open Channel

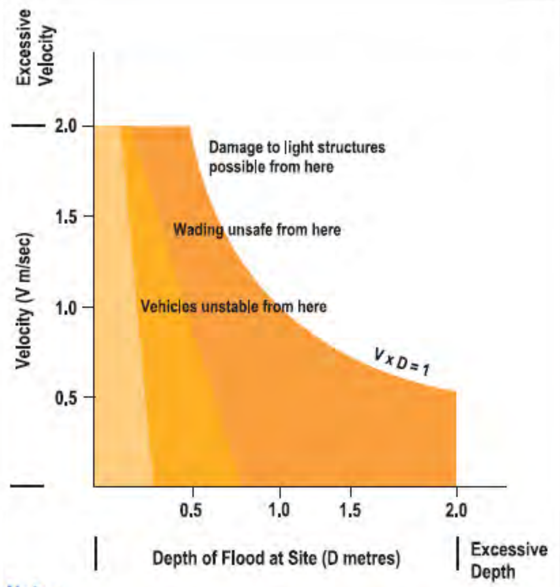
Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Timbrell Dr	Overtopping Structure	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Upstream of Timbrell Dr	Open Channel	1.4	1.6	1.8	2.0	2.1	2.7	3.9
Ramsey Rd	Overtopping Structure	0.0	0.0	0.0	0.0	0.0	0.0	1.7
Upstream of Ramsey Rd	Open Channel	2.1	2.2	2.3	2.4	2.5	2.6	2.6
Parramatta Rd	Overtopping Structure	0.0	0.0	0.0	0.0	0.0	0.0	1.8
Upstream of Parramatta Rd	Open Channel	2.3	2.3	2.4	2.4	2.6	2.7	5.9
Church St	Overtopping Structure	0.0	0.0	0.0	0.0	0.0	0.0	2.3
Upstream of Church St	Open Channel	2.5	2.6	2.7	2.7	2.7	2.7	6.2
John St	Overtopping Structure	0.0	0.0	0.0	0.7	0.9	1.1	2.5
Upstream of John St	Open Channel	4.3	4.5	4.5	4.6	4.6	4.9	14.3
Banks St	Overtopping Structure	0.0	0.0	0.0	0.2	0.5	0.7	1.7
Upstream of Banks St	Open Channel	2.7	2.9	3.2	3.5	3.8	4.1	8.5
Elizabeth St	Overtopping Structure	0.0	0.3	0.6	0.8	0.9	1.0	1.8
Upstream of Elizabeth St	Open Channel	2.3	2.7	3.1	3.5	3.7	3.9	6.0
Heighway Ave	Overtopping Structure	0.0	0.0	0.5	0.8	0.8	0.8	2.0
Upstream of Heighway Ave	Open Channel	2.4	2.7	2.9	3.2	3.3	3.3	3.4
Liverpool Rd	Overtopping Structure	0.0	0.0	0.0	0.5	0.8	0.9	1.9
Upstream of Liverpool Rd	Open Channel	3.0	3.1	3.2	3.2	3.6	3.9	5.9

7.4.2. Provisional Flood Hazard Categorisation

Hazard categories were determined in accordance with Appendix L of the NSW Floodplain Development Manual, the relevant section of which is shown in Diagram 2. For the purposes of this report, the transition zone presented in Diagram 2 (L2) was considered to be high hazard.

Maps of provisional hydraulic hazard in the Dobroyd Canal catchment are presented in Figure 21 to Figure 24.

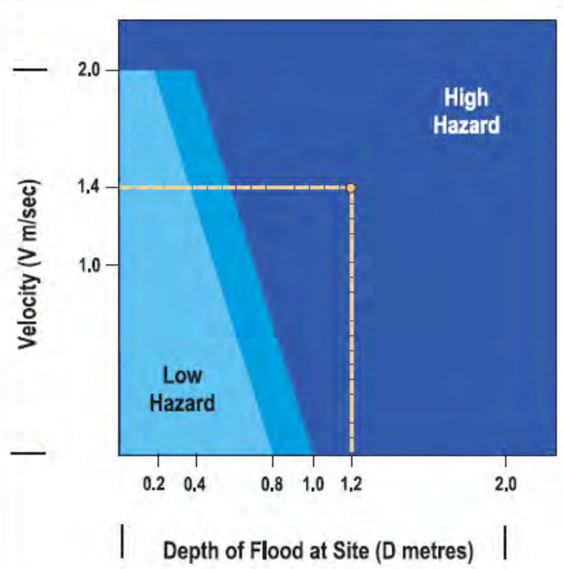
Diagram 2: (L1) Velocity and Depth Relationship; (L2) Provisional Hydraulic Hazard Categories (NSW State Government, 2005)



Notes

1. At velocities in excess of 2.0 m/s, the stability of foundations and poles can be affected by scour. Also, grass and earth surfaces begin to scour and can become rough and unstable
2. The velocity of floodwaters passing between buildings can produce a hazard, which may not be apparent if only the average velocity is considered. For instance, the velocity of floodwaters in a model test has risen from an average of 1 m/sec to 3 m/sec between houses.
3. Vehicle instability is initially by buoyancy.
4. At floodwater depths in excess of 2.0 meters and even at low velocities, there can be damage to light-framed buildings from water pressure, flotation and debris impact.

Derived from laboratory testing and flood conditions which caused damage.



Notes

The degree of hazard may be either -

- reduced by establishment of an effective flood evacuation procedure.
- increased if evacuation difficulties exist.

In the transition zone highlight by the median colour, the degree of hazard is dependant on site conditions and the nature of the proposed development.

Example:

If the depth of flood water is **1.2 m**
and the velocity of floodwater is **1.4 m/sec**
then the provisional hazard is **high**

7.4.3. Provisional Hydraulic Categorisation

The hydraulic categories, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (NSW State Government, 2005). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study catchment in question.

For this study, hydraulic categories were defined by the following criteria, which correspond in part with the criteria proposed by Howells et. al. (2003):

- Floodway is defined as areas where:
  - o the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s **AND** peak velocity > 0.25 m/s, **OR**
  - o peak velocity > 1.0 m/s **AND** peak depth > 0.15 m

The remainder of the floodplain is either Flood Storage or Flood Fringe,

- Flood Storage comprises areas outside the floodway where peak depth > 0.5 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 0.5 m.

However, councils are increasingly moving away from the practice of defining Floodway, Flood Storage and Flood Fringe, as the mapping of Flood Fringe may allow landowners to bypass a Council Development Application and instead apply to a private certifier, under the 2008 Exempt and Complying SEPP. To avoid this, a "Low Risk" and "High Risk" classification was adopted where:

- High Risk corresponds with areas classified as Floodway and Flood Storage; and
- Low Risk corresponds with areas classified as Flood Fringe.

Figure 25, Figure 26, Figure 27 and Figure 28 show the provisional hydraulic categorisations for the Dobroyd Canal catchment for the 20% AEP, 5% AEP, 1% AEP and PMF events respectively.

7.4.4. Preliminary Flood Emergency Response Classification of Communities

The Floodplain Development Manual, 2005 requires flood studies to address the management of continuing flood risk to both existing and future development areas. As continuing flood risk varies across the floodplain so does the type and scale of emergency response problem and therefore the information necessary for effective Emergency Response Planning (ERP). Classification provides an indication of the vulnerability of the community in flood emergency response and identifies the type and scale of information needed by the SES to assist in emergency response planning (ERP).

Criteria for determining flood ERP classifications and an indication of the emergency response required for these classifications are provided in the Floodplain Risk Management Guideline, 2007 (Flood Emergency Response Planning: Classification of Communities). Table 27 summarises the response required for areas of different classification. However, these may vary depending on local flood characteristics and resultant flood behaviour, i.e. in flash flooding or overland flood areas.

Table 27: Response Required for Different Flood ERP Classifications

Classification	Response Required		
	Resupply	**Rescue/Medivac**	**Evacuation**
High Flood Island	Yes	Possibly	Possibly
Low Flood Island	No	Yes	Yes
Area with Rising Road Access	No	Possibly	Yes
Area with Overland Escape Routes	No	Possibly	Yes
Low Trapped Perimeter	No	Yes	Yes
High Trapped Perimeter	Yes	Possibly	Possibly
Indirectly Affected Areas	Possibly	Possibly	Possibly

The criteria for classification of floodplain communities are generally more applicable to riverine flooding where significant flood warning time is available and emergency response action can be taken prior to the flood. In urban areas like the Dobroyd Canal Catchment, flash flooding from local catchment and overland flow will generally occur as a direct response to intense rainfall without significant warning. For most (if not all) flood affected properties in the catchment, remaining inside the building is likely to present less risk to life than attempting to drive or wade through floodwaters, as flow velocities and depths are likely to be greater in the roadway.

ERP classification for the Dobroyd Canal catchment is shown in Figure 30. Areas that are likely to be isolated due to floodwater and contain properties that are likely to be inundated were classified as either Low Flood Island (LFI) or Low Trapped Perimeter (LTP) Areas. These high priority areas include properties along Dobroyd Parade, Queen Street, Heighway Avenue and Paisley Road. The areas classified as Rising Road Access are likely to be inundated but have roads rising uphill and away from the rising floodwaters. Therefore, residents should not be trapped unless they delay evacuation from their homes.

8. SENSITIVITY ANALYSIS

8.1. Overview

The following sensitivity analyses were undertaken to establish the variation in design flood levels and flow that may occur if different parameter assumptions were made:

- Routing Lag: The hydrologic routing length values were increased and decreased by 20% for all sub-catchments;
- Manning's "n": The hydraulic roughness values were increased and decreased by 20%;
- Blockage (pipes): Sensitivity to blockage of all pipes was assessed for 20% and 50% blockage
- Blockage (bridges): Sensitivity to blockage of all culverts and bridges over open channel was assessed for 20% and 50% blockage;
- Blockage (railway embankment): Sensitivity to blockage of key drainage infrastructure underneath the railway embankment was assessed for 20% and 50% blockage;
- Climate Change (Rainfall Increase): Sensitivity to rainfall/runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30% as recommended under current guidelines;
- Climate Change (Sea Level Rise): Sea level rise scenarios of 0.4 m and 0.9 m were assessed.

These sensitivity scenarios were undertaken for the 1% AEP rainfall event with the 5% AEP ocean level.

8.2. Climate Change Background

Intensive scientific investigation is ongoing to estimate the effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) are having on the average earth surface temperature. Changes to surface and atmospheric temperatures may affect climate and sea levels. The extent of any permanent climatic or sea level change can only be established with certainty through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change, evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing greenhouse gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase;
- global sea level has risen about 0.1 m to 0.25 m in the past century;
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

8.2.1. Rainfall Increase

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however this information is not of sufficient accuracy for use as yet (NSW State Government, 2007).

Any increase in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation (IPO) index (Westra et al, 2009). Although mean daily rainfall intensity is not observed to differ significantly between IPO phases, runoff is significantly reduced during periods with fewer rain days.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the Dobroyd Canal catchment under warmer climate scenarios

In light of this uncertainty, the NSW State Government (2007) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

8.2.2. Sea Level Rise

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009. This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (NSW State Government, 2009) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010.*

The Policy Statement says:

> *"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are*

expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… However, the 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible" (NSW State Government, 2009)

In light of this uncertainty, the NSW State Government's advice is subject to periodical review. As of 2012 and after the commencement of this Flood Study, the NSW State Government withdrew endorsement of sea level rise predictions but still require sea level rise to be considered. At the commencement of this Flood Study the benchmarks required Council to plan for projected sea level rise of 0.4 m by 2050 and 0.9 m by 2100 (NSW State Government, 2010), relative to 1990 levels.

8.3. Results

The sensitivity scenario results were compared to the 1% AEP rainfall event with the 5% AEP ocean level. A summary of peak flood level and peak flow differences at various locations are provided in:

- Table 28 and Table 29 for variations in routing and roughness;
- Table 30 and Table 31 for variations in blockage;
- Table 32 and Table 33 for variations in climate conditions.

Comparison of peak flood levels have been highlighted such that yellow highlighting indicates that the magnitude of the change is greater than 0.1 m, while red highlighting indicates changes greater than 0.3 m in magnitude.

8.3.1. Routing and Roughness Variations

Overall peak flood level results were shown to be relatively insensitivity to variations in the routing parameter and increases to the roughness parameter. Generally, these results were found to be within ± 0.1 m, which can usually be accommodated within the freeboard (typically 0.5 m), applied to the 1% AEP results to determine the Flood Planning Levels.

However, decreasing the roughness parameter resulted in increased peak flood levels at two key locations. These locations (Timbrell Drive and the open channel section upstream of Timbrell Drive) are both influenced by downstream hydraulic structures. As such, the cumulative effects of decreased attenuation upstream of these locations resulted in a faster concentration of flows at this flow constriction.

Table 28: Results of Sensitivity Analysis – 1% AEP Depths (m)

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)			
			Routing Decreased by 20%	Routing Increased by 20%	Roughness Decreased by 20%	Roughness Increased by 20%
H01	Open Channel – Upstream of Timbrell Dr	2.78	0.08	0.09	0.13	0.04
H02	Timbrell Drive	0.00	0.09	0.10	0.15	0.08
H03	Dobroyd Parade	0.95	0.00	0.00	0.00	0.00
H04	Open Channel – Downstream of Parramatta Rd	2.49	0.00	0.00	0.07	-0.02
H05	Open Channel – Upstream of Church St	3.35	0.00	0.00	0.07	-0.08
H06	Open Channel – Upstream of Banks St	3.44	0.00	0.00	0.00	-0.01
H07	Heighway Avenue	1.61	0.00	-0.01	0.05	-0.05
H08	Norton Street	1.03	0.00	0.00	-0.02	0.02
H09	Hume Highway	0.94	0.00	0.00	-0.01	0.03
H10	Brown Street	2.71	0.01	-0.01	-0.01	0.02
H11	Frederick Street	0.52	0.00	0.00	-0.01	0.01
H12	Queen Street	1.72	0.00	0.00	0.00	0.00
H13	Webb Street	0.95	0.00	0.00	-0.02	0.02
H14	Paisley Road	2.02	0.00	0.00	0.01	0.00

Table 29: Results of Sensitivity Analysis – 1% AEP Flows (m^3/s)

ID	Location	1% AEP	Routing Decreased by 20%	Routing Increased by 20%	Roughness Decreased by 20%	Roughness Increased by 20%
Q01	Open Channel – Upstream of Timbrell Dr					
	Overland	0.4	0.9	1.1	2.4	0.4
	Pipe/Channel	139.1	127.4	129.1	124.5	133.5
Q02	Open Channel – Downstream of Parramatta Rd					
	Overland	12.3	12.3	12.2	12.6	11.3
	Pipe/Channel	98.0	98.1	97.8	101.1	94.9
Q03	Open Channel – Upstream of Banks St					
	Overland	5.4	5.4	5.4	6.7	4.2
	Pipe/Channel	56.6	56.7	56.5	57.1	56.2
Q04	Under Railway Embankment – Heighway Ave					
	Overland	0.6	0.6	0.7	1.0	0.3
	Pipe/Channel	40.3	41.4	40.3	41.6	39.4
Q05	Open Channel – Downstream of Hume Hwy					
	Overland	8.4	8.4	8.1	9.7	7.7
	Pipe/Channel	35.8	35.9	35.8	36.4	34.6
Q06	Hume Highway					
	Overland	28.0	28.3	27.8	29.0	27.0
	Pipe/Channel	5.2	5.1	5.2	5.2	5.1
Q07	Bland Street					
	Overland	5.3	5.3	5.2	5.4	5.1
	Pipe/Channel	0.7	0.7	0.7	0.7	0.7
Q08	Frederick Street					
	Overland	16.6	16.8	16.5	17.5	15.6
	Pipe/Channel	3.9	3.9	3.9	3.9	3.9
Q09	Queen Street					
	Overland	8.0	8.0	8.0	8.9	7.2
	Pipe/Channel	7.9	7.9	7.9	7.9	7.9
Q10	Webb Street					
	Overland	8.7	8.8	8.7	9.1	8.3
	Pipe/Channel	6.6	6.6	6.6	6.6	6.6
Q11	Under Railway Embankment – Paisley Rd					
	Overland	0.0	0.0	0.0	0.0	0.0
	Pipe/Channel	7.2	7.2	7.2	7.2	7.2

8.3.2. Blockage Variations

Peak flood level results were found to be relatively insensitivity to blockage of the underground pipes in the drainage system. In all but one location, blockage of the pipes resulted in less than a 0.1 m variation in peak flood levels. Where the flood level varied by greater than 0.1 m (at the Paisley Road hotspot) this sensitivity appears to be dominated by the pipes under the railway embankment, with little to no impact from blockage of surrounding pipes. As such, there is no difference in levels between the scenario with all pipes blocked and the scenario with only the railway embankment pipes blocked.

Generally, blockage of all bridge and culvert structures over the open channel resulted in increased flood levels in the vicinity of the channel. However, locations subject to overland flow were relatively insensitive to this blockage scenario.

Blockage of the drainage infrastructure under the railway embankment resulted in increased flood levels immediately upstream of the embankment and decreased flood levels along the flow paths downstream of the embankment.

Table 30: Results of Blockage Analysis – 1% AEP Depths (m)

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)					
			Blockage (Pipes) by 20%	Blockage (Pipes) by 50%	Blockage (Bridges) by 20%	Blockage (Bridges) by 50%	Blockage (Railway) by 20%	Blockage (Railway) by 50%
H01	Open Channel – Upstream of Timbrell Dr	2.78	-0.01	0.05	0.21	0.32	0.04	-0.02
H02	Timbrell Drive	0.00	0.00	0.08	0.21	0.35	0.08	0.00
H03	Dobroyd Parade	0.95	0.00	0.00	0.00	0.00	0.00	0.00
H04	Open Channel – Downstream of Parramatta Rd	2.49	-0.01	-0.02	0.28	0.93	-0.07	-0.23
H05	Open Channel – Upstream of Church St	3.35	-0.01	-0.03	0.26	1.03	-0.13	-0.40
H06	Open Channel – Upstream of Banks St	3.44	0.00	0.00	0.02	0.04	-0.06	-0.19
H07	Heighway Avenue	1.61	0.00	0.01	0.24	1.13	0.20	1.29
H08	Norton Street	1.03	0.02	0.05	0.00	0.01	0.00	0.00
H09	Hume Highway	0.94	0.03	0.06	0.00	0.00	0.00	0.00
H10	Brown Street	2.71	0.00	0.00	0.00	0.00	0.00	0.00
H11	Frederick Street	0.52	0.02	0.05	0.00	0.00	0.00	0.00
H12	Queen Street	1.72	0.03	0.07	0.01	0.02	-0.01	-0.03
H13	Webb Street	0.95	0.01	0.03	0.00	0.00	-0.02	-0.06
H14	Paisley Road	2.02	0.06	0.20	0.00	0.00	0.06	0.20

Table 31: Results of Blockage Analysis – 1% AEP Flows (m^3/s)

ID	Location	1% AEP	Blockage (Pipes) by 20%	Blockage (Pipes) by 50%	Blockage (Bridges) by 20%	Blockage (Bridges) by 50%	Blockage (Railway) by 20%	Blockage (Railway) by 50%
Q01	Open Channel – Upstream of Timbrell Dr							
	Overland	0.4	0.4	0.7	4.5	14.6	0.7	0.2
	Pipe/Channel	139.1	134.4	118.3	104.5	68.2	127.4	114.3
Q02	Open Channel – Downstream of Parramatta Rd							
	Overland	12.3	13.0	13.8	12.6	13.3	12.3	12.1
	Pipe/Channel	98.0	97.2	95.3	90.2	73.0	93.2	81.8
Q03	Open Channel – Upstream of Banks St							
	Overland	5.4	5.4	5.4	5.4	5.1	3.9	1.6
	Pipe/Channel	56.6	56.8	56.8	50.6	39.9	52.3	45.1
Q04	Under Railway Embankment – Heighway Ave							
	Overland	0.6	0.6	0.7	2.7	14.1	2.4	12.6
	Pipe/Channel	40.3	41.2	40.4	35.2	22.3	34.7	22.1
Q05	Open Channel – Downstream of Hume Hwy							
	Overland	8.4	8.3	8.2	10.0	14.5	8.3	8.3
	Pipe/Channel	35.8	35.8	35.9	34.2	29.7	35.8	35.8
Q06	Hume Highway							
	Overland	28.0	29.3	30.8	28.1	28.0	28.1	28.0
	Pipe/Channel	5.2	4.0	2.4	4.7	4.7	5.0	4.7
Q07	Bland Street							
	Overland	5.3	5.3	5.3	5.3	5.2	5.3	5.2
	Pipe/Channel	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Q08	Frederick Street							
	Overland	16.6	17.9	19.9	16.6	16.6	16.6	16.6
	Pipe/Channel	3.9	3.2	2.0	3.9	3.9	3.9	3.9
Q09	Queen Street							
	Overland	8.0	9.2	10.8	8.2	8.7	7.7	7.1
	Pipe/Channel	7.9	6.3	3.8	7.9	7.8	7.9	8.0
Q10	Webb Street							
	Overland	8.7	9.0	9.7	8.7	8.7	8.2	7.0
	Pipe/Channel	6.6	5.8	3.8	6.6	6.6	6.5	6.5
Q11	Under Railway Embankment – Paisley Rd							
	Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pipe/Channel	7.2	6.5	4.9	7.2	7.2	6.5	4.9

8.3.3. Climate Variations

The effect of increasing the design rainfalls by 10%, 20% and 30% has been evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the study area. Generally speaking, each incremental 10% increase in rainfall results in an approximately 0.1 m increase in peak flood levels at most of the locations analysed. The 1% AEP event with a rainfall increase of 30% is approximately equivalent to a 0.2% AEP event in present day conditions and an impact on flood levels is not unexpected.

The sea level rise scenarios were found not to have a significant effect on peak flood levels, except in the most downstream reaches of the catchment. Timbrell Drive and Timbrell Park were particularly vulnerable to sea level rise, with the lowest point along Timbrell Drive being approximately 1.5 m AHD and below the raised sea levels. In contrast, the propagation of sea level rise impacts within the open channel was found to be restricted by structures traversing the channel, particularly the Timbrell Drive Bridge. This is shown in the profiles for the sea level rise scenarios found in Figure 11.

Table 32: Results of Climate Change Analysis – 1% AEP Depths (m)

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)				
			Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	2050 Sea Level Rise + 0.4 m	2100 Sea Level Rise + 0.9 m
H01	Open Channel – Upstream of Timbrell Dr	2.78	0.28	0.30	0.34	0.15	0.54
H02	Timbrell Drive	0.00	0.22	0.34	0.38	0.30	0.79
H03	Dobroyd Parade	0.95	0.01	0.02	0.02	0.01	0.13
H04	Open Channel – Downstream of Parramatta Rd	2.49	0.22	0.48	0.76	0.00	0.01
H05	Open Channel – Upstream of Church St	3.35	0.17	0.39	0.64	0.00	0.00
H06	Open Channel – Upstream of Banks St	3.44	0.06	0.14	0.19	0.00	0.00
H07	Heighway Avenue	1.61	0.20	0.37	1.09	0.00	0.00
H08	Norton Street	1.03	0.07	0.13	0.19	0.00	0.00
H09	Hume Highway	0.94	0.08	0.15	0.21	0.00	0.00
H10	Brown Street	2.71	0.08	0.15	0.21	0.00	0.00
H11	Frederick Street	0.52	0.04	0.08	0.11	0.00	0.00
H12	Queen Street	1.72	0.05	0.10	0.15	0.00	0.00
H13	Webb Street	0.95	0.04	0.08	0.12	0.00	0.00
H14	Paisley Road	2.02	0.18	0.35	0.51	0.00	0.00

Table 33: Results of Climate Change Analysis – 1% AEP Flows (m^3/s)

ID	Location	1% AEP	Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	2050 Sea Level Rise + 0.4 m	2100 Sea Level Rise + 0.9 m
Q01	Open Channel – Upstream of Timbrell Dr						
	Overland	0.4	5.6	15.7	21.1	2.8	36.1
	Pipe/Channel	139.1	135.9	126.2	135.4	123.0	99.7
Q02	Open Channel – Downstream of Parramatta Rd						
	Overland	12.3	13.9	16.3	18.5	12.3	12.3
	Pipe/Channel	98.0	107.1	117.2	126.1	98.0	97.9
Q03	Open Channel – Upstream of Banks St						
	Overland	5.4	7.1	9.8	12.2	5.4	5.4
	Pipe/Channel	56.6	61.0	67.1	71.6	56.6	56.7
Q04	Under Railway Embankment – Heighway Ave						
	Overland	0.6	2.3	5.9	10.5	0.6	0.8
	Pipe/Channel	40.3	44.2	46.3	52.8	40.3	41.3
Q05	Open Channel – Downstream of Hume Hwy						
	Overland	8.4	11.1	13.9	16.7	8.4	8.4
	Pipe/Channel	35.8	39.2	42.6	46.1	35.8	35.8
Q06	Hume Highway						
	Overland	28.0	32.6	37.0	41.2	28.0	28.0
	Pipe/Channel	5.2	5.1	5.1	5.1	5.2	5.2
Q07	Bland Street						
	Overland	5.3	6.2	7.2	8.3	5.3	5.3
	Pipe/Channel	0.7	0.7	0.7	0.7	0.7	0.7
Q08	Frederick Street						
	Overland	16.6	19.6	22.7	25.5	16.6	16.6
	Pipe/Channel	3.9	3.9	4.0	3.9	3.9	3.9
Q09	Queen Street						
	Overland	8.0	10.1	12.2	14.6	8.0	8.0
	Pipe/Channel	7.9	7.9	7.9	7.9	7.9	7.9
Q10	Webb Street						
	Overland	8.7	10.1	11.5	12.9	8.7	8.7
	Pipe/Channel	6.6	6.6	6.6	6.6	6.6	6.6
Q11	Under Railway Embankment – Paisley Rd						
	Overland	0.0	0.0	0.0	0.0	0.0	0.0
	Pipe/Channel	7.2	7.4	7.6	7.7	7.2	7.2

9. PRELIMINARY FLOOD PLANNING AREAS – PROPERTY TAGGING

9.1. Background

Land use planning is considered to be one of the most effective means of minimising flood risk and damages from flooding. The Flood Planning Area (FPA) identifies land that is subject to flood related development controls and the Flood Planning Level (FPL) is the minimum floor level applied to new developments within the FPA.

The process of defining FPA's and FPL's is somewhat complicated by the variability of flow conditions between mainstream and local overland flow, particularly in urban areas. The more traditional approaches typically having been developed for riverine environments and mainstream flow.

Defining the area of flood affectation due to overland flow (which by its nature includes shallow flow) often involves determining at which point it becomes significant enough to classify as "flooding". The difference in peak flood level between events of varying magnitude may be minor in areas of overland flow, such that applying the typical freeboard can result in a FPL greater than the Probable Maximum Flood (PMF) level.

The FPA should include properties where future development would result in impacts on flood behaviour in the surrounding area and areas of high hazard that pose a risk to safety or life. Further to this, the FPL is determined with the purpose to decrease the likelihood of over-floor flooding of buildings and the associated damages.

The Floodplain Development Manual suggests that the FPL generally be based on the 1% AEP event plus an appropriate freeboard. The typical freeboard cited in the manual is that of 0.5 m; however it also recognises that different freeboards may be deemed more appropriate due to local conditions. In these circumstances, some justification is called for where a lower value is adopted.

Further consideration of flood planning areas and levels are typically undertaken as part of the Floodplain Management Study where council decides which approach to adopt for inclusion in their Floodplain Management Plan.

9.2. Methodology and Criteria

The methodology used in this report is consistent with that adopted in a number of previous studies. It divides flooding between Mainstream flooding and Overland flooding using the following criteria:

- Mainstream flooding: Any percentage of the cadastral area is affected by mainstream flooding in the 1% AEP event. This has been defined as the peak flood level within the open channel section of Dobroyd Canal plus a 0.5 m freeboard, with the level extended perpendicular to the flow direction.

- Overland flooding: Greater than or equal to 10% of the “active” cadastral area is affected by the 1% AEP peak flood depth of greater than 0.15 m. The “active” cadastral area was considered to be the cadastral area excluding the building area that was modelled as impermeable.

In situations where a cadastral lot is subject to both mainstream flooding and overland flooding, the mechanism that produces the highest Flood Planning Level is given precedence, although both levels have been provided.

9.3. Results

A summary of properties tagged is provided in Table 34. Figure 31 identifies the extent of mainstream or overland flow property affectation.

Table 34: Number of Properties Tagged

	Mainstream	**Overland**	**Both Mainstream and Overland**	**Total**
Ashfield	145	852	431	1428
Burwood	0	400	0	400
Total	145	1252	431	1828

A total of 1428 properties were tagged for flood related development controls in Ashfield and 400 properties in Burwood. This gives total averages of 1.7 properties per hectare for Burwood and 2.9 properties per hectare for Ashfield. Considering only overland flow affectation, the average was 1.7 properties per hectare for Ashfield Council. As such, mainstream flood affectation accounted for the difference in total average properties per hectare between the two Councils, with the open channel situated solely within Ashfield Council.

Properties that are not tagged as part of this process may not be excluded from development controls. It is advisable that new developments (regardless of whether they are tagged as flood liable or not) have habitable floor levels a minimum of 300 mm above the surrounding ground level to minimise affectation due to local overland flow.

10. DISCUSSION

Various locations were identified as “hotspots” or “areas of interest” within the Dobroyd Canal Catchment. These locations were identified based upon flood behaviour occurring at ground level. The above floor flood liability of these locations has not yet been determined due to a lack of surveyed floor levels at this stage. However, some over floor flood liability is likely at each of these locations.

10.1. Hotspots

The following discussion examines areas identified herein as “hotspots” within the Dobroyd Canal Catchment. The locations were identified based upon areas defined in the hydraulic model as being subject to significant levels of flooding.

10.1.1. Heighway Avenue

The main open channel in the Dobroyd Canal catchment is crossed by a railway embankment that is the property of City Rail. The embankment has an elevation greater than the surrounding streets by greater than 6 m. Heighway Avenue is aligned parallel to the embankment and is directly upstream of this flow constriction.

Figure C 2 shows the 1% AEP peak flood depths at this location and the location of flood height and flow hydrographs shown in Figure C 3 and Figure C 4.

Flooding Behaviour

The contributing catchment area is approximately 286 ha, the largest of the hotspots examined. Two culverts with a cross-sectional area of approximately 14.7 m^2 and 5.3 m^2 convey flow underneath the railway embankment. The alternative route for flow from this area of the catchment is through the Frederick Street roadway tunnel. Due to the difference in elevation between the embankment and the upstream ground level, the embankment at this location is not overtopped in events up to and including the PMF.

The elevation of Frederick Street is approximately 14.0 m AHD along the roadway from the junction with Heighway Avenue to the embankment. This increases on the downstream (north) side of the embankment, with the elevation of the Frederick Street roadway found to be approximately 14.5 m AHD. By comparison, the elevation of the roadway at Heighway Avenue adjacent to the open channel is approximately 13.2 m AHD. As such, flood depths on Heighway Avenue have to reach approximately 1.3 m before the alternative flow path through the Frederick Street roadway tunnel occurs.

The obvert of the smaller culvert is 12.8 m AHD and below the elevation of the Heighway Avenue roadway. The obvert of the larger culvert is 14.86 m AHD and above the elevation of the Frederick Street roadway. As such, flow occurs through the Frederick Street roadway tunnel prior to the submergence of the larger culvert.

The peak flood depths and flows at this location are shown in Table 35 and Table 36, corresponding with those presented in Section 7.4.1.

Table 35: Heighway Avenue – Peak Flood Levels (m AHD) and Depths (m)

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H07	Heighway Avenue	Level	13.26	13.30	13.57	13.89	14.21	14.50	17.48
		Depth	0.37	0.41	0.68	1.00	1.32	1.61	4.59

Table 36: Heighway Avenue – Peak Flows (m^3/s)

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q04	Under Railway Embankment – Heighway Ave	Overland (Frederick St)	0.0	0.0	0.0	0.0	0.1	0.6	93.0
		Pipe/Channel	13.0	20.3	27.1	31.6	36.6	40.3	78.8

The Heighway Avenue hotspot has the largest area of affectation within the Dobroyd Canal Catchment in a 1% AEP event, however the duration of inundation is comparatively short and the area typically drains within 30 minutes after rainfall has ceased.

This location is very sensitive to blockage. Blockage of all bridges over the open channel and blockage of the culverts underneath the railway embankment resulted in increases in peak flood levels greater than 1 m in the case of 50% blockage (discussed in Section 8.3.2).

10.1.2. Paisley Road

The railway embankment intersects one of the major natural overland flow paths between Brady Street and Reed Street. Paisley Road, which is parallel to the railway embankment on the upstream side of this intersection, follows the natural topography and is lower in elevation than the embankment. With the exception of pipes under the embankment, this flow path is effectively blocked and water ponds to the south of the embankment along Paisley Road and surrounding streets.

Figure C 5 shows the 1% AEP peak flood depths at this location and the location of flood height and flow hydrographs shown in Figure C 6 and Figure C 7.

Flooding Behaviour

The contributing catchment area is approximately 70 ha. Two pipes, each with a cross-sectional area of approximately 2.5 m^2, convey flow underneath the railway embankment. The capacity of this pipe and the surrounding pipes in this location was found to be less than a 2 year ARI event. In a PMF event, the embankment is overtopped at this location. The peak flows within the pipe and the overland flow path across the embankment are provided in Table 37.

Table 37: Paisley Road – Peak Flows (m^3/s)

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q11	Under Railway Embankment – Paisley Rd	Overland	0.0	0.0	0.0	0.0	0.0	0.0	14.9
		Pipe/Channel	5.2	5.9	6.3	6.6	7.0	7.2	8.7

The peak flood levels and depths at this location are shown in Table 38. The ground elevation of the railway embankment was approximately 21.5 m AHD, resulting in depths of approximately 0.35 m on the embankment during a PMF event.

Table 38: Paisley Road – Peak Flood Levels (m AHD) and Depths (m)

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H14	Paisley Road	Level	18.51	18.92	19.13	19.38	19.64	19.87	21.85
		Depth	0.65	1.06	1.28	1.53	1.79	2.02	4.00

This location was found to be relatively insensitive to blockage of the trunk drainage pipes underneath the railway embankment, with increases in peak flood levels up to 0.2 m in the case of 50% blockage (discussed in Section 8.3.2).

10.1.3. Queen Street

The Queen Street low point is located in the roadway adjacent to the south-east edge of Centenary Park. The park grounds are separated from the roadway with a retaining wall and have an elevation greater than the roadway by approximately 3-4 m. The front yards of the properties opposite the park are at approximately the same elevation as the roadway.

This hotspot is located downstream of the Paisley Road hotspot and is on the border between the Burwood City Council LGA and the Ashfield City Council LGA. Downstream of this hotspot the trunk drainage pipes discharge into the open channel east of Croydon Road.

Figure C 8 shows the 1% AEP peak flood depths at this location and the location of flood height and flow hydrographs shown in Figure C 9 and Figure C 10.

Flooding Behaviour

The pipe draining this area is roughly oval shaped, with dimensions of 2.275 m (width) by 1.525 m (height) and a cross-sectional area of approximately 2.6 m^2. The capacity of this pipe and the surrounding pipes in this location was found to be less than a 2 year ARI event. The peak flows within the pipe and the overland flow path from Queen Street are provided in Table 39.

Table 39: Queen Street – Peak Flows (m^3/s)

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q09	Queen Street	Overland	0.0	0.0	1.6	3.5	5.9	8.0	108.9
		Pipe/Channel	8.0	8.6	8.5	8.5	7.9	8.5	8.1

The peak flood levels and depths at this location are shown in Table 40.

Table 40: Queen Street – Peak Flood Levels (m AHD) and Depths (m)

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H12	Queen Street	Level	7.58	8.49	8.78	8.88	8.97	9.03	10.02
		Depth	0.27	1.18	1.46	1.56	1.65	1.72	2.70

The duration of inundation was greater at this location than the other hotspots discussed, with the area generally still draining 2 hours after rainfall has ceased (for the 1 hour storm duration).

This location was found to be relatively insensitive to the various blockage scenarios assessed. Given the location of this hotspot relative to the Paisley Road hotspot, it is relevant to note that the blockage of the pipes draining the Paisley Road hotspot had minimal impact on the peak flood levels at the Queen Street hotspot, with a decrease of 0.03 m in the case of 50% blocked (discussed in Section 8.3.2).

10.1.4. Brown Street / Bland Street

The vehicle and pedestrian road tunnel underneath the railway embankment has a lower elevation than either of the two streets that approach it, namely Bland Street and Brown Street. Bland Street, which approaches the tunnel from the north side, increases in elevation by approximately 5 m from the tunnel to the junction with Elizabeth Street. Brown Street to the south of the embankment has a similar elevation rise from the tunnel to the junction with Foxs Lane. As such, the road under the railway embankment acts as a trapped low point.

Parallel to the road tunnel and approximately 70 m to the east is a pedestrian tunnel underneath the railway embankment. It has an approximate elevation 4 m higher than that of the road tunnel.

Figure C 11 shows the 1% AEP peak flood depths at this location and the location of flood height hydrographs shown in Figure C 12.

Flooding Behaviour

The peak flood depths and flows discharging from this location are shown in Table 41 and Table 42, corresponding with those presented in Section 7.4.1.

Table 41: Brown Street / Bland Street – Peak Flood Levels (m AHD) and Depths (m)

ID	Location	Type	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H10	Brown Street	Level	21.89	22.12	22.22	22.33	22.42	22.52	23.23
		Depth	2.09	2.31	2.41	2.52	2.62	2.71	3.43

Table 42: Downstream of Bland Street – Peak Flows (m^3/s)

ID	Location	Type	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q07	Bland Street	Overland	0.3	1.4	2.2	3.2	4.2	5.3	23.0
		Pipe/Channel	0.6	0.7	0.7	0.7	0.7	0.7	0.7

Underneath the Bland Street road tunnel is a box culvert with a width of 1.2 m and a height of 0.9 m. Although there are inlet pits at the start and end of this roadway tunnel, the pipes connecting these inlets to the box culvert were smaller than 450 mm in diameter. As such, these pipes were assumed to be blocked as per the discussion in Section 5.5.

Consequent to these pipes being blocked, a flood depth of 1.9 m was found to remain in this area and not drain away (shown in the flood height hydrograph). However, in the hypothetical scenario that the inlets connected directly to the box culvert, the 1% AEP peak flood level at this location decreased by merely 0.14 m and drained within 1 hour after rainfall ceased.

An additional feature at this location that is pertinent to the flood behaviour is an underground car park. It is located on Brown Street to the south of the railway embankment and has an entrance approximately level with the low point of the roadway. This feature was unable to be modelled due to the lack of data, particularly relating to volume capacity and private pipe drainage infrastructure. By excluding the flood storage that would be provided by the car park, the model may produce a conservative over-estimation of flood levels at this location.

10.2. Additional Areas of Interest

Additional areas of interest were identified by council, in some cases based upon flooding concerns raised by residents prior to commencement of this flood study.

10.2.1. Alexandra Street and Church Street, Ashfield

Church Street traverses the main open channel. Alexandra Street does not cross the open channel and is aligned generally perpendicular to the channel alignment. It is located upstream of Church Street, adjacent to the junction between the main open channel and the trunk drainage system originating from the Burwood-Croydon branch.

Flooding Behaviour

Within this area, there are two flood mechanisms operating. These are mainstream flooding and local overland flow flooding. The Floodplain Development Manual (2005) definition for these categories can be found in the glossary provided in Appendix A.

In events up to and including the 1% AEP event, the Church Street bridge structure is not overtopped, as demonstrated in Table 43. Furthermore, the flood level in the open channel is lower than both the ground level and the peak flood level in the surrounding Church Street area, shown in Table 44. This indicates that flow experienced on Church Street during events of this magnitude is primarily from overland flow rather than mainstream flow. However, in the PMF event the flood level exceeded the banks of the open channel and mainstream flooding was found to occur.

Table 43: Church Street – Peak Velocities (m/s)

Location	Type	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Church St	Overtopping Structure	0.0	0.0	0.0	0.0	0.0	0.0	2.3
Upstream of Church St	Open Channel	2.5	2.6	2.7	2.7	2.7	2.7	6.2

Table 44: Church Street – Peak Flood Levels (m AHD) and Depths (m)

Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Open Channel Upstream of Church Street	Level	4.41	4.53	4.69	4.93	5.17	5.38	8.44
	Depth	2.33	2.44	2.59	2.82	3.05	3.24	6.26
Church Street (Ground Level 6.36 m AHD)	Level	6.43	6.46	6.47	6.47	6.48	6.49	10.19
	Depth	0.09	0.10	0.11	0.12	0.12	0.13	3.84

The section of Alexandra Street closest to the open channel is subject to mainstream flooding in events of a magnitude greater than and including the 5% AEP event. In events of a smaller magnitude than this, the peak flood level in the open channel is less than the ground level and the peak flood level in Alexandra Street, shown in Table 45. This indicates that flow experienced on Alexandra Street during events of a magnitude smaller than the 5% AEP event is primarily from overland flow rather than mainstream flow.

Table 45: Alexandra Street – Peak Flood Levels (m AHD) and Depths (m)

Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Open Channel Adjacent to Alexandra Street	Level	4.41	4.55	4.71	4.94	5.19	5.39	8.20
	Depth	2.09	2.22	2.37	2.59	2.81	3.00	5.79
Alexandra Street (Ground Level 4.76 m AHD)	Level	4.90	4.90	4.91	4.98	5.20	5.42	8.32
	Depth	0.14	0.14	0.15	0.22	0.44	0.66	3.56

10.2.2. Algie Park, Ashfield

The ground level inside Algie Park is generally lower than the surrounding property. A concrete wall is situated along the western boundary adjacent to residential property and a grassed ridge is located along the northern boundary. Collectively, these features form a detention basin within Algie Park.

Flooding Behaviour

Flows entered Algie Park via overland flow and pipes from the east, south and west. The pipes convey flow from Bland Street, Empire Street and Ramsay Street to converge into one 0.9 m diameter pipe entering the Algie Park grounds. The pipe network draining the Algie Park detention basin consisted of two pipes with a 0.9 m diameter. The peak flows entering and discharging from the park are shown in Table 46.

Table 46: Algie Park – Peak Flows (m^3/s)

Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Inflow	Pipe	1.5	1.7	1.8	1.9	1.9	1.9	2.0
	Overland	5.1	7.3	8.8	10.5	11.8	13.5	35.6
Outflow	Pipe (east)	1.5	1.8	1.9	1.9	1.9	1.9	1.9
	Pipe (west)	0.9	1.0	1.0	1.3	1.4	1.4	1.5
	Overland (spillway)	0.0	0.0	0.1	1.0	2.0	3.4	21.7
	Overland (bypass)	0.4	1.0	1.5	2.1	2.7	3.2	5.0

The grass ridge and concrete wall had an elevation of approximately 7.0 m AHD at the northern boundary. A spillway is located on the grass ridge and had a width of 20 m and an elevation of 6.5 m AHD. The lowest point within the detention basin was approximately 4.8 m AHD and required flood depths to reach 1.7 m for the spillway to be activated.

The lowest elevation on the Ramsay Street roadway upstream of the park was approximately 8.7 m AHD. The backyard of the properties to the east of the detention basin had a lower elevation than the roadway, with elevations of 6.0 m AHD in some locations. Although a small wall was located on the southern boundary of these properties, flow that was impeded from exiting the detention basin was found to accumulate and extend upstream through the park whereby the backyards of properties to the east of the concrete wall acted as an alternative flow-path. The peak flood levels and depths within Algie Park and the streets downstream of the park are shown in Table 47.

Table 47: Algie Park – Peak Flood Levels (m AHD) and Depths (m)

Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Algie Park	Level	6.24	6.46	6.57	6.67	6.75	6.82	6.58
	Depth	1.32	1.53	1.65	1.75	1.83	1.90	1.66
Laneway Downstream of Algie Park	Level	4.20	4.24	4.28	4.35	4.42	4.48	4.92
	Depth	0.35	0.39	0.43	0.50	0.57	0.63	1.07
Alt Street	Level	3.59	3.62	3.64	3.71	3.79	3.86	4.55
	Depth	0.21	0.25	0.26	0.33	0.41	0.48	1.17
Martin Street	Level	3.30	3.36	3.39	3.45	3.59	3.70	4.36
	Depth	0.18	0.23	0.26	0.32	0.46	0.57	1.23

10.2.3. Appian Way, Burwood

Appian Way is located in the upper reaches of the catchment. The flows discharging from this area contribute to the flows received at the Paisley Road hotspot, which is situated downstream of this location.

Flooding Behaviour

The contributing catchment area is approximately 8.4 ha. The pipe draining this area has a diameter of 450 mm. When the capacity of the pipe is exceeded, overland flow occurs along the topographical low point. The topography was defined by the ALS (discussed in Section 2.3), with the natural low point found to occur through property and generally perpendicular to the roadway. The capacity of the pipe draining this location was found to be less than a 2 year ARI event. The peak flows within the pipe and the overland flow path from Appian Way are provided in Table 48.

Table 48: Appian Way – Peak Flows (m^3/s)

Location	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Overland Flow	1.2	1.8	2.2	2.7	3.1	3.6	10.1
Pipe Flow (450mm diameter)	0.3	0.3	0.3	0.3	0.3	0.3	0.3

The peak flood levels and depths adjacent to the roadway are provided in Table 49. Peak flood levels at this location were insensitive to blockage of the pipes, with a difference in peak flood levels less than 0.001 m across the various blockage scenarios assessed.

Table 49: Appian Way – Peak Flood Levels (m AHD) and Depths (m)

Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Appian Way	Level	36.15	36.18	36.19	36.20	36.21	36.22	36.30
	Depth	0.10	0.12	0.13	0.14	0.15	0.16	0.24

10.2.4. Webb Street, Burwood

Webb Street is located between the Paisley Road hotspot and the Queen Street hotspot. Both the land and the building floor level of the Hampton Court complex (along the eastern edge of the roadway) is elevated above the level of the road. This residential block was constructed after the Brown Consulting (2004) report wherein this area was referred to as Croydon Gardens.

Flooding Behaviour

Within the previous report, flow was considered to travel from Webb Street through Croydon Gardens before being conveyed onto Irrara Street. The current conditions are such that flow from upstream of Webb Street is conveyed into Irrara Street through the roadways. Flow generated within the majority of Hampton Court is retained in an open-space detention basin that was defined in the current study by the ALS ground topography.

Underneath Webb Street two upstream branches of the trunk drainage system converge. These branches originate from Paisley Road and the Burwood Town Centre. In the vicinity of Webb Street these pipes have a diameter of 1.65 m (from the Paisley Road branch) and 0.965 m (from the Burwood Town Centre branch). The pipe downstream of this convergence is irregularly shaped, with a cross-sectional area of approximately 2.9 m^2. Flow from the detention basin is conveyed into this irregular shaped pipe via a 0.6 m diameter pipe.

The inlet draining the Hampton Court detention basin is located towards the crest of the basin, thereby restricting flows from entering the pipe until flood levels within the basin have reached the necessary height. The ground level in the area surrounding the detention basin inlet is approximately 13.1 m AHD. By comparison, the lowest ground level within the basin is approximately 11.5 m AHD. Therefore, a flood depth of 1.6 m is attained within the detention basin prior to flood waters draining into the trunk drainage system.

Peak flows in the vicinity of this location are shown in Table 50 and an ID is provided where these locations correspond with those presented in Section 7.4.1. The pipes in this area were found to be functioning at capacity in the 2 year ARI event and greater. The pipe draining the detention basin was also at capacity in the 2 year ARI event. However this was due to backflow entering the pipe from the trunk drainage system rather than from the detention basin.

Table 50: Webb Street – Peak Flows (m^3/s)

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
	Upstream of Webb St – From Paisley Rd	Pipe (1.65m diameter)	4.4	4.3	4.3	4.3	4.3	4.4	3.3
	Upstream of Webb St – From Burwood Town Centre	Pipe (0.965m diameter)	1.9	1.8	1.8	1.8	1.8	1.8	1.7
Q10	Webb Street	Overland	1.2	3.0	4.2	5.6	7.1	8.7	62.9
		Pipe	6.4	6.4	6.5	6.5	6.5	6.6	6.7
	Detention Basin	Pipe (0.6m diameter)	0.0	0.5	0.5	0.5	0.5	0.5	0.3
	Irrara Street	Pipe	6.3	6.3	6.4	6.4	6.4	6.5	6.4

The peak flood levels and depths at this location are shown in Table 51, corresponding with those presented in Section 7.4.1. Peak flood levels at this location were not particularly sensitive to blockage of the pipes in the trunk drainage system.

Table 51: Webb Street – Peak Flood Levels (m AHD) and Depths (m)

ID	Location	Type	2 yr ARI	5 yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H13	Webb Street	Level	15.28	15.40	15.45	15.51	15.57	15.63	16.58
		Depth	0.61	0.72	0.77	0.83	0.89	0.95	1.91
	Hampton Court Detention Basin	Level	12.82	13.50	13.58	13.64	13.70	13.74	14.70
		Depth	1.32	1.99	2.08	2.13	2.19	2.23	3.19

11. ACKNOWLEDGEMENTS

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SWC 53 Dobroyd Canal and SWC 62 Hawthorne Canal
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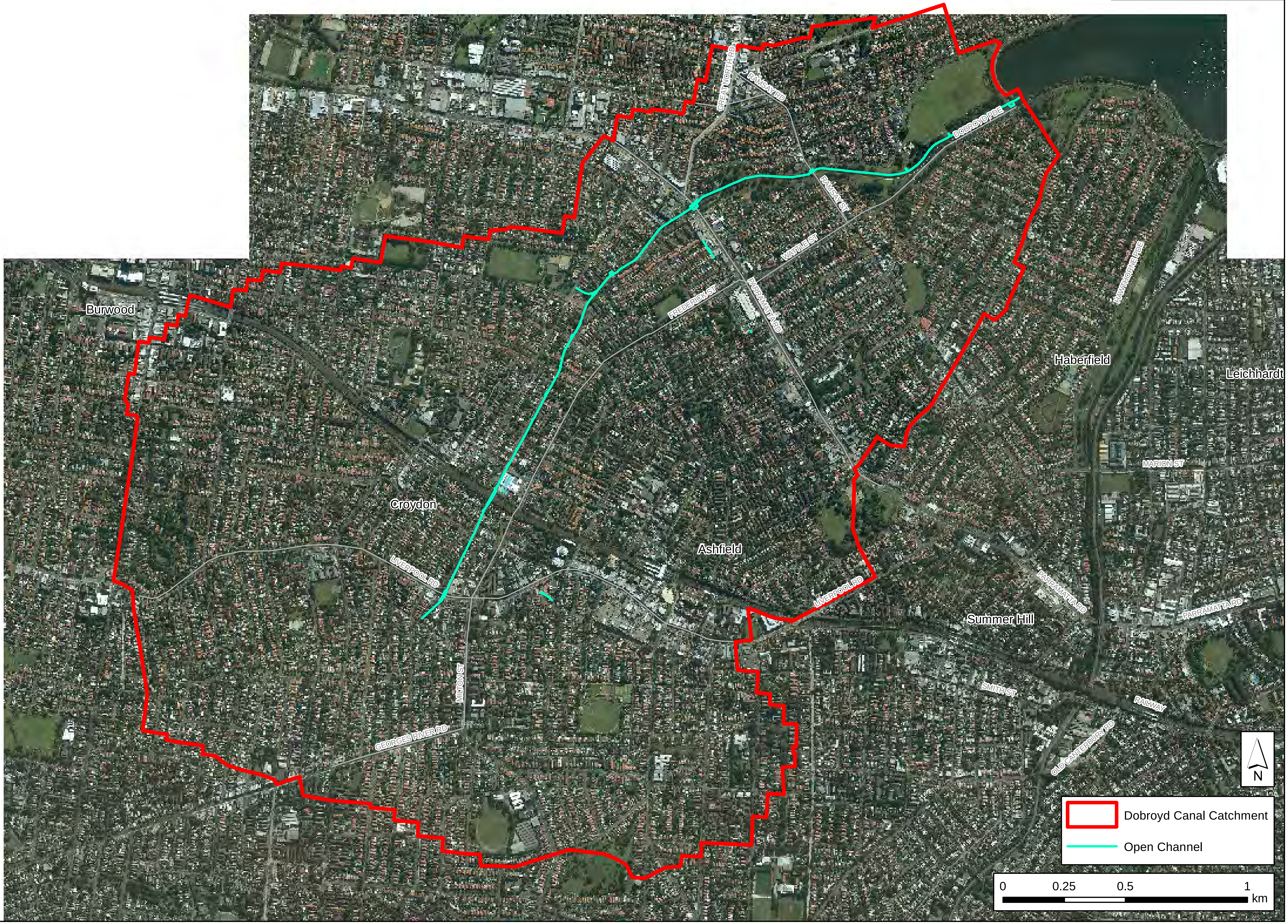
Proc. Joint NSW and Victorian Flood Management Conference, February 2009

Figures

FIGURE 1
STUDY AREA



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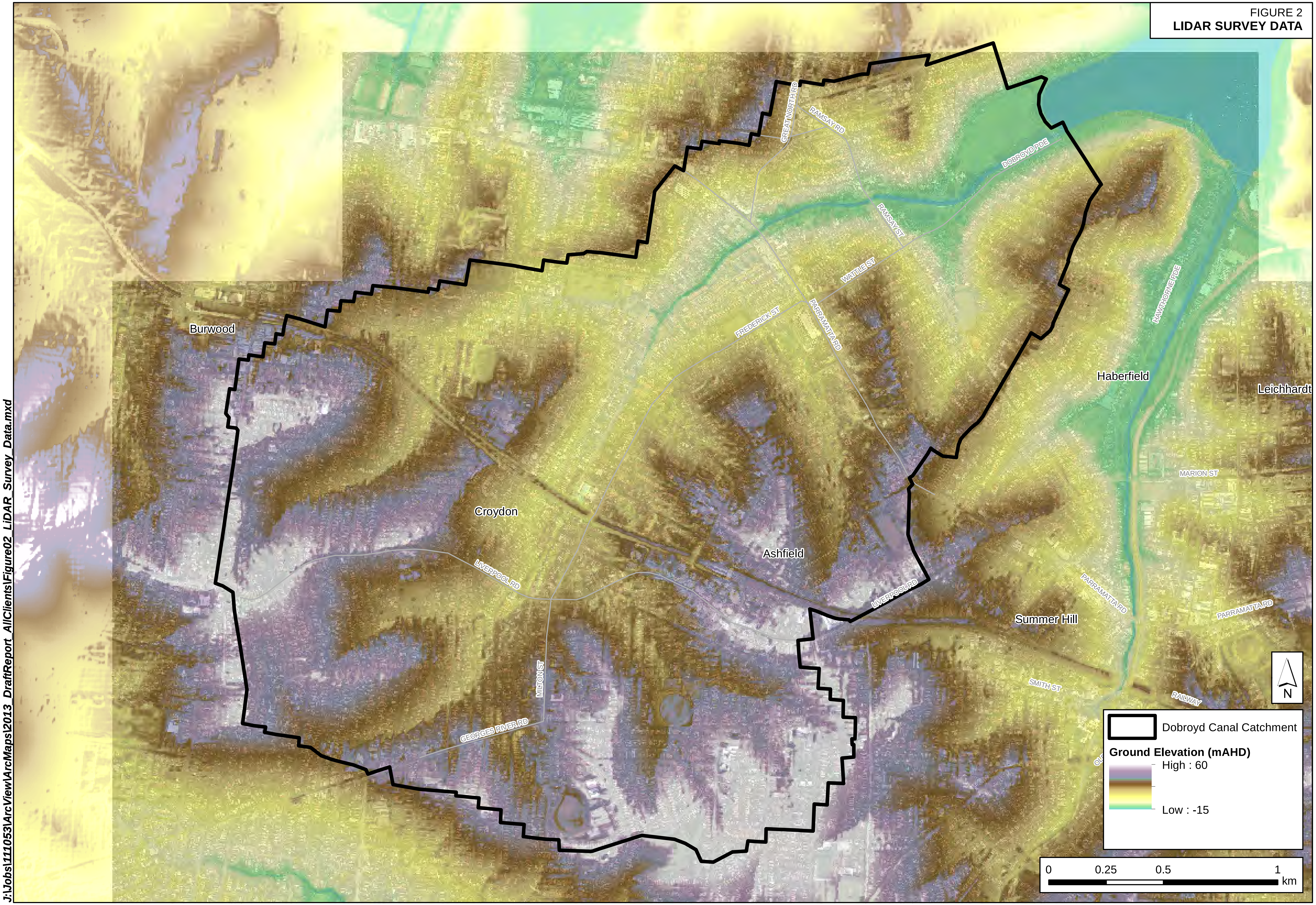
FIGURE 2
LIDAR SURVEY DATA
Burwood
Croydon
Ashfield
Haberfield
Leichhardt
Summer Hill
GREAT NORTH RD
RAMSAY RD
DOBROYD PDE
RAMSAY ST
WATTLE ST
FREDERICK ST
PARRAMATTA RD
HAWTHORNE PDE
MARION ST
LIVERPOOL RD
MILTON ST
GEORGES RIVER RD
SMITH ST
RAILWAY
N
Dobroyd Canal Catchment
Ground Elevation (mAHD)
High : 60
Low : -15
0
0.25
0.5
1
km
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FIGURE 3
CBH SURVEY DATA

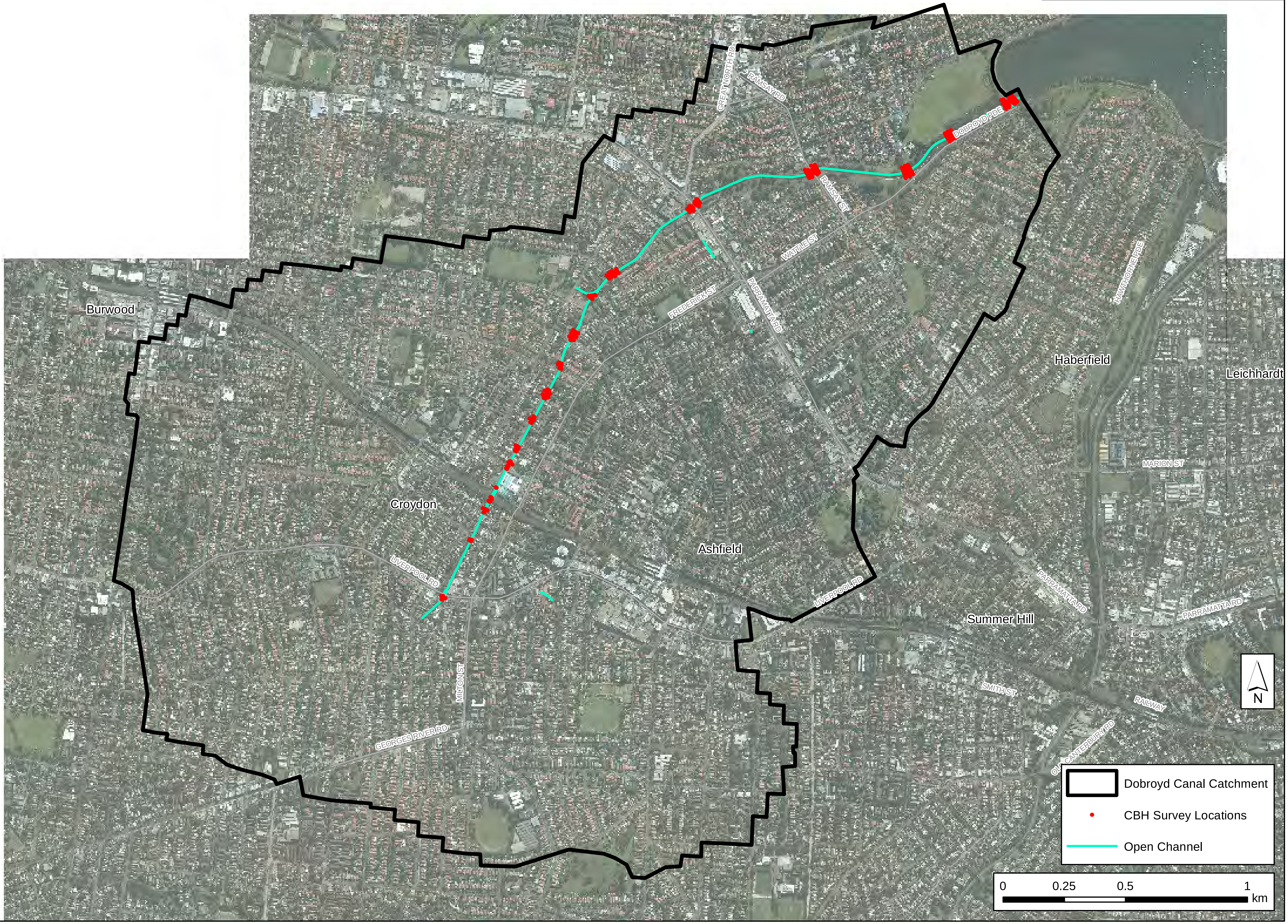

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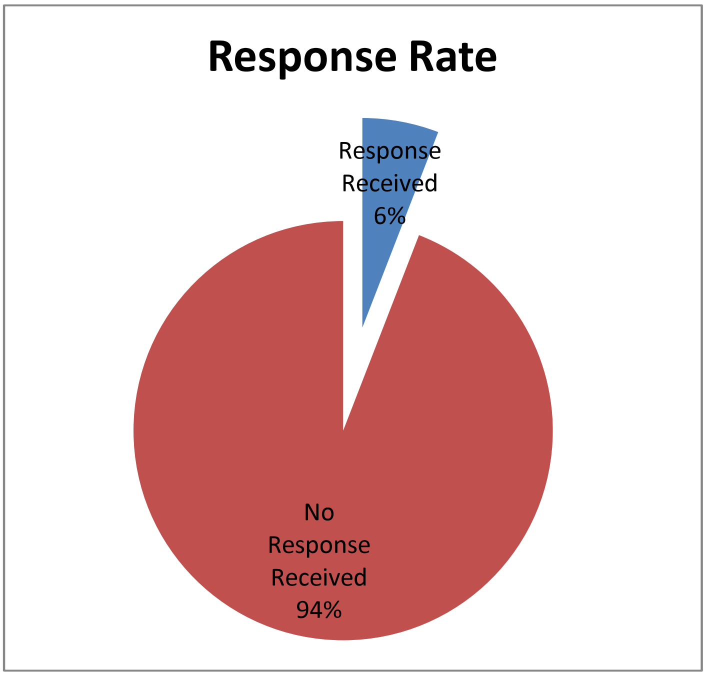
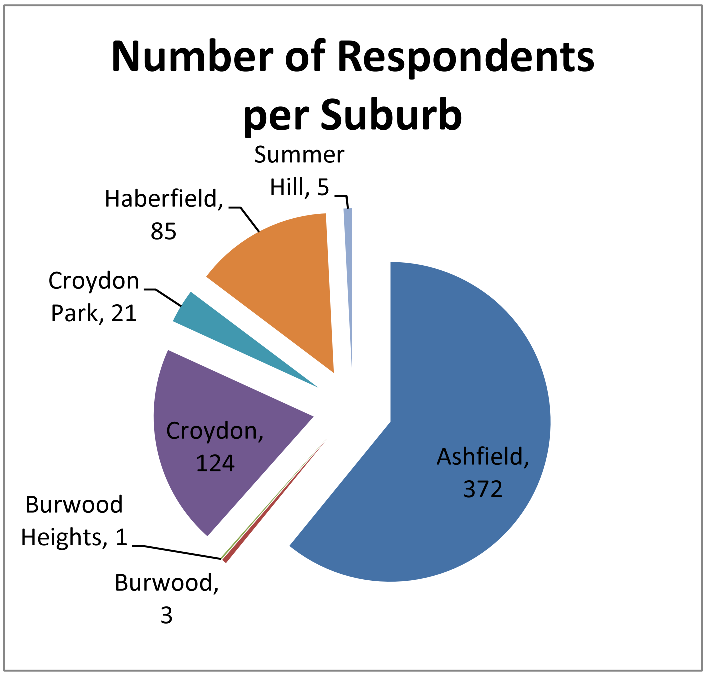
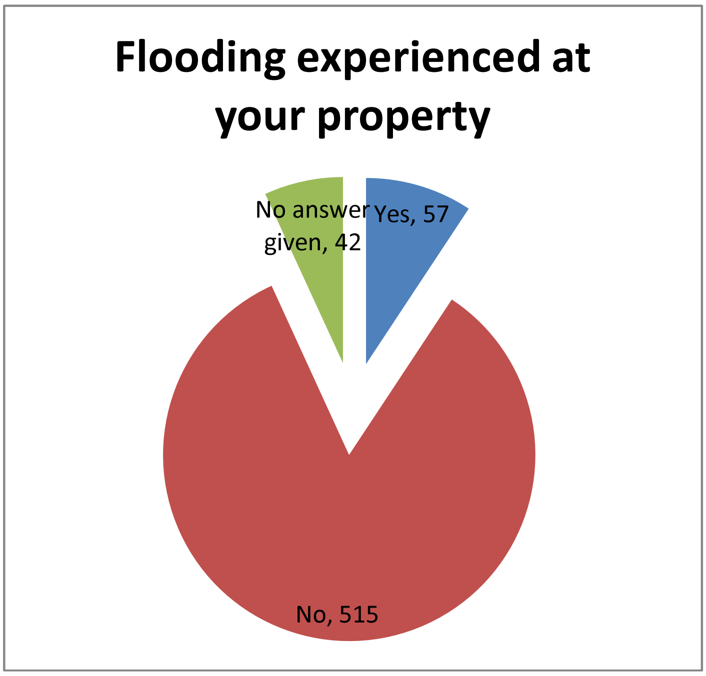
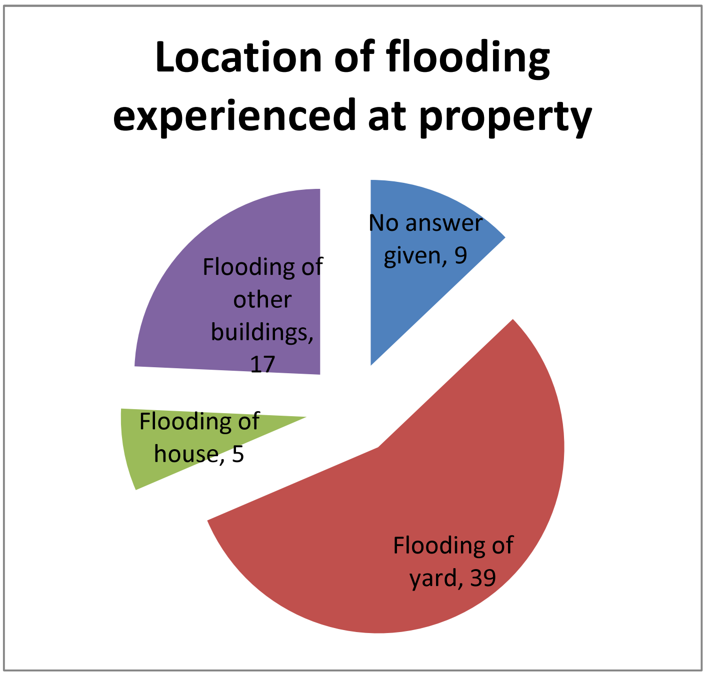
FIGURE 4A
COMMUNITY CONSULTATION
STATISTICAL ANAYLSIS









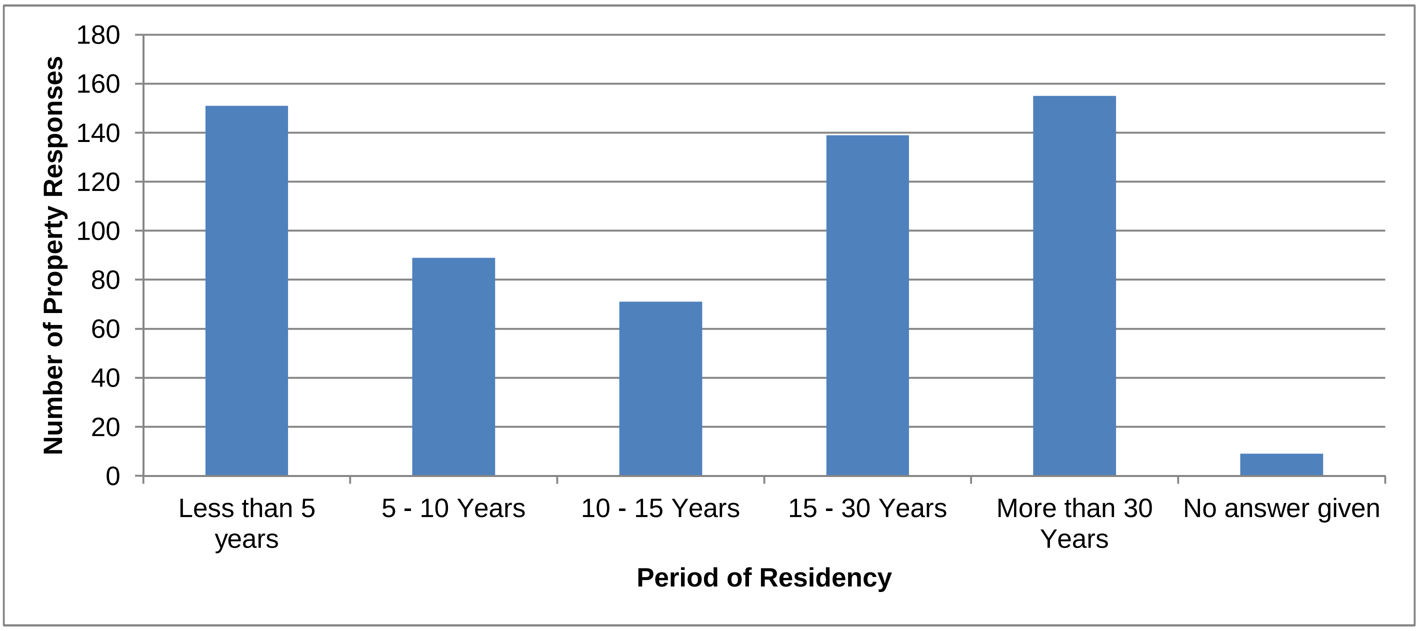


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FIGURE 4B
COMMUNITY CONSULTATION
PHOTOGRAPHS OF FLOODING PROVIDED

FIGURE 5A
HISTORIC FLOOD LEVEL LOCATIONS

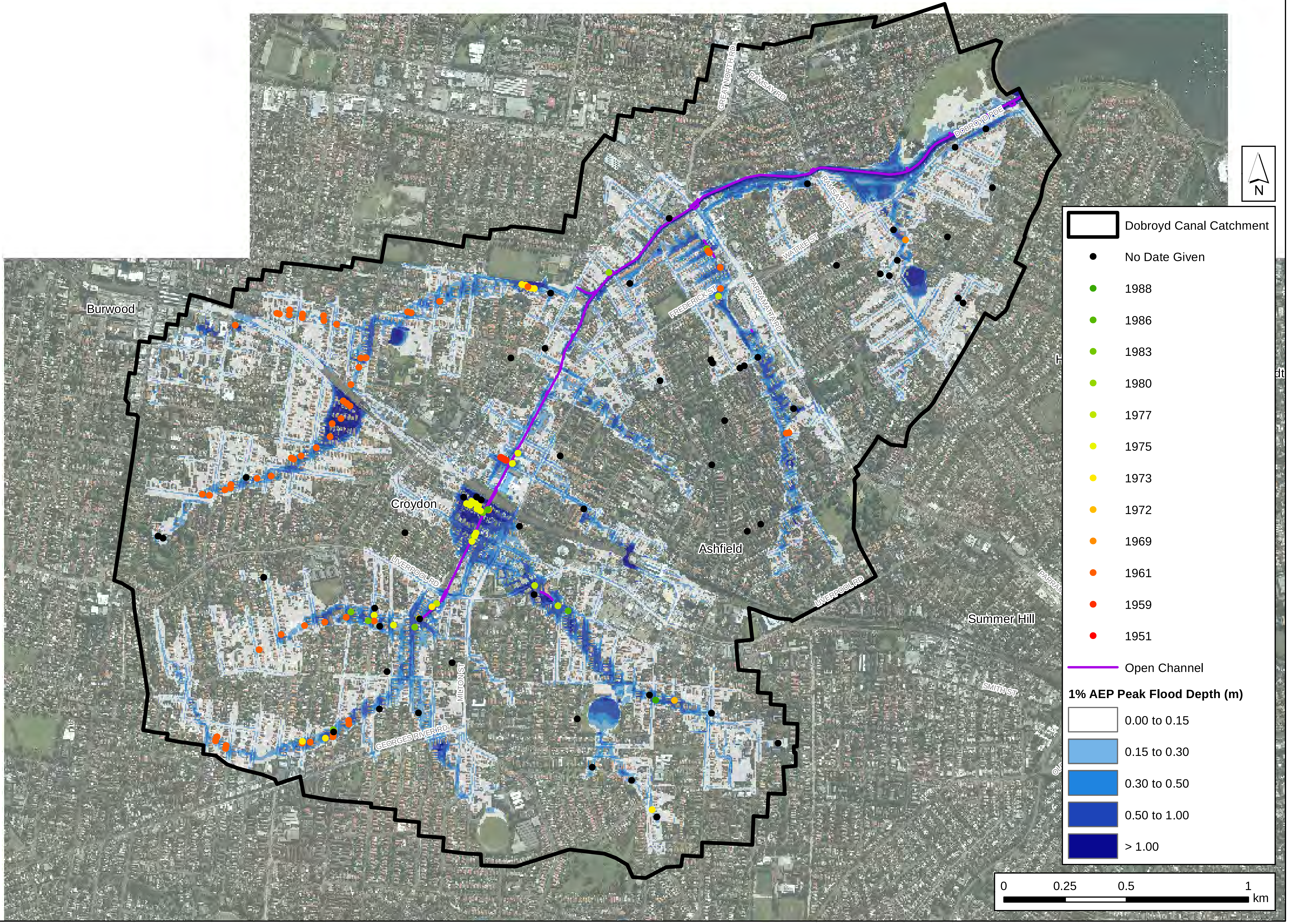

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FIGURE 5B
ROBINSON GRC CONSULTING (2002)
HOTSPOT LOCATIONS

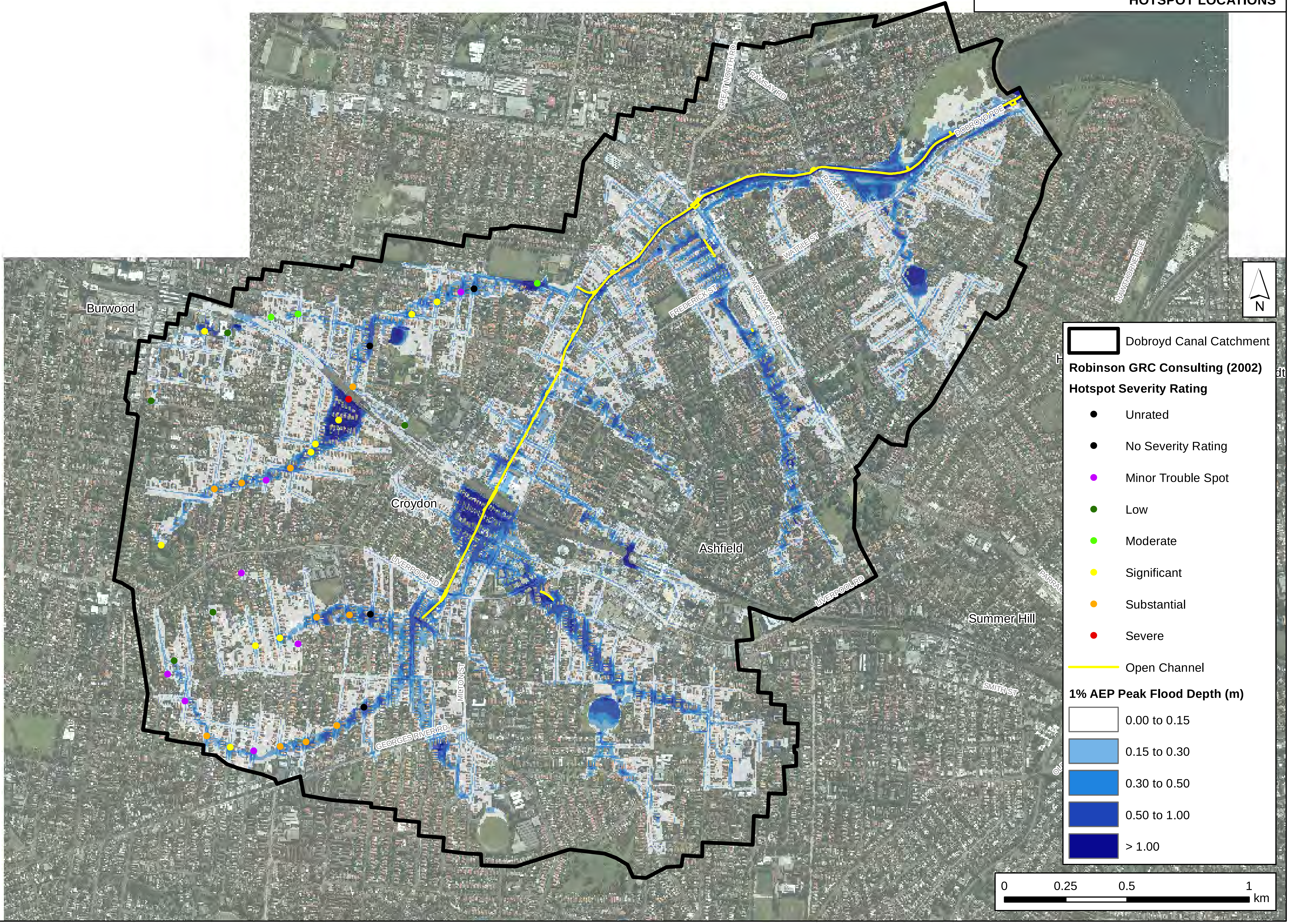

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FIGURE 6
GAUGE LOCATIONS

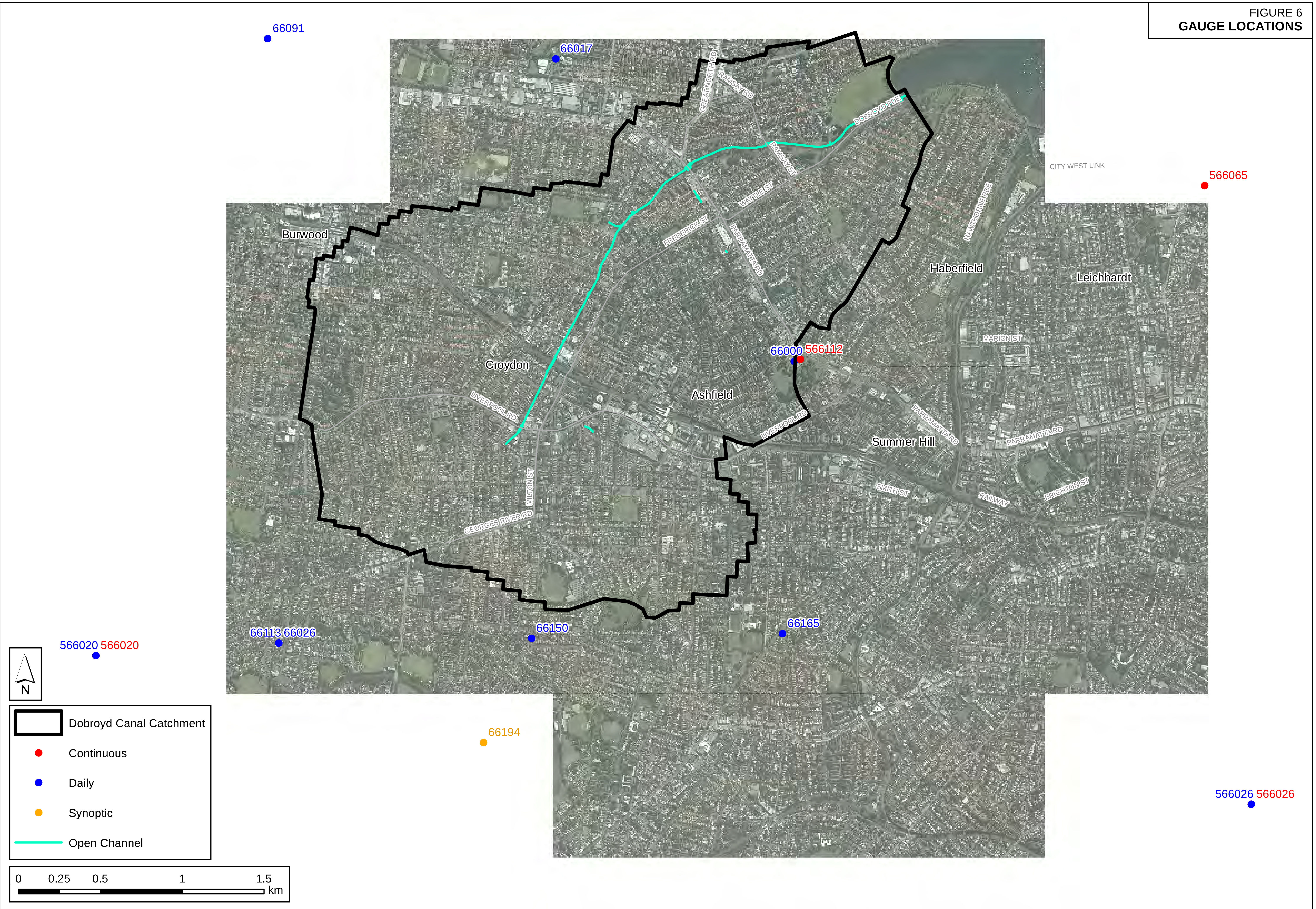

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FIGURE 7
HYDROLOGIC MODEL SCHEMATISATION

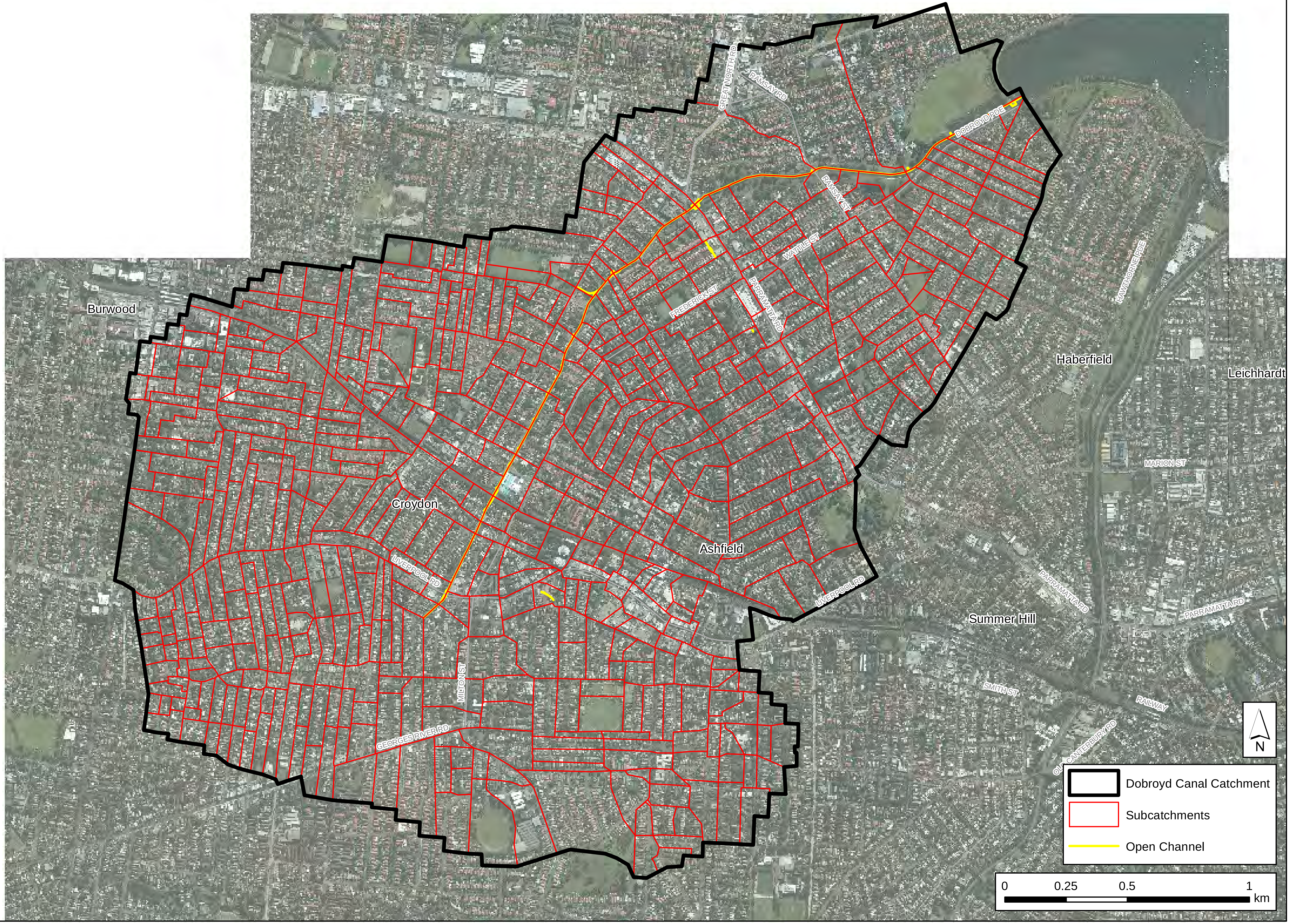

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FIGURE 8
HYDRAULIC MODEL SCHEMATISATION

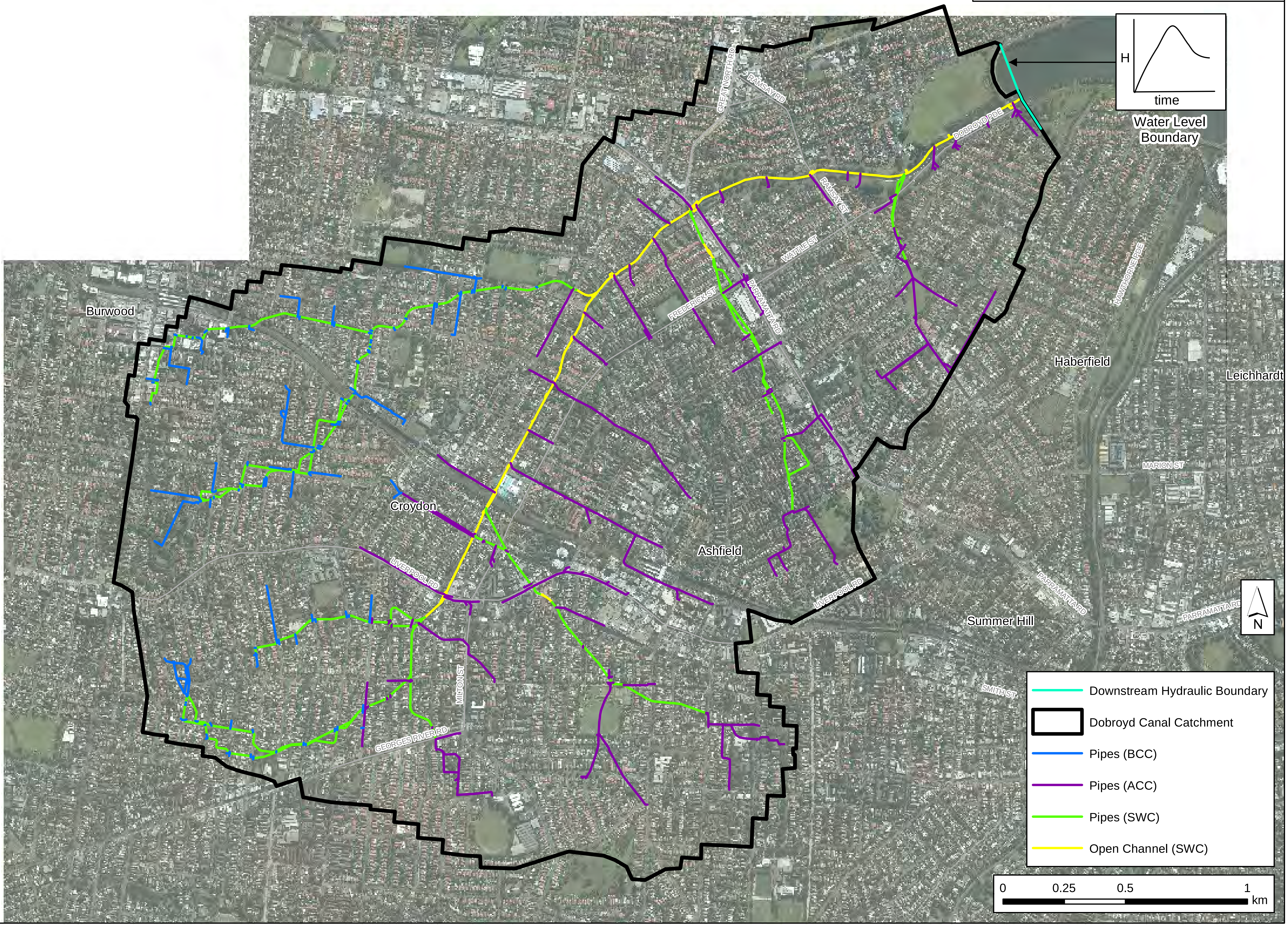

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FIGURE 9
HYDRAULIC MODEL ROUGHNESS VALUES

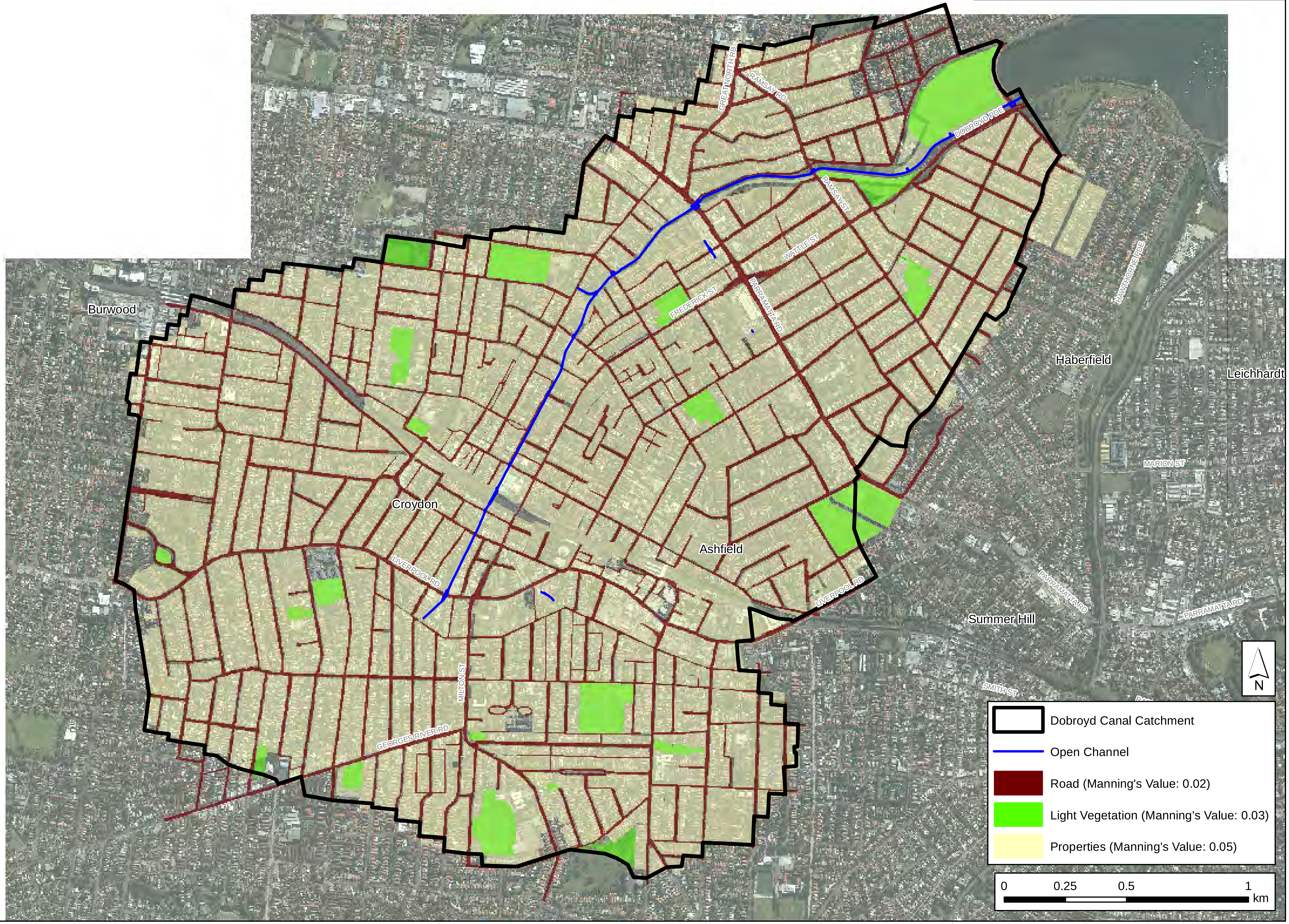

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FIGURE 10
RESULTS LAYOUT

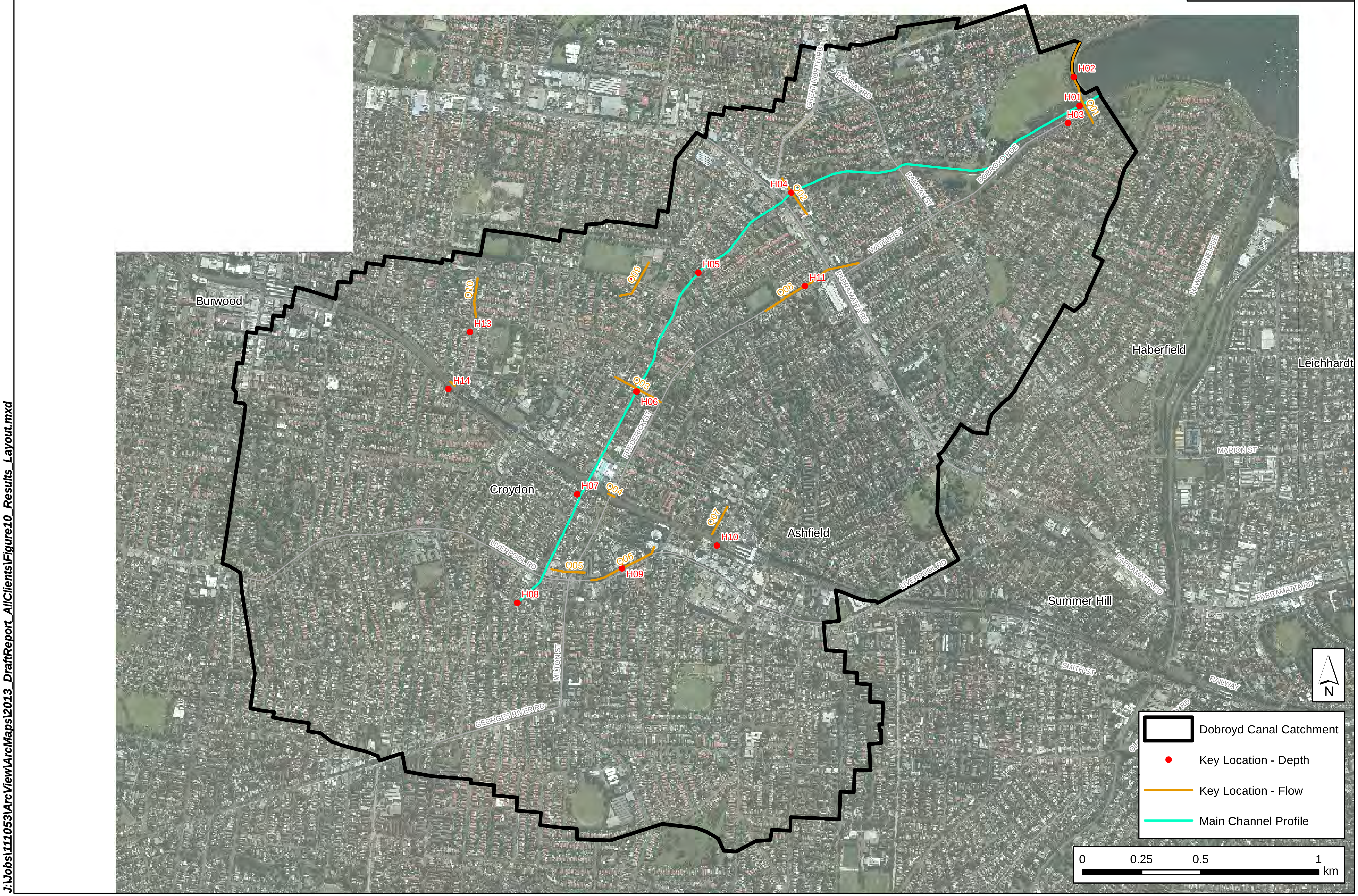

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FIGURE 11A
**PEAK FLOOD LEVEL PROFILES
DESIGN EVENTS**

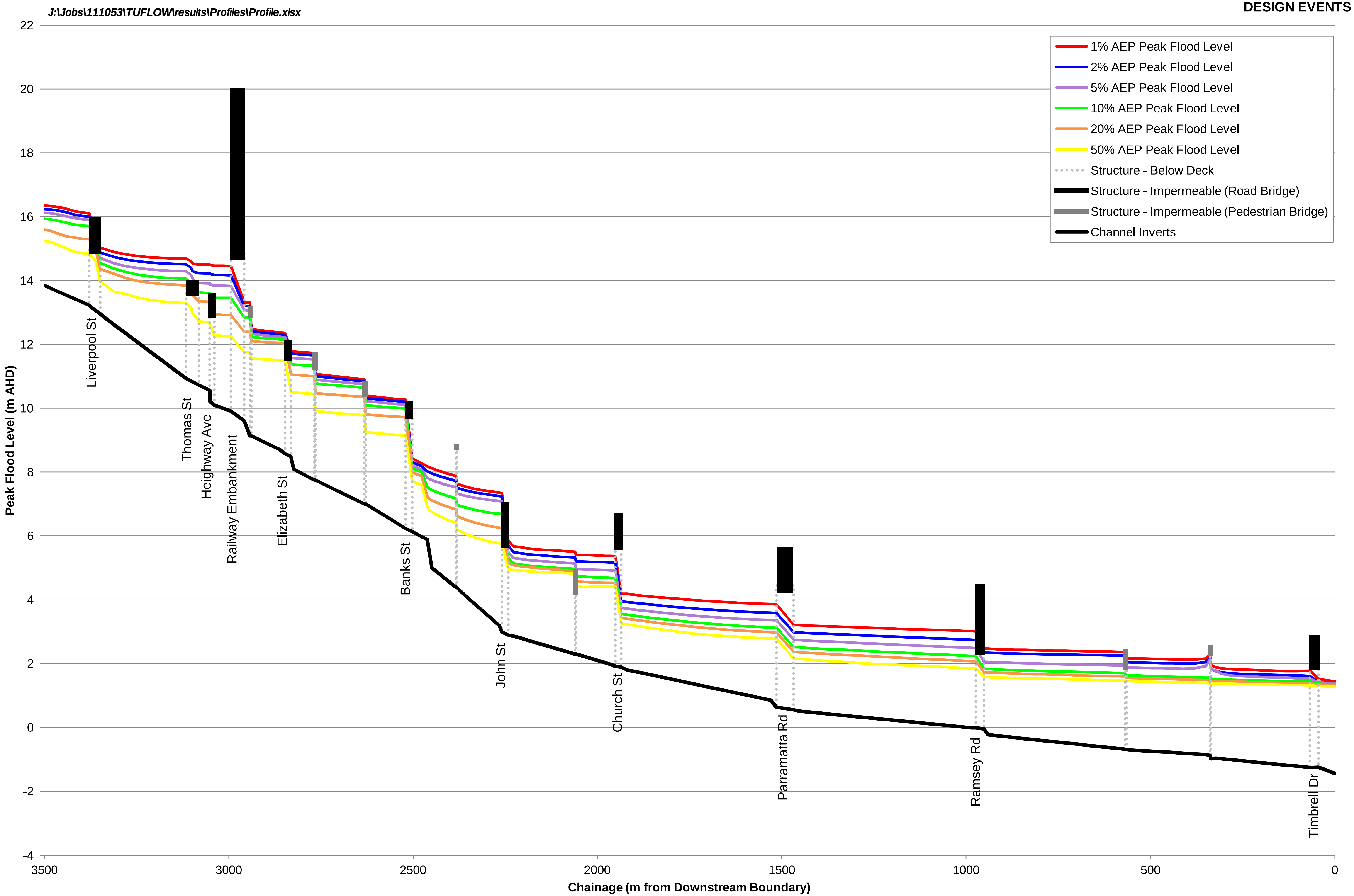
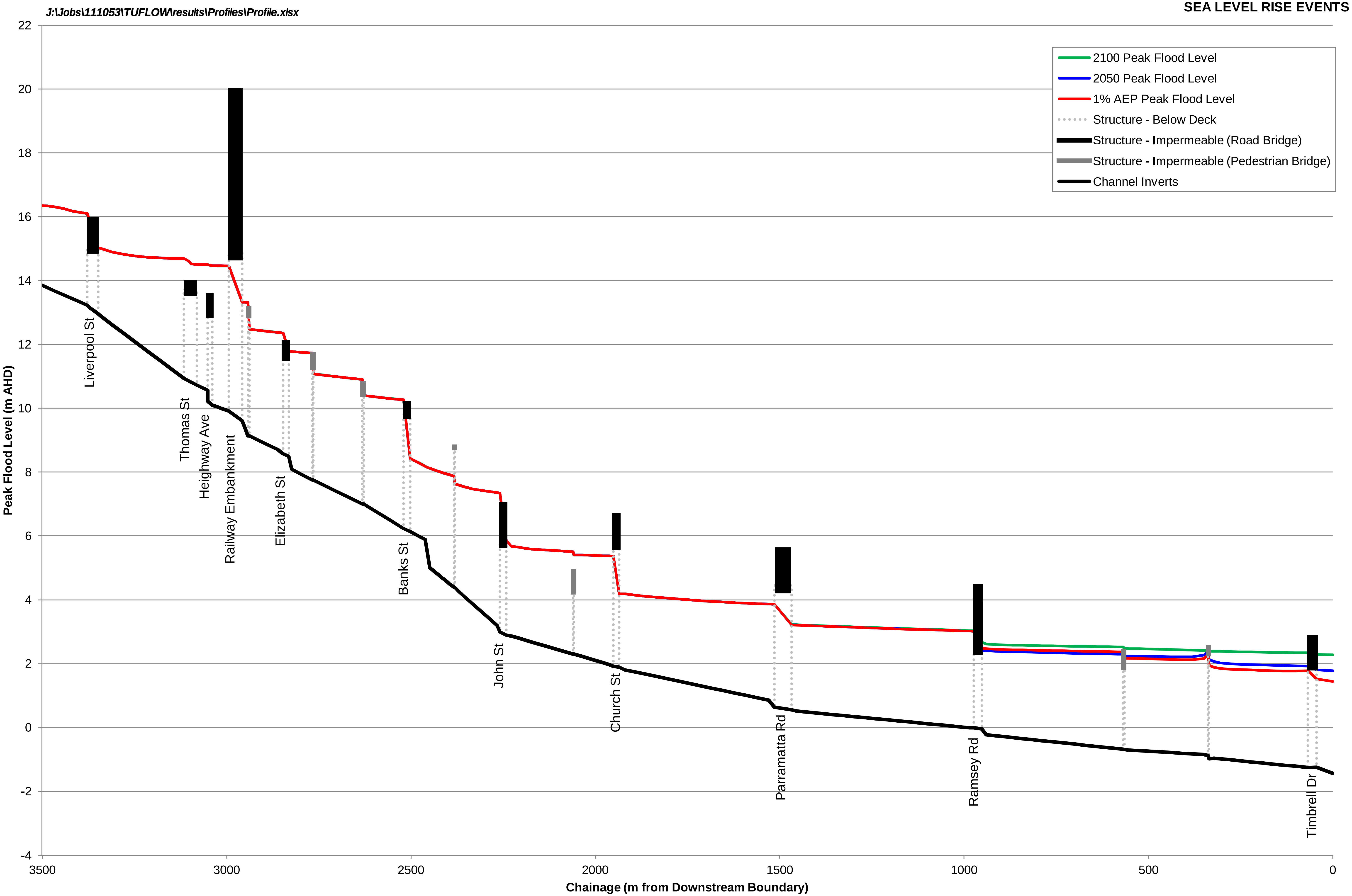


FIGURE 11B
PEAK FLOOD LEVEL PROFILES
SEA LEVEL RISE EVENTS



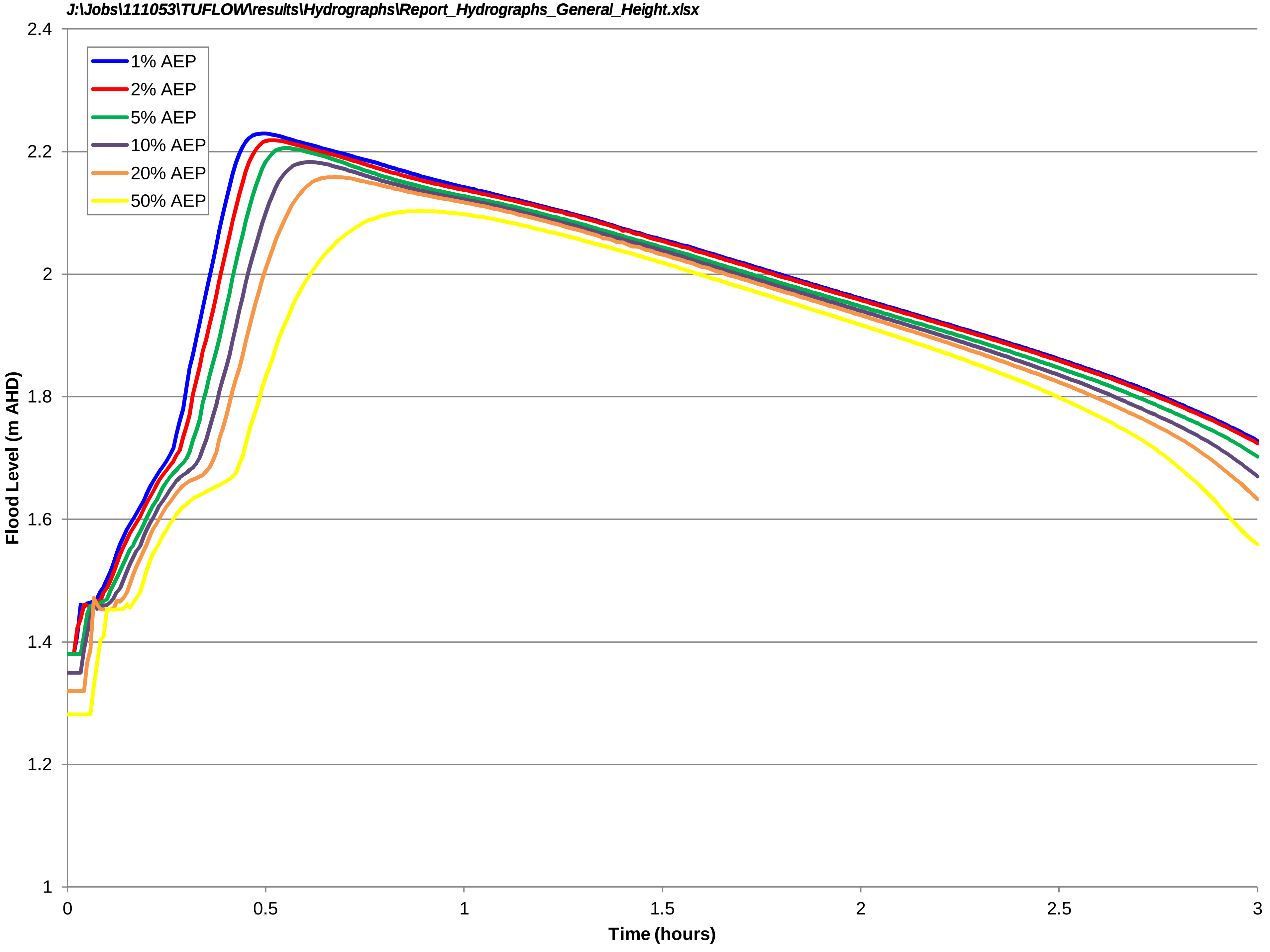


FIGURE 12A
DESIGN FLOOD LEVEL HYDROGRAPH
DOBROYD PARADE

J:\Jobs\111053\TUFLOW\results\Hydrographs\Report_Hydrographs_General_Height.xlsx

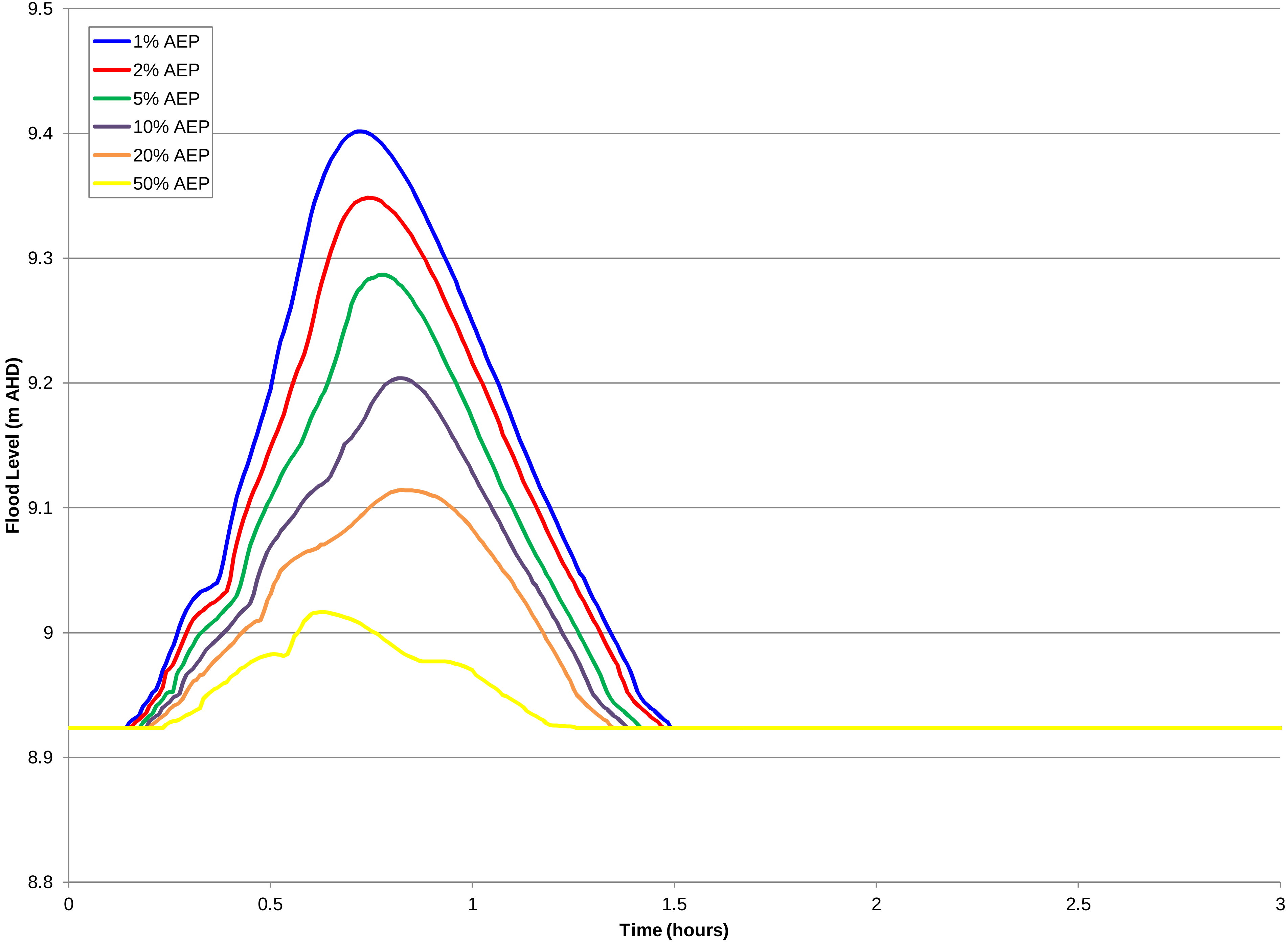


FIGURE 12B

DESIGN FLOOD LEVEL HYDROGRAPH

FREDERICK STREET

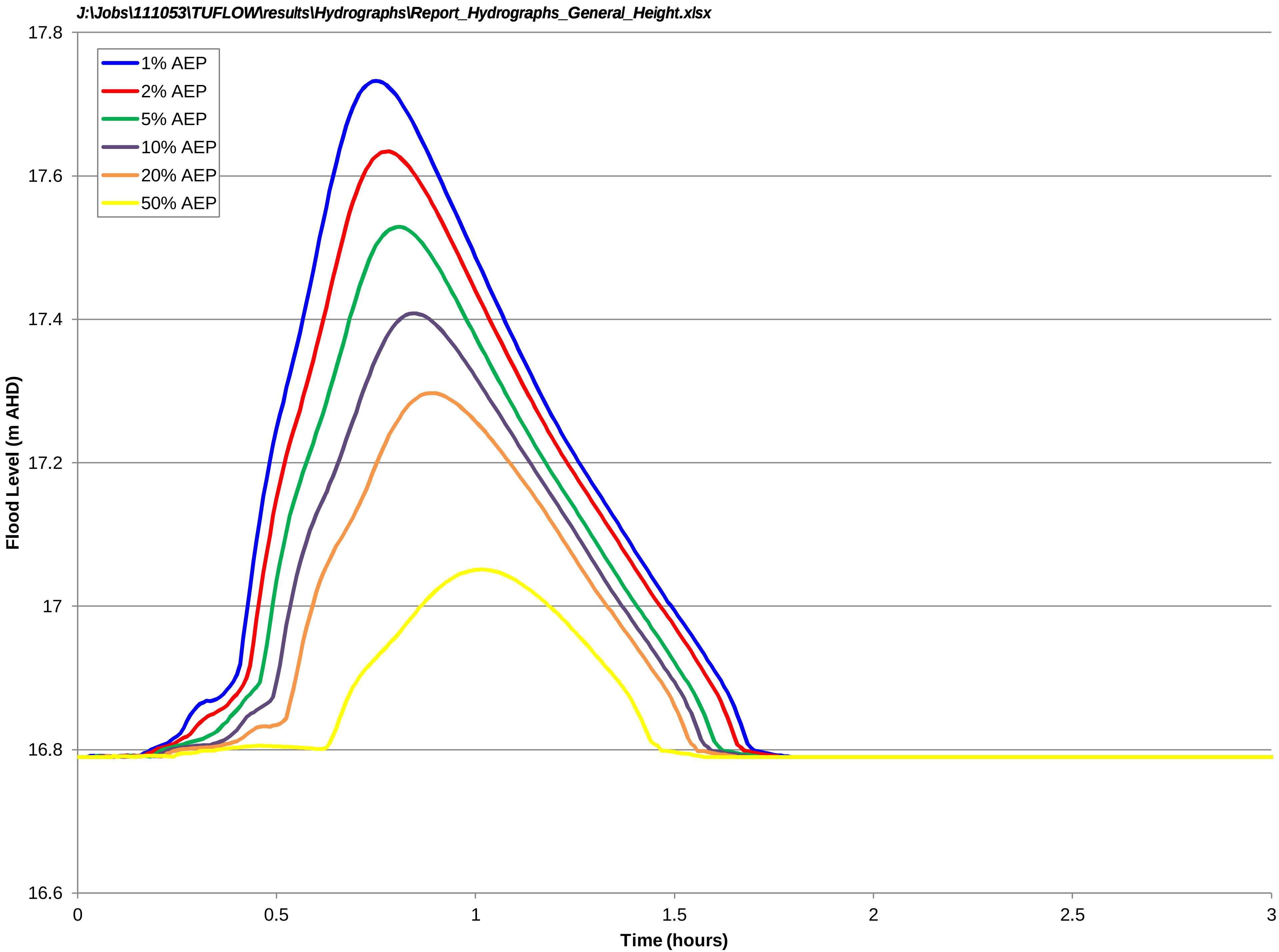


FIGURE 12C
DESIGN FLOOD LEVEL HYDROGRAPH
HUME HIGHWAY

FIGURE 13
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS
50% AEP

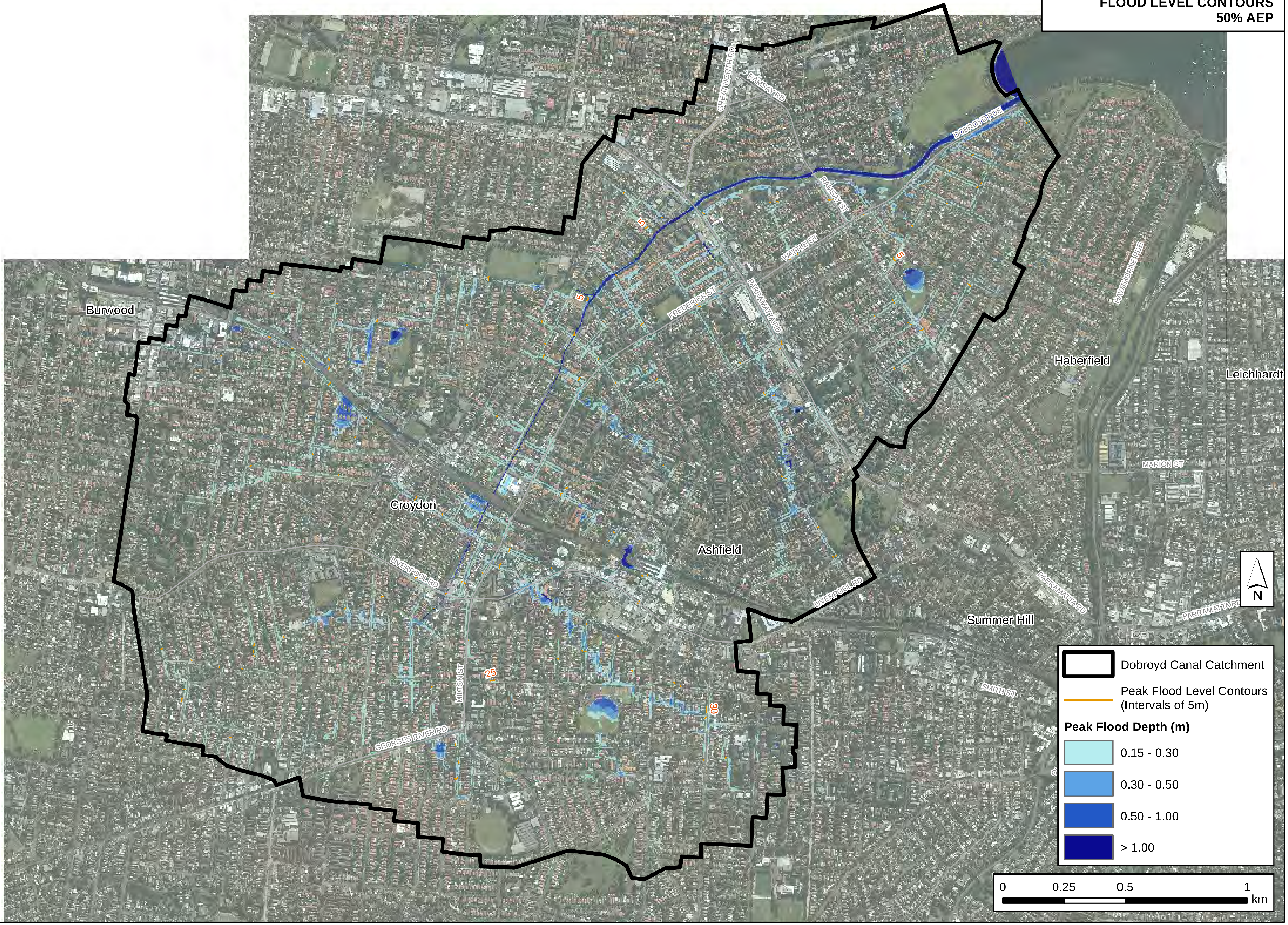


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FIGURE 14
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 20% AEP

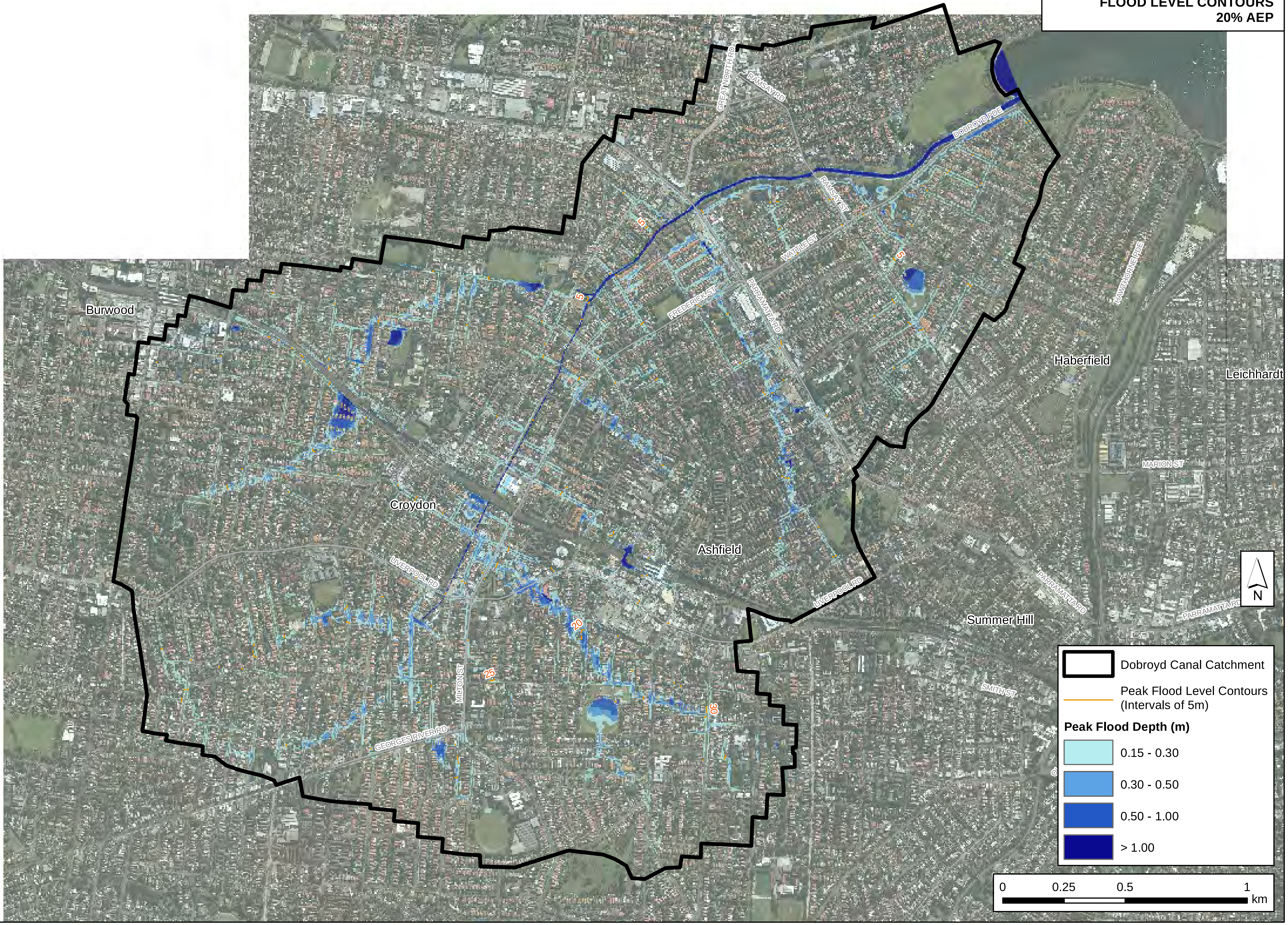

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FIGURE 15
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 10% AEP

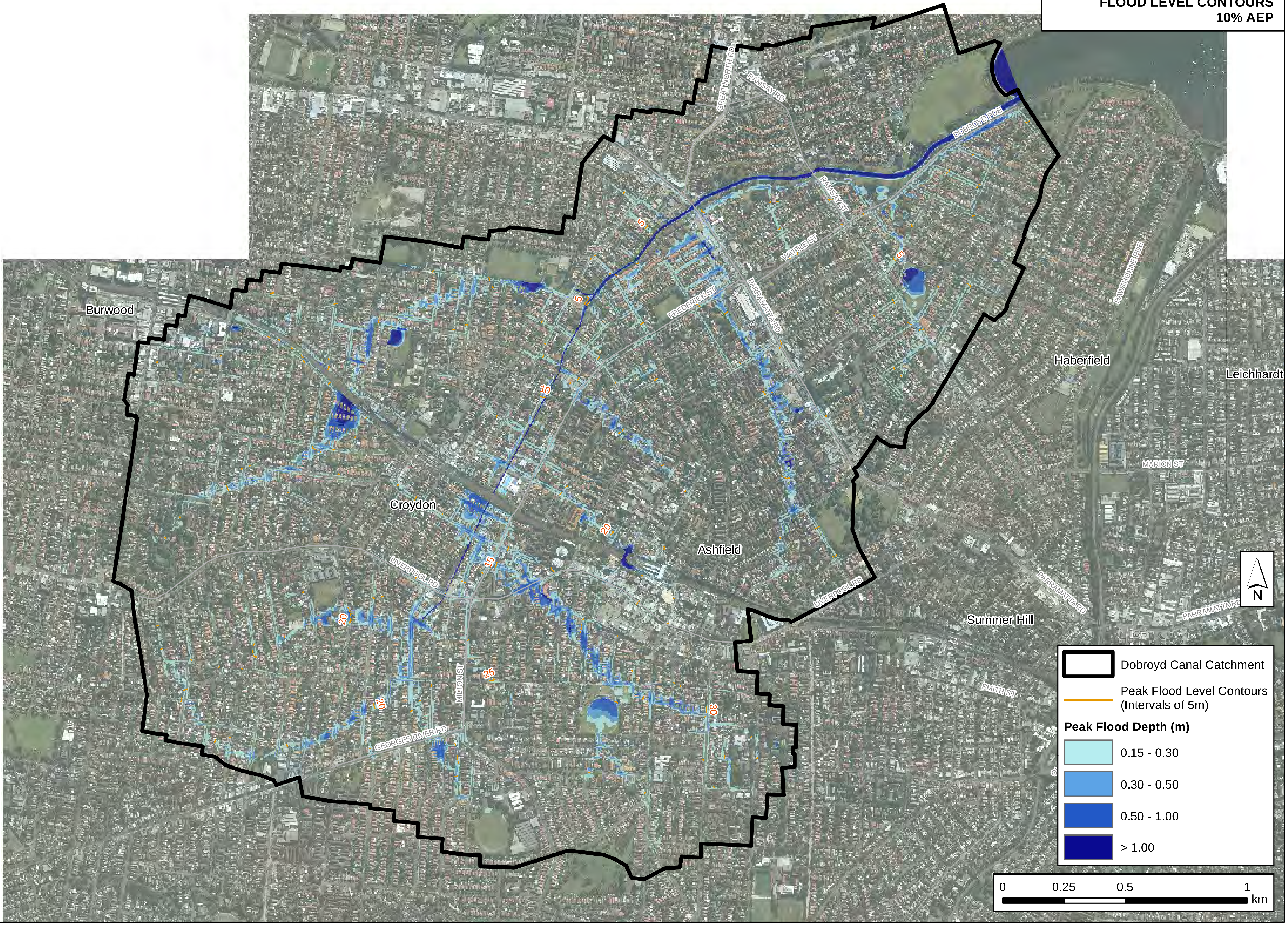

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FIGURE 16
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 5% AEP

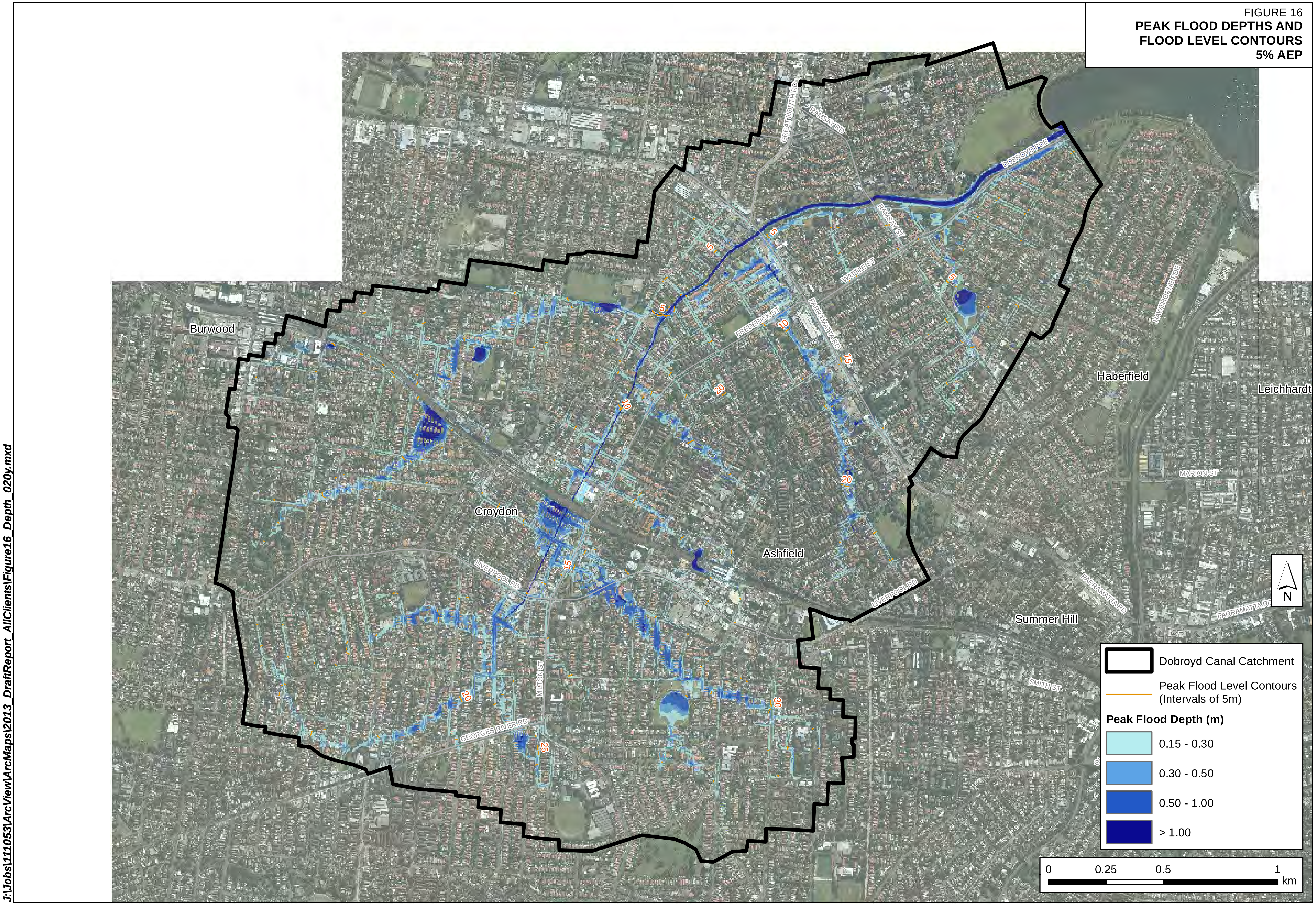

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FIGURE 17
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 2% AEP

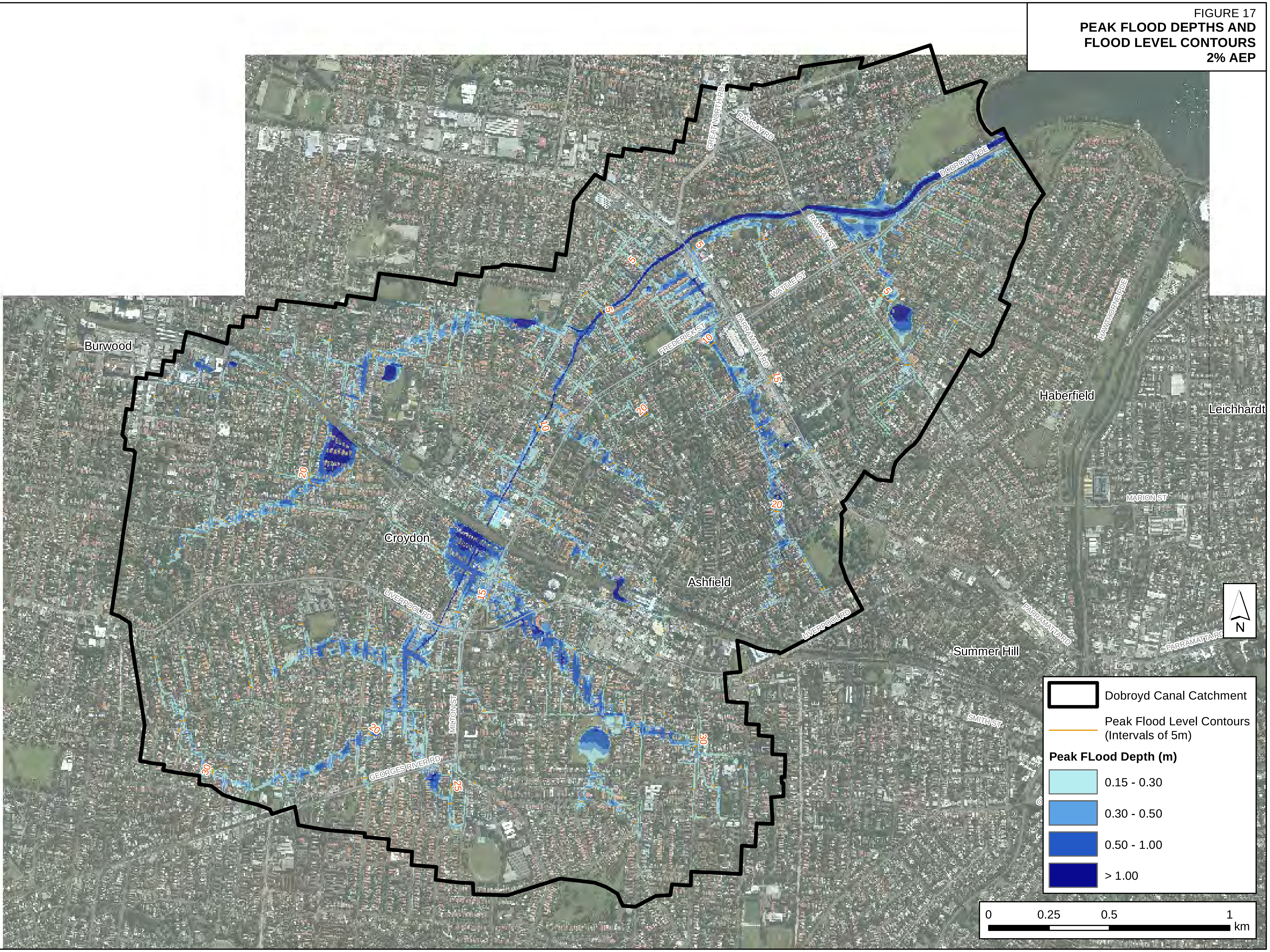

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FIGURE 18
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 1% AEP

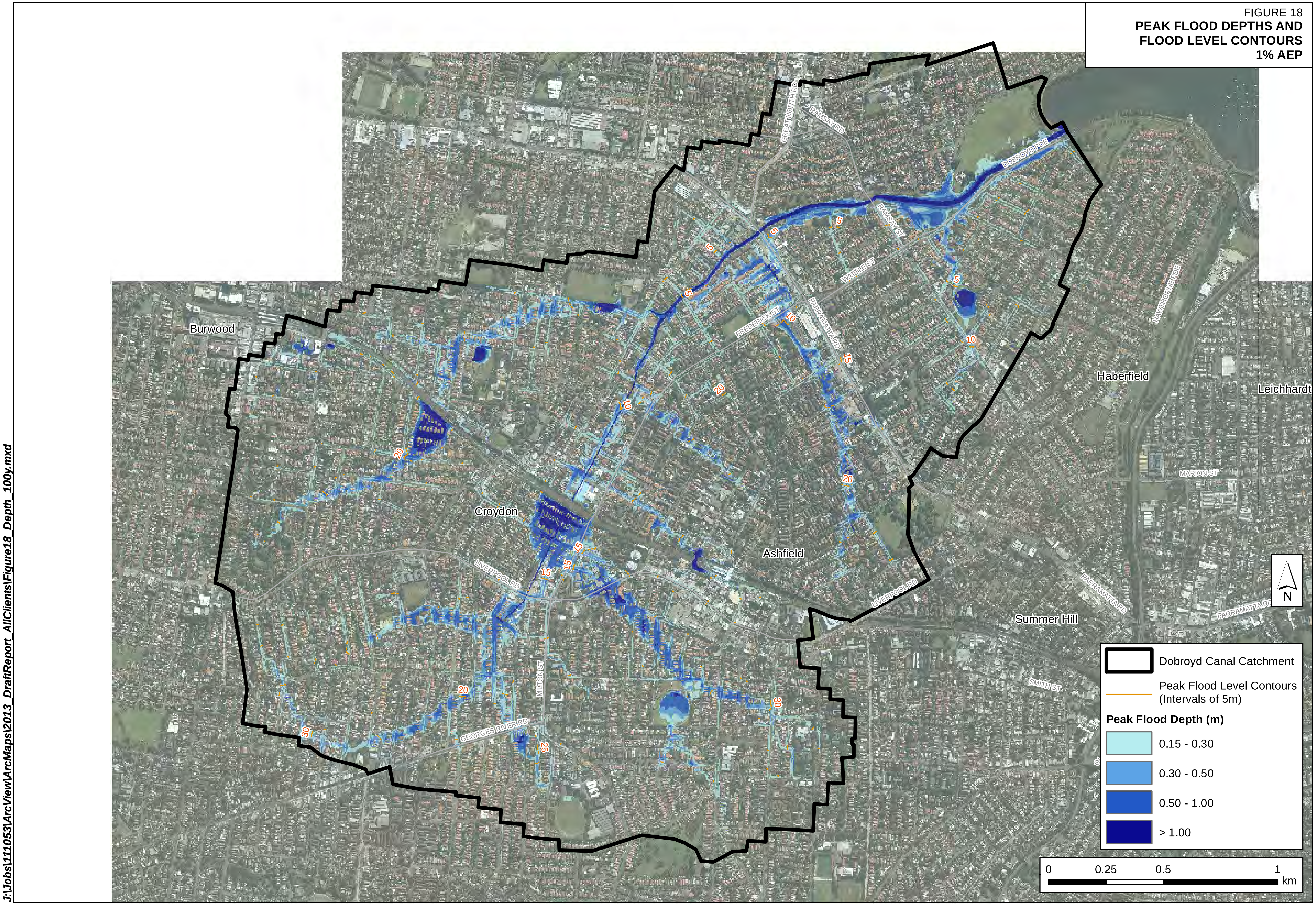

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FIGURE 19
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PMF

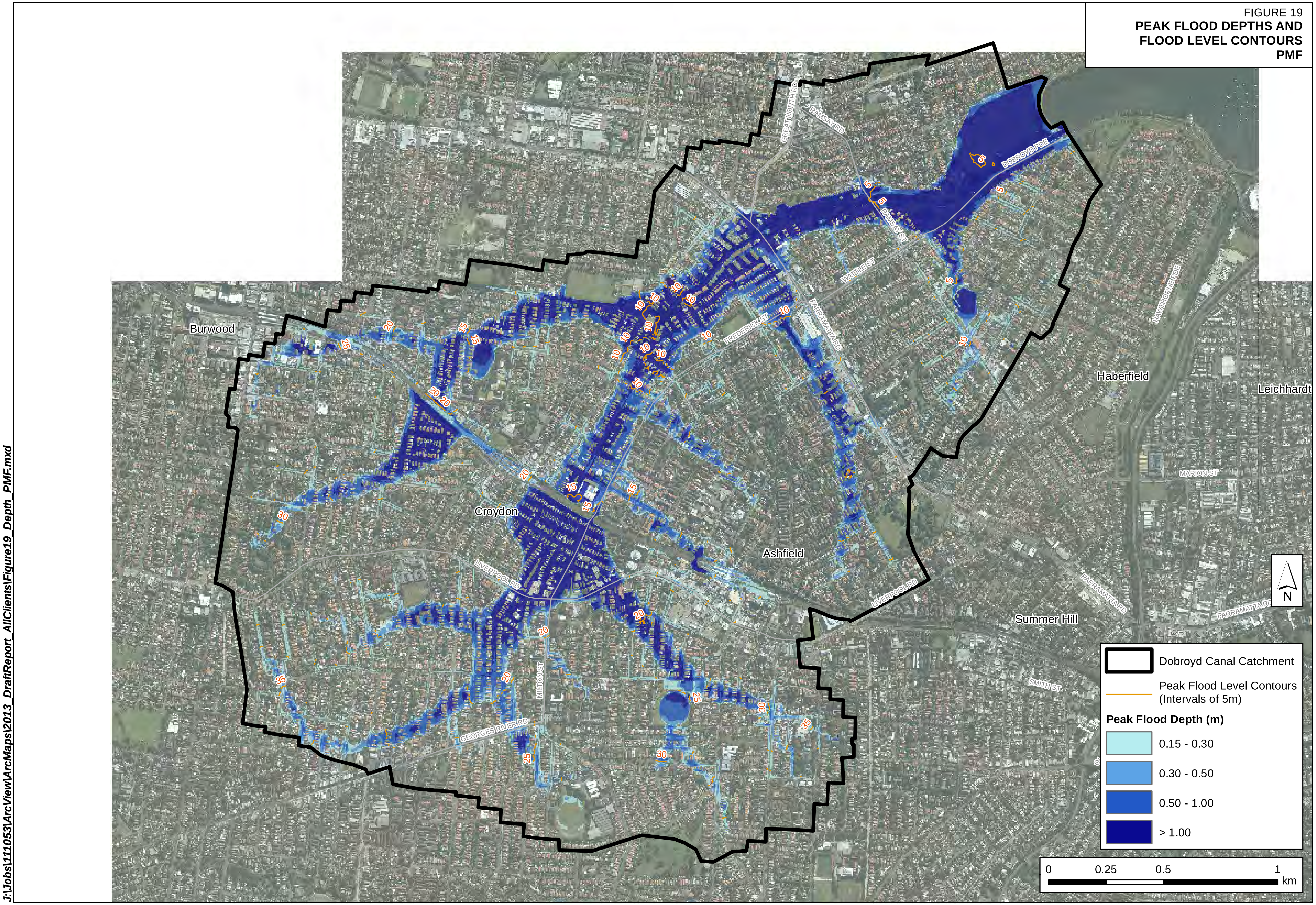

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FIGURE 20
PEAK FLOOD VELOCITY
1% AEP

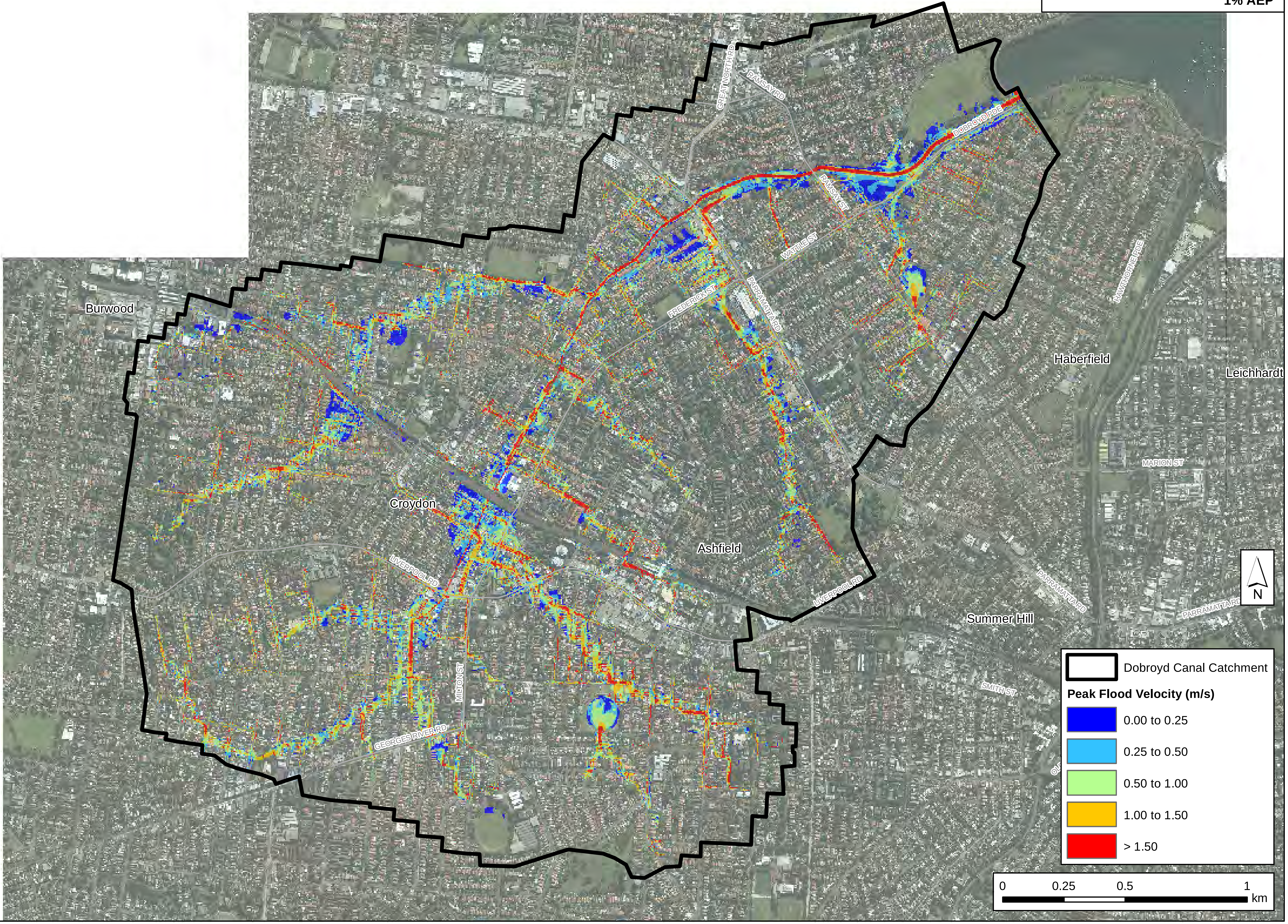

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FIGURE 21
PROVISIONAL HYDRAULIC HAZARD
20% AEP

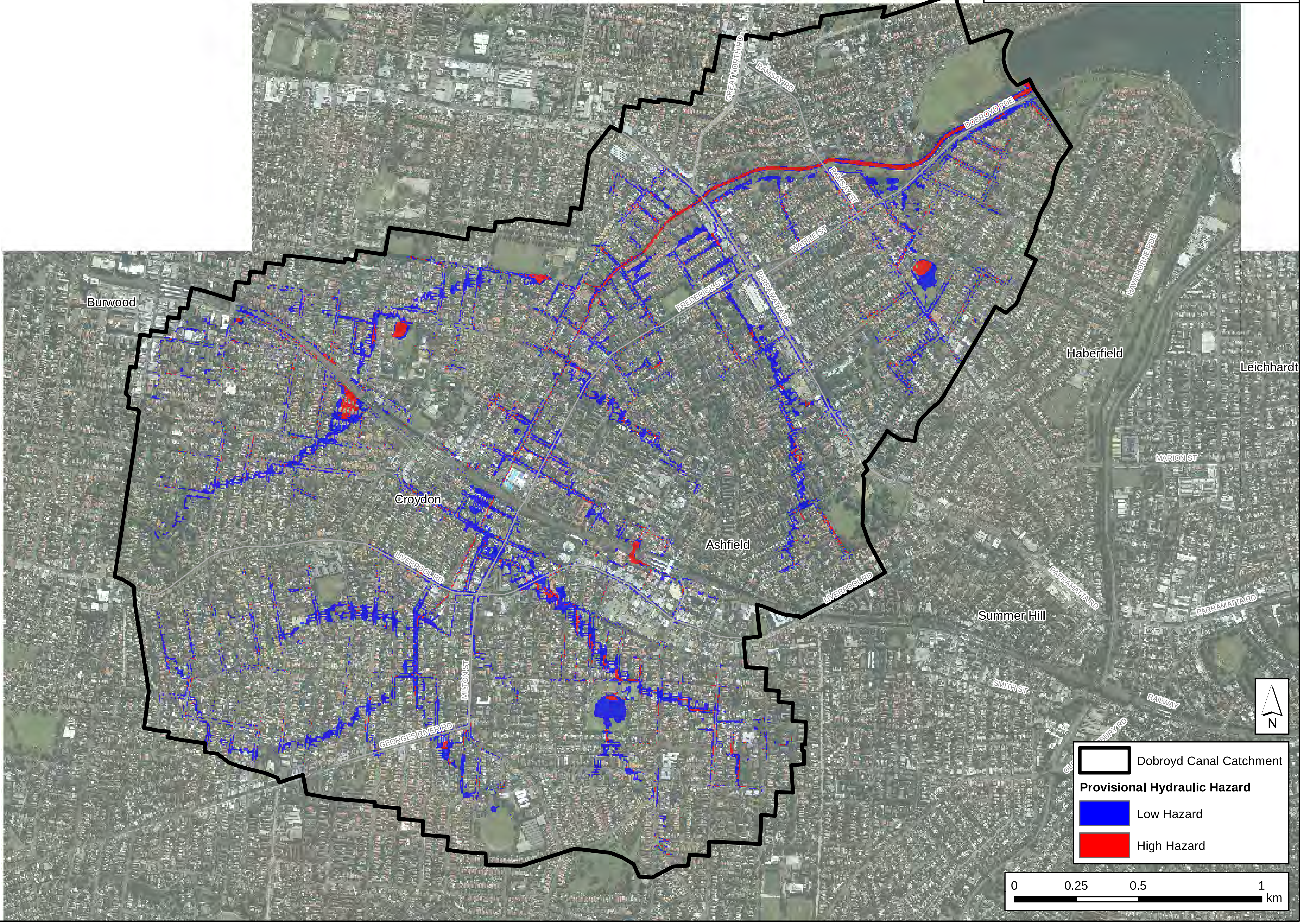

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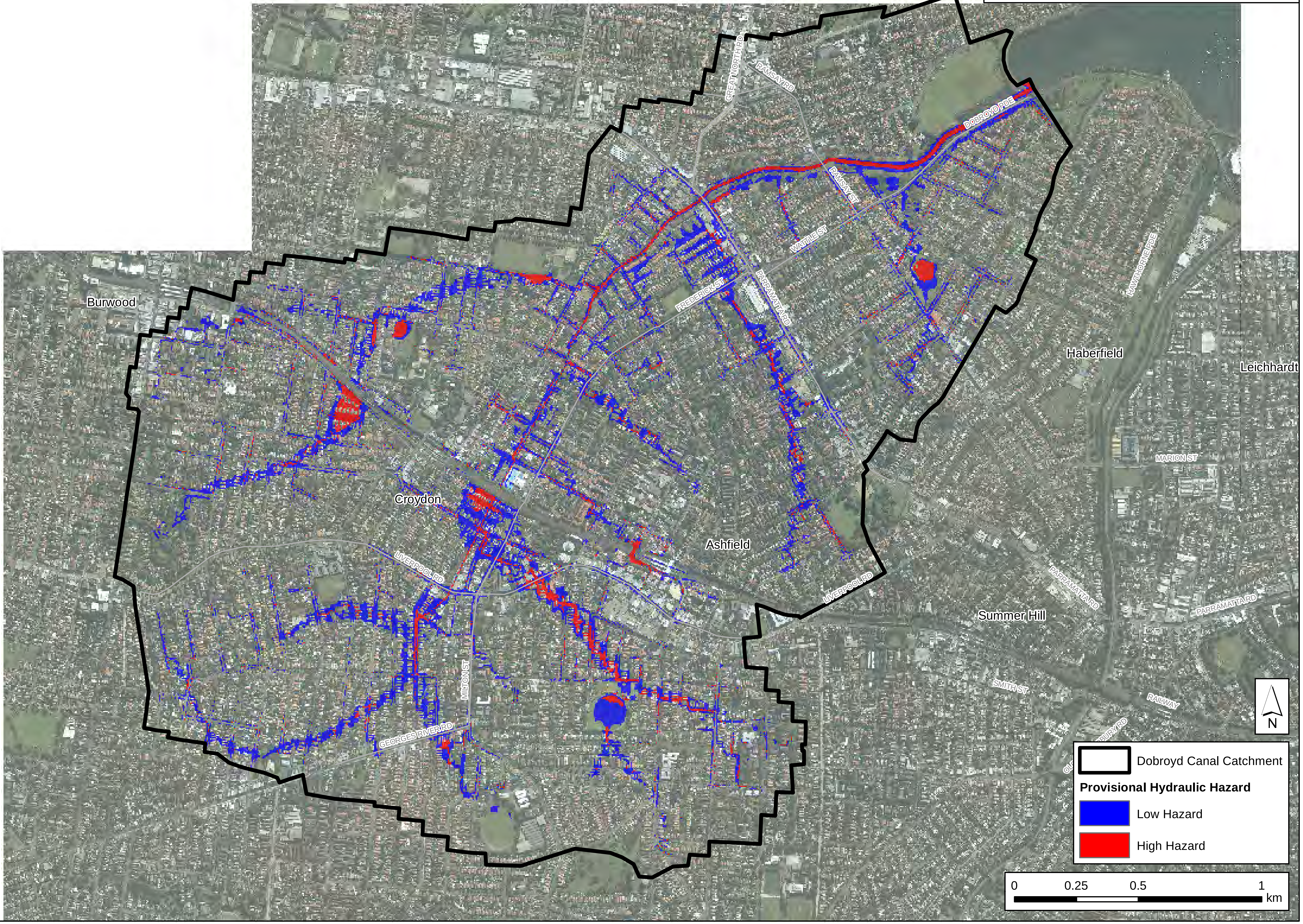
FIGURE 22
PROVISIONAL HYDRAULIC HAZARD
5% AEP



J:\Jobs\111053\ArcView\ArcMaps\2013_DraftReport_AllClients\Figure22_Hazard_020y.mxd

FIGURE 23
PROVISIONAL HYDRAULIC HAZARD
1% AEP

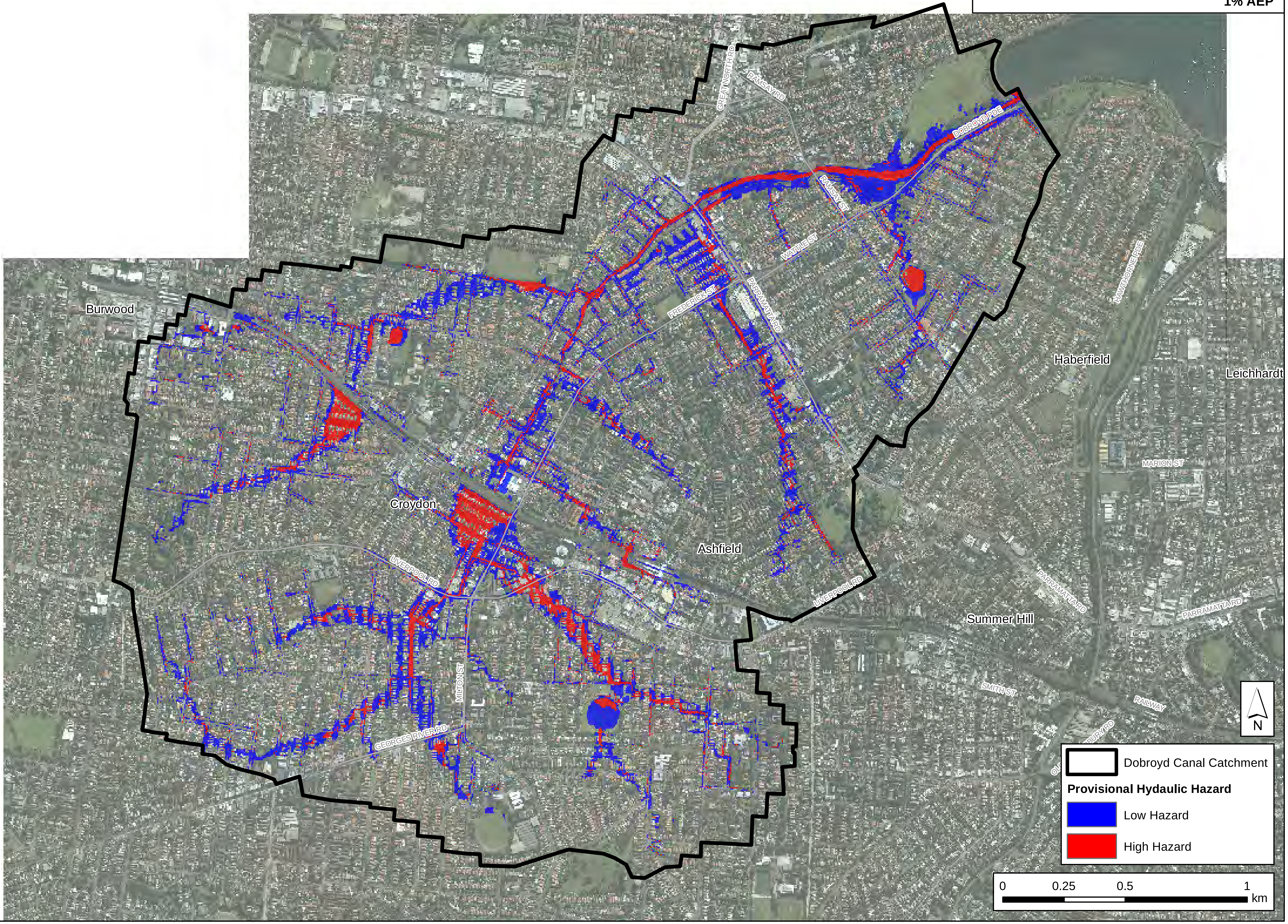


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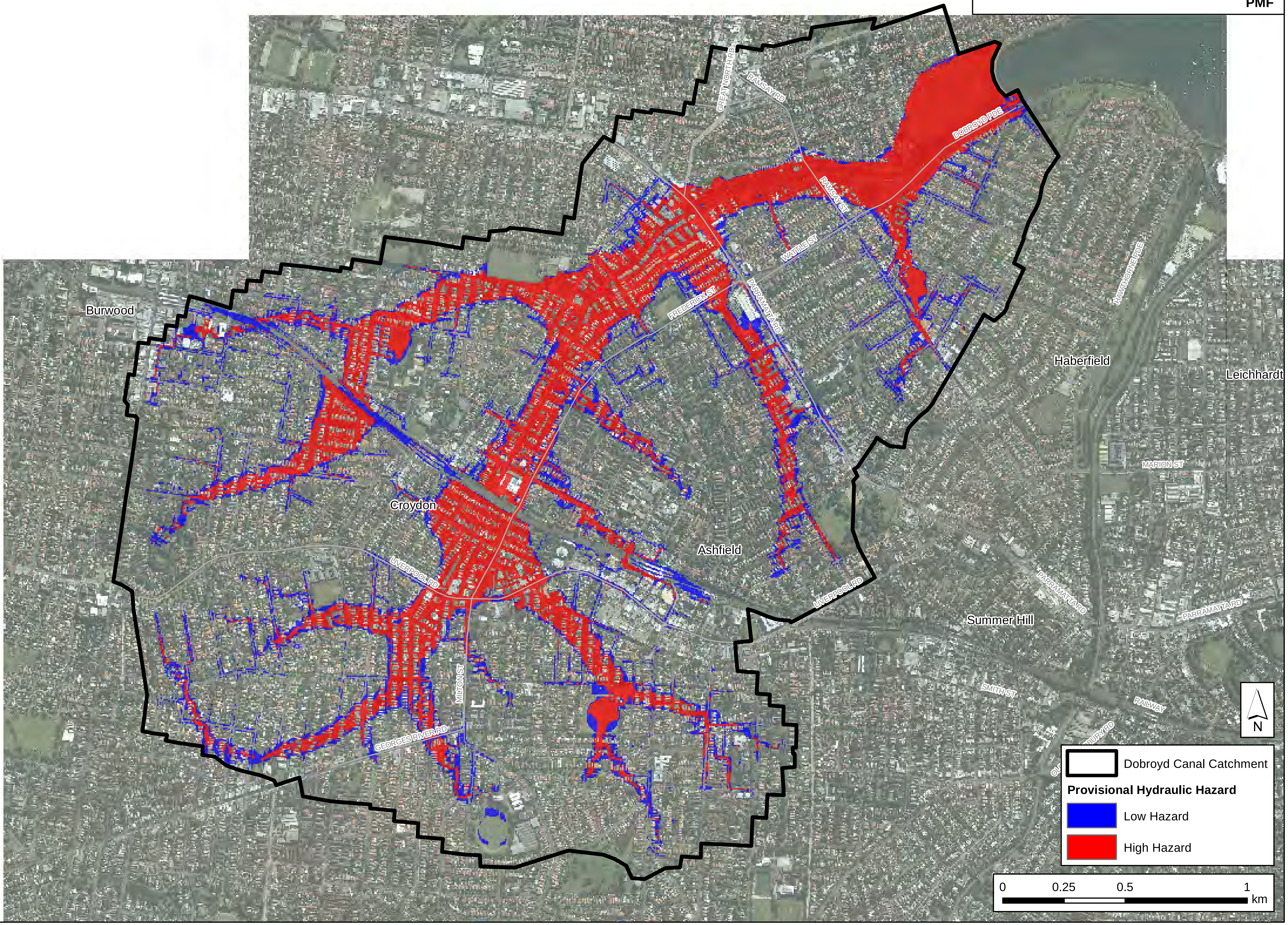
FIGURE 24
PROVISIONAL HYDRAULIC HAZARD
PMF



Dobroyd Canal Catchment
Provisional Hydraulic Hazard
Low Hazard
High Hazard

0 0.25 0.5 1 km

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FIGURE 25
PROVISIONAL HYDRAULIC CATEGORISATION
20% AEP

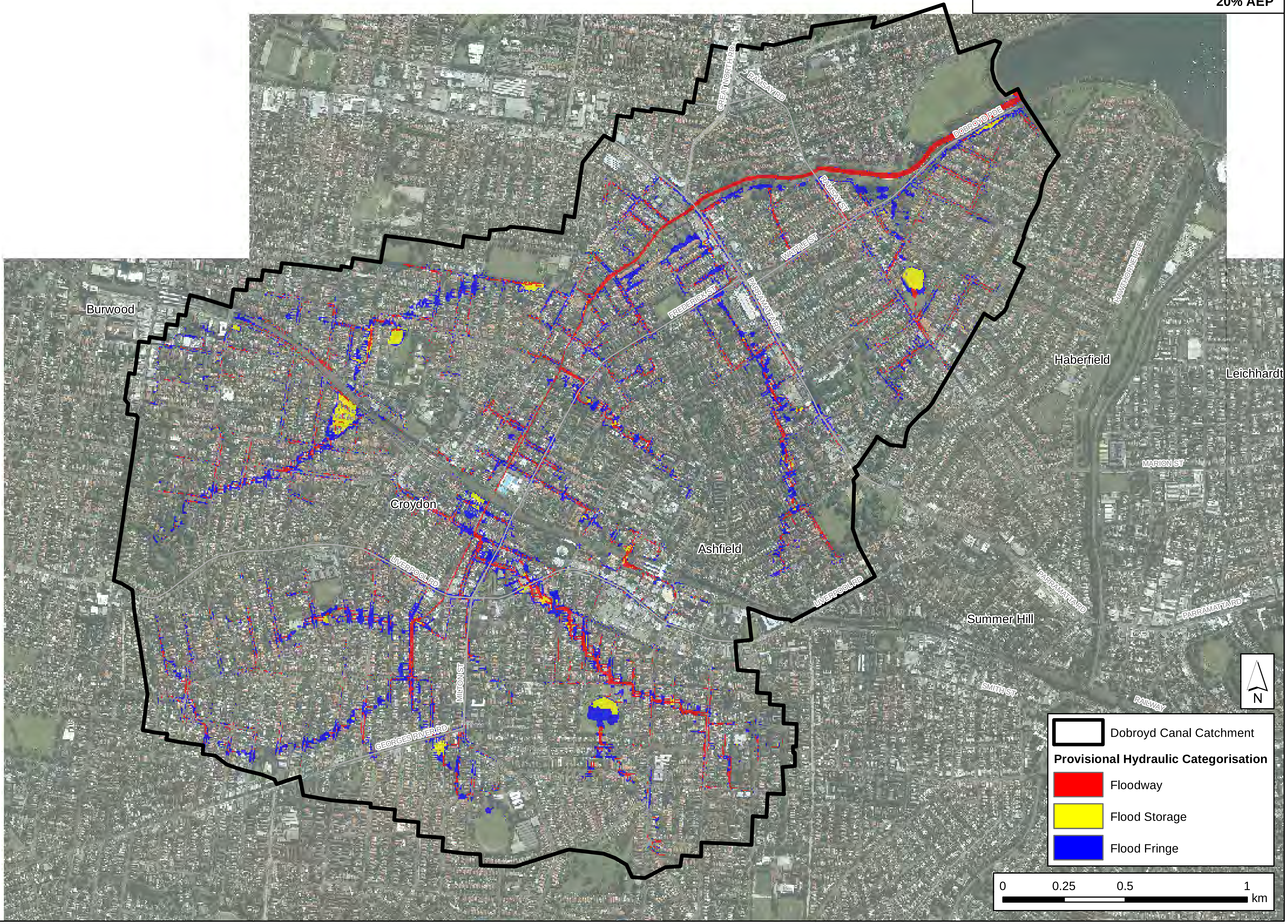

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FIGURE 26
PROVISIONAL HYDRAULIC CATEGORISATION
5% AEP

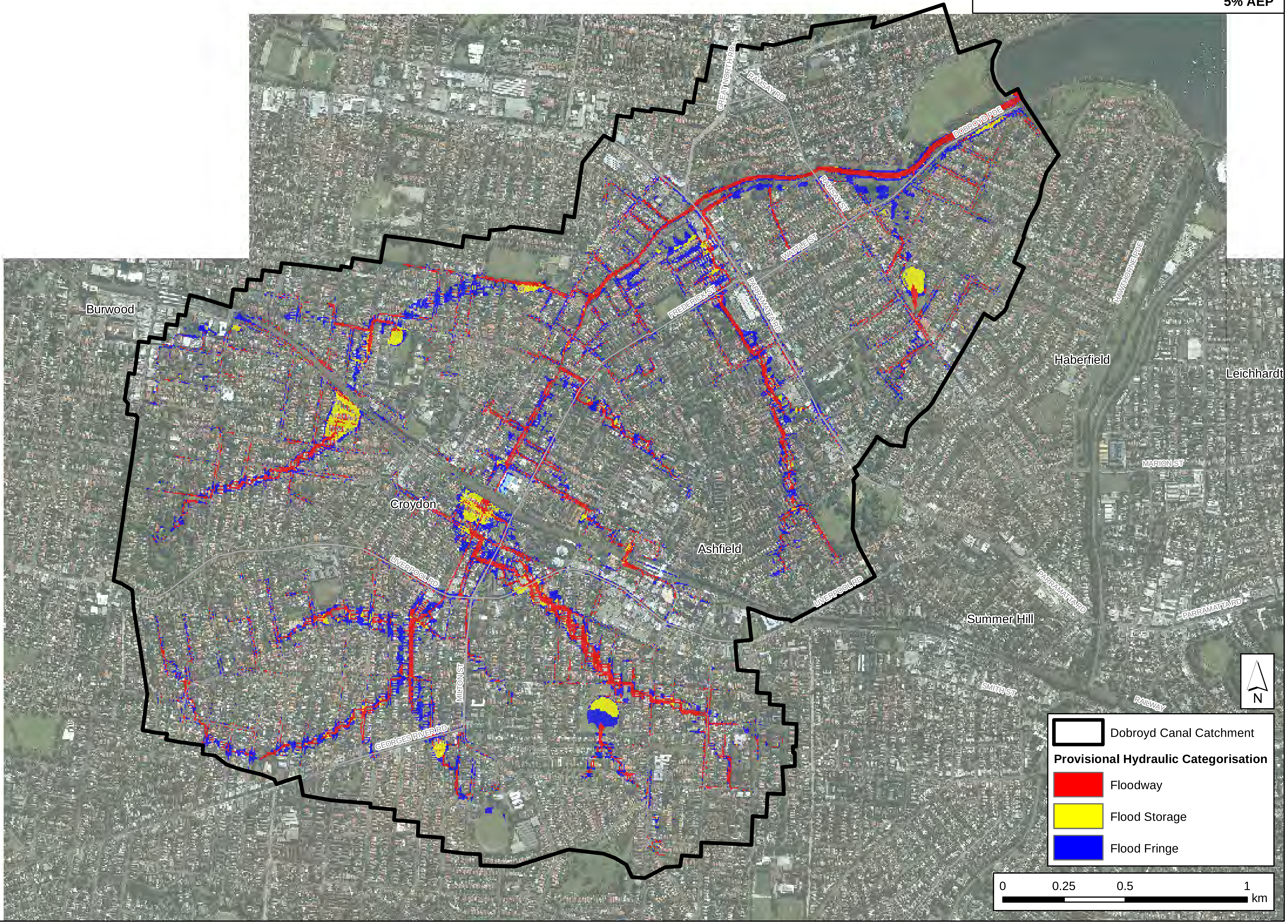

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FIGURE 27
PROVISIONAL HYDRAULIC CATEGORISATION
1% AEP

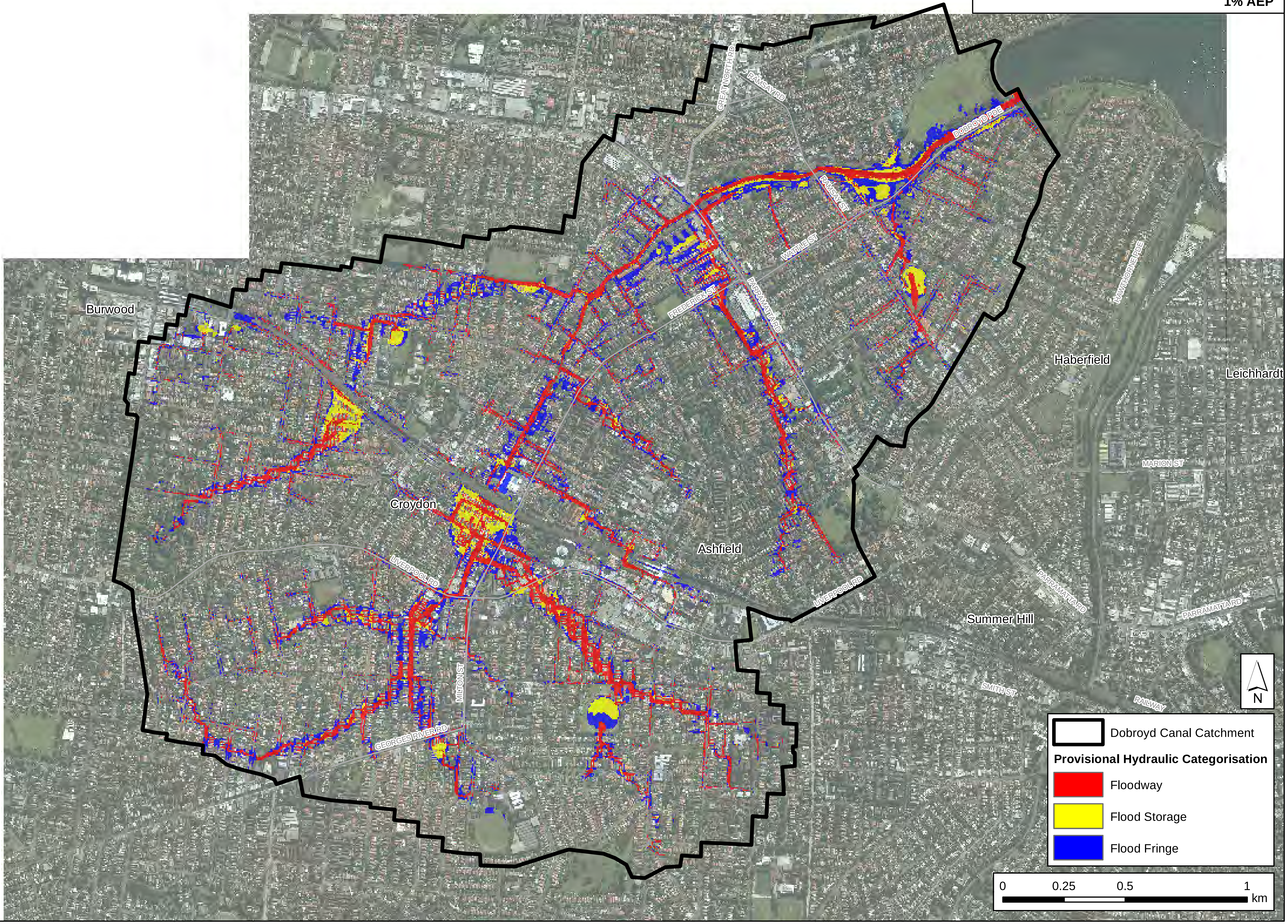

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FIGURE 28
PROVISIONAL HYDRAULIC CATEGORISATION
PMF

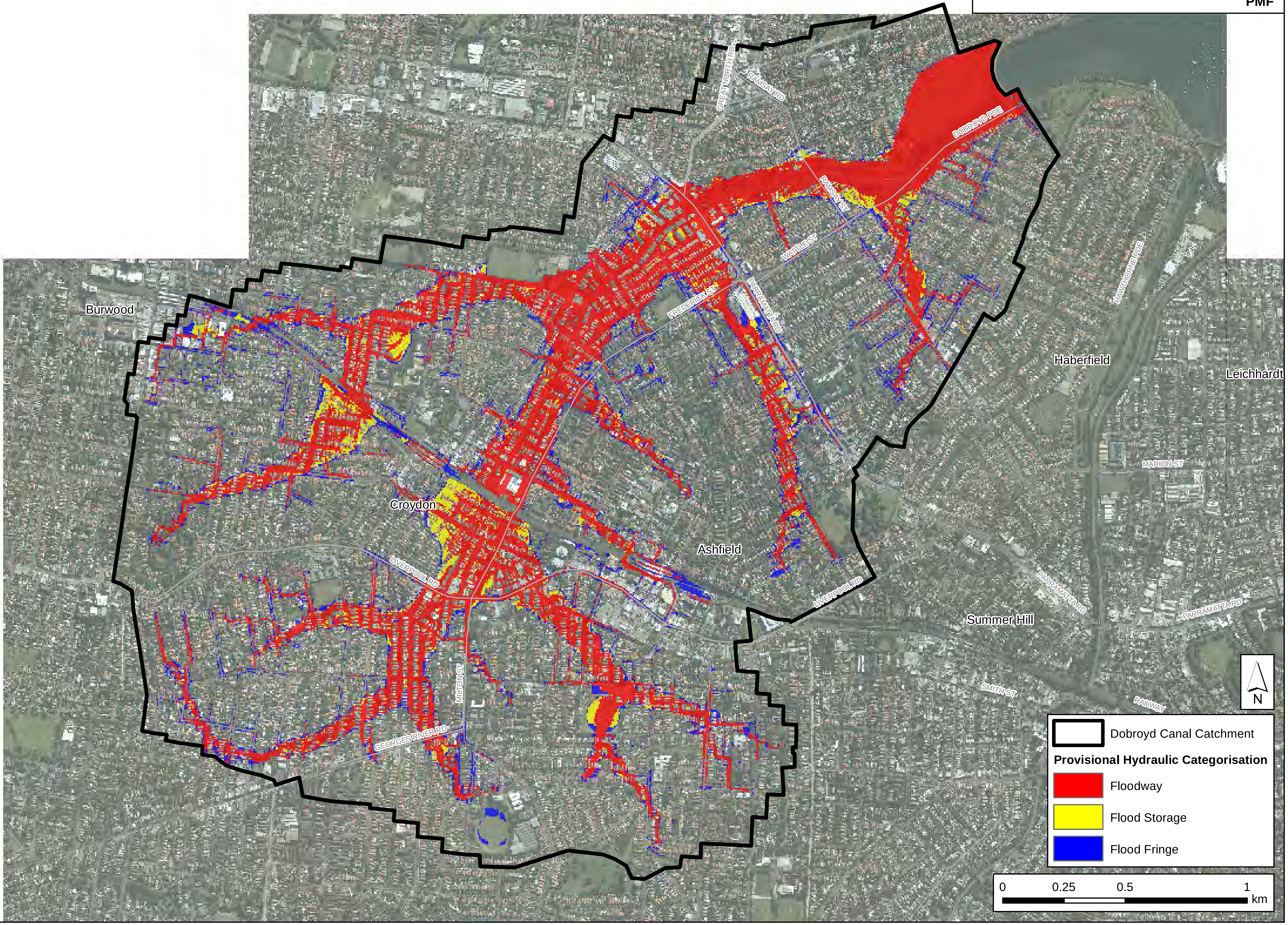

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FIGURE 29
PROVISIONAL HYDRAULIC CATEGORISATION
HIGH / LOW RISK
1% AEP

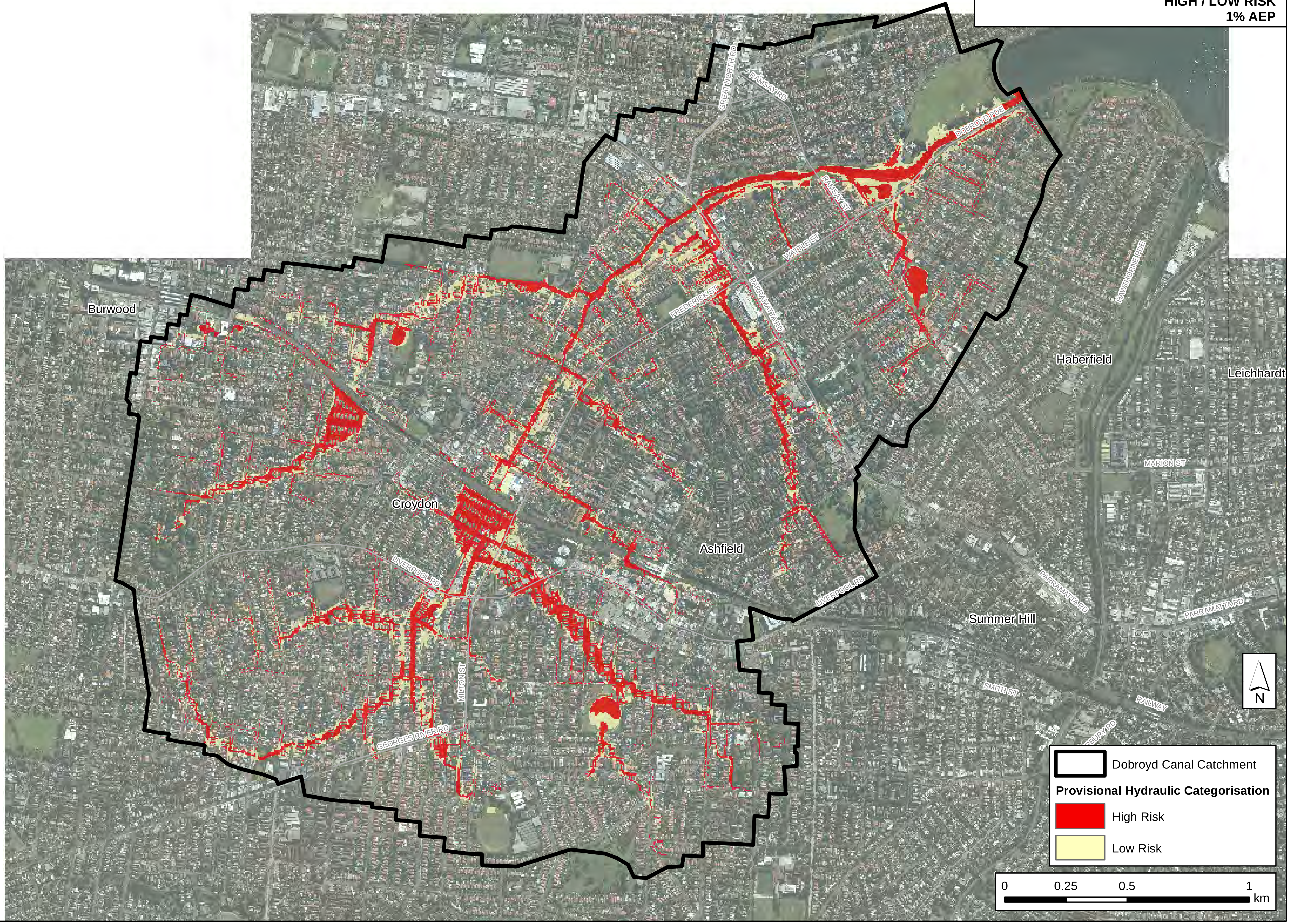

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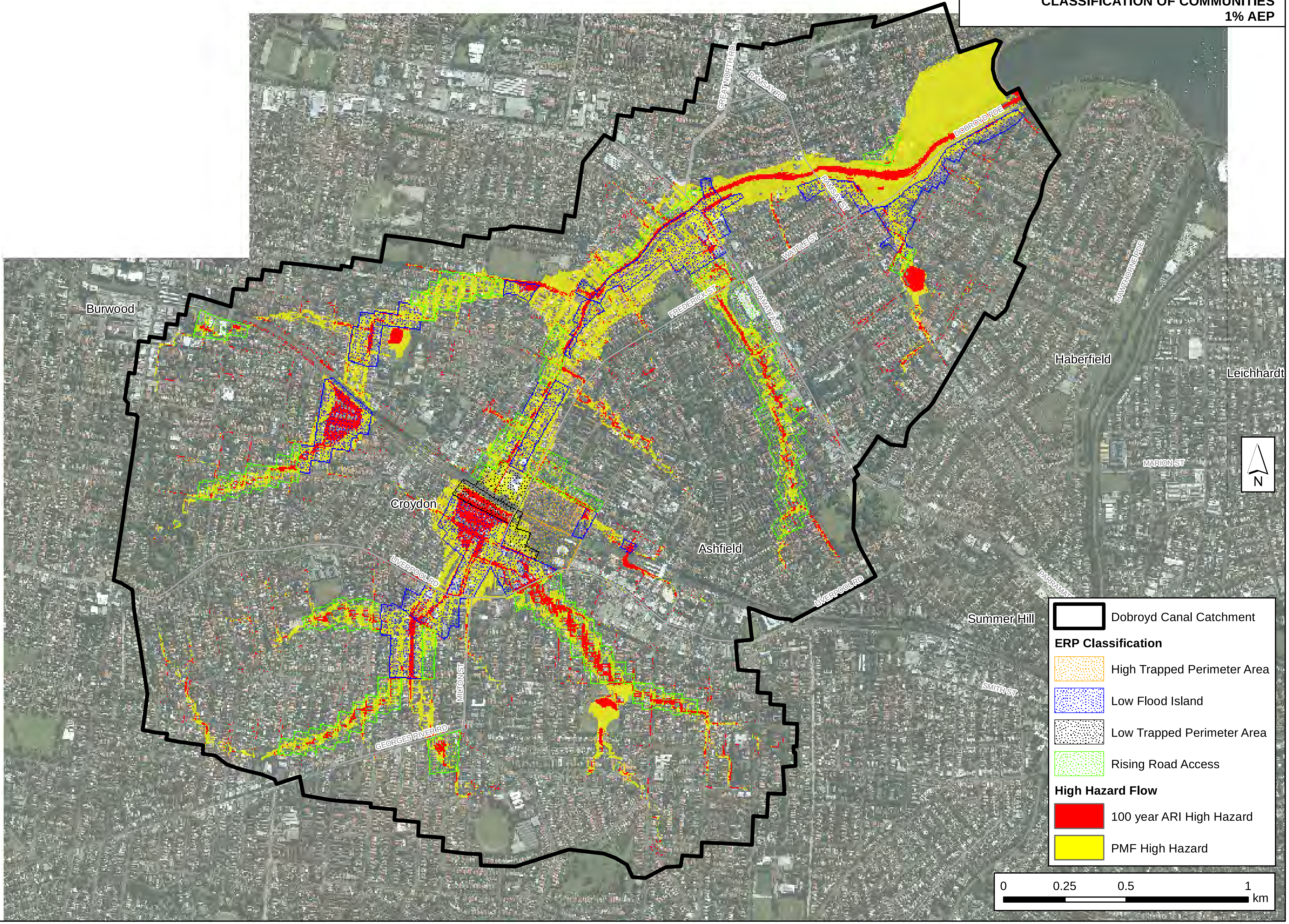
FIGURE 30
PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION OF COMMUNITIES 1% AEP



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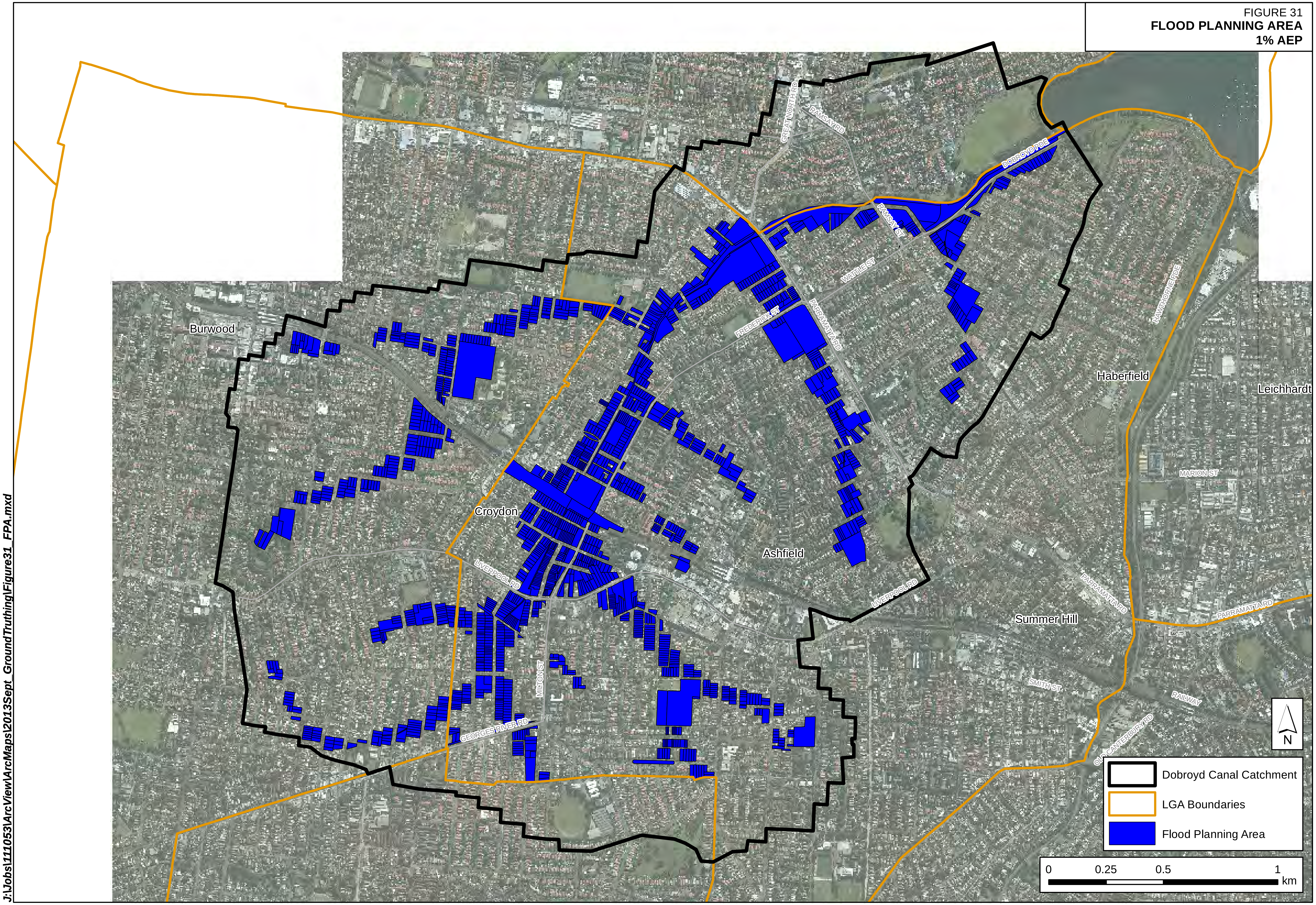

FIGURE 31
FLOOD PLANNING AREA
1% AEP

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Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate 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. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
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 LG 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 DIPNR, 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 the 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).
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 the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
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 diagrammetic 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 State Emergency Service.

flood planning area — The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the flood liable land concept in the 1986 Manual.

Flood Planning Levels (FPLs) — 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. FPLs supersede the standard flood event in the 1986 manual.

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

flood prone land — Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.

flood readiness — Flood readiness is an ability to react within the effective warning time.

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

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

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

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

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

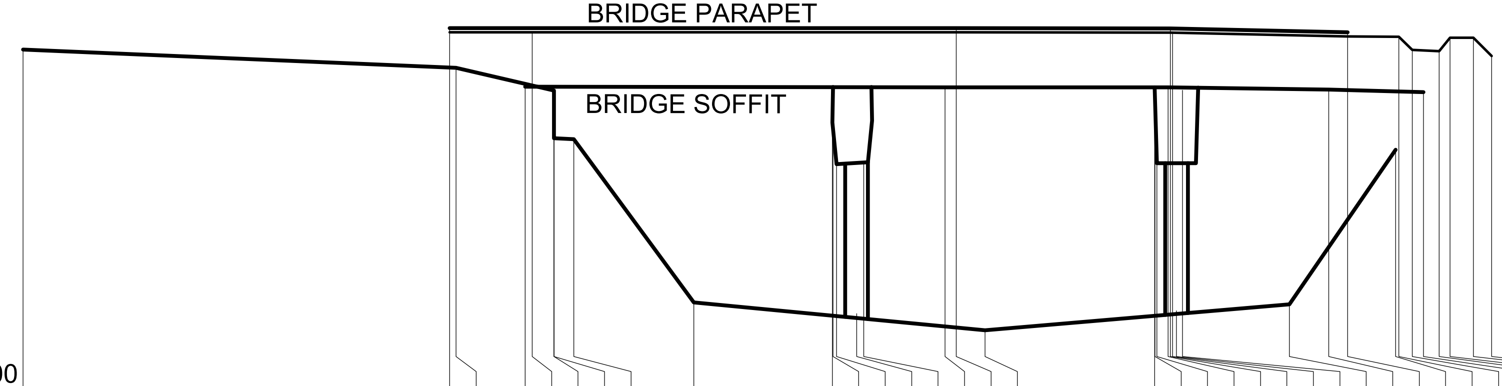
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
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	Are 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. For the purpose of this manual 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 0.3 m (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 flow paths 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 States rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).

risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to water level. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
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.

Appendix B

TIMBRELL DRIVE



Datum R.L. -2.00

CHAINAGE	SURFACE LEVEL
0.00	2.46
11.29	2.74
11.46	2.22
13.29	1.97
13.47	2.70
14.05	1.29
14.05	1.92
14.57	1.27
17.75	-0.89
21.41	1.50
21.43	1.92
21.53	0.94
22.06	-1.03
22.24	0.96
24.39	1.96
24.69	2.74
25.46	-1.25
29.94	1.49
29.95	1.92
30.00	0.96
30.30	1.96
30.36	2.74
30.42	2.68
30.52	-1.00
30.68	1.92
33.51	-0.91
34.55	1.93
35.05	2.69
36.32	1.13
36.40	2.63
36.76	2.46
37.05	1.90
37.47	2.44
37.76	2.61
38.37	2.62
38.86	2.37

D_St001 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:200 VERTICAL 1:100

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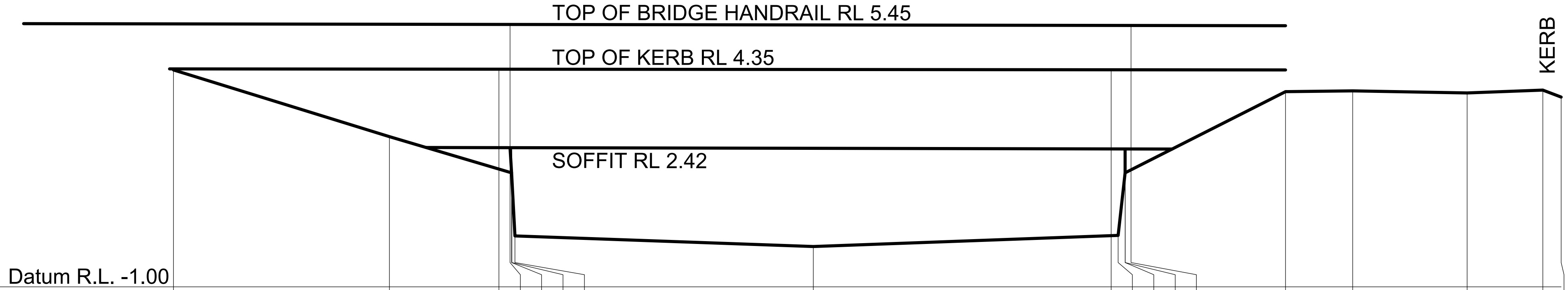
DOBROYD CHANNEL
BRIDGE CROSS SECTION D_St001
TIMBRELL DRIVE, FIVE DOCK



Datum R.L. -1.00

SURFACE LEVEL	4.33	2.69	4.35	5.45	1.80	2.42	0.25	-0.01	4.33	0.26	1.80	2.39	5.42	3.80	3.82	3.76	3.84	3.67
CHAINAGE	0.00	5.31	8.00	8.27	8.31	8.32	8.40	15.73	23.05	23.22	23.40	23.40	23.54	27.34	28.99	31.80	33.66	34.11

D_St002 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:150 VERTICAL 1:150

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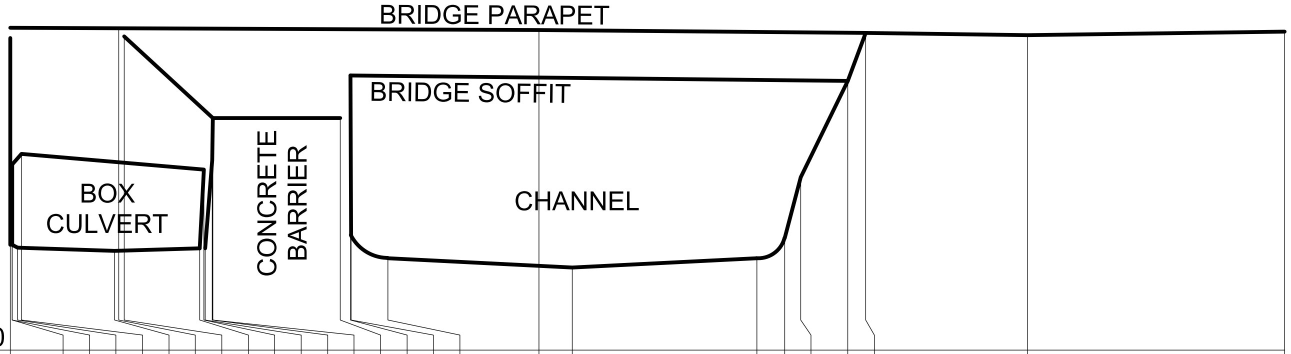
DOBROYD CHANNEL
BRIDGE CROSS SECTION D_St002
RAMSAY ROAD



Datum R.L. -1.00

SURFACE LEVEL	5.20	1.09	2.69	1.03	2.89	0.97	5.39	5.23	1.02	2.58	1.02	2.77	3.60	3.61	4.45	1.28	0.83	5.35	0.64	0.83	1.23	2.43	4.35	5.30	5.25	5.32
CHAINAGE	0.00	0.04	0.04	0.15	0.23	2.07	2.16	2.26	3.76	3.84	3.87	4.01	4.02	6.55	6.76	6.76	7.50	10.50	11.15	14.82	15.37	15.69	16.63	16.98	20.19	25.29

D_St003 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:150 VERTICAL 1:150

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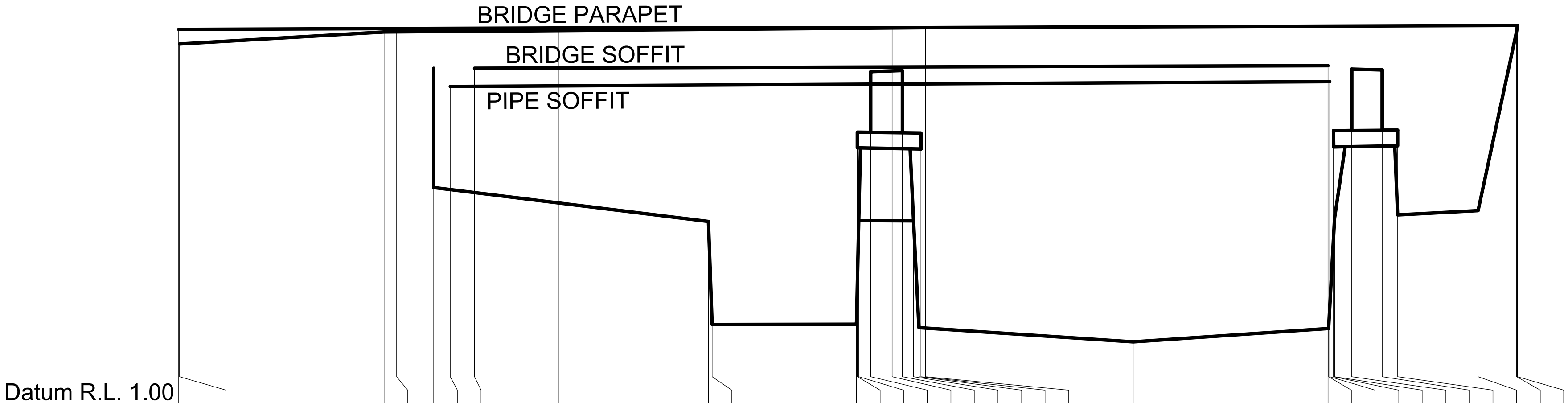
DOBROYD CHANNEL
BRIDGE CROSS SECTION D_St003
PARRAMATTA ROAD



SURFACE LEVEL	CHAINAGE
6.55	0.00
6.34	0.01
6.51	3.05
6.57	3.23
4.21	3.79
5.71	4.03
5.97	4.39
6.57	5.63
3.70	7.86
2.17	7.91
2.18	10.06
5.03	10.07
3.72	10.09
5.92	10.27
6.58	10.59
5.94	10.74
3.71	10.91
2.13	10.99
5.01	11.01
6.58	11.08
1.92	14.17
6.01	17.06
2.12	17.06
5.78	17.08
5.05	17.14
3.75	17.16
5.96	17.41
5.95	17.86
5.06	18.09
3.86	19.28
6.52	19.85
6.61	19.87

D_St004 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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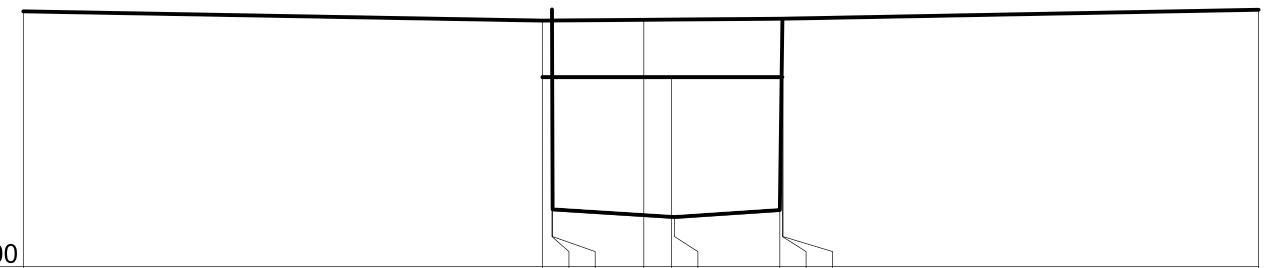
DOBROYD CHANNEL
CULVERT CROSS SECTION D_St004
CHURCH STREET



SURFACE LEVEL	7.07	6.89	7.11	3.14	6.89	5.77	2.99	3.12	6.88	6.93	7.11
CHAINAGE	0.00	10.30	10.49	10.50	12.31	12.87	12.92	15.01	15.07	15.08	24.52

D_St005 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:150 VERTICAL 1:150

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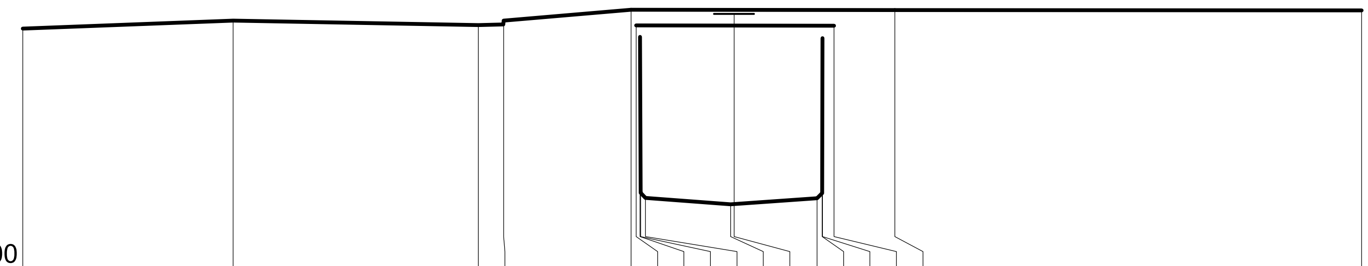
BRIDGE CROSS SECTION D_St005

JOHN STREET



Datum R.L. 5.00

SURFACE LEVEL	9.73	9.89	9.80	9.89	10.11	9.79	9.57	6.47	6.37	6.24	10.03	6.36	6.46	9.54	9.79	10.10	10.09
CHAINAGE	0.00	4.17	9.04	9.54	12.07	12.17	12.24	12.25	12.35	14.04	14.11	15.76	15.85	15.86	16.09	17.30	26.56

D_St006 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:150 VERTICAL 1:150

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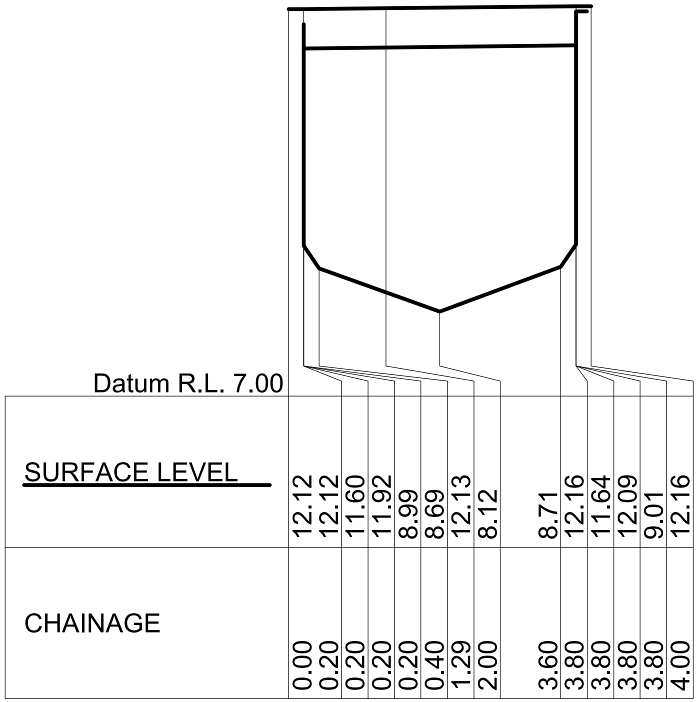
CHASE BURKE HARVEY

DOBROYD CHANNEL

BRIDGE CROSS SECTION D_St006

BANKS STREET



D_St007 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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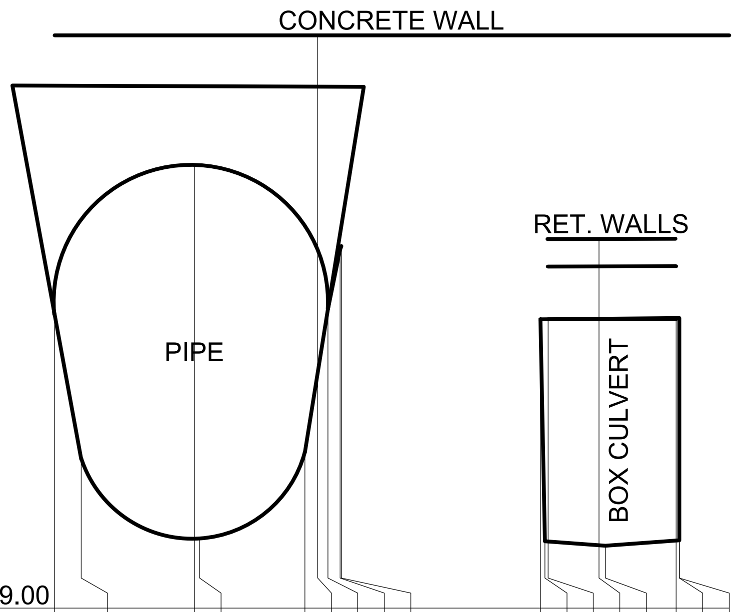
DOBROYD CHANNEL
CULVERT CROSS SECTION D_St007
ELIZABETH STREET

CULVERT DIAMETER	3.6m
CULVERT LENGTH	15.38m
UPSTREAM INVERT	RL 8.12
DOWNSTREAM INVERT	RL 7.43



Datum R.L. 9.00

SURFACE LEVEL	12.89	10.98	14.86	9.92	11.06	16.59	12.96	13.75	13.80	12.82	9.88	12.82	13.89	9.83	12.83	12.84	9.90
CHAINAGE	0.00	0.35	1.85	1.92	3.31	3.48	3.62	3.78	3.79	6.43	6.48	6.53	7.20	7.28	8.22	8.26	8.26

D_St008 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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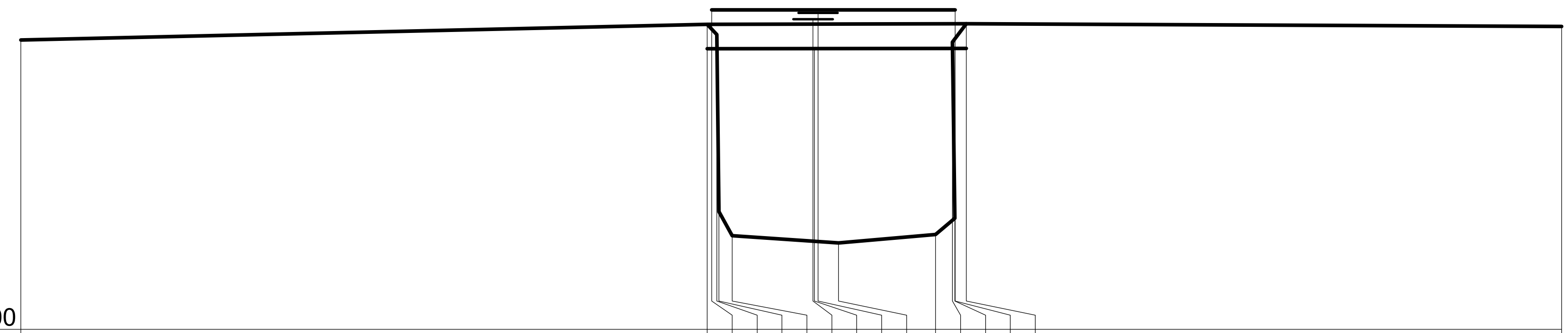
DOBROYD CHANNEL
CULVERT CROSS SECTION D_St008
RAILWAY LINE

PIPE DIAMETER	3.0m
PIPE LENGTH	37.02m
UPSTREAM INVERT	RL 9.92
DOWNSTREAM INVERT	RL 9.62



Datum R.L. 9.00

SURFACE LEVEL	13.07	13.29	13.49	13.15	10.66	10.32	13.36	12.95	13.45	10.22	10.33	13.04	10.56	13.50	13.30	13.26
CHAINAGE	0.00	9.65	9.71	9.78	9.81	10.00	11.13	11.15	11.20	11.49	12.85	13.09	13.12	13.13	13.29	21.65

D_St009 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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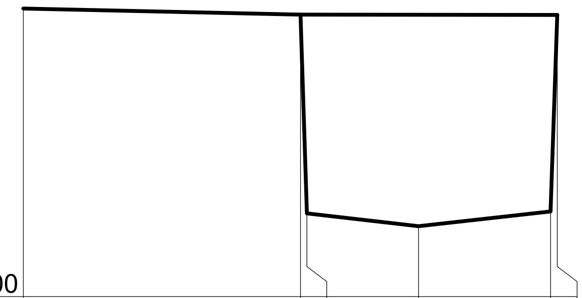
CHASE BURKE HARVEY

DOBROYD CHANNEL

CULVERT CROSS SECTION D_St009

HEIGHWAY AVENUE

CULVERT DIAMETER	3.31m
CULVERT LENGTH	14.10m
UPSTREAM INVERT	RL 10.22
DOWNSTREAM INVERT	RL 10.10



Datum R.L. 10.00

SURFACE LEVEL	13.81	13.73	11.10	10.93	11.13	13.73
CHAINAGE	0.00	3.67	3.75	5.24	6.98	7.07

D_St010 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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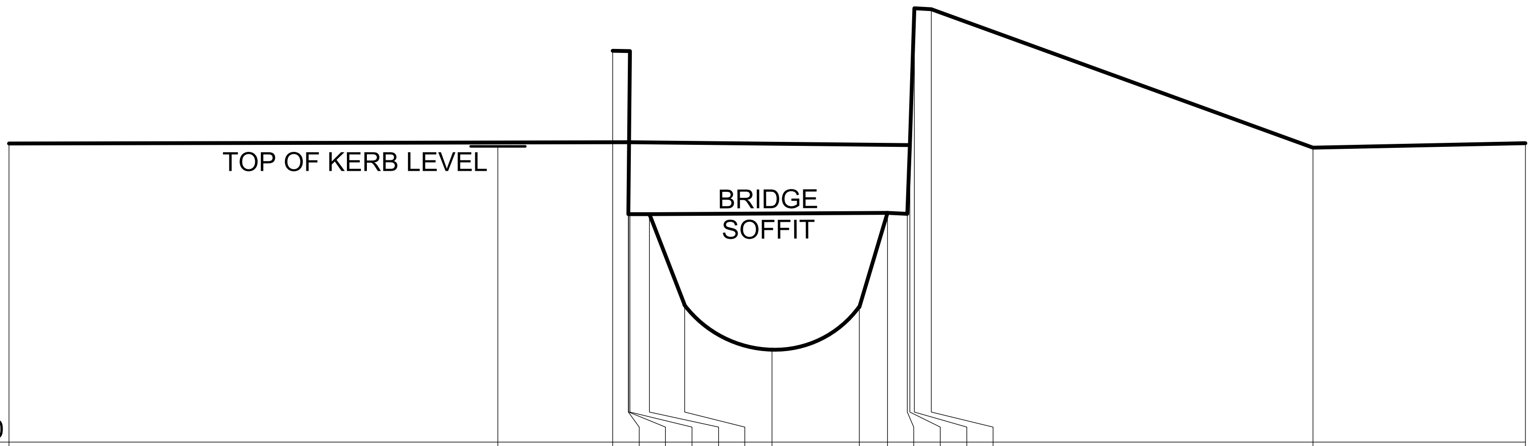
CULVERT CROSS SECTION D_St010

THOMAS STREET



Datum R.L. 12.00

SURFACE LEVEL	15.96	15.92	17.18	15.02	15.97	17.18	15.02	13.82	13.22	13.79	15.03	15.02	15.93	17.74	17.73	15.90	15.96
CHAINAGE	0.00	6.47	7.99	8.19	8.20	8.22	8.48	8.94	10.10	11.25	11.62	11.89	11.92	11.98	12.20	17.26	20.07

D_St011 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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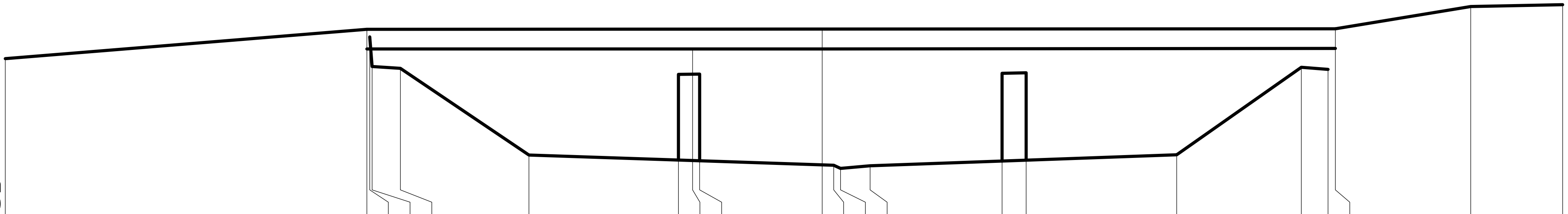
DOBROYD CHANNEL
CULVERT CROSS SECTION D_St011
HUME HIGHWAY



Datum
R.L. -2.00

SURFACE LEVEL	1.78	2.49	2.31	1.59	1.54	-0.55	1.40	2.02	1.40	2.50	-0.80	-0.88	-0.81	1.43	1.43	-0.55	1.57	1.52	2.51	3.04	3.09
CHAINAGE	0.00	8.77	8.84	8.90	9.58	12.70	16.32	16.67	16.84	19.81	20.09	20.26	20.98	24.18	24.76	28.41	31.43	32.08	32.26	35.54	37.77

D_St012 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:150 VERTICAL 1:150

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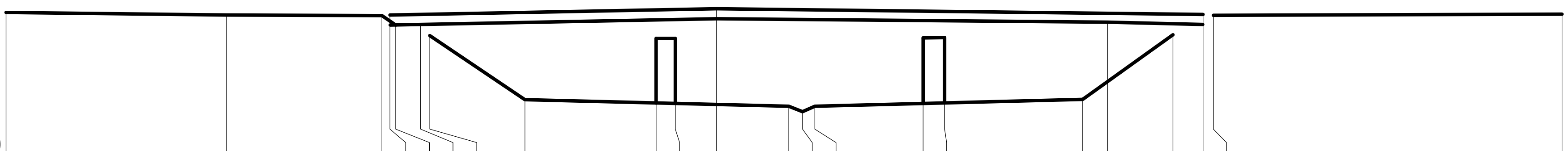
CHASE BURKE HARVEY

DOBROYD CHANNEL

FOOTBRIDGE CROSS SECTION D_St012

CRANE AVENUE, FIVE DOCK



Datum R.L. -2.00

SURFACE LEVEL	2.25	2.17	2.16	2.17	1.88	1.89	1.57	-0.33	1.48	1.48	2.36	-0.53	-0.68	-0.52	1.50	1.51	-0.32	1.96	1.59	2.19	2.17	2.20
CHAINAGE	0.00	6.52	11.11	11.35	11.52	12.25	12.52	15.33	19.21	19.78	21.00	23.13	23.54	23.90	27.10	27.74	31.82	32.56	34.48	35.37	35.68	45.99

D_St013 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:200 VERTICAL 1:200

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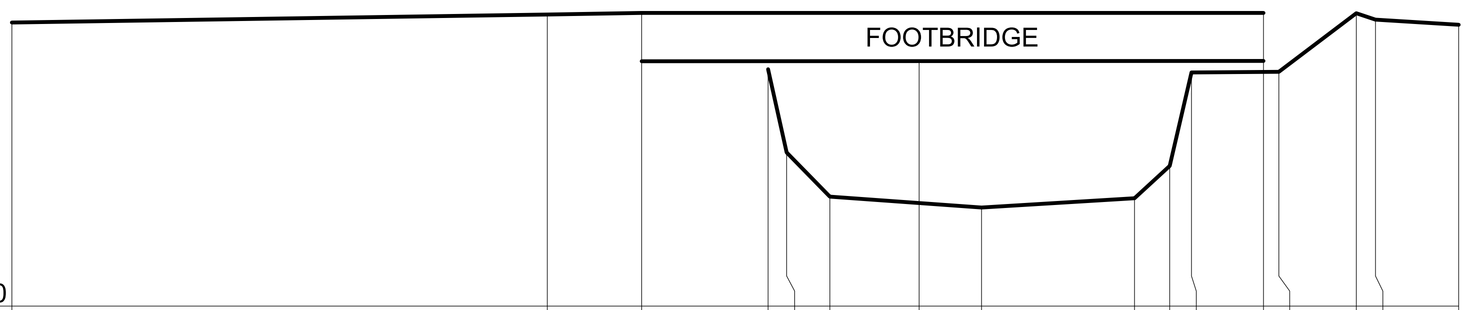
CHASE BURKE HARVEY

DOBROYD CHANNEL

FOOTBRIDGE CROSS SECTION D_St013

WARATAH STREET, FIVE DOCK



Datum R.L. 1.00

SURFACE LEVEL	4.75	4.86	4.88	4.14	3.03	2.45	4.24	2.30	2.43	2.85	4.09	4.88	4.10	4.87	4.79	4.72
CHAINAGE	0.00	7.08	8.33	10.00	10.25	10.82	12.00	12.83	14.85	15.32	15.61	16.56	16.76	17.79	18.04	19.14

D_St014 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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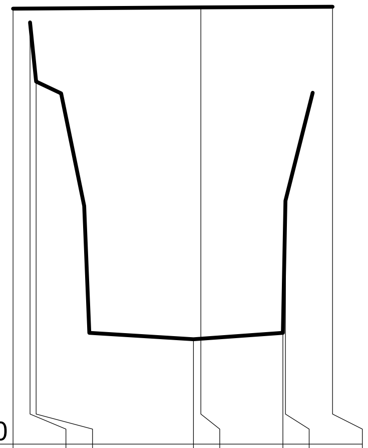
FOOTBRIDGE CROSS SECTION D_St014
ALEXANDRA STREET



Datum R.L. 3.00

SURFACE LEVEL	8.77	8.59	7.80	4.39	8.78	4.47	6.22	8.79
CHAINAGE	0.00	0.23	0.31	2.38	2.48	3.56	3.60	4.22

D_St015 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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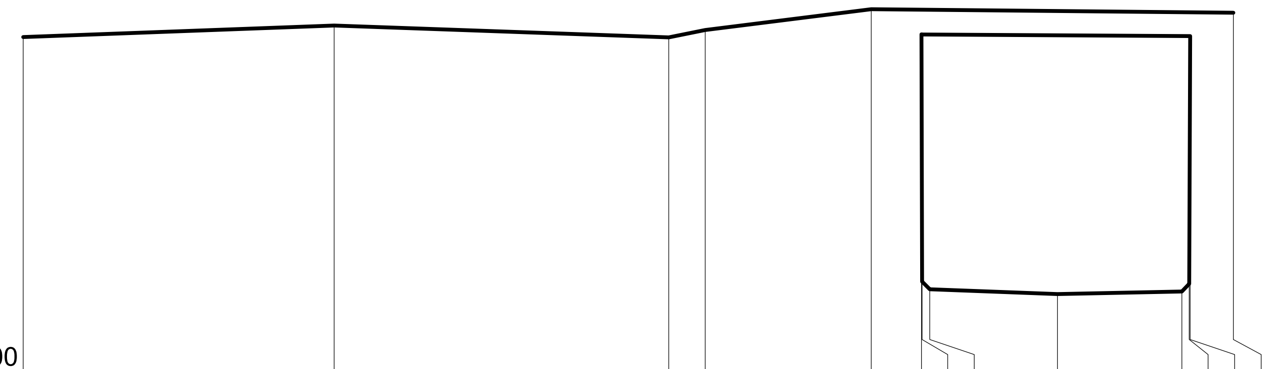
DOBROYD CHANNEL

FOOTBRIDGE CROSS SECTION D_St015

BETWEEN GREGORY AVE & HEDGER AVE



Datum R.L. 6.00

SURFACE LEVEL	10.40	10.55	10.40	10.49	10.77	10.43	7.17	7.07	7.00	7.04	7.14	10.41	10.72
CHAINAGE	0.00	4.12	8.54	9.03	11.23	11.89	11.90	12.00	13.69	15.33	15.43	15.44	16.02

D_St016 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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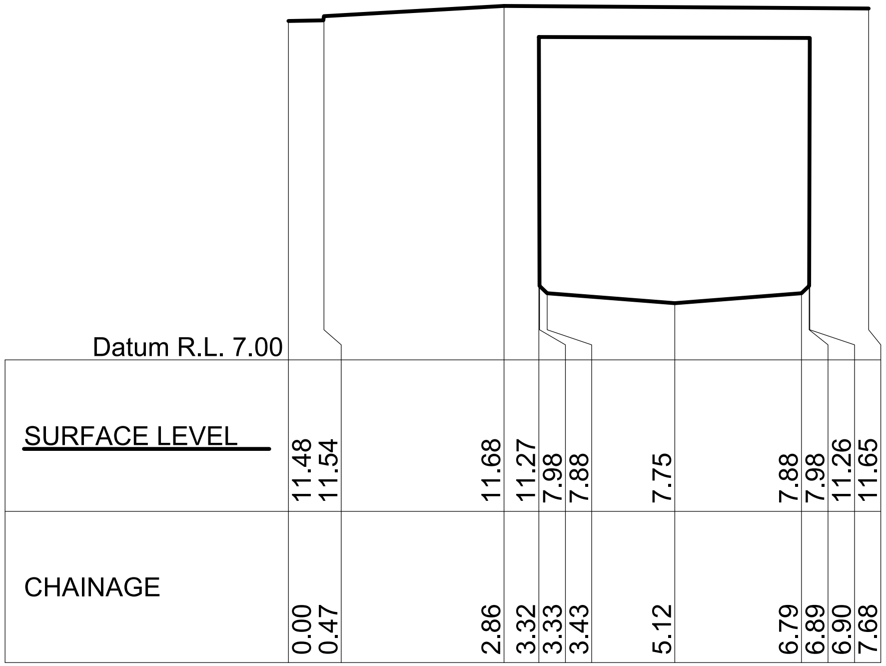
FOOTBRIDGE CROSS SECTION D_St016

ETONVILLE PARADE NEAR ANTHONY STREET



D_St017 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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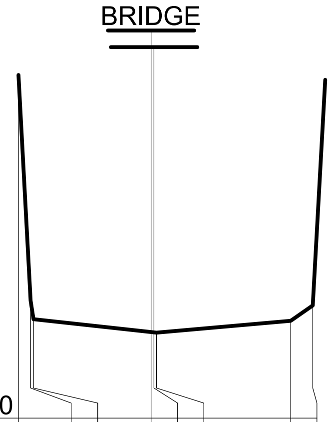
DOBROYD CHANNEL
FOOTBRIDGE CROSS SECTION D_St017
ETONVILLE PARADE



Datum R.L. 8.00

SURFACE LEVEL	12.54	9.56	9.31	13.13	12.91	9.13	9.29	9.49
CHAINAGE	0.00	0.16	0.20	1.76	1.80	1.83	3.61	3.90

D_St018 (UPSTREAM APPROACH)

SCALE HORIZONTAL 1:100 VERTICAL 1:100

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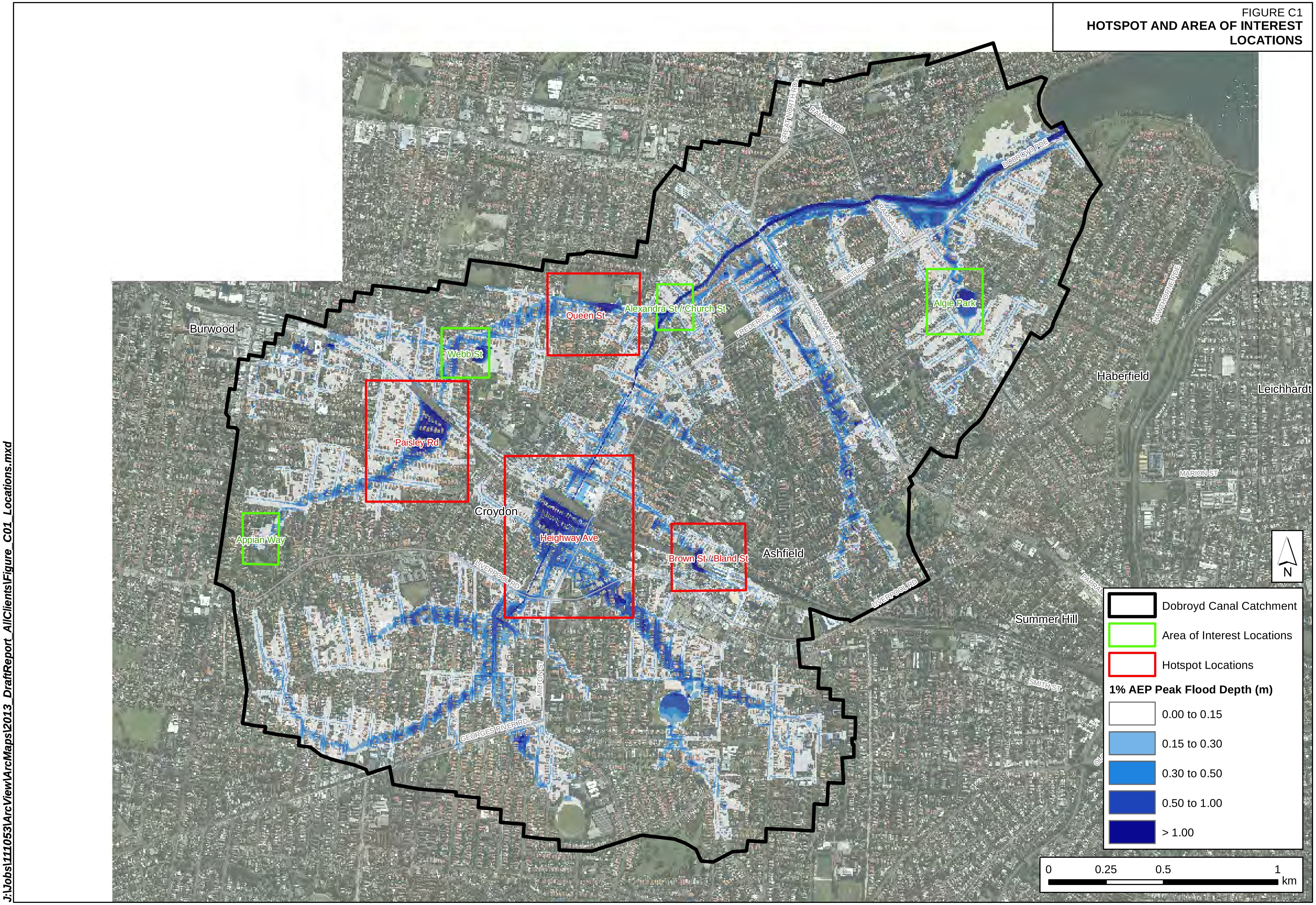
DOBROYD CHANNEL
FOOTBRIDGE CROSS SECTION D_St018
NORTH OF RAILWAY LINE

Appendix C

FIGURE C1
HOTSPOT AND AREA OF INTEREST LOCATIONS



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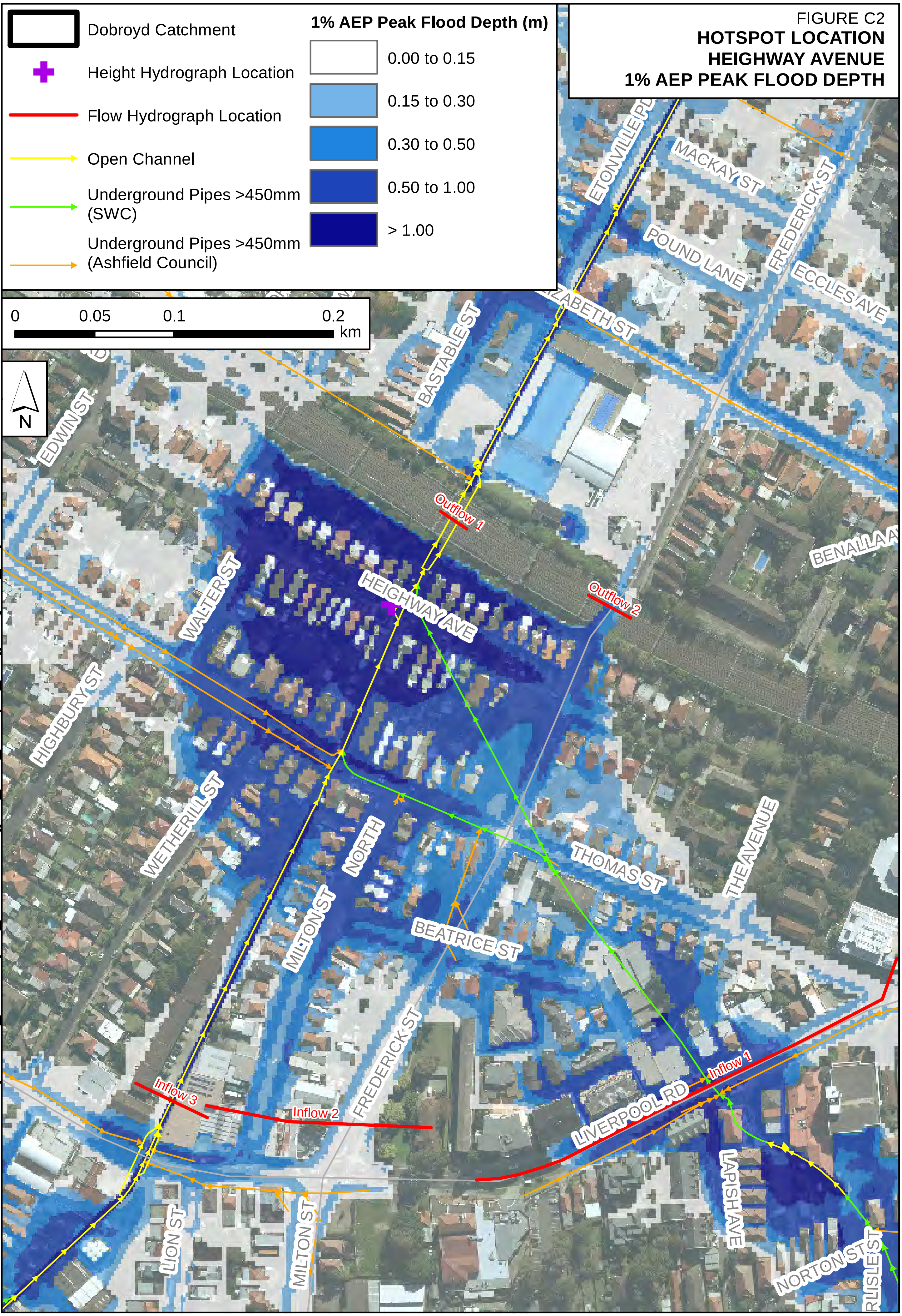

FIGURE C2
HOTSPOT LOCATION
HEIGHWAY AVENUE
1% AEP PEAK FLOOD DEPTH

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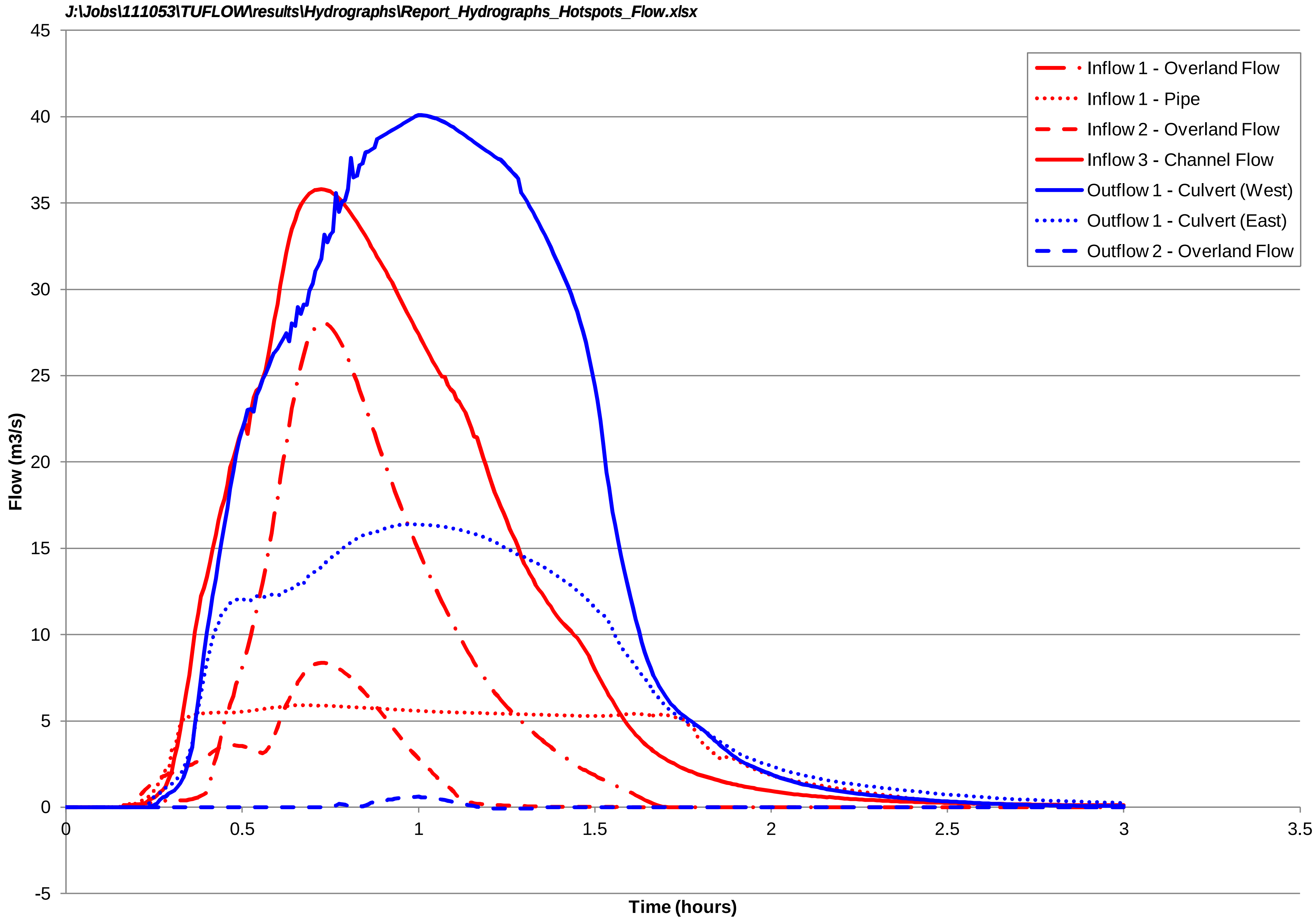

1% AEP FLOW HYDROGRAPHS
HEIGHWAY AVENUE
HOTSPOT LOCATION
FIGURE C3

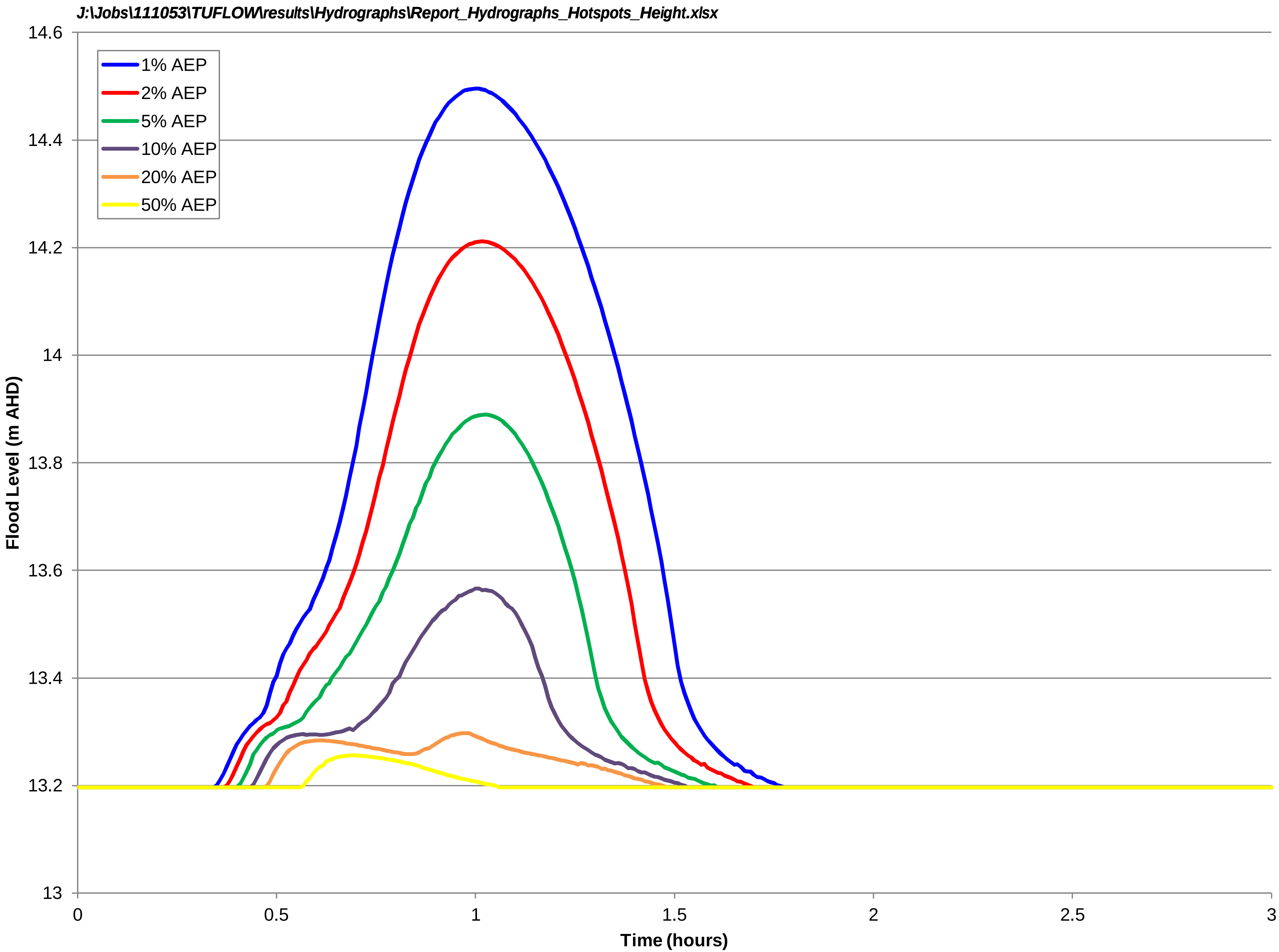

FIGURE C4
HOTSPOT LOCATION
HEIGHWAY AVENUE
FLOOD LEVEL HYDROGRAPH

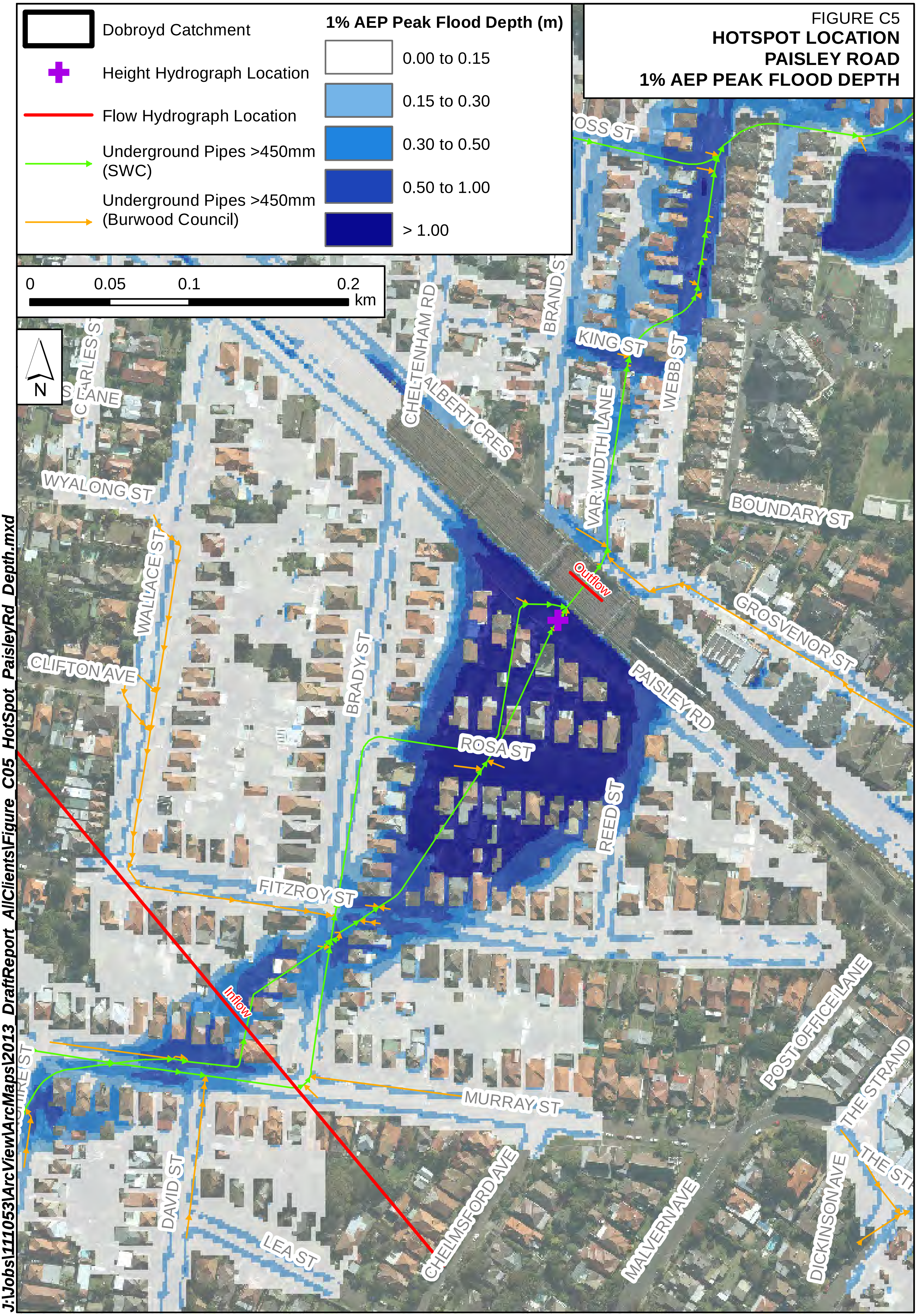

FIGURE C5
HOTSPOT LOCATION
PAISLEY ROAD
1% AEP PEAK FLOOD DEPTH
Dobroyd Catchment
Height Hydrograph Location
Flow Hydrograph Location
Underground Pipes >450mm (SWC)
Underground Pipes >450mm (Burwood Council)
1% AEP Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
0
0.05
0.1
0.2
km
N
KING ST
WEBB ST
BOUNDARY ST
GROSVENOR ST
PAISLEY RD
ROSA ST
REED ST
FITZROY ST
MURRAY ST
BRADY ST
WALLACE ST
CLIFTON AVE
WYALONG ST
CHELTENHAM RD
ALBERT CRES
VAR.WIDTH LANE
Outflow
Inflow
DAVID ST
LEA ST
CHELMSFORD AVE
MALVERN AVE
DICKINSON AVE
POST OFFICE LANE
THE STRAND
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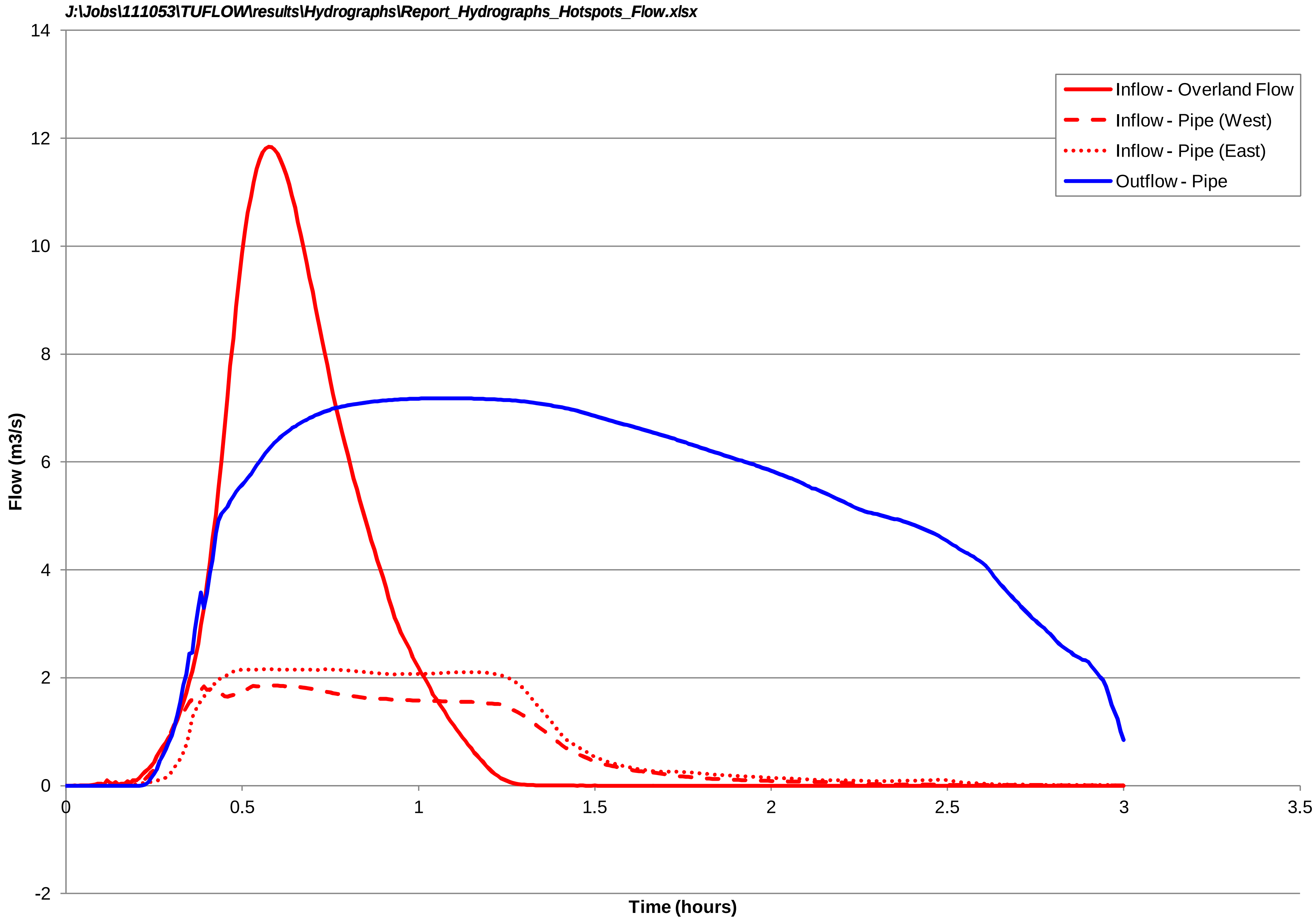


FIGURE C6
HOTSPOT LOCATION
PAISLEY ROAD
1% AEP FLOW HYDROGRAPHS

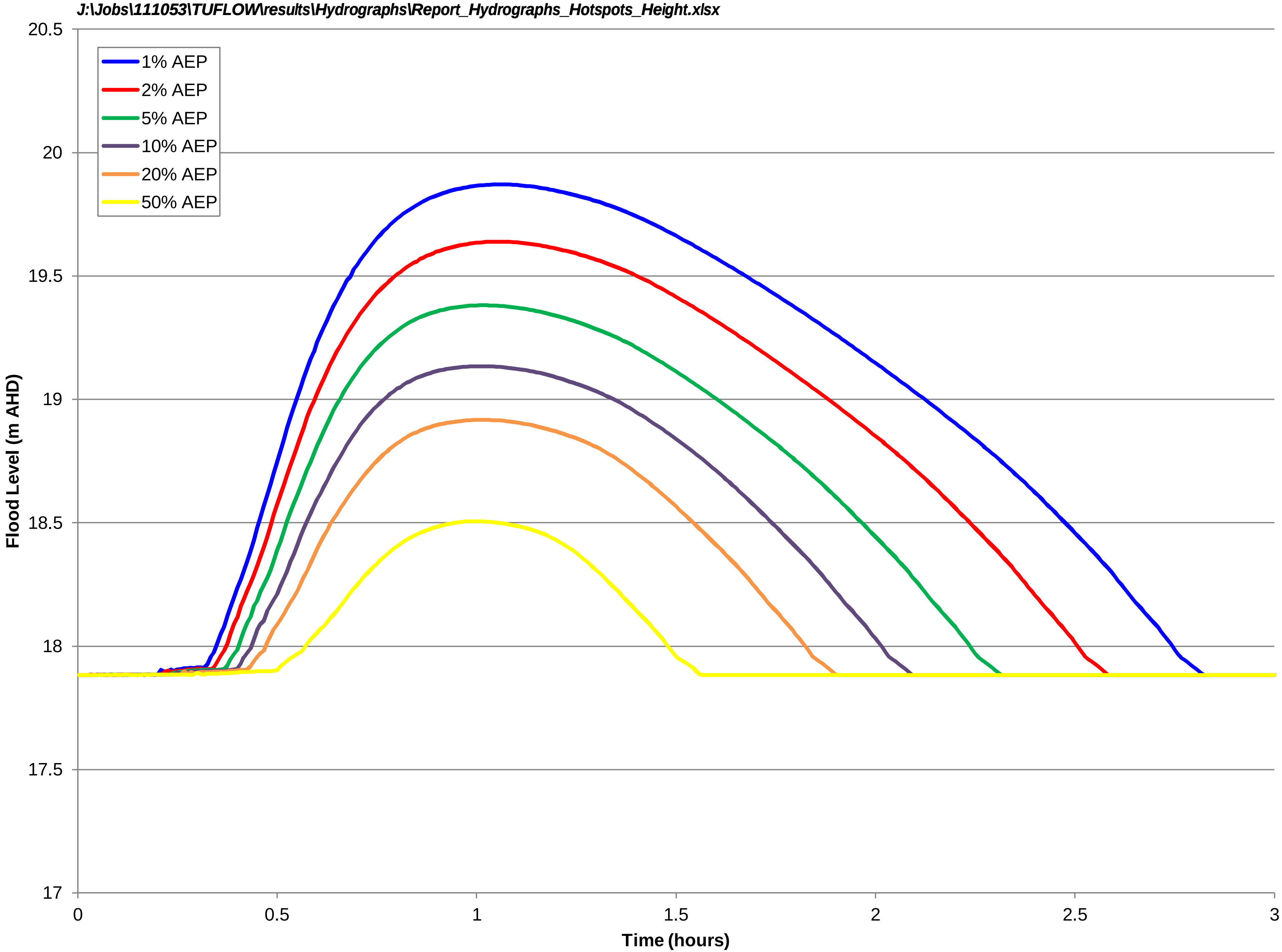
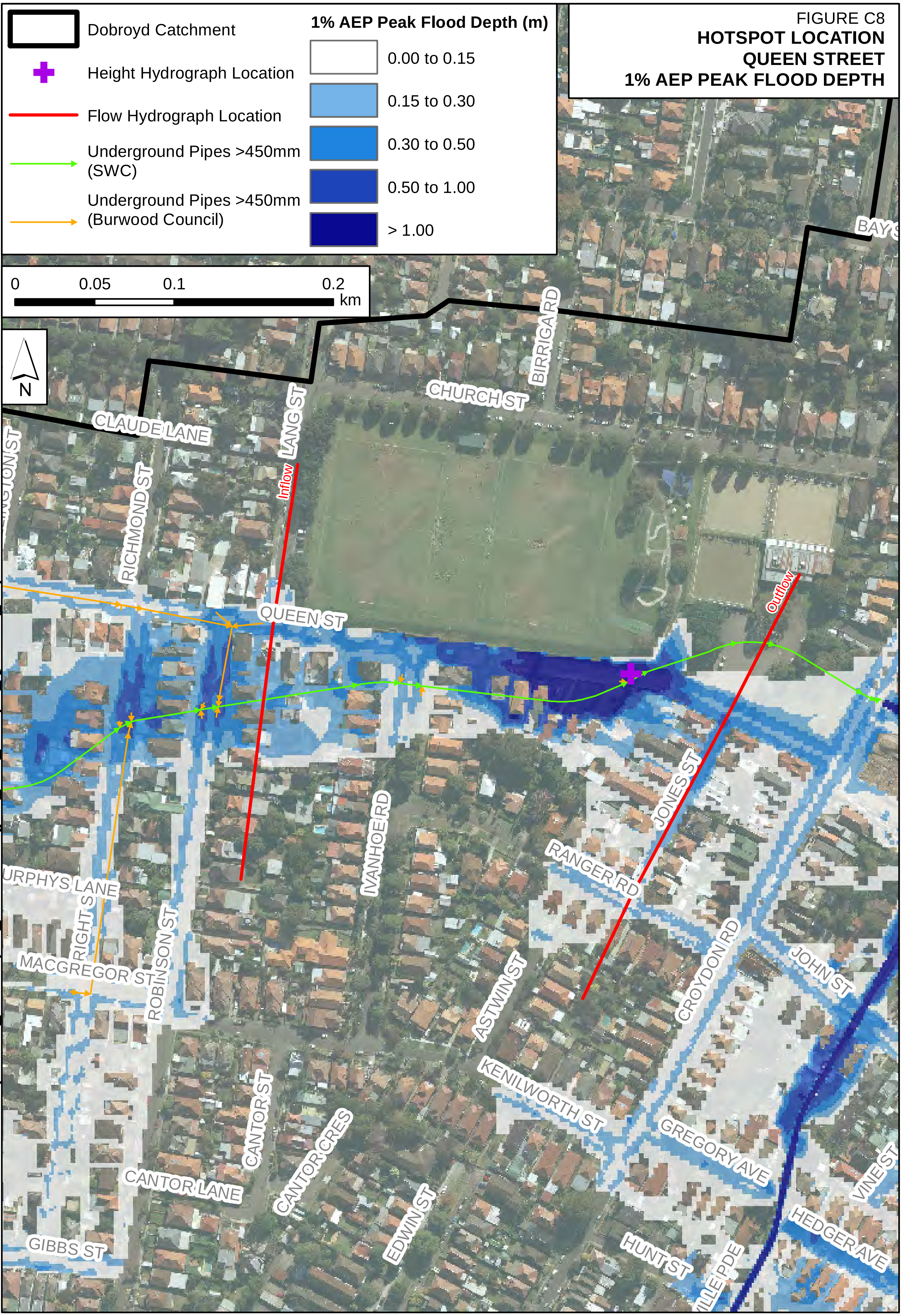


FIGURE C7
HOTSPOT LOCATION
PAISLEY ROAD
FLOOD LEVEL HYDROGRAPH

FIGURE C8
HOTSPOT LOCATION
QUEEN STREET
1% AEP PEAK FLOOD DEPTH



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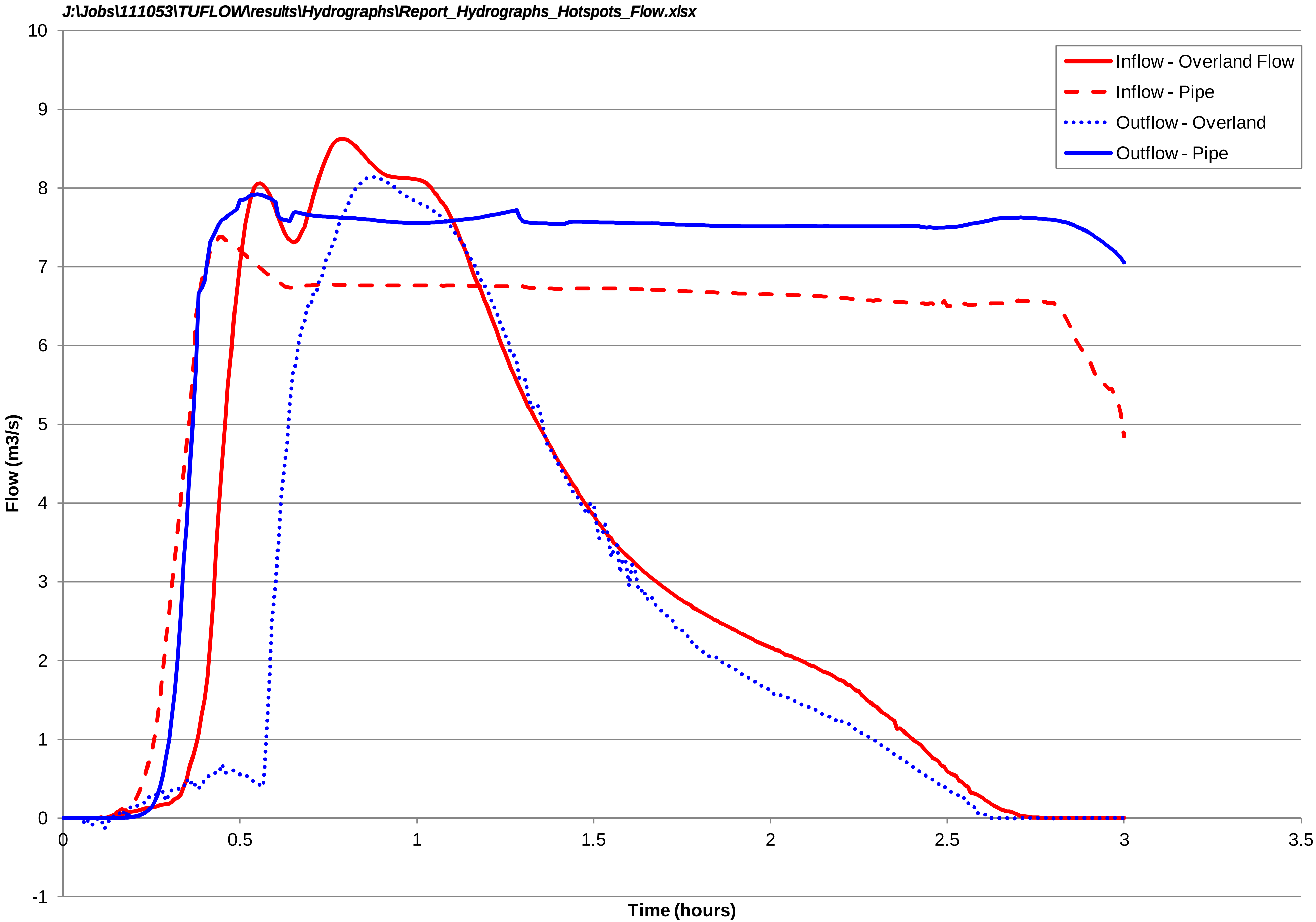


FIGURE C9
HOTSPOT LOCATION
QUEEN STREET
1% AEP FLOW HYDROGRAPHS

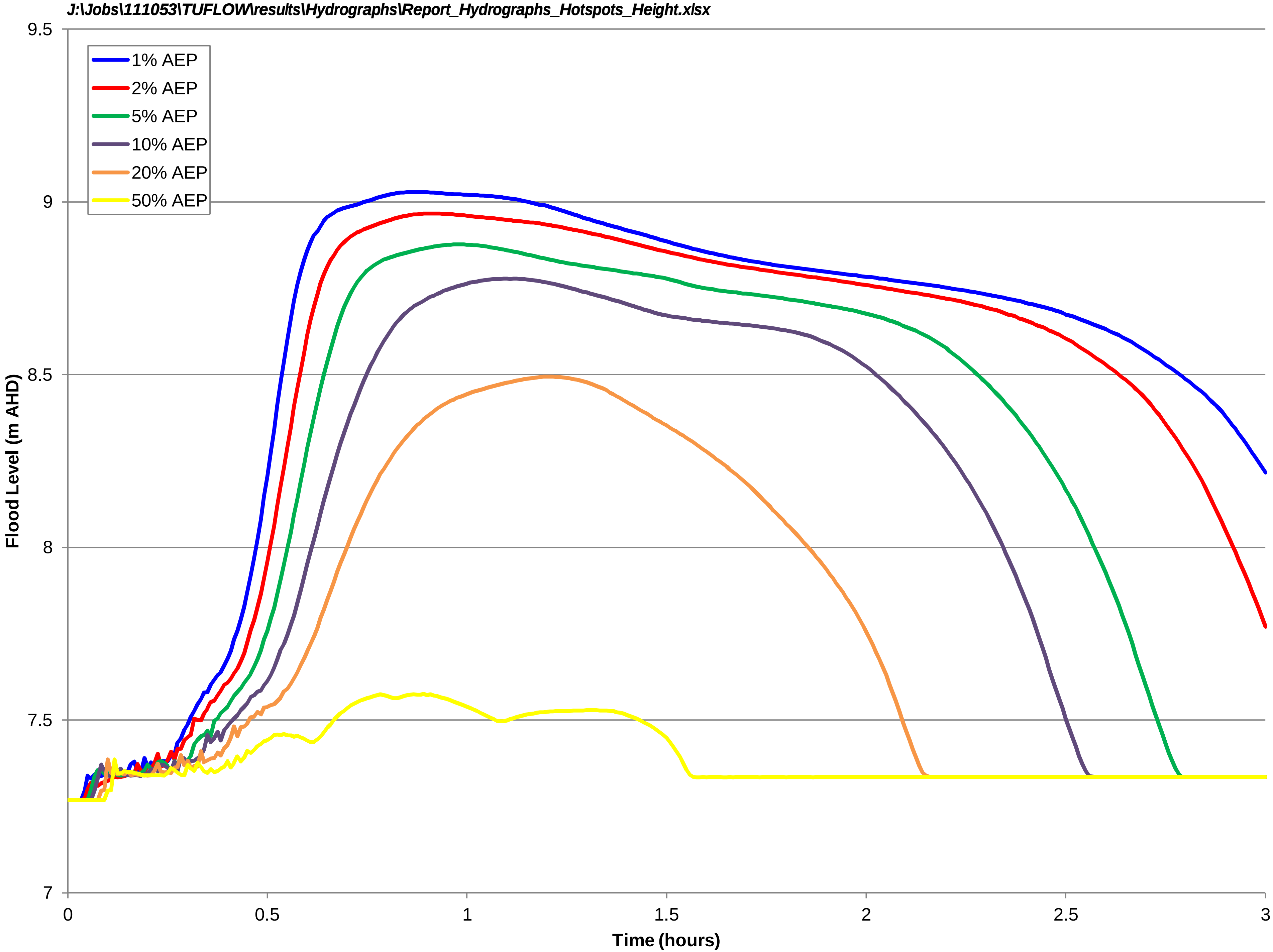
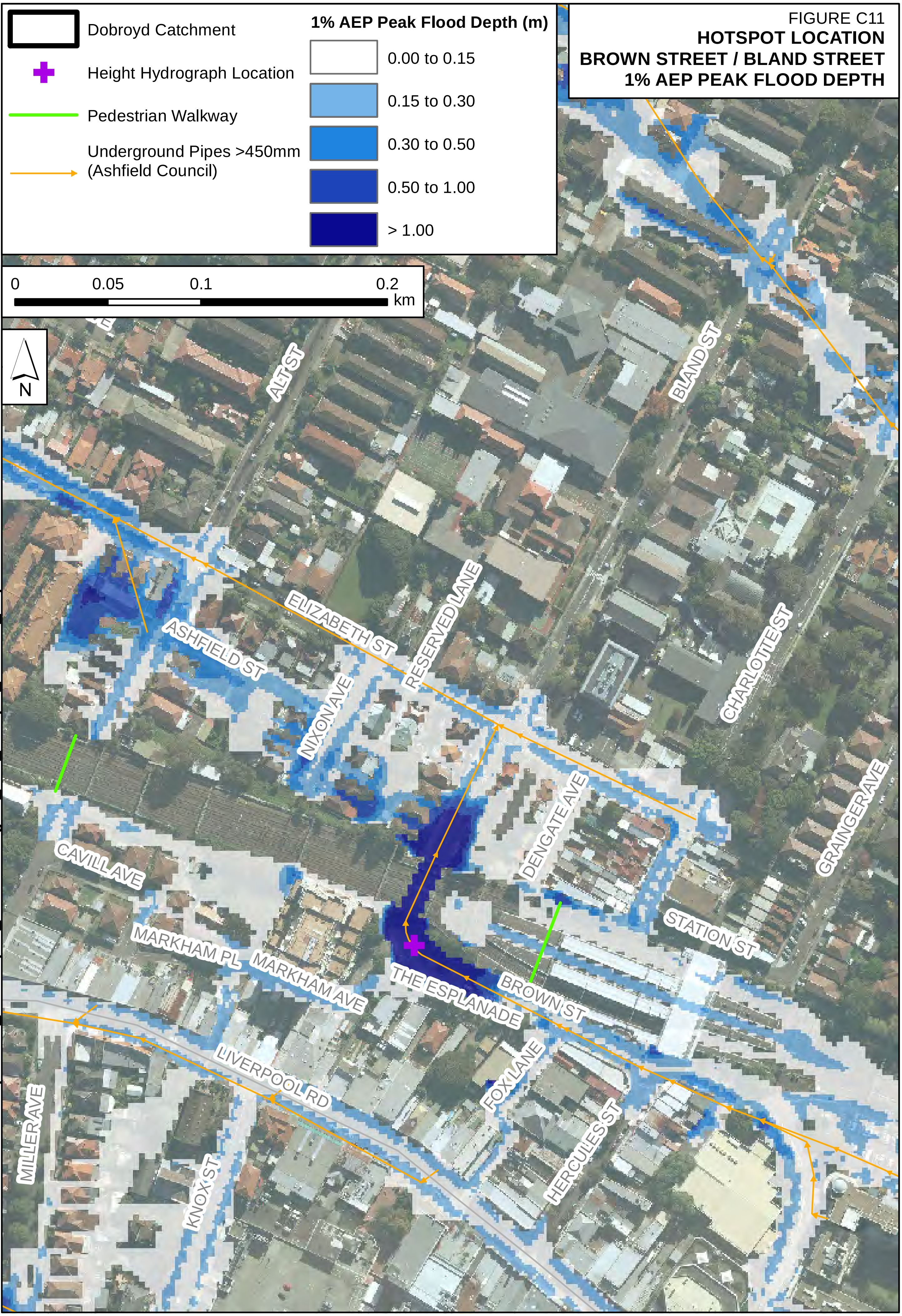


FIGURE C10
HOTSPOT LOCATION
QUEEN STREET
FLOOD LEVEL HYDROGRAPH

FIGURE C11
HOTSPOT LOCATION
BROWN STREET / BLAND STREET
1% AEP PEAK FLOOD DEPTH



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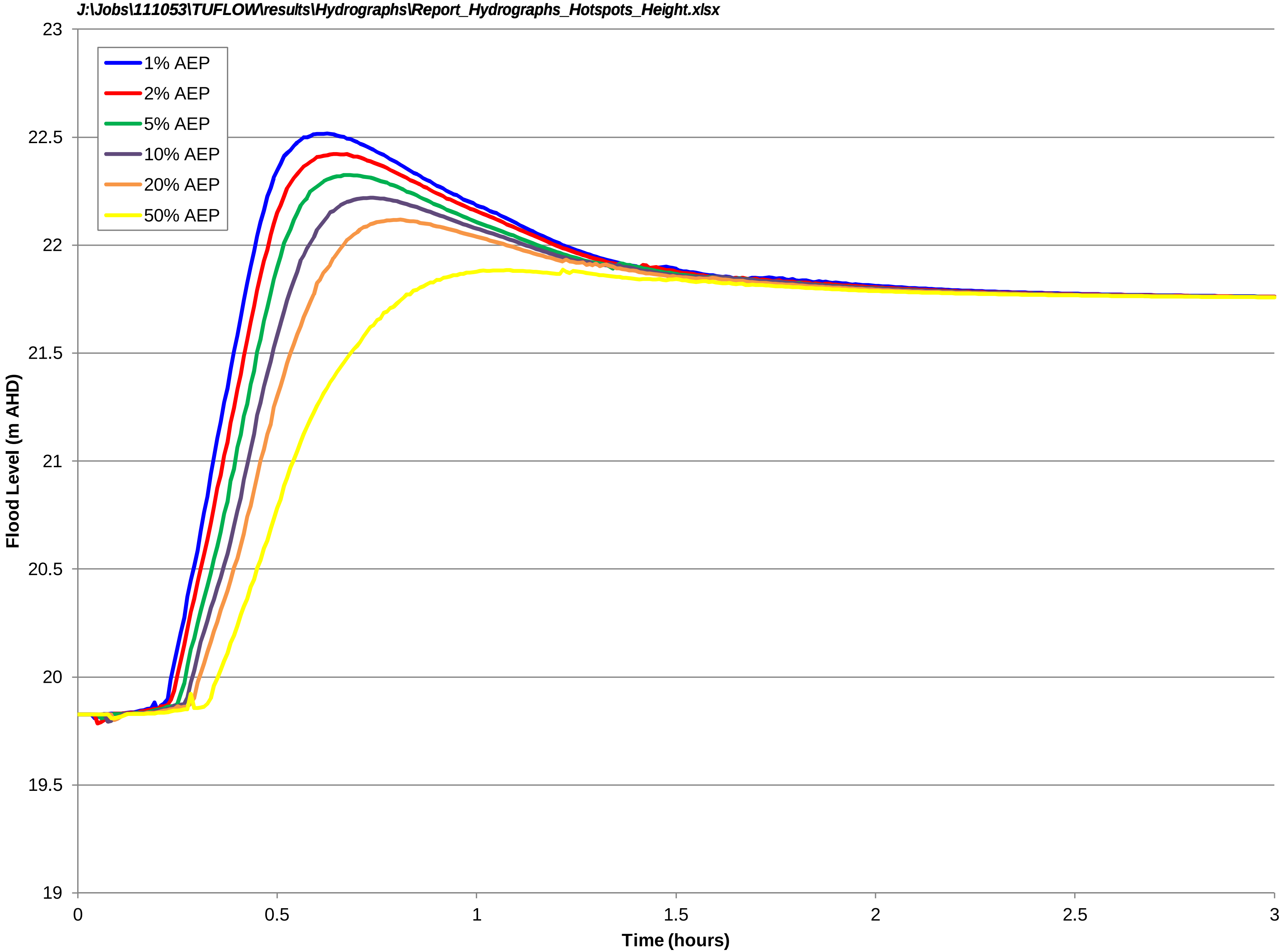

FIGURE C12
HOTSPOT LOCATION
BROWN STREET
FLOOD LEVEL HYDROGRAPH

FIGURE C13
AREA OF INTEREST
ALEXANDRA ST / CHURCH ST
1% AEP PEAK FLOOD DEPTH

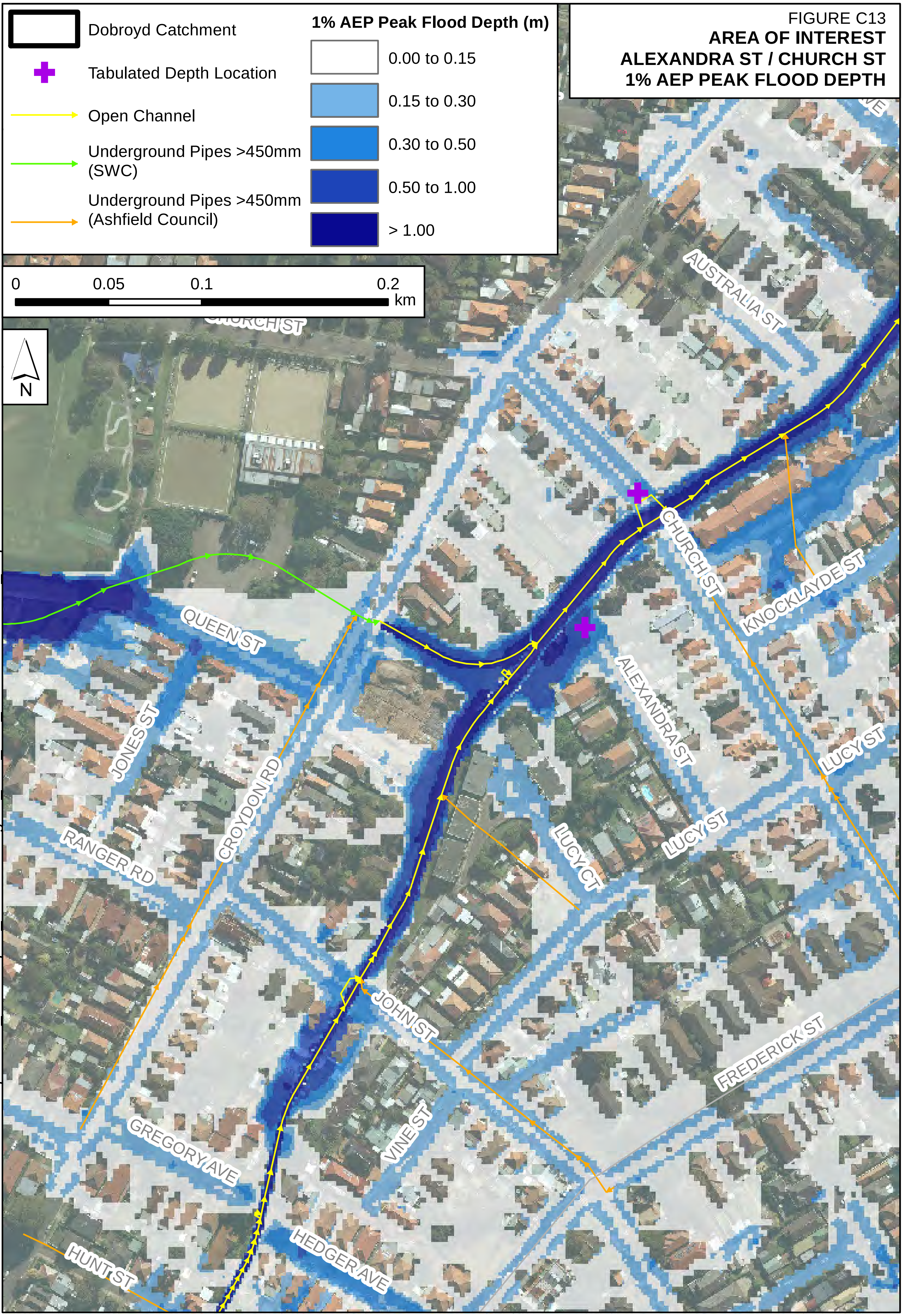

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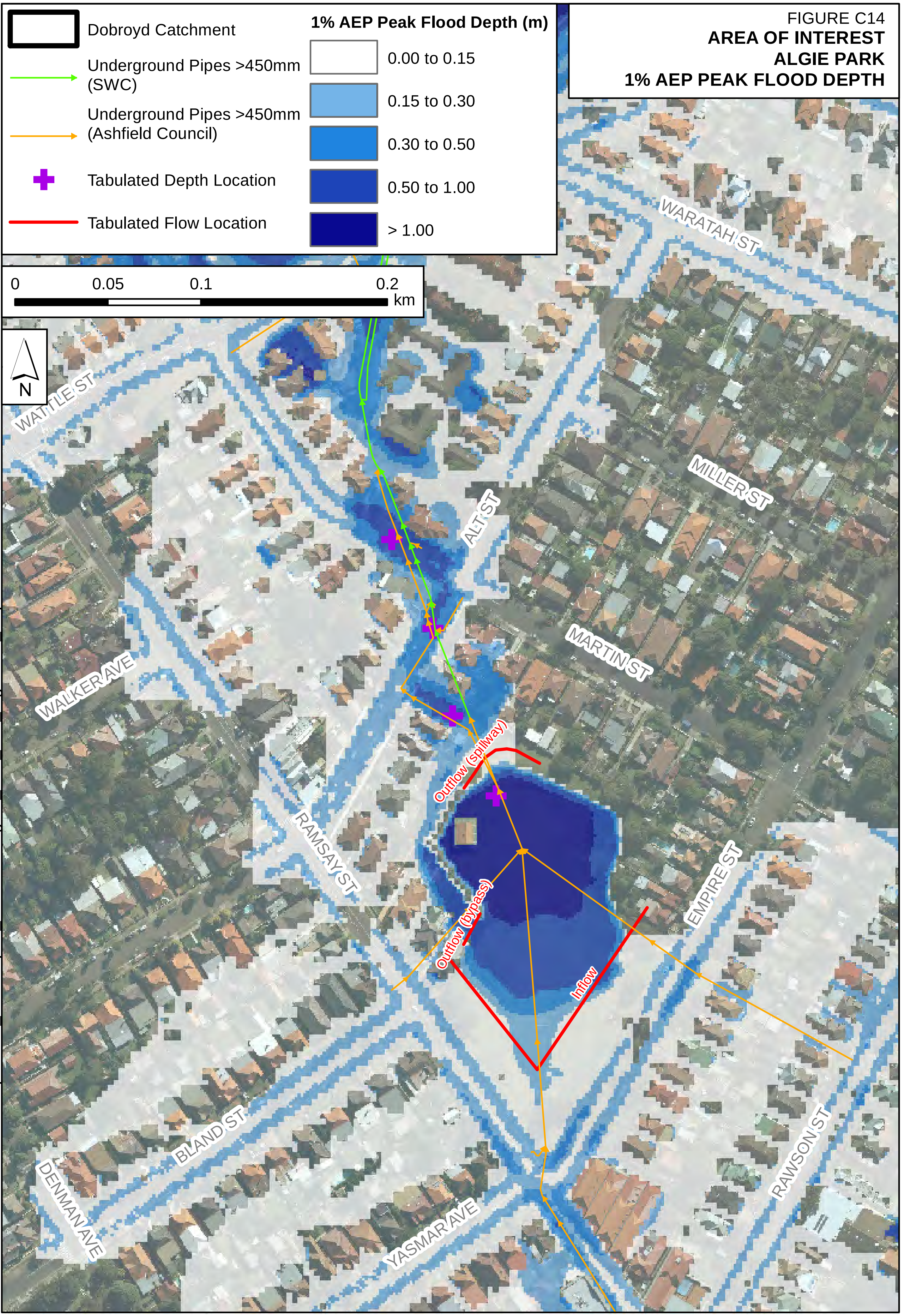
FIGURE C14
AREA OF INTEREST
ALGIE PARK
1% AEP PEAK FLOOD DEPTH



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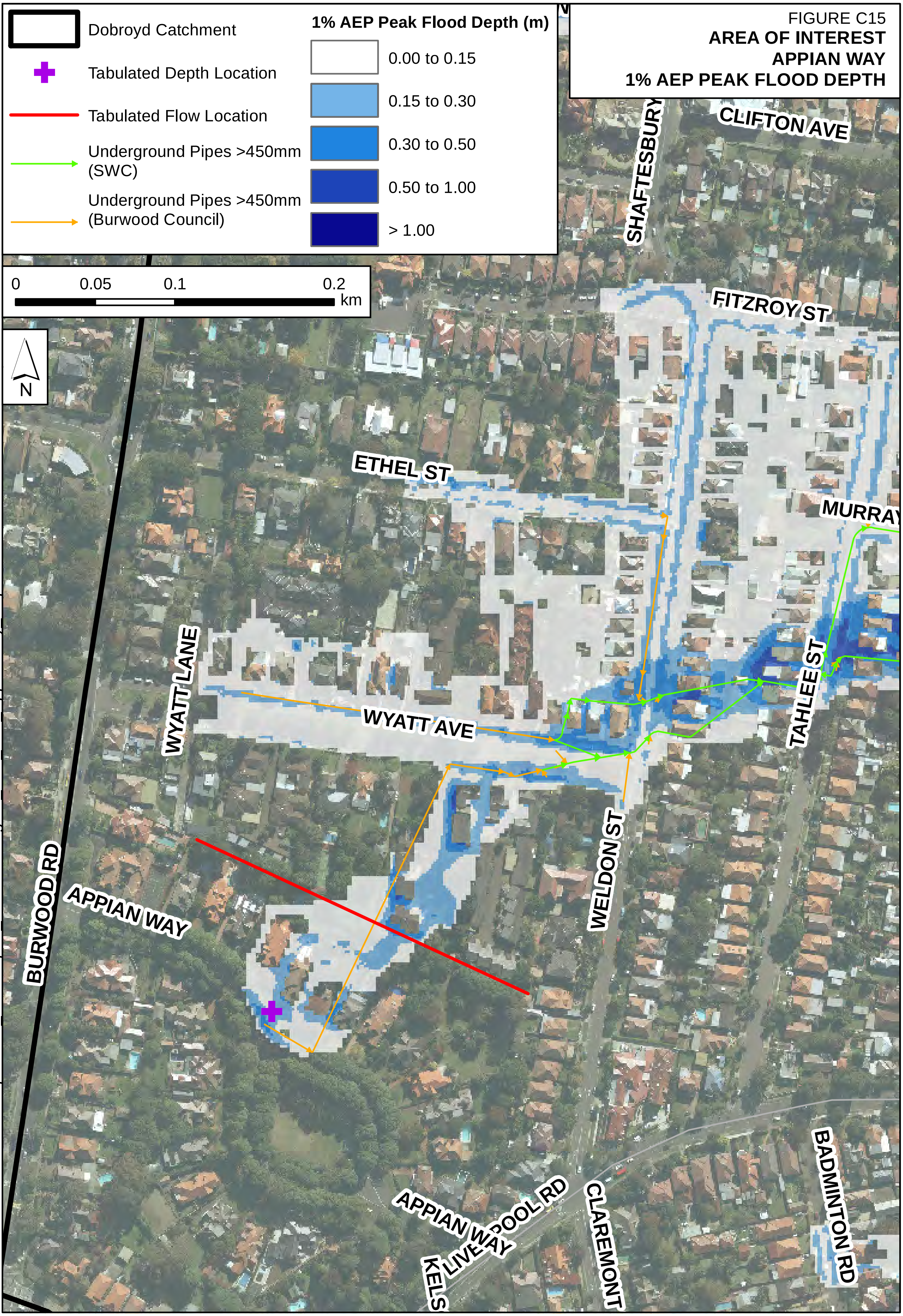

FIGURE C15
AREA OF INTEREST
APPIAN WAY
1% AEP PEAK FLOOD DEPTH

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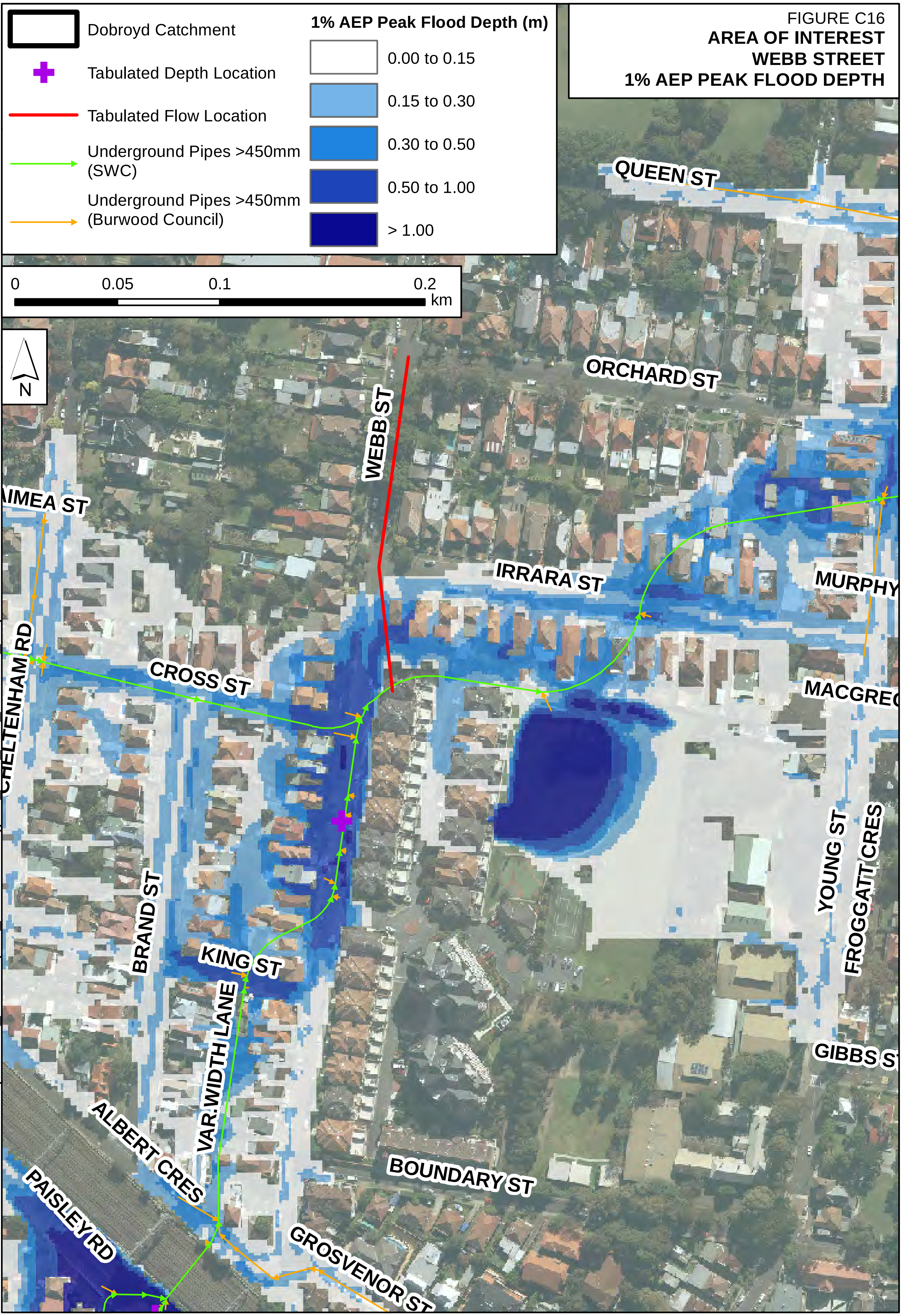
FIGURE C16
AREA OF INTEREST
WEBB STREET
1% AEP PEAK FLOOD DEPTH



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