ALEXANDRA CANAL CATCHMENT FLOOD STUDY MODEL UPDATE – ARR2019 HYDROLOGY

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Project **Alexandra Canal Catchment – Flood Study Model Update ARR2019 Hydrology**	**Project Number** **117049-04**
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TABLE OF CONTENTS

PAGE

LIST OF APPENDICES

LIST OF DIAGRAMS

LIST OF TABLES

LIST OF FIGURES

Appendix B – Changes in Peak Flood Level from Model Updates

Appendix C – Design Flood Mapping

Appendix D – Sensitivity Testing:

LIST OF ACRONYMS

1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model
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
DRAINS	Hydrologic computer model
EY	Exceedances per Year
GIS	Geographic Information System
m	metre
MIKE- FLOOD	Combined Hydrologic and Hydraulic computer model
MIKE- STORM	Hydrologic computer model
m^3/s	cubic metres per second (flow measurement)
m/s	metres per second (velocity measurement)
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SOBEK	2D hydraulic computer model
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
WRL	Water Research Laboratory

EXECUTIVE SUMMARY

The Alexandra Canal Catchment Flood Study Model Update has been prepared for the City of Sydney to provide a comprehensive catchment-wide flood model, and to ensure recent (and known upcoming) major developments are accurately accounted for, as well as current best practice data and methods for estimating design floods.

The Alexandra Canal catchment has been subject to extensive development in recent years, and there are several new residential and commercial precincts at various stages of development. City of Sydney required an up-to-date flood model that includes each of these precincts to establish current flood conditions, and also provides a realistic scenario against which to assess the flood impacts of future developments.

The Alexandra Canal catchment has been the subject of many flood investigations in the last ten years. These models are effectively already out of date following significant development and infrastructure renewal throughout the catchment. Completion of this modelling update provides an opportunity to assess the cumulative impact of a wide range of developments that have been designed and approved in recent years. Because of staging practicalities, many of these assessments involved assumptions about other developments occurring in parallel. While these assessment were generally well coordinated, it was not possible to be conclusive about the flood behaviour of the entire constructed system, especially for some of the major trunk drainage upgrades and precinct development changes.

Generally, the modelling undertaken in this report is entirely consistent with the previous modelling undertaken by WMAwater within the catchment. This modelling uses the same input datasets and modelling methodologies, except in instances where more detailed or accurate information has since become available. The previous studies from which modelling has been incorporated into this comprehensive catchment model include:

- Previous flood model update work for Alexandra Canal using ARR87 hydrology (Reference 1),
- The Alexandra Canal Catchment Flood Study, Floodplain Risk Management Study and Plan (References 4 and 5),
- The Green-Square West Kensington Flood Study, Floodplain Risk Management Study and Plan (References 6, 7, and 8),
- Flood modelling impact assessments of various trunk drainage infrastructure projects including:
    - The Green Square Trunk Drain (References 9, 10, and 11),
    - The Joynton Avenue / Zetland Avenue Trunk Upgrade Works (References 1 and 25),
    - The Ashmore Precinct and Erskineville FloodSafe Projects (Reference 24), and
    - The WestConnex New M5 project (Reference 22).

Estimates of tangible flood damages for the catchment were updated for this study. The updated estimates are significantly lower (approximately 46%), with a reduction in Average Annual Damages from $13 million to $7 million compared to the estimates from the 2014 FRMS. This does not include damages to cars and intangible damages such as stress and disruption to economic activity, which have also been substantially reduced due to reductions in flood risk as Botany Road, O'Riordan Street, Joynton Avenue and O'Dea Avenue. The primary contributing factors for this reduction are:

- Major trunk drainage upgrades, such as the Green Square Trunk Drain, O'Dea Avenue, Joynton Avenue, and the Lachlan and Ashmore precincts have significantly improved the capacity of the drainage network, resulting in less overland flow and reduced flood affectation. These upgrades have reduced flood risk in some of the more severely flood prone parts of the catchments, directly reducing the tangible flood damages.
- There has been significant redevelopment of urban renewal precincts. The redevelopment includes revisions to road layouts and stormwater networks that are more effective at retaining and conveying flow within the road reserves rather than in property. The new buildings constructed in these precincts have been designed with minimum floor levels to mitigate flood risk, such that the new buildings are significantly higher than previously. Some of these precincts previously contained a high concentration of flood-affected property, such as Green Square, Victoria Park, Lachlan (Midblock), Epsom Park and Ashmore. The redevelopment of these precincts has resulted in a significant reduction in tangible damages due to improved compatibility of the development with flood risk.
- The update to ARR2019 hydrology generally reduces the modelled flood levels and flows compared to the previous ARR1987 hydrology, due primarily to the updated information about design rainfall intensities and temporal patterns. These reduced levels result in reduced flood damage estimates. The reductions are not "real" in the sense that the underlying real flood risk has not changed, but the data for estimating the flood risk has become more accurate and indicates that the tangible damages are lower than previously thought.

This indicates that the investment in trunk drainage infrastructure upgrades by City of Sydney and Sydney Water, and the application of flood-related development controls such as minimum floor heights for new buildings, have been very successful measures for mitigating flood risks and damages throughout the catchment.

The primary outcome of this study is an updated flood model that describes design flood behaviour for a range of flood magnitudes, which can be used by City of Sydney to undertake its responsibilities relating to ongoing management of flood risk in the Alexandra Canal catchment. The model ties together the completion of a significant program of works by the City of Sydney to mitigate flood risk in the Alexandra Canal catchment, and provides the best estimate of the continuing flood risk in the catchment at the completion of these works.

1. INTRODUCTION

1.1. Overview

This Flood Study for the Alexandra Canal Catchment includes the following updates to the previously available flood modelling by WMAwater (Reference 1, July 2018):

- Updated design rainfall data and design flood methods from Australian Rainfall and Runoff 2019 (ARR2019, Reference 2). Previous modelling used the now superseded information from Australian Rainfall and Runoff 1987 (ARR1987, Reference 3).
- Inclusion of upgraded drainage infrastructure built in the catchment in recent years.
- Inclusion of recent developments in the catchment, including private development, precinct developments (including new road layouts and drainage), and major public infrastructure like WestConnex.
- Refinements to the model schematisation to reflect features identified during catchment inspections.

City of Sydney required an up-to-date flood model that includes each of these precincts to establish current flood conditions, using current best practice design hydrology inputs, which provides an accurate representation of the current flood risk in the catchment, and a baseline against which to assess the flood impacts of future developments.

The Alexandra Canal catchment has been the subject of multiple flood investigations in the last fifteen years. A catchment-wide Flood Study (Reference 4) and Floodplain Risk Management Study & Plan (Reference 5) was completed by Cardno in 2014. In parallel to this, part of the catchment was modelled separately (Flood Study and Floodplain Risk Management Study and Plan) for Green Square - West Kensington, and a number of major mitigation works including trunk drain upgrades were identified in these studies for implementation.

These models are effectively out of date following significant development and infrastructure renewal throughout the catchment. Many of these projects and developments were assessed and approved using either the Cardno study or smaller subcatchment models such as the Green Square - West Kensington model, which was modified to assess the Green Square Trunk Drain and other works. This was an appropriate process using the best information available at the time. However there was no comprehensive modelling of all the cumulative changes undertaken throughout the catchment.

In 2016, BMT WBM undertook a model conversion project to convert the existing catchment wide SOBEK model to a 1D/2D TUFLOW model, and amalgamate the Green Square – West Kensington flood modelling. This study was not adopted for further use.

In Reference 1, WMAwater developed an updated TUFLOW model reflecting “2017 Ultimate Development” conditions, including several already-completed developments and a number of proposed (or approved) future developments, using ARR1987 hydrology. This report documents further refinement of that model, and updates to use ARR2019 hydrology.

The primary outcome of this study is an updated flood model that describes design flood behaviour for a range of flood magnitudes, which can be used by City of Sydney to undertake its responsibilities relating to ongoing management of flood risk in the Alexandra Canal catchment. The model ties together the completion of a significant program of works by the City of Sydney to mitigate flood risk in the Alexandra Canal catchment, and provides the best estimate of the continuing flood risk in the catchment at the completion of these works.

1.2. Scope of Work

The tasks undertaken were:

- to update hydrologic and hydraulic models of the Alexandra Canal catchment to include current development information;
- to retain consistency with the previous models where appropriate with regards to key modelling parameters such as boundary conditions, calibration events, etc.;
- to review the completeness and accuracy of the drainage data in the models;
- to accurately define flood behaviour in the study area for 2019 Ultimate Development Conditions;
- to produce information on flood flows, levels, depth, velocities, extent, hydraulic and hazard categories for a full range of flood events;
- to undertake sensitivity analyses for key parameters including climate change impact;
- to update estimates of flood damages for the catchment;
- to provide flood modelling outputs in a suitable format for incorporating into Council's Geographic Information System (ArcMap); and
- provide a report documenting the methodology and outcomes.

1.3. Summary of Major Developments in the Catchment

Within the Alexandra Canal catchment area there are several urban renewal areas at various stages, from final concept to construction. In these areas, precinct-wide designs for civil and stormwater drainage in place, although refinements are expected during the detailed design stage as individual portions are constructed. The projects included in the hydrological and hydraulic models for 2019 Ultimate Development Conditions modelling include:

- Green Square Town Centre;
- Lachlan Precinct;
- Epsom Park Precinct;
- East- West Relief Road;
- Dyuralya Square;
- Green Square Trunk Drain;
- Joynton Avenue Trunk Drain;
- O'Dea Avenue Trunk Drain;
- Alexandra Canal Cycleway;
- Ashmore Precinct;
- WestConnex Stage 2 New M5; and
- Ashmore Trunk Drain.

1.4. Limitations

In addition to the major precinct developments and trunk drain upgrades identified above, there have also been several individual site based developments within the catchment in the period since the base models were developed. WMAwater identified some of these, but it was outside the scope of this assessment to comprehensively review changes for every lot within the study area. There may be locations where the updated model does not reflect current site conditions (e.g. individual building footprints, etc.). These lots may require further revision if the model is used for detailed assessment of further DAs within or adjacent to those lots.

2. BACKGROUND

2.1. Alexandra Canal Catchment

The 14 km^2 Alexandra Canal catchment (Figure 1) is located to the south of the Sydney central business district and drains to the Cooks River and ultimately Botany Bay. The main creek is termed Sheas Creek, with two main branches, one extending up through Green Square and Zetland to West Kensington, and the other to Redfern and Surry Hills. There are two other main sub-catchments – the Munni Street Drain from Erskineville and Macdonaldtown, and the Beaconsfield Drain in the southern part of the catchment. The Alexandra Canal catchment within City of Sydney comprises the suburbs of Alexandria, Rosebery, Erskineville, Beaconsfield, Zetland, West Kensington, Waterloo, Redfern, Newtown, Eveleigh, Surry Hills and Moore Park.

Most of the catchment is fully developed and consists predominantly of medium to high density residential developments as well as commercial and light industrial developments. There are several areas of open space in the upper parts including Moore Park and The Australian golf courses, Moore Park playing fields and Sydney, Redfern, Waterloo and Alexandria Parks.

The drainage systems in the upper parts are owned primarily by the City of Sydney, and by Randwick City Council in the West Kensington area, and mainly comprise pit and underground pipe/box culvert systems with some concrete lined open channels. These systems feed into the Sydney Water owned trunk drainage systems which comprise large underground pipe/box culvert systems and concrete-lined open channels. Sheas Creek has several concrete-lined open sections, and Alexandra Canal is a man-made canal created as part of the development of Kingsford Smith Airport.

Approximately 93% of the study is within the City of Sydney Local Government Area (LGA), with West Kensington to the east within the Randwick LGA. Flooding of roads and private property has occurred many times in recorded history, particular in the major storms of 1984 and 1989, but there are no systematic records of heights or depths.

2.2. Previous Studies

The NSW flood program process has previously been completed for both the entire Alexandra Canal catchment and for a subset of the catchment termed Green Square - West Kensington. The program requires periodic review and update, and the present study represents a step in that update process. The previous studies are summarised below.

2.2.1. Green Square – West Kensington (Sheas Creek Victoria Branch) Flood Study, April 2008 (Reference 6)

The Green Square – West Kensington (GSWK) Flood Study was initiated as a joint project between City of Sydney and Randwick City Council to establish flood behaviour for existing conditions across the catchment. In the absence of long term historical flood data, the Flood Study established a rainfall and runoff model using the MIKE Storm software to estimate flows throughout the study catchment. The MIKE Storm model was also used to assess the hydraulic performance of sub-surface and overland flow systems in the West Kensington catchment. A SOBEK hydraulic model was established for the area west of South Dowling Street to define the nature and extent of design flood behaviour in the lower reaches of the catchment. The various models were validated against historic flood information available for the two events in early November 1984.

The Mike-Storm model comprised over 550 sub-catchments and used what is known as an "embedded storm" design approach. Initially various durations were analysed and the adopted critical event incorporated a 1 hour peak burst rainfall embedded in a 6 hour duration event. This approach was undertaken to more closely reflect historical events where the peak burst is part of a longer duration event, while still being consistent with the Australian Rainfall and Runoff design storm method.

The 2D/1D hydraulic modelling software used was SOBEK, produced by Delft Hydraulics, and used a 2 m resolution ground grid. Buildings were blocked out from the model grid. The Flood Study defined the flood behaviour for the 50% AEP, 20% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP events and the Probable Maximum Flood (PMF).

2.2.2. Green Square – West Kensington FRMS/P, July 2013 (Reference 7)

The Green Square – West Kensington FRMS/P used the SOBEK model developed in the Green Square – West Kensington Flood Study (Reference 6) to assess various flood risk mitigation options for the catchment. A range of planning and flood response measures were recommended. Key flood modification measures recommended included:

- Retarding (detention basins) to reduce flows from upper catchment areas were to be considered as a means of mitigating the effects of urban development;
- Measures to manage blockage were to be actively supported; and
- Pit/pipe and Trunk System Upgrades were to be considered as part of urban re-development activities.

The Study identified a number of opportunities for potential pipe/ trunk system upgrades, a number of which have now been completed or are being constructed. Amongst these are the Green Square Trunk Drain, Joynton Avenue Upgrade and the O'Dea Avenue Upgrade.

2.2.3. West Kensington Flood Study (Reference 8)

Design flood behaviour within the West Kensington area, which is in the upper Alexandra Canal catchment (Sheas Creek branch), was previously analysed as part of the 2008 Green Square – West Kensington (GSWK) Flood Study (Reference 6). Due to limitations in the data then available, the model representation of flow paths and other hydraulic features within the West Kensington area was limited in detail. After Reference 6 was completed, Randwick City Council made available more detailed topographic data within the West Kensington area. Hence RCC requested that WMAwater refine the existing hydraulic modelling based on the more detailed topographic datasets of the West Kensington area. In addition, the model was converted to TUFLOW. The specific aims of the study were to establish a more refined hydraulic model and to then:

- define flood behaviour across the West Kensington area,

- prepare flood hazard and flood extent mapping,
- prepare suitable models of the catchment and floodplain for use in the GSWK Floodplain Risk Management Study (FPRMS) and Plan (Reference 7).

2.2.4. Green Square Trunk Drain – Hydraulic and Flood Modelling (Reference 9)

The Green Square Trunk Drain – Hydraulic and Flood Modelling was undertaken in order to prepare the reference design for the Green Square Trunk Drain project. In this modelling exercise, the SOBEK model used in the Green Square – West Kensington Flood Study and Floodplain Risk Management Study (References 6 & 7) was converted to a TUFLOW hydraulic model in a manner that produced consistent results, and the model domain was extended to Alexandra Canal. The TUFLOW model prepared for the West Kensington Flood Study update (Reference 8) was also incorporated.

The TUFLOW model developed for Reference 9 forms the core of the updated catchment-wide model developed for this present study. A consistent modelling approach across the catchment was desirable, as the previous models formed the basis of design and approval of several key trunk upgrades (Green Square Trunk Drain, O'Dea Avenue and Joynton Avenue) as well as the development of the Green Square, Lachlan, Epsom Park and Victoria Park precincts.

Further to this, the DRAINS model established in this study covered the full catchment and has formed the basis of the DRAINS modelling for the current study.

The DG Alliance reports (References 10 and 11) used this same model, updated for the Detailed Design & Construction phase of the Green Square Trunk Drain project.

2.2.5. Alexandra Canal Flood Study – May 2014, Cardno (Reference 4)

This study adopted the direct rainfall approach and incorporated all pits and pipes in the catchment within a 4m by 4m SOBEK 1D/2D hydraulic model. Historical flood height data suitable for model verification in the study area were available for November 1984, January 1991, April 1998 and February 2001. Industrial buildings were blocked out by raising their footprint and residential buildings were simulated assuming a higher roughness value.

Results from the direct rainfall method were compared to those from the traditional hydrologic approach using XP-RAFTS at two sub-catchments. Design results were created using a range of critical durations from 1 hour to 3 hours. Detailed sensitivity analyses were undertaken. The study determined the flood behaviour for the 100, 20, 10, 5, 2 and 1 year ARI events together with the Probable Maximum Flood (PMF).

2.2.6. Alexandra Canal Catchment Floodplain Risk Management Study and Plan – May 2014, Cardno, (Reference 5)

The Alexandra Canal Floodplain Risk Management Study and Plan (FRMS&P) followed on from the Flood Study (Reference 4) and assessed a range of mitigation options including flood modification measures, property modification measures and emergency response modification measures.

Recommended flood modification measures included:

- FM9 Link Road to Alexandra Canal Upgrade – Maddox Street Alignment;
- FM6 Additional pipes from Macdonald Street and Coulson Street to Alexandra Canal (alternatively FM21 Detention Basin in Sydney Park – Offset Storage from Macdonald Street);
- FM7 Detention basins in Redfern Park;
- FM18 Additional Drainage Network at Harcourt Parade to Gardeners Road;
- FM17 Detention basin in Turruwul Park; and
- FM20 Sheas Creek Channel Flood Walls.

2.2.7. Alexandra Canal Model Conversion – March 2016, BMT WBM (Reference 12)

The SOBEK 1D/2D flood model (Reference 4 model) established for the Alexandra Canal Flood Study (2014) was converted into TUFLOW, and a DRAINS model was established for estimating runoff and routing through the stormwater network for the entire Alexandra Canal catchment.

A linked 1D/2D TUFLOW flood model was established to describe the flooding behaviour throughout the study area. This model incorporated all pit and pipe data and had a 2.2 metre terrain grid resolution. The terrain model for this study mimicked the Alexandra Canal Catchment Flood Study (2014) terrain, which did not include all future developments within the catchment.

The models were calibrated and verified against three historical storms; November 1984, January 1991 and March 2001. City of Sydney elected not to adopt this model conversion for ongoing floodplain management purposes.

2.2.8. Alexandra Canal Flood Study Model Update (2017 Conditions) – July 2018, WMAwater (Reference 1)

The main objective of this study was to develop an updated DRAINS/TUFLOW flood model for two scenarios:

- the Base Case (2013 conditions), which was essentially a conversion and refinement of the existing SOBEK model from Reference 4 together with the localised sub-catchment models from Reference 8 and 9; and
- the Ultimate Development 2017 Scenario, which incorporated several already-completed developments and a number of proposed (or approved) future developments as of 2017.

It was found that the Ultimate Development 2017 Scenario resulted generally in peak flood level reductions across the catchment, without producing areas of significant increases in peak flood levels. This was found to be primarily a result of the improvements to trunk drainage infrastructure. The results were generally consistent with the individual assessments for each project, which confirmed that the flood modelling undertaken for the design of these upgrades was valid and provided confidence in the modelling outcomes for City of Sydney's ongoing planning and decision making.

The outcome of the 2017 study was a consolidated and updated flood model that described design flood behaviour for a range of flood magnitudes across the entire Alexandra Canal catchment, and which provided consistency with previous flood modelling completed throughout the catchment. The models from the 2017 update were used as the basis for the present study.

3. ADOPTED MODEL APPROACH

The overall guidelines for the modelling approach are taken from the 2005 NSW Government's Floodplain Development Manual (Reference 13) with technical details based on best practice from Reference 14. Design rainfall information and hydrologic modelling methods were used from ARR2019 (Reference 2). The update to ARR2019 from ARR1987 is the primary change for this model update, with some additional refinements to the model schematisation based on additional data and site inspections.

3.1. DRAINS Hydrologic Model

DRAINS (Reference 15) 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.

The use of DRAINS within this study was limited to some minor upstream catchment routing and development of hydrological inputs into the TUFLOW hydraulic model. The hydraulic components of DRAINS were not used, such as the routing of flows between sub-catchments ("total" flows), and modelling of the pit/pipe network.

DRAINS generates a full hydrograph of surface flows arriving at each pit. Runoff hydrographs for each sub-catchment area are calculated using the time area method.

The DRAINS model utilised for the study was based on the model developed for Reference 12, which included several sub-domains within the Alexandra Canal catchment. These models were combined into a single catchment model and refined where appropriate based on review of the stormwater network. The subcatchment delineation for the DRAINS model is shown on Figure 2. The DRAINS model was updated to utilise ARR2019 input for this study.

3.2. TUFLOW Hydraulic Model

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.

Further details regarding TUFLOW software can be found in the User Manual (Reference 16).

In TUFLOW the ground topography is represented as a uniform grid with a ground elevation and Manning's *n* roughness value assigned to each grid cell. The size of the grid is determined as a balance between the model result definition required, the dimensions of streets (as a rough guide the street should have over 4 cells widths in order to accurately define it) and the computer run time (depends on the number of grid cells).

The adopted approach was to establish a 2 m by 2 m 2D grid TUFLOW model, with channels defined as linked 1D elements where the grid structure was not appropriate.

The model extents, assumed building footprints, and layout of the 1D stormwater drainage elements are shown on Figure 3.

3.3. Calibration

The choice of calibration events for flood modelling depends on a combination of the flood event and the quality and quantity of available flood data. It is preferable to use the largest events on record for calibration, but often the largest events occurred some time ago, and reliable data is only available for smaller, more recent events.

The 2017 TUFLOW model update (Reference 1) was re-calibrated using the same three historic events as in the 2014 SOBEK model (Reference 12). These three historical events were the most significant recorded flood-producing storms in the catchment, and have not been additional significant flood events since these studies were undertaken.

The existing models have already been calibrated to historical design events. The changes to the models as part of this study were localised and do not significantly affect the results in locations where calibration information was available. Additional calibration was therefore not undertaken for this study.

3.4. Available Data

3.4.1. Aerial Topographic Survey

There are various LIDAR aerial survey datasets available for the study area. The most recent was obtained in by the NSW Department of Land and Property Information (LPI) in 2013. The 1 m resolution Digital Elevation Model (DEM) grids from the 2013 LPI dataset were used as the base topographic layer for this assessment.

3.4.2. Development and Detail Survey

A range of datasets provided detailed information about existing and proposed development within the catchment, details of key hydraulic structures and trunk drainage channels, and concept plans for ongoing precinct-wide developments. The datasets included previous flood studies and models, works-as-executed survey plans, drainage capacity assessments by Sydney Water Corporation, and precinct-wide design plans provided by City of Sydney. Table 1 lists the datasets available, and identifies the scenario in which they are used.

Table 1 Data Sources

Location	Model Update 2017	Model Update 2019	Title	Document Type (and No. if applicable)	Source / Author	Date
Munni Street Drain Catchment	✓	✓	Sydney & Suburbs Storm Water Drainage Munni Street to Sheas Creek Storm Water Channel	Drawings	Provided by Sydney Water	Various
	✓	✓	Munni Street SWC 74 Capacity Assessment	Report (Reference 17)	Sydney Water	01-10-98
	✓	✓	Alexandria Stormwater Drainage	Drawings	Provided by Sydney Water	01-08-34
	✓	✓	Munni St SWC No. 74 Amplification	Drawings W.N. 500003	M.W.S & D.B Sydney, NSW	21-08-85
	✓	✓	Munni Street Drain Culvert Under Euston Road at 1km East of St Peters Interchange	Drawing No. M5N-AJV-DWG-700-400-BR-7302	AJJV	24-05-17
	✓	✓	Hydrology Model Development Report St Peters Interchange and Local Road Upgrades Flood Modelling	Report: M5N-AJV-TER-100-114-HY-01499	AJJV	17-03-17
		✓	Development at 18 Huntley Street including upgraded pipe and Sydney Water drainage connection.	Report (Reference 21)	WMAwater	December 2019
		✓	Revised Westconnex culvert transition at Euston Road	Report (Reference 22)	WMAwater	February 2019
Ashmore Precinct			Ashmore Precinct Trunk Drainage Review	Report: AAJV-0416- P01	AJJV	10-06-16
	✓	✓	Stormwater and Flood Management, Ashmore Estate	Report:59915083 R001 Rev3	Cardno	08-06-16
	✓	✓	Ashmore Public Domain Strategy	Drawing: 60318562-SHT-CI-0001	AECOM	01-07-16
	✓	✓	Ashmore Public Domain Strategy (Layout & Long Section)	Drawing: 60318562-SHT-CI-0502	AECOM	05-02-16
Rosebery	✓	✓	Botany Road - Doody Street SWC 31 Capacity Assessment	Report (Reference 18)	Sydney Water	01-11-98
Redfern	✓	✓	Sheas Creek SWC 89 Capacity Assessment	Report (References 19 and 20)	Sydney Water	01-08-98
Epsom Park	✓	✓	Drainage and Utilities Key Plan - Epsom Park Precinct Infrastructure Concept Design	Drawing: E2-13/1164 – 500 series	City of Sydney	21-09-2015
	✓	✓	Epsom Park Final Civil Concept Design - Drainage Design 100% GA Plan	Drawing: 2015-585829	City of Sydney	01-12-2015

Location	Model Update 2017	Model Update 2019	Title	Document Type (and No. if applicable)	Source / Author	Date
	✓	✓	Epsom Park Final Civil Concept Design - Drainage Design - SB080814 Middle Removed	Drawing: 2015-585829	City of Sydney	1-12-2015
	✓	✓	Epsom Park Final Civil Concept Design - Drainage Design - Version 2	Drawing: 2015-585829	City of Sydney	1-12-2015
Lachlan Precinct	✓	✓	Waterfall by Crown Group: 18-20 O'Dea Avenue, Waterloo NSW 2017	Drawing - SY131-106	van de Meer Consulting	01-01-15
	✓	✓	Plan Showing Works as Executed Survey of Stormwater	Drawing - 116181553	Cardno Hard & Forester	30-10-14
	✓	✓	Waterfall by Crown Group: 18-20 O'Dea Avenue, Waterloo NSW 2017 - Drainage Layout	DWG SY 131 - 106	van de Meer Consulting	15-12-16
	✓	✓	Green Square Midblock Lachlan Precinct: Proposed Road & Drainage Layout	DWG E3 - 13/1164	City of Sydney	02-02-15
O'Dea Avenue Trunk Drain	✓	✓	O'Dea Avenue, Zetland - Trunk Drain	DWG E3-15/1341	City of Sydney	26-06-15
Joynton Ave Trunk Drain	✓	✓	Joynton Avenue, Zetland - Trunk Drain	E3 - 15/1342	City of Sydney	04-12-15
Green Square Town Centre	✓	✓	Green Square Town Centre – Civil Works Phase 1	Drawings 60300384-MOD-C-1	AECOM	16-06-2016
Green Square Trunk Drain	✓	✓	Final GSTD design model	Modelling files and Drawings	PB	12-02-2016
	✓	✓	Epsom Park Final Civil Concept Design - Zetland Short Term Cul-de-sac arrangement	Drawing - 2015-58529	City of Sydney	Unknown
	✓	✓	Sheas Creek Amplification – SWC89AMP Works As Constructed	Drawings DC0089-000	DG Alliance	17-07-2017
	✓	✓	Green Square Stormwater Drain: Hydraulics Design Report	Report	DG Alliance	01-12-15
GSTC to Ashmore Relief Road	✓	✓	Green Square to Ashmore Connector: Green Square Town Centre EIPD Package 06	Drawing 60300384-SHT-02-06-G-0001	AECOM	09-10-17

Table 1 is not a comprehensive summary of the development that has occurred in the catchment since 2013. In addition to the major precinct developments and trunk drain upgrades, there have also been several individual site-based developments in the period since the original flood models were developed. WMAwater identified some of these and updated the model accordingly. Building footprints throughout the catchment were reviewed with 2019 aerial photography, but it was outside the scope of this assessment to comprehensively review changes for every lot within the study area. It is likely that for individual lots there will be locations where the updated model does not reflect current site conditions (e.g. individual building footprints, etc.). These lots would have required individual assessment to ensure that re-development did not produce adverse changes to flood behaviour, so the catchment-wide effects are not likely to be significant. However, at some locations it may become apparent that minor further of the model may be required for detailed assessment of future development changes.

The base topographic LIDAR was supplemented within the study area of the Green Square – West Kensington FRMSP (Reference 7) using the detail survey of the streets obtained for that study, since that dataset was judged to be of high accuracy and consistency with the stormwater network survey in the same area.

3.4.3. Aerial Photograph

Updated aerial photography for the catchment was used to inform modelling revisions to building footprints, and other development changes such as new roads and the light rail corridor. The most recent aerial photograph available from the NSW Department of Lands and Property Information was used (accessed via the SIX maps exchange server on October 2019, as displayed on Figure 1).

3.4.4. Site Inspection

WMAwater personnel undertook a site inspection on 2 October 2019. Locations where previous modelling indicated significant flood depths were visited to confirm that key hydraulic features had been correctly schematised in the model. Observations from the site visit generally indicated that the model was capturing most overland flow features adequately. Some localised modifications were made to include flow paths or features that had not previously been captured. These modifications included:

- Representation of the CBD and South East Light Rail Corridor (see Photo 1 and Photo 2), which was not captured by LIDAR. The ground levels were estimated by interpolating between adjacent streets, and incorporating observations for the site visit.
- Inclusion of flow between buildings backing onto the sag point in Parkes Lane, Erskineville (see Photo 3). Previous modelling did not allow flow between the buildings, leading to accumulation of significant depths of water in the lane. Gaps were introduced in the model schematisation between the buildings to mimic the observed conditions.
- Refinement of the schematisation of the flow paths linking sag points in Milroy Street, MacDougall Street and Virginia Street in West Kensington (Photo 4 and Photo 5).
- Refinement of the schematisation of the flow paths linking sag points in John Street, Charles Street and Burren Street in Erskineville (examples in Photo 6 and Photo 7).

Photo 1: CBD and South East Light Rail Corridor

Photo 2: Light Rail Corridor Drainage

Photo 3: Parkes Lane Sag Point

Photo 4: MacDougall Street to Virginia Street Walkway Flow Path

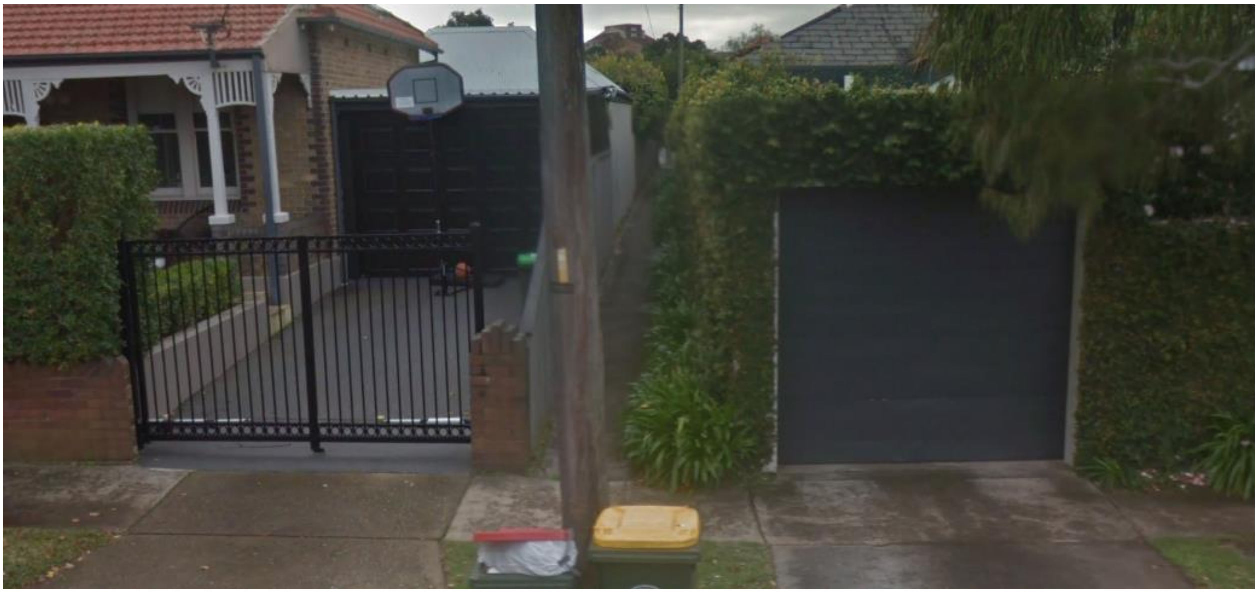


Photo 5: Milroy Street to MacDougall Street Walkway Flow Path

Photo 6: John Street to Charles Street Overland Flow Path

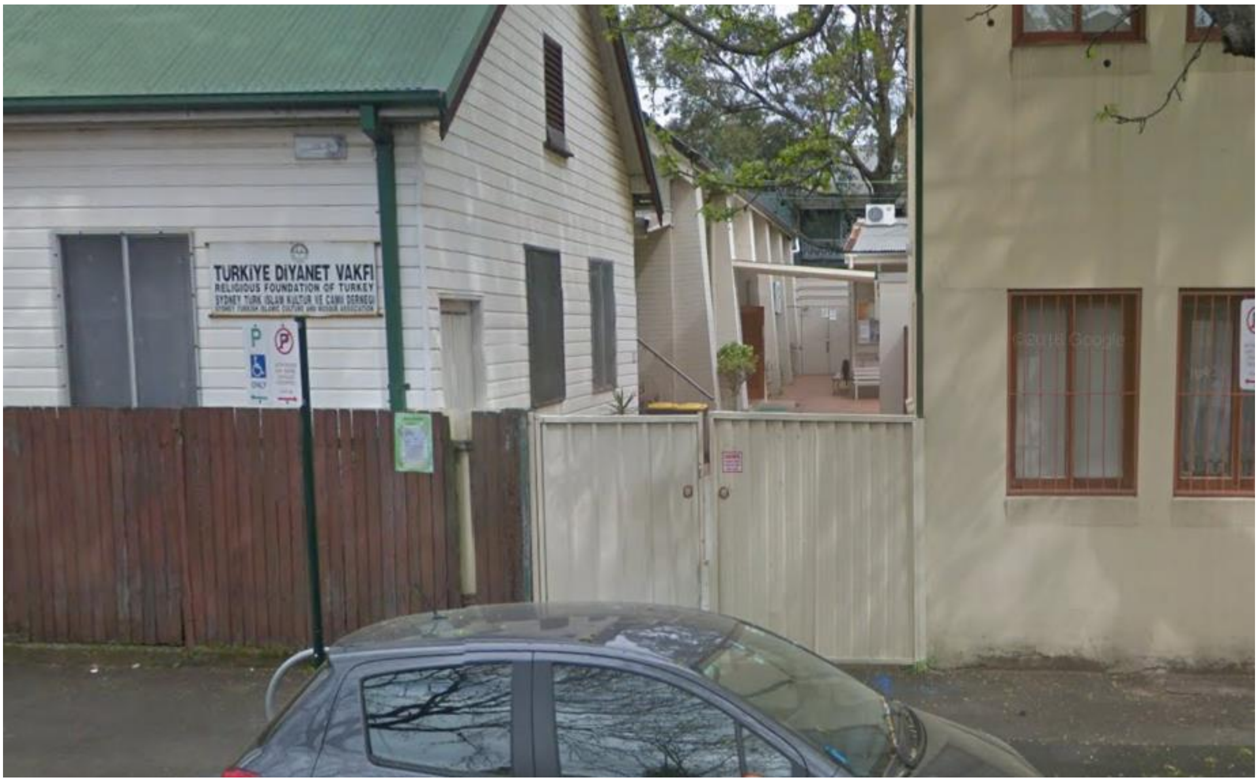


Photo 7: Charles Street to Burren Street Overland Flow Path

4. HYDROLOGIC MODEL SETUP

4.1. Sub-catchment Delineation

The total catchment represented by the DRAINS model is 14 km^2. The catchment was represented by a total of 2,476 sub-catchments (shown in Figure 2), giving an average sub-catchment size of approximately 0.57 ha. This relatively small sub-catchment delineation ensures that where significant overland flow paths exist that these are accounted for and able to be appropriately incorporated into hydraulic routing in the TUFLOW model.

In order to provide a consistent approach across the study area, the subcatchment delineation for the updated model is different from the original modelling for the Green Square – West Kensington Flood Study (Reference 6), in that part of the catchment. Flows at key locations were assessed and found to be reasonably consistent with the original modelling in those areas.

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 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 all sub-catchments, a uniform 5% was adopted as a supplementary area across the catchment. The remaining 95% was attributed to impervious (paved) and pervious surface areas, as estimated for each individual sub-catchment. The percentage of pervious surface was estimated by determining the proportion of the sub-catchment area covered by different land zoning classifications. The estimated impervious percentage of the chosen zoning classifications are summarised in Table 2.

Table 2: Impervious Percentage for Land-use types

Material	Impervious Percentage
Urban Residential	50%
Open Space	5%
Industrial-Commercial	70%
Roads	100%
Buildings	100%

The proportion of each land use type within each sub-catchment was adopted from Reference 12.

4.3. Sub-catchment Slope

The slope of each sub-catchment was determined using an automated algorithm based on the following characteristics of each area:

- Minimum and maximum elevations based on LiDAR
- The ratio of the catchment area to its perimeter, used to estimate an indicative length

The minimum sub-catchment slope was 0.47% and the maximum was 25%, with an average slope of 4%. The slope parameter for the West Kensington area was taken from Reference 6.

4.4. Rainfall Losses

The methods used for modelling the proportion of rainfall that is "lost" to infiltration are outlined in ARR19 (Reference 2). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data is available. A method frequently used for design flood estimation, and used in this model, 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 infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only a small initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from pervious areas are comprised of an initial loss and a continuing loss. The adopted loss parameters are based on a combination of the soil characteristics and the antecedent rainfall prior to the flood-producing storm. These values, particularly antecedent rainfall, are variable and ARR19 provides a statistical distribution of the probable values. For this study, the probability neutral values obtained from the mean of the distribution were used, in accordance with best practice guidance from the NSW Department of Planning Industry and Environment (Reference 23).

The adopted initial loss values (accounting for pre-burst rainfalls) are summarised in Table 3. This values are adjusted for each subcatchment depending on the assumed connected and indirectly connected impervious fractions for each subcatchment. For events shorter than 1 hour, the 1 hour values were adopted. For the 0.5% AEP and 0.2% AEP events, the 1% AEP loss values were used. A continuing loss value of 0.84 mm/hr was adopted for impervious surfaces, obtained by using 40% of the value specified on the ARR Datahub (as per Reference 23).

Table 3: Probability Neutral Initial Losses for Pervious Surfaces (mm)

Duration (minutes)	**Event AEP**					
	50%	20%	10%	5%	2%	1%
60	11.6	7.8	8.9	8.5	8.2	6.4
90	11.9	8.3	9.5	9.5	9.4	6.5
120	13.3	8.9	9.9	9.7	9.4	5.7
180	13.3	9.7	10.7	10.2	8.8	4.5
360	13	8.8	8.6	7.9	9	3
720	18.3	13	12.7	10.9	12.1	3.2
1080	18.6	13.6	14.4	12	12.4	3.9

5. TUFLOW HYDRAULIC MODELLING

This section documents the key data sources, methodology and assumptions for the hydraulic model schematisation.

5.1. Overview

Hydraulic modelling is the simulation of how floodwaters move through across the terrain. A hydraulic model can estimate the flood levels, depths, velocities and extents across the floodplain. It also provides information about how the flooding changes over time. The hydraulic model can simulate floodwater both within the creek banks, and when it breaks out and flows overland, including flows through structures (such as bridges and culverts), over roads and around buildings.

2D hydraulic modelling is currently the best practice standard for flood modelling. It requires high resolution information about the topography, which is available for this study from the LiDAR aerial survey. Various 2D software packages are available (SOBEK, TUFLOW, RMA-2). The TUFLOW package was adopted as it meets requirements for best practice, and is currently the most widely used model of this type in Australia for riverine flood modelling.

The TUFLOW modelling package includes a finite difference or finite volume 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 version used in this study was 2018-03-AD-iSP (using the finite volume HPC solver), and further details regarding TUFLOW software can be found in the User Manual (Reference 16). Previous studies used the finite different “classic” formulation of TUFLOW, but the model was upgraded to use the HPC solver for this study. The TUFLOW webpage states the following:

> *HPC’s 2nd Order Finite Volume solver offers similar performance to the world leading, proven and tried, TUFLOW Classic 2D Solver, with the addition of being unconditionally stable, mass conserving and benefiting from FV shock capturing.*

5.2. Inclusions since 2013

The model was updated to represent the catchment conditions inclusive of major development renewal precincts and infrastructure that have been constructed (or approved) since the 2013 conditions captured by the LIDAR and the SOBEK model from Reference 4. It incorporates full development of the Lachlan Precinct, Ashmore Precinct, Green Square Town Centre and Epsom Park Precinct. It also includes major trunk drain upgrades at Joynton Avenue, O’Dea Avenue and Green Square, and others. It includes the widening of Euston Road and the modification to the Munni Street drain made as part of the WestConnex project, but does not incorporate potential future upgrades to the Munni Street drain being investigated as part of the Erskineville Flood Safe project (Reference 24).

Design flood event results are presented for this scenario in Appendix C.

Details of the specific catchment features included in the model are provided below.

5.2.1. Topographic Features – 2019 Conditions

The following developments are represented in the Ultimate Development 2019 Scenario via incorporation of newly constructed or proposed building footprints and localised topographical changes (for example new green spaces, roads, kerb and gutter systems and raised intersections or pedestrian crossings). The Ultimate Development 2019 DEM was prepared by overlaying relevant information from Table 1. At each location, elevation data was incorporated into the TUFLOW hydraulic model, generally as Triangulated Irregular Networks (TINs) generated from electronic design files. The locations with major DEM changes included:

- The new Dyuralya Square within the Lachlan Precinct;
- New roads and buildings layout in the Lachlan precinct;
- A new set of roads and buildings proposed at Epsom Park.
- Green Square Town Centre – Stage 4. Option 2;
- A new road proposed to link the Proposed Green Square Town Centre and Ashmore Precinct between Bourke Road and Botany Road (East-West relief road);
- New roads and buildings layout at Ashmore precinct,
- New building footprint and stormwater upgrade at 18 Huntley Street;
- The CBD and South East Light Rail corridor;
- Overland flow paths and local features as discussed in Section 3.4.4; and
- The WestConnex widening of Euston Road.

The resulting model DEM for the 2019 Conditions Scenario topographic conditions is shown on Figure 5.

Exclusions

The following has not been included in the Ultimate Development 2019 Scenario:

- The section of the Epsom Precinct between the Council depot and Link Road remains as it is in the Base Case. This area was intended to be upgraded as part of the Green Square Trunk Drain project, but some existing landowners and tenants preferred to remain in place. This corresponds to the “Do Nothing” option that retained the existing open channel between the council depot and Link Road (Reference 10). WMAwater understands that the Green Square Trunk Drain has been built in such a way that facilitates completion of the culverts through this area when development renewal takes place, but current conditions will remain for the medium term.
- Other developments have occurred throughout the catchment for individual lots, but it was beyond the scope of this exercise to identify all of these individual lots. It is assumed that these developments were undertaken in accordance with Council requirements to not cause adverse impacts on flood behaviour external to the lots.

5.2.2. Stormwater Features – 2019 Conditions

The following proposed works were included in the Ultimate case, as they are either constructed or approval has been finalised and construction will commence soon:

- O'Dea Avenue: a 381 metre long, twin 1.50 m diameter pipe has been constructed. The pipes run from South Dowling Street to Joynton Avenue;
- Joynton Avenue: a new trunk drain is proposed. It includes a 350 metre long 1.8 metre pipe followed by a 150 metre section of twin 1.8 metre pipes (the potential use of 1.5 m pipes instead of 1.8 m pipes was also investigated in this study and reported separately to City of Sydney – refer to Reference 25 for results);
- At 18-20 O'Dea Avenue: 1 box culvert 3 metres wide by 0.9 m high and 160 metres long;
- An upgraded pipe in 18 Huntley Street;
- The Green Square Trunk Drain is being constructed between Link Road and Sheas Creek at Maddox Street. The trunk varies from a twin 2.41 metre wide by 1.27 metre high box culverts (at the existing portion), to twin 1.8 m diameter pipes, to triple 1.8 m diameter pipes. The entry and exit loss coefficients were modelled as per Reference 10. This corresponds to the "Do Nothing" option that retained the existing open channel between the council depot and Link Road (Reference 10);
- Sheas Creek is proposed to be enlarged between Maddox Street and Alexandra Canal. It includes an enlargement of the Huntley Street bridge/culvert as well as a regraded road. The design comes from the PB model (Reference 10);
- New stormwater systems are proposed or under construction at Lachlan, Ashmore, Epsom Park and Green Square Town Centre Precinct.

Exclusions

- Munni Street Trunk Drain Upgrade between the Ashmore precinct and Alexandra Canal (See Section 5.2.3).

5.2.3. Munni St Upgrade Investigations

Trunk upgrade options for the Munni Street Drain catchment have not been included in the Ultimate Development 2019 Scenario.

-

A separate feasibility study and flood impact assessment on the options for upgrading this trunk system was completed by WMAwater in February 2018 (Reference 24), including discussion the potential options listed above.

The hydraulic modelling and assessment presented in the report aimed to:

- Quantify the 5% AEP total system peak flow requirement for the trunk upgrade design;
- Provide input about refinement of concept design options to meet the required objectives;
- Assess the impacts of various concept options on peak flood levels; and
- Assess the performance of the options in reducing flood hazard throughout the Study Area.

The report found that the existing system already provided sufficient capacity for the 5% AEP flows between the Ashmore Precinct and Sydney Park, due to the improved stormwater system throughout the Ashmore Precinct and improved connections to the existing Sydney Water system. It was identified that the system from Euston Road to Sydney Park did not meet the City's capacity requirements, and there was a residual area of higher hazard flooding at the sag point in Coulson Street.

At the time of writing, the following options were still being considered to address these findings:

- An upgrade to inlet capacity at the sag point in Coulson Street; and
- Either an upgrade to the channel between Euston Road and Alexandra Canal, or additional local drainage at Burrows Road, to convey the increased flows from upstream if the Coulson Street inlet upgrade is constructed.

The Ashmore Precinct development itself, including drainage within the precinct were included in the Ultimate Development 2019 Scenario, but not the options listed above. These upgrades were not included in modelling for this study because at the time of modelling the design had not been confirmed and the timeframe for funding allocations, detailed design and construction was unclear.

5.3. Boundary Locations

5.3.1. Inflows

Subcatchment inflows are input into the TUFLOW at the location of the receiving stormwater inlet pits for each subcatchment. In some subcatchments where no receiving pits are present, the inflows were input into the road reserve or other overland flow path. In the majority of subcatchments, the inflows are introduced to the hydraulic model at pit inlet locations.

5.3.2. Downstream Boundary

Downstream of the study area, the Alexandra Canal joins the Cooks River before flowing into Botany Bay. Flooding within the lower Alexandra Canal can therefore be a result of three primary mechanisms:

a) Intense rainfall producing runoff within the Alexandra Canal catchment; and/or
b) Flooding of the Cooks River, causing elevated tailwater levels (backwater) within the Alexandra Canal channel; and/or
c) Elevated water levels within Botany Bay from tides/storm surge.

Table 4: Adopted tailwater levels for design event modelling

Design Event (ARI)	Tailwater Level in Alexandra Canal / Cooks River (mAHD)
1 year	1.5
2 year	1.65
5 year	2.0
10 year	2.1
20 year	2.15
50 year	2.3
100 year	2.5
PMF	3.95

The Cooks River and Botany Bay mechanisms can potentially cause lower catchment flooding without significant rainfall on the Alexandra Canal catchment, or they can exacerbate flooding by preventing storm runoff from draining from the catchment. Table 4 summarises the adopted tailwater levels for the design events, consistent with those used in Reference 4 (based on Reference 26).

Sensitivity analysis of tailwater levels was undertaken and is reported in Section 7.

5.4. Roughness Coefficient

The hydraulic efficiency of the flow paths within the TUFLOW model is represented in part by the hydraulic roughness or friction factor formulated as Mannings "n" values. This factor describes the influence of surface roughness and incorporates the effects of vegetation and other features which may affect resistance to flow.

The adopted roughness values of varying land use types are generally consistent with those used in Reference 4 and Reference 12, with the following modifications:

- The separate, formerly overlapping materials layers from previous models were merged into one layer and simplified;
- Building footprints were removed from the material layer and the representation of buildings was changed, so that instead of using high manning's n values and storage reduction factors to represent the obstruction caused by buildings, building footprints were nulled out of the model (see Section 5.5 for treatment of buildings);

The adopted roughness values for different land use types are presented in Table 5. A map of the adopted land use types for the 2D TUFLOW domain is shown on Figure 4.

Table 5: Adopted Manning's "n" Roughness Values

Elements	Manning's *n* value
Railway	0.06
Alexandra Canal	0.018
Highly dense area (commercial and industrial)	0.04
Residential Area	0.04
Open Space	0.03
Roads	0.02
Storm water	0.015
New Trunk Drains	0.012
Open channel	0.012 to 0.013

5.5. Buildings and Other Obstructions

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. It was assumed that no flow occurs through buildings. That is, buildings were modelled as impermeable obstructions and were removed from the model grid. These types of features were modelled as impermeable obstructions to flow and are shown in Figure 3. Thus there is no assumed flood storage capacity within the building. Building delineation was based on aerial photographs, previous studies and available details of new developments. See Section 5.2.1 for a list of included development precincts. Note that although efforts were made to identify changes in the catchment, it is possible in some cases the building footprints will not reflect recent localised developments.

Buildings were "blocked out" from the 2D model grid, in line with research undertaken for the AR&R revision (Reference 14). The research project found that *"Numerical model trials showed that on the basis of the available data sets, the best performing method when representing buildings in a numerical model was to either remove the computational points under the building footprint completely from the solution or to increase the elevation of the building footprint to be above the maximum expected flood height.*" The project also found that "*Analysis of flood volumes on the floodplain has shown that in a floodplain with flows passing through the floodplain, achieving peak levels due to peak flow rate rather than peak stored volume, the influence of the flow volume stored inside buildings is not significant to the presented flood levels in the prototype floodplain.*"

5.6. Stormwater Trunk Drainage Network

Stormwater trunk drainage infrastructure, such as pipes, culverts, stormwater pits and open channels were modelled as 1D elements linked to the 2D model grid where appropriate. The locations of these 1D elements are indicated on Figure 3. Details of the network geometry such as invert levels, inlet/pipe sizes, connectivity and location were imported directly from previous hydraulic models, and revised based on detailed survey where available. Refer to Section 3.4.2 for specific details on the stormwater drainage network information used for particular precincts.

5.7. Blockage Assumptions

5.7.1. Stormwater Inlet Pits

For the design modelling undertaken in this current study, each pit has been modelled as an "R" type pit channel with a width (grate perimeter or lintel length) determined from the survey or existing model information. Blockage of pits was modelled by reducing this width by the designated blockage percentage.

For design modelling, on-grade pits were assumed to be 20% blocked and sag pits were assumed to be 50% blocked. Sensitivity to these parameters was analysed, with results presented in Section 7.

5.7.2. Open Channel Bridges and Culverts

The bridges and culverts at road crossings on open concrete channels were assumed to be unaffected by debris blockage for the design flood modelling. This is consistent with the approach adopted for the previous studies in this catchment, as well as flood studies undertaken for other catchments within the City of Sydney Local Government Area.

Sensitivity to the blockage assumption was undertaken and is presented in Section 7.1.

5.8. Other Hydraulic Energy Losses

A hydraulically efficient system would have a straight pipe without interruption, at relatively consistent grade, delivering flows directly to the receiving waters. These features are typically impractical for real systems. Practical realities require that flows in pipes merge at junctions, change direction, and accelerate/decelerate as they travel through the network. These events create turbulence resulting in energy loss from the flow, making the system less efficient and reducing the total flow conveyed.

TUFLOW implements an automatic approach for estimating the hydraulic energy losses inherent in a pit and pipe stormwater network, referred to as the "Engelhund Approach" within the TUFLOW documentation (Reference 16), which states:

> *The Engelhund approach provides an automatic method for determining the following energy loss coefficients. The coefficients calculated and their equations are presented below. Of note is that the coefficients are recalculated every timestep, and therefore vary depending on the flow distribution between inlet and outlet culverts and the depth of water within the manhole.*

The approach estimates losses from the following mechanisms:

- Expansion and deceleration of flow from an outlet pipe as it enters manhole;
- Changes in flow direction between inlet and outlet pipes at a junction;
- Changes in level where the invert of a pipe is higher than the invert of the downstream pit, resulting in a drop as the flow inters the manhole; and
- Contraction, acceleration and re-expansion of flow through a vena contracta as the flow exits the manhole and enters the downstream pipe.

The losses are formulated as a *K* energy loss coefficient applied to the downstream pipe at each manhole (pit), where change in total head in the system (in metres) is equivalent to *K* multiplied by the velocity head, $V^2/2g$.

Additional energy losses are also applied at culverts and bridges where the structures provide an obstruction to flow, or there is significant expansion/contraction of flow through the structure.

5.9. Summary of Changes from 2017 Update to 2019 Update

This study involved a series of updates to the modelling developed in Reference 1. The changes, which are discussed in detail in various sections of this report, are summarised briefly below. For each of the changes, the incremental changes in the model results for the 1% AEP peak flood level were calculated, to determine the magnitude of the change, and also to ensure that the changes did not accidentally introduce modifications to unexpected areas. Maps of the incremental effects of the changes are presented in Appendix B.

A brief summary of the changes is as follows

- Building Footprints were updated based on current aerial photography (see Sections 3.4.3 and 5.5). The peak flood level changes resulting from this update are shown on Figure B1.
- The base DEM was updated to use the 2013 LIDAR survey across the entire study area. This primarily affected areas of Rosebery, West Kensington and the central Sheas Creek branch around Waterloo and Alexandria, which were still based on earlier LIDAR information. Other parts of the model had previously been updated to include 2013 LIDAR already. The peak flood level changes resulting from this update are shown on Figure B2.
- Some overland flow paths were refined based on the catchment site inspection (see Section 3.4.4). These changes mainly affected areas around John/Charles Street and Parkes Lane in Erskineville, and Milroy/MacDougall/Virginia Streets in West Kensington. The peak flood level changes resulting from this update are shown on Figure B3.
- The model extent was refined to more accurately represent the catchment boundary. The peak flood level changes resulting from this update were minor and are shown on Figure B4.
- The model schematisation for inlet pits was revised to use a consistent approach across the entire catchment. The peak flood level changes resulting from this update were minor and are shown on Figure B5.
- The model was updated to use a more modern version of TUFLOW, including an update to use the “HPC” finite volume solver rather than the “Classic” finite difference solver (see Section 5.1). The peak flood level changes resulting from this update are shown on Figure B6.
- The combined changes resulting from the changes above are shown on Figure B7. These changes were all assessed for the 1% AEP event using the previous hydrology from the 2017 Model Update. The additional changes to the hydrology were implemented after the model changes above, and the influence on the results from the hydrology update is discussed in Section 8.

6. DESIGN FLOOD BEHAVIOUR

6.1. Overview

ARR2019 guidelines for design flood modelling were adopted for this study, including the use of ARR2019 design rainfall information for all events except the Probable Maximum Precipitation (PMP). The PMF flows were derived using the Bureau of Meteorology's Generalised Short Duration Method (Reference 27) to estimate the PMP as the input rainfall to DRAINS.

The flows generated by the DRAINS model for each design flood event were then used as inflows in the calibrated TUFLOW model to define the flood behaviour across the catchment using the representative critical duration patterns. The rainfall data, temporal patterns and the procedure for the selection of the critical pattern duration are discussed in the following sections. The resulting flood behaviour simulated in the TUFLOW model is subsequently presented.

6.2. ARR2019 IFD

ARR2019 IFD information was obtained from the Bureau of Meteorology (BoM). IFD information was sourced for each subcatchment individually from the BoM's gridded IFD data and applied in the DRAINS hydrologic model. A summary of average design rainfall depths across the catchment is provided in Table 6.

Table 6: Catchment average design rainfall depths (mm)

Duration	AEP						
(min)	20%	10%	5%	2%	1%	0.5%	0.2%
20	20.5	27.3	31.8	36.1	41.8	50.1	56.7
25	22.7	30	35	39.8	46.1	55.3	62.6
30	24.5	32.4	37.7	42.9	49.6	59.7	67.6
45	28.6	37.8	44	50	58	70	79.2
60	31.7	41.8	48.7	55.4	64.4	77.9	88.2
90	36.6	48.2	56.2	64.1	74.7	90.6	103
120	40.5	53.4	62.3	71.2	83.3	101	114
180	46.8	62	72.6	83.3	97.9	119	134
270	54.6	72.7	85.6	98.7	116	141	160
360	61.2	82	96.9	112	133	161	182
540	72.3	97.8	116	135	161	196	221
720	81.5	111	133	155	185	225	255
1080	96.6	133	160	188	225	275	312
1440	109	151	182	214	257	316	358

For AEPs of 0.5% and 0.2%, the BoM does not provide design rainfall for durations shorter than 24 hours. Therefore, growth factors were derived for these AEPs for the 24 hour storm duration relative to the 1% AEP event. These factors were applied to the 1% AEP design rainfalls to derive the 0.5% and 0.2% AEP rainfalls for storm durations less than 24 hours. No areal reduction factors were applied to these rainfalls.

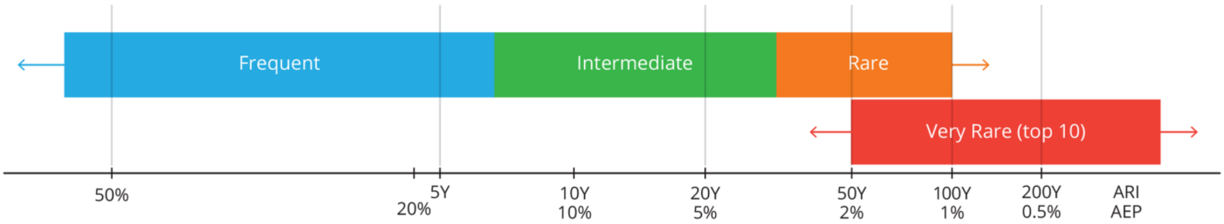
6.3. Temporal Patterns

Temporal patterns are a hydrologic tool that describe how rainfall falls over time and are often used in hydrograph estimation. Previously in ARR1987, a single burst temporal pattern has been adopted for each rainfall event duration. However ARR2019 discusses the potential inaccuracies with adopting a single temporal pattern, and recommends an approach where an ensemble of different temporal patterns are investigated.

Temporal patterns for this study were obtained from ARR2019. There are a wide variety of temporal patterns possible for rainfall events of similar magnitude. This variation in temporal pattern can result in significant effects on the estimated peak flow. As such, the recommended methodology is to consider an ensemble of design rainfall events and determine the median catchment response from this ensemble.

The ARR2019 method divides Australia into 12 temporal pattern regions, with the Alexandra Canal catchment falling within the East Coast (South) region. ARR2019 provides 30 patterns for each duration, which are sub-divided into three bins based on the frequency of the events. Diagram 1 shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. The “very rare” bin is in the experimental stage and was not used in this flood study. There are ten temporal patterns for each AEP/duration in ARR2019 that were utilised in this study for the 50% AEP to 0.2% AEP events.

Diagram 1: Temporal Pattern Bins



The method employed to estimate the PMP utilises a single temporal pattern (Reference 27).

6.4. Critical Duration Analysis

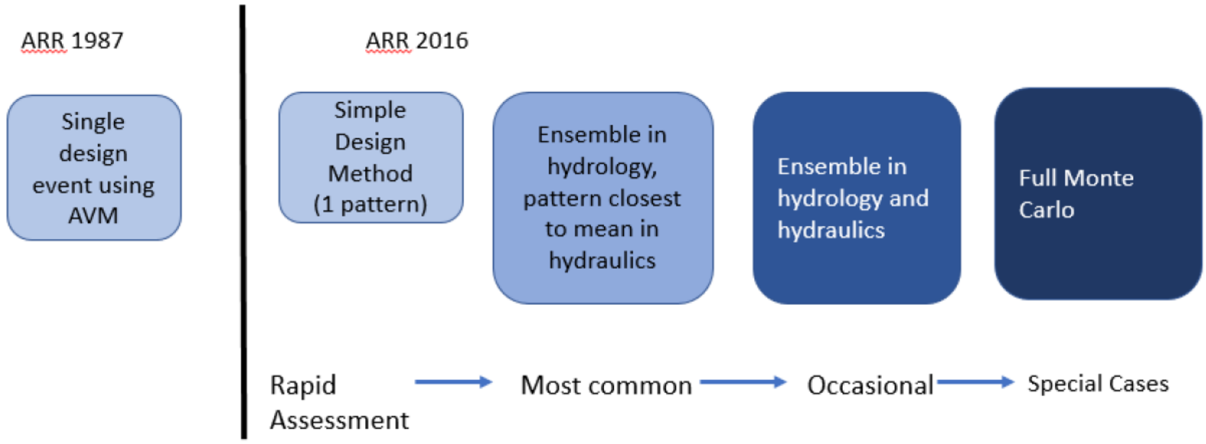
The critical duration is the temporal pattern and duration that best represents the flood behaviour (e.g. flow, level) for a specific design magnitude. It is generally related to the catchment size, as flow takes longer to concentrate at the outlet from a larger catchment, as well as other considerations like land use, shape, stream characteristics, etc.

With ARR2019 methodology, the critical duration is the storm duration that produces the highest mean flow or level at a point of interest (where the mean is calculated from the ensemble of ten temporal patterns for that duration. Where there are multiple locations of interest with different contributing catchment sizes, there can be multiple critical durations that need to be considered.

Once the critical duration is established, it is usually desirable to select a representative design storm temporal pattern that reproduces this behaviour for all points of interest. This representative storm can then be used for determining design flood behaviour and for future modelling to inform floodplain management decisions.

The potential methods for the ensemble modelling approach are outlined in Reference 23, reproduced in Diagram 2.

Diagram 2: Ensemble Hydrology Approaches in ARR2019



The “Most common” approach is to rely on a hydrologic model to determine the critical duration before proceeding with hydraulic modelling. For this study, due to the complex interactions between the hydrology and hydraulics, the relatively more complex “Occasional” approach was used where the full ensemble of temporal patterns were run in both the hydrologic and hydraulic models for a range of durations up to 180 minutes. For each duration, a grid of the mean peak level at each grid cell was calculated, and then a maximum grid was calculated taking the highest peak mean level for each grid cell. The source of the peak mean level for each grid cell was mapped to show the variation in critical duration across the catchment.

The process above indicated that the 30 minute and 60 minute durations are critical for the majority of the catchment, apart from some flood storage areas in open spaces such as parks, playing fields and golf courses (see Figure 7). It was determined that an envelope of a representative pattern for each of the 30 minute and 60 minute durations provided a good representation of the catchment-wide peak flood behaviour (see Figure 8).

The critical duration assessment for the PMF was completed in Reference 1, and this was not revised since there are no changes to the PMP hydrology for this study. The 90 minute storm generally produced peak flood levels within 0.1 m of the peak depths obtained from the envelope of multiple storm durations for the PMP.

6.5. Results

Maps of estimated peak flood depths and flood level contours of the Ultimate Scenario from the design modelling process are presented in Appendix C for a range of flood magnitudes:

- Peak flood depths are presented in Figure C1 to Figure C8 ;
- Peak flood velocities are presented in Figure C10 to Figure C18;
- Peak flood levels are presented in Figure C19 to Figure C27.

The results are also tabulated at key locations in Table 7 and Table 8. See Figure 6 for the locations referred to in the tables.

Table 7 Peak Flood Level Results at Key Locations

Location	50% AEP	20% AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP	0.2 % AEP	PMF
P01	24.5	24.5	24.6	24.7	24.7	24.8	24.8	24.9	25.5
P02	23.7	23.9	24.0	24.1	24.3	24.4	24.4	24.5	25.2
P03	24.1	24.2	24.2	24.2	24.2	24.2	24.2	24.2	24.6
P04	21.4	21.5	21.5	21.6	21.6	21.6	21.7	21.7	22.3
P05	18.4	18.4	18.5	18.5	18.5	18.5	18.5	18.5	19.7
P06	0.0	0.0	0.0	13.7	14.0	14.0	14.1	14.1	14.6
P07	0.0	11.0	11.1	11.3	11.3	11.4	11.5	11.6	12.3
P08	12.1	12.3	12.6	12.7	12.7	12.8	12.8	12.8	14.0
P09	6.6	6.6	6.6	6.7	6.7	6.7	6.8	6.9	9.5
P10	12.0	12.2	12.4	12.5	12.7	12.8	13.0	13.1	13.6
P11	13.1	13.3	13.5	13.6	13.7	13.8	13.8	13.9	14.7
P12	11.5	11.7	11.8	11.8	11.9	11.9	12.0	12.0	12.7
P13	28.3	28.6	28.8	29.0	29.3	29.4	29.5	29.6	31.2
P14	30.2	30.4	30.5	30.5	30.6	30.7	30.7	30.8	32.6

Table 8 Peak Flow Results at Key Locations

Location	50% AEP	20% AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP	0.2 % AEP	PMF
1D01	11.1	13.7	17.3	17.8	19.5	19.7	19.2	19.2	20.8
1D02	7.6	8.4	9.2	9.7	9.9	10.3	10.9	11.8	20.9
1D03	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3
1D04	5.6	7.8	10.2	12.1	14.0	14.9	15.4	15.9	18.8
1D05	55.5	64.5	71.6	77.1	82.1	87.1	99.1	102.5	296.8
1D06	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6
1D07	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1D08	11.8	13.9	15.8	17.6	19.0	20.6	22.1	24.4	30.6
1D09	13.8	16.7	19.0	20.9	22.5	24.3	25.7	27.7	31.3
2D01	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	20.6
2D02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.1
2D03	0.0	0.1	0.3	0.5	0.7	1.6	2.4	3.6	66.5
2D04	0.2	0.2	0.3	0.3	0.4	0.4	0.6	1.9	29.8
2D05	86.4	103.5	114.3	124.6	134.6	143.2	149.9	159.3	403.6
2D06	0.9	1.4	1.6	1.9	4.3	6.2	7.9	10.9	75.9
2D07	59.0	68.4	75.9	82.5	90.7	96.8	101.7	109.8	337.8
2D08	119.6	149.0	162.7	177.2	188.0	203.9	213.7	226.7	586.7
2D09	0.5	0.7	0.9	1.0	1.1	1.3	1.3	1.5	2.6
2D10	0.1	0.3	1.2	2.0	2.6	3.4	4.1	5.1	16.4

6.6. Provisional Flood Hazard Categorisation

Hazard classification plays an important role in informing floodplain risk management in an area. In the Floodplain Development Manual (Reference 13) hazard classifications are essentially binary – either Low or High Hazard as described in Figure L2 of that document. However, in recent years there has been a number of developments in the classification of hazard especially in *Managing the floodplain: a guide to best practice in flood risk management in Australia* (Reference 28).

For this study Provisional Flood Hazard Categorisation mapping has been provided utilising techniques form both of the above mentioned references. The techniques are outlined in the following reference material:

<u>Managing the Floodplain: A Guide to the Best Practice in Flood Risk Management in Australia</u>

Managing the floodplain: a guide to best practice in flood risk management in Australia (Reference 28) provides revised hazard classifications which add clarity to the hazard categories and what they mean in practice. The classification is divided into 6 categories which indicate the restrictions on people, buildings and vehicles:

- H1 - No constraints;
- H2 – Unsafe for small vehicles;
- H3 - Unsafe for all vehicles, children and the elderly;
- H4 - Unsafe for all people and all vehicles;
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction; and
- H6 – Unsafe for people or vehicles. All buildings types considered vulnerable to failure.

Diagram 3: Hazard Classifications

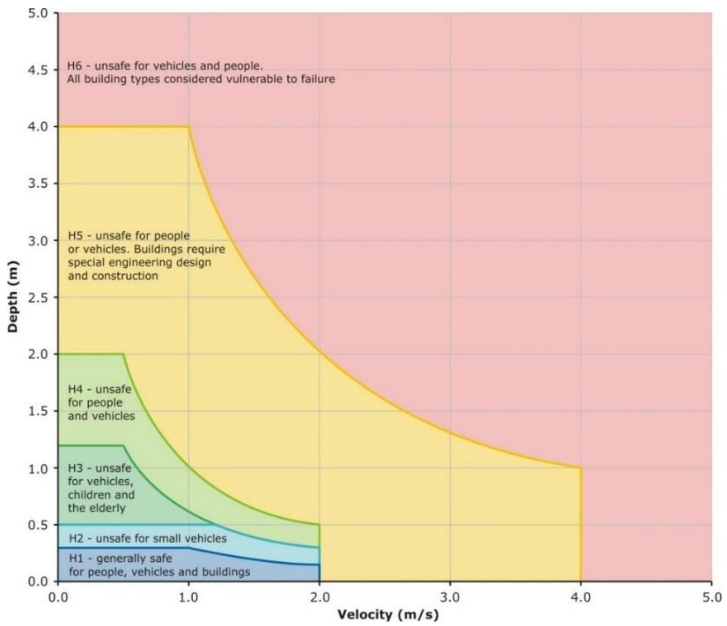


Figure C28 to Figure C36 provide the hazard classification for the full range of design storm events, according to the above classification. Under this classification, the most hazardous areas of the floodplain are generally constrained to the non-habitable areas, the parks, reserves, golf courses etc., lying adjacent to the waterways.

6.7. Provisional Hydraulic Categorisation

The 2005 NSW Government's Floodplain Development Manual (Reference 13) defines three hydraulic categories which can be applied to define different areas of the floodplain, namely;

- Floodways;
- Flood Storage; and
- Flood Fringe.

Floodways are areas of the floodplain where a significant discharge of water occurs during flood events and by definition, if blocked would have a significant effect on flood flows, velocities and/or depths. Flood storage are areas of importance for the temporary storage of floodwaters and if filled would significantly increase flood levels due to the loss of flood attenuation. The remainder of the floodplain is usually defined as flood fringe.

There is no quantitative definition of these three categories or accepted approach to differentiate between the various classifications. The delineation of these areas is somewhat subjective based on knowledge of an area, hydraulic modelling and previous experiences. A number of approaches, such as that of Howells et al (Reference 29), suggest the use of the product of velocity and depth as well as velocity itself to establish hydraulic categories.

For this study, hydraulic categories were defined by the following criteria, which correspond in part with the criteria proposed by Howells *et al*, 2003 (Reference 29):

- 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

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

- Flood Storage comprises areas outside the floodway where peak depth > 0.2 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 0.2 m.

Provisional hydraulic categories for the full range of design storm events are shown on Figure C37 to Figure C45.

6.8. Pipe Capacity Assessment

The design flood results were used to determine how frequently the stormwater pipe system capacity is likely to be exceeded throughout the catchment. Defining the capacity of a pipe is not straightforward, as it depends on multiple factors including shape, the flow regime (e.g. upstream or downstream controlled), inlet and outlet connection, pipe grade, and other factors.

TUFLOW provides output indicating the proportion of the cross-section area of a pipe that has flow in it. For this assessment, pipes were assumed to be "full" when the flow area was equal to or in excess of 85% of the pipe's cross-sectional area. This is the point at which circular pipes tend to be close to their most efficient, since at 100% of cross-sectional area the additional friction from the top of the pipe reduces pipe conveyance. Similarly, box culverts designed for a supercritical flow regime will typically be designed for free surface flow approximately 80% of the depth of the culvert, as when flow touches the pipe soffit it will typically “trip” the flow regime to become pressurised, resulting in lower capacity, depending on the pipe grade. Additionally, due to energy losses associated with adjoining pits, inlets, bends etc., some culverts may never reach “100% full” capacity by waterway area, although they may be 90% full for a range of design events (e.g. from the 5% AEP through to the PMF). In such circumstances, it is informative to know the design storm for which the pipe is almost at its maximum capacity.

Figure 12 and Figure 13 show the results of the pipe capacity assessment for the modelled range of design events. A large proportion (approximately 70%) of the pipes are full in the 50% AEP event.

7. SENSITIVITY ANALYSIS

A number of assumptions have been made for the selection of the design approach/parameters, primarily relying on default parameter values or values used in similar studies in the Sydney Metropolitan area. Sensitivity analyses were undertaken for the 1% AEP event to establish the variation in design flood level that may occur for different model parameters:

- Rainfall losses: The initial and continuing losses were varied by ±50% to test different infiltration characteristics;
- Hydraulic roughness (Mannings “n”): the roughness values were varied by ±20%;
- Inlet Blockage: The effect of 0% blockage and 50% (on grade)/100% (sag) stormwater inlet blockages was tested;
- Culvert/Bridge blockage: The effect of 10% and 25% debris blockage at open channel culvert inlets was tested;
- Pipe blockage; The effect of system-wide pipe blockages of 20% was tested;
- Inflows / Climate Change: Sensitivity to rainfall/runoff estimates was assessed by increasing the rainfall intensities by 10%, 20% and 30%; and
- Sea Level Rise: Sea level rise scenarios of 0.4 m and 0.9 m were tested in accordance with the guidelines in References 30 and 31.

Results from each sensitivity test are presented below. See Figure 6 for the locations referred to in the tables.

7.1. Blockage

The sensitivity of peak flood levels to the blockage factors at inlet pits and culvert inlets was tested. For culvert inlets in open channels or at headwalls, blockage factors of 10% and 25% were applied. The change in peak flood level is shown on Figure D1 and Figure D4 for the 1% AEP and 5% AEP respectively, and in Table 9. Pipe blockages would generally cause localised increases in flood level upstream of the blockage up to 0.2 m for 10% blockage, and up to 0.5 m for 25% blockage.

Pit inlet blockages were applied in the design modelling assuming 20% blockage for on-grade pits, and 50% for sag pits. The sensitivity scenarios tested the effect of applying 0% blockage for both types of pits, and 50% (inlet) / 100% (sag) blockage. The change in peak flood level for these scenarios is shown on Figure D5 to Figure D8.

As presented in Table 10 there is limited sensitivity to the modelled scenario which assumes 0% blockage for both on-grade and sag pits. A higher sensitivity is noted to the scenario that assumes both pit types are heavily blocked, as would be expected if drainage through the underground stormwater network was severely limited. Modelled peak flood levels increase in the order of 0.05 m up to 0.4 m for the high inlet blockage scenario, primarily at sag pits, reflecting the increase in overland flow that would occur in that situation. 100% blockage is an extreme scenario that would generally only occur at localised inlets, rather than across the entire catchment for a single event. Nonetheless, localised flood levels can be relatively sensitive to this situation, particularly in trapped sag points.

Table 9: Peak Flood Level Changes for Blockage Sensitivity Tests - Culverts

ID	Peak flood Level (mAHD)		Change (m) Culvert Blockage 10 %		Change (m) Culvert Blockage 25 %	
	5% AEP event	1% AEP event	5% AEP event	1% AEP event	5% AEP event	1% AEP event
P01	24.7	24.8	0.00	0.00	0.00	0.00
P02	24.1	24.4	0.00	0.00	0.00	0.00
P03	24.2	24.2	0.00	0.00	0.00	0.00
P04	21.6	21.6	0.00	0.00	0.00	0.00
P05	18.5	18.5	0.00	0.00	0.00	0.00
P06	13.7	14.0	-0.01	0.00	-0.01	0.00
P07	11.3	11.4	0.00	0.00	0.00	0.00
P08	12.7	12.8	0.00	0.00	0.00	0.00
P09	6.7	6.7	0.00	0.01	0.03	0.13
P10	12.5	12.8	-0.01	0.01	0.01	0.04
P11	13.6	13.8	0.00	0.00	0.00	0.00
P12	11.8	11.9	0.00	0.00	0.01	0.01
P13	29.0	29.4	0.00	0.00	0.00	0.00
P14	30.5	30.7	0.00	0.00	0.00	0.00

Table 10: Peak Flood Level Changes for Blockage Sensitivity Tests - Pits

ID	Peak flood Level (mAHD)		Change (m) Pits Inlet fully unblocked		Change (m) On Grade pits blocked 50% and Sag pit blocked 100%	
	5% AEP event	1% AEP event	5% AEP event	1% AEP event	5% AEP event	1% AEP event
P01	24.7	24.8	-0.01	-0.01	0.02	0.00
P02	24.1	24.4	-0.01	-0.01	0.07	0.04
P03	24.2	24.2	0.01	0.01	0.01	0.01
P04	21.6	21.6	0.00	0.00	0.02	0.00
P05	18.5	18.5	-0.01	-0.01	0.09	0.14
P06	13.7	14.0	-0.05	0.01	0.10	-0.04
P07	11.3	11.4	-0.03	-0.01	0.16	0.15
P08	12.7	12.8	-0.02	-0.01	0.07	0.04
P09	6.7	6.7	-0.03	-0.02	0.07	0.05
P10	12.5	12.8	-0.03	-0.03	0.24	0.16
P11	13.6	13.8	0.00	0.00	-0.01	-0.01
P12	11.8	11.9	0.00	0.00	0.00	0.00
P13	29.0	29.4	0.01	0.00	0.09	0.04
P14	30.5	30.7	-0.01	-0.01	0.02	0.02

7.2. Rainfall Losses

The initial losses were varied by ±50% to test different infiltration characteristics. Continuing losses were not varied because they account for a trivial rainfall depth over the course of the 30 minute and 60 minute storm durations of interest. The change in peak flood level for these scenarios is shown on Figure D9 to Figure D12. As shown on the maps and in Table 11, the modelled peak flood level for different initial losses typically change by less than 0.05 m. This limited sensitivity is due primarily to the high proportion of impervious surfaces within the catchment.

Table 11: Peak Flood Level Changes for Initial Loss Sensitivity Tests

ID	Peak flood Level (mAHD)		Change (m) Initial Loss Reduced 50%		Change (m) Initial Loss Increased 50%	
	5% AEP event	1% AEP event	5% AEP event	1% AEP event	5% AEP event	1% AEP event
P01	24.7	24.8	0.00	0.00	-0.02	0.00
P02	24.1	24.4	0.01	0.00	-0.02	-0.01
P03	24.2	24.2	0.00	0.00	0.00	0.00
P04	21.6	21.6	0.01	0.00	-0.03	0.00
P05	18.5	18.5	0.00	0.00	0.00	0.00
P06	13.7	14.0	0.04	0.01	-0.10	-0.01
P07	11.3	11.4	0.01	0.01	-0.02	-0.01
P08	12.7	12.8	0.01	0.00	-0.01	0.00
P09	6.7	6.7	0.00	0.00	0.00	0.00
P10	12.5	12.8	0.01	0.01	-0.03	-0.01
P11	13.6	13.8	0.01	0.00	-0.02	0.00
P12	11.8	11.9	0.01	0.00	-0.01	0.00
P13	29.0	29.4	0.01	0.01	-0.04	-0.01
P14	30.5	30.7	0.01	0.01	-0.01	-0.01

7.3. Hydrologic Model Lag

DRAINS contains a lag parameter for flow routing, which was set to 2 minutes for the design flood modelling. The sensitivity of the flood level results was tested by applying a ±50% change to this parameter. The change in peak flood level for these scenarios is shown on Figure D13 to Figure D16. The impacts on peak flood level estimates in the 1% AEP event are negligible, as shown in Table 12.

Table 12: Peak Flood Level Changes for Hydrologic Lag Sensitivity Tests

ID	Peak flood Level (mAHD)		Change (m) Lag parameter Reduced 50%		Change (m) Lag parameter Increased 50%	
	5% AEP event	1% AEP event	5% AEP event	1% AEP event	5% AEP event	1% AEP event
P01	24.7	24.8	0.00	0.00	0.00	0.00
P02	24.1	24.4	0.00	0.00	0.00	0.00
P03	24.2	24.2	0.00	0.00	0.00	0.00
P04	21.6	21.6	0.00	0.00	0.00	0.00
P05	18.5	18.5	0.00	0.00	0.00	0.00
P06	13.7	14.0	0.01	0.00	-0.03	0.00
P07	11.3	11.4	0.00	0.00	0.00	0.00
P08	12.7	12.8	0.00	0.00	0.00	0.00
P09	6.7	6.7	0.00	0.00	0.00	0.00
P10	12.5	12.8	0.00	0.00	-0.01	0.00
P11	13.6	13.8	0.00	0.00	0.00	0.00
P12	11.8	11.9	0.00	0.00	0.00	0.00
P13	29.0	29.4	0.00	0.00	0.00	0.00
P14	30.5	30.7	0.00	0.00	0.00	0.00

7.4. Downstream Tailwater Boundary

Table 13: Peak Flood Level Changes for Downstream Tailwater Sensitivity Tests

ID	Peak flood Level (mAHD)		Change (m) Tailwater level reduced by 0.5m		Change (m) Tailwater level increased by 0.5m	
	5% AEP event	1% AEP event	5% AEP event	1% AEP event	5% AEP event	1% AEP event
P01	24.7	24.8	0.00	0.00	0.00	0.00
P02	24.1	24.4	0.00	0.00	0.00	0.00
P03	24.2	24.2	0.00	0.00	0.00	0.00
P04	21.6	21.6	0.00	0.00	0.00	0.00
P05	18.5	18.5	0.00	0.00	0.00	0.00
P06	13.7	14.0	-0.01	0.00	-0.01	0.00
P07	11.3	11.4	0.00	0.00	0.00	0.00
P08	12.7	12.8	0.00	0.00	0.00	0.00
P09	6.7	6.7	0.00	0.00	0.00	0.00
P10	12.5	12.8	0.00	0.00	0.00	0.00
P11	13.6	13.8	0.00	0.00	0.00	0.00
P12	11.8	11.9	0.00	0.00	0.00	0.00
P13	29.0	29.4	0.00	0.00	0.00	0.00
P14	30.5	30.7	0.00	0.00	0.00	0.00

The assumed tailwater boundary condition was varied up and down 0.5 m for the 1% AEP and 5% AEP, compared to the assumptions from Section 5.3.2. The change in peak flood level for these scenarios is shown on Figure D17 to Figure D20. The impacts on peak flood level from this assumption are confined to development immediately fronting Alexandra Canal at the bottom of the catchment, bounded by Burrows Road on the west side and Bourke Street on the east side of the canal.

7.5. Hydraulic Roughness

The sensitivity of the flood level results to hydraulic roughness was tested by applying a +/- 20% change to the adopted baseline values of Manning's n. The change in peak flood level for these scenarios is shown on Figure D21 to Figure D24. The impacts on peak flood level estimates in the 1% AEP event are generally not significant, as shown in Table 14.

Table 14: Peak Flood Level Changes for Mannings Roughness Sensitivity Tests

ID	Peak flood Level (mAHD)		Change (m) Mannings Roughness Reduced 20%		Change (m) Manning Roughness Increased 20%	
	5% AEP event	1% AEP event	5% AEP event	1% AEP event	5% AEP event	1% AEP event
P01	24.7	24.8	0.00	0.00	0.01	0.00
P02	24.1	24.4	0.00	0.00	0.00	0.00
P03	24.2	24.2	0.00	0.00	0.00	0.00
P04	21.6	21.6	0.00	0.00	0.00	0.00
P05	18.5	18.5	0.00	0.00	0.00	0.00
P06	13.7	14.0	0.02	-0.01	-0.04	0.00
P07	11.3	11.4	0.00	0.01	0.00	-0.01
P08	12.7	12.8	0.01	0.00	-0.01	0.00
P09	6.7	6.7	0.00	0.00	0.00	0.00
P10	12.5	12.8	0.02	0.03	-0.03	-0.04
P11	13.6	13.8	0.02	0.00	-0.02	-0.01
P12	11.8	11.9	0.00	0.00	0.00	0.00
P13	29.0	29.4	0.02	0.01	-0.02	-0.01
P14	30.5	30.7	0.00	0.00	0.00	0.00

7.6. Climate Change – Rainfall Intensity

Sensitivity analysis of an increase in rainfall intensity was undertaken by comparing the 0.5% AEP and 0.2% AEP events with the 1% AEP event. These events are commonly used as proxies to assess an increase in rainfall intensity (per Reference 23). The change in peak flood level is shown on Figure D25 and Figure D26 for the 0.5% AEP and 0.2% AEP events respectively. Results at key locations are presented in Table 15.

Increases would be generally less than 0.1 m for the 0.5% AEP event, and up to 0.3 m for the higher intensity rainfall associated 0.2% AEP event. These peak flood level increases correspond to increased catchment flows derived from rainfall intensity increases.

Table 15: Sensitivity Analysis Results: Increases in Rainfall Intensity

ID	Peak flood Level (mAHD)	Change (m) Increased Rainfall Intensity	
	1% AEP event	0.5% AEP event	0.2% AEP event
P01	24.8	0.04	0.09
P02	24.4	0.08	0.18
P03	24.2	0.01	0.02
P04	21.6	0.02	0.05
P05	18.5	0.00	0.01
P06	14.0	0.03	0.06
P07	11.4	0.06	0.14
P08	12.8	0.04	0.08
P09	6.7	0.03	0.11
P10	12.8	0.14	0.26
P11	13.8	0.06	0.13
P12	11.9	0.04	0.10
P13	29.4	0.08	0.19
P14	30.7	0.07	0.17

7.7. Climate Change: Sea Level Rise

Design ocean boundary conditions were raised by 0.4 m and 0.9 m in line with References 30 and 31 to assess the potential impact of sea level rise on flood behaviour in the catchment for the year 2050 and 2100 respectively. The locations shown in Table 16 in are not materially impacted by an increase in sea level rise or tailwater levels. There are locations in the lower floodplain that would be more sensitive to sea level rise, which can be identified from Figure D27 and Figure D28.

Table 16: Sensitivity Analysis Results: Sea Level Rise

ID	Peak flood Level (mAHD)	Change (m) Sea Level Rise Scenario	
	1% AEP event	2050 SLR	2100 SLR
P01	24.8	0.00	0.00
P02	24.4	0.00	0.00
P03	24.2	0.00	0.00
P04	21.6	0.00	0.00
P05	18.5	0.00	0.00
P06	14.0	0.00	0.00
P07	11.4	0.00	0.00
P08	12.8	0.00	0.00
P09	6.7	0.00	0.00
P10	12.8	0.00	0.00
P11	13.8	0.00	0.00
P12	11.9	0.00	0.00
P13	29.4	0.00	0.00
P14	30.7	0.00	0.00

8. COMPARISON OF RESULTS

The current study update provided an opportunity to:

- Update the modelling software to more recent versions, improving the computational efficiency;
- review the sources of data used in the model configuration, allowing previous deficiencies in data availability about the stormwater network to be updated;
- review localised overland flow paths and introduce more detail into the model to represent important features and hydraulic controls;
- adopt a consistent modelling methodology across the entire catchment; and
- compare the results with previous assessments to understand the effects of these changes.

The incremental changes to the modelling results from refinements to the model schematisation and changes in modelling software are discussed in Section 5.9.

After the model schematisation changes were implemented, the hydrology was updated from ARR1987 to ARR2019. Changes to the results occurring solely as a result of the hydrology updates, using the same model schematisation, are summarised in Table 17 and Table 18. Maps of the change to peak flood levels from the hydrology updates are shown on Figure B8, Figure B9 and Figure B10 for the 20% AEP, 5% AEP and 1% AEP events respectively.

Table 17: Comparison of ARR1987 and ARR2019 hydrology results (Peak Flood Level)

ID	Peak flood level (mAHD) 0.2 EY event		Change (m)	Peak flood level (mAHD) 5% AEP event		Change (m)	Peak flood level (mAHD) 1% AEP event		Change (m)
	ARR 1987	ARR 2019		ARR 1987	ARR 2019		ARR 1987	ARR 2019	
P01	24.6	24.5	-0.09	24.8	24.7	-0.10	24.9	24.8	-0.13
P02	24.0	23.9	-0.10	24.3	24.1	-0.19	24.5	24.4	-0.19
P03	24.2	24.2	-0.02	24.2	24.2	-0.03	24.2	24.2	-0.03
P04	21.5	21.5	-0.06	21.6	21.6	-0.02	21.7	21.6	-0.02
P05	18.5	18.4	-0.01	18.5	18.5	-0.01	18.5	18.5	-0.02
P06	0.0	0.0	0.00	14.0	13.7	-0.25	14.1	14.0	-0.07
P07	11.2	11.0	-0.22	11.4	11.3	-0.13	11.6	11.4	-0.15
P08	12.6	12.3	-0.27	12.8	12.7	-0.11	12.9	12.8	-0.12
P09	6.6	6.6	-0.05	6.8	6.7	-0.08	6.9	6.7	-0.11
P10	12.4	12.2	-0.17	12.8	12.5	-0.33	13.1	12.8	-0.27
P11	13.5	13.3	-0.18	13.8	13.6	-0.20	13.9	13.8	-0.13
P12	11.8	11.7	-0.07	11.9	11.8	-0.09	12.1	11.9	-0.11
P13	29.0	28.6	-0.35	29.3	29.0	-0.28	29.5	29.4	-0.16
P14	30.5	30.4	-0.09	30.6	30.5	-0.10	30.8	30.7	-0.17

Table 18: Comparison of ARR1987 and ARR2019 hydrology results (Peak Flow)

ID	Peak flow (m^3/s) 20% AEP		Change (m^3/s)	Peak flow (m^3/s) 5% AEP		Change (m^3/s)	Peak flow (m^3/s) 1% AEP event		Change (m^3/s)
	2017	Current		2017	Current		2017	Current	
1D01	17.5	13.9	-3.6	18.9	17.9	-1.0	19.8	18.9	-0.9
1D02	9.3	8.4	-0.9	10.6	9.7	-0.9	11.9	10.3	-1.6
1D03	1.2	1.2	0.0	1.3	1.2	0.0	1.3	1.3	0.0
1D04	9.2	7.8	-1.4	14.4	12.1	-2.3	15.9	14.9	-1.0
1D05	74.3	64.5	-9.8	88.2	77.2	-11.0	104.2	87.2	-17.1
1D06	1.6	1.5	-0.1	1.6	1.6	0.0	1.6	1.6	0.0
1D07	0.8	0.7	0.0	0.8	0.8	0.0	0.8	0.8	0.0
1D08	16.6	13.9	-2.7	20.9	17.6	-3.3	25.0	20.6	-4.3
1D09	19.9	16.7	-3.3	24.5	20.9	-3.6	28.6	24.3	-4.4
2D01	0.0	0.0	0.0	0.1	0.1	0.0	0.2	0.1	-0.1
2D02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2D03	0.3	0.1	-0.2	1.1	0.5	-0.6	3.8	1.6	-2.2
2D04	0.3	0.2	-0.1	0.5	0.3	-0.2	2.2	0.4	-1.8
2D05	112.6	101.0	-11.7	133.1	121.8	-11.3	149.5	142.1	-7.5
2D06	1.8	1.4	-0.3	4.6	1.9	-2.7	10.0	6.3	-3.8
2D07	79.6	68.4	-11.3	95.3	83.1	-12.2	111.1	96.5	-14.6
2D08	155.6	144.7	-11.0	184.3	175.1	-9.2	208.1	201.4	-6.7
2D09	1.0	0.7	-0.3	1.2	1.0	-0.2	1.3	1.3	0.0
2D10	1.1	0.3	-0.8	3.4	2.0	-1.4	5.8	3.4	-2.4

The changes in peak flood level results from this study compared to the 2017 Model Update (Reference 1) are shown on Figure 9, Figure 10 and Figure 11 for the 20% AEP, 5% AEP and 1% AEP event respectively. These changes are the total combined effects of each of the model schematisation updates and hydrology updates.

Table 19: Comparison against 2017 Model Update (Peak Flood Level)

ID	Peak flood level (mAHD) 20% AEP		Change (m)	Peak flood level (mAHD) 5% AEP		Change (m)	Peak flood level (mAHD) 1% AEP		Change (m)
	2017	Current		2017	Current		2017	Current	
P01	24.8	24.5	-0.27	24.9	24.7	-0.22	25.0	24.8	-0.19
P02	23.9	23.9	-0.02	24.0	24.1	0.09	24.1	24.4	0.28
P03	24.1	24.2	0.09	24.1	24.2	0.08	24.1	24.2	0.08
P04	21.5	21.5	-0.06	21.6	21.6	-0.03	21.7	21.6	-0.02
P05	18.5	18.4	-0.06	18.6	18.5	-0.09	18.6	18.5	-0.15
P06	13.6	0.0	No longer flooded	13.9	13.7	-0.14	14.1	14.0	-0.04
P07	11.2	11.0	-0.23	11.3	11.3	-0.08	11.6	11.4	-0.13
P08	12.6	12.3	-0.25	12.8	12.7	-0.09	12.9	12.8	-0.13
P09	6.8	6.6	-0.24	6.9	6.7	-0.27	7.1	6.7	-0.38
P10	12.5	12.2	-0.33	12.9	12.5	-0.38	13.1	12.8	-0.25
P11	13.4	13.3	-0.12	13.7	13.6	-0.17	13.9	13.8	-0.12
P12	11.8	11.7	-0.11	11.9	11.8	-0.12	12.1	11.9	-0.13
P13	29.0	28.6	-0.32	29.3	29.0	-0.27	29.5	29.4	-0.16
P14	30.5	30.4	-0.10	30.6	30.5	-0.10	30.8	30.7	-0.17

Table 20: Comparison against 2017 Model Update (Peak Flow)

ID	Peak flow (m^3/s) 20% AEP		Change (m^3/s)	Peak flow (m^3/s) 5% AEP		Change (m^3/s)	Peak flow (m^3/s) 1% AEP event		Change (m^3/s)
	2017	Current		2017	Current		2017	Current	
1D01	16.3	13.7	-2.6	18.5	17.8	-0.7	19.1	19.7	0.6
1D02	8.6	8.4	-0.2	9.9	9.7	-0.2	11.4	10.3	-1.0
1D03	1.2	1.2	0.0	1.2	1.2	0.0	1.3	1.3	0.0
1D04	8.4	7.8	-0.7	12.2	12.1	-0.1	15.5	14.9	-0.5
1D05	72.9	64.5	-8.5	87.5	77.1	-10.4	105.1	87.1	-17.9
1D06	1.6	1.5	-0.1	1.6	1.6	0.0	1.6	1.6	0.0
1D07	0.7	0.7	0.1	0.7	0.8	0.1	0.7	0.8	0.1
1D08	16.6	13.9	-2.6	20.9	17.6	-3.4	25.3	20.6	-4.7
1D09	19.5	16.7	-2.9	24.4	20.9	-3.5	28.6	24.3	-4.3
2D01	0.5	0.0	-0.5	1.1	0.1	-1.0	1.8	0.1	-1.7
2D02	0.0	0.0	0.0	0.1	0.0	-0.1	0.5	0.0	-0.5
2D03	0.7	0.1	-0.6	1.1	0.5	-0.6	3.0	1.6	-1.4
2D04	0.3	0.2	-0.1	0.5	0.3	-0.2	2.3	0.4	-1.8
2D05	111.9	103.5	-8.5	131.8	124.6	-7.2	152.5	143.2	-9.4
2D06	1.8	1.4	-0.4	4.9	1.9	-2.9	10.5	6.2	-4.3
2D07	85.7	68.4	-17.2	95.8	82.5	-13.2	112.7	96.8	-15.9
2D08	150.0	149.0	-1.0	181.6	177.2	-4.4	212.6	203.9	-8.8
2D09	0.8	0.7	-0.2	1.1	1.0	0.0	1.1	1.3	0.1
2D10	0.9	0.3	-0.6	2.7	2.0	-0.7	5.5	3.4	-2.1

9. FLOOD DAMAGES UPDATE

A flood damages assessment was completed as part of the 2014 FRMS (Reference 5). An update to the damages assessment was undertaken for this study. Table 21 shows the updated property affectation and damage estimates for various design storms, comparable with Table 6-5 of Reference 5.

Table 21: Revised Flood Damage Assessment Summary

Property Type	Properties with Over-floor Flooding	Average Over-floor Flooding Depth (m)	Maximum Over-floor Flooding Depth (m)	Properties with over-ground flooding	Total Damage
PMF					
Residential	1134	1.03	3.33	1186	$89,290,177
Commercial	152	0.77	2.79	156	$68,702,848
Industrial	80	0.86	3.68	86	$87,140,743
PMF Total	1366			1428	$245,133,768
1% AEP					
Residential	402	0.25	0.96	597	$22,303,910
Commercial	44	0.32	0.95	54	$5,796,691
Industrial	30	0.28	1.39	37	$11,225,201
1% AEP Total	476			688	$39,325,803
5% AEP					
Residential	206	0.19	0.69	349	$12,066,868
Commercial	22	0.29	0.9	30	$2,570,303
Industrial	17	0.21	0.83	21	$7,777,650
5% AEP Total	245			400	$22,414,822
10% AEP					
Residential	119	0.17	0.54	239	$6,917,662
Commercial	13	0.22	0.83	18	$1,377,022
Industrial	14	0.21	0.66	19	$6,352,063
10% AEP Total	146			276	$14,646,747
20% AEP					
Residential	57	0.14	0.37	138	$3,339,656
Commercial	7	0.20	0.74	9	$322,658
Industrial	8	0.18	0.49	12	$4,591,224
20% AEP Total	72			159	$8,253,538
50% AEP					
Residential	10	0.10	0.28	29	$501,094
Commercial	2	0.23	0.52	3	$24,273
Industrial	3	0.11	0	5	$1,297,046
50% AEP Total	15			37	$1,822,413

Table 22 shows the change in the affected property numbers, flood depths and damage estimates, comparing Table 21 above to Table 6-5 from Reference 5. Table 23 shows the Average Annual Damages (AAD), including comparison to the values from Reference 5.

Table 22: Comparison of Flood Damage Summary with FRMS

Property Type	Properties with over-floor flooding	Properties with over-ground flooding	Total Damage
PMF			
Residential	-129	-159	-$2,510,563
Commercial	-44	-51	-$28,904,721
Industrial	-45	-45	-$106,486,664
PMF Total	-218	-255	-$137,901,948
1% AEP			
Residential	-178	-391	-$7,817,727
Commercial	-27	-56	-$13,443,734
Industrial	-24	-52	-$21,965,631
1% AEP Total	-229	-499	-$43,227,092
5% AEP			
Residential	-65	-253	-$4,169,504
Commercial	-20	-46	-$7,357,704
Industrial	-18	-39	-$11,713,618
5% AEP Total	-103	-338	-$23,240,825
10% AEP			
Residential	-56	-200	-$3,354,919
Commercial	-13	-32	-$4,786,426
Industrial	-15	-24	-$7,465,006
10% AEP Total	-84	-256	-$15,606,351
20% AEP			
Residential	-49	-200	-$2,922,910
Commercial	-1	-18	-$2,163,087
Industrial	-8	-23	-$298,036
20% AEP Total	-58	-241	-$5,384,032
50% AEP			
Residential	-20	-103	-$1,152,161
Commercial	-1	-11	-$1,372,988
Industrial	-3	-10	$440,172
50% AEP Total	-24	-124	-$2,084,976

Table 23: Average Annual Damages

	Probability	Damage	Residential Over-floor Damage
up to 1 year	**100%**	**$0**	**$0**
1 Year to 2 Year ARI	50%	**$820,570**	**$128,690**
2 Year to 5 Year ARI	20%	**$1,511,393**	**$551,063**
5 Year to 10 Year ARI	10%	**$1,145,014**	**$494,016**
10 Year to 20 Year	5%	**$926,539**	**$459,913**
20 Year to 100 Year	1%	**$1,234,812**	**$668,496**
100yr to PMF	0.0%	**$1,422,298**	**$1,334,203**
Total Annual Average Damage		**$7,060,627**	**$3,636,380**
AAD from 2014 FRMS (Reference 5)		$12,957,924	$5,888,666
Difference (%)		-46%	-38%

The updated estimates are significantly lower than the estimates from the 2014 FRMS. The primary contributing factors for this reduction are:

- Major trunk drainage upgrades, such as the Green Square Trunk Drain, O'Dea Avenue, Joynton Avenue, and the Lachlan and Ashmore precincts have significantly improved the capacity of the drainage network, resulting in less overland flow and reduced flood affectation. These upgrades have reduced flood risk in some of the more severely flood prone parts of the catchments, directly reducing the tangible flood damages.

- There has been significant redevelopment of urban renewal precincts. The redevelopment includes revisions to road layouts and stormwater networks that are more effective at retaining and conveying flow within the road reserves rather than in property. The new buildings constructed in these precincts have been designed with minimum floor levels to mitigate flood risk, such that the new buildings are significantly higher than previously. Some of these precincts previously contained a high concentration of flood-affected property, such as Green Square, Victoria Park, Lachlan (Midblock), Epsom Park and Ashmore. The redevelopment of these precincts has resulted in a significant reduction in tangible damages due to improved compatibility of the development with flood risk.
- The update to ARR2019 hydrology generally reduces the modelled flood levels and flows compared to the previous ARR1987 hydrology, due primarily to the updated information about design rainfall intensities and temporal patterns. These reduced levels result in reduced flood damage estimates. The reductions are not “real” in the sense that the underlying real flood risk has not changed, but the data for estimating the flood risk has become more accurate and indicates that the tangible damages are lower than previously thought.

Comments on the methodology, assumptions and limitations of the damages update are as follows:

- The updated damages were calculated using the same spreadsheet as the 2014 FRMS, provided by Cardno to City of Sydney Council. The calculation assumptions, damage curves, and economic assumptions were not modified. The only changes were to update the flood level estimates for each property based on the updated modelling.
- The update used the same floor level database obtained for the 2014 FRMS. No additional flood level information was collected. This will affect results for properties that have been redeveloped. Redevelopment in flood-prone areas requires higher floor levels, so the true updated damages are likely to be even lower still compared to the previous estimates than indicated in the tables above.
- The data provided by Cardno for the FRMS damage calculations did not contain spatial information for approximately 20% of the surveyed floor level database. It was therefore not possible to identify where the flood depths should be sampled to update the damages estimates for these properties. At these locations, the previous flood level estimates from the 2014 SOBEK model were retained. Generally, the updated flood levels from modelling in this study are lower than the 2014 SOBEK model, so if the spatial information for these 20% of properties was obtained and the results updated, it is likely the damages estimates would drop further.

The estimate of tangible flood damages is a high level exercise, intended to capture the catchment-scale flood damages. It can provide a good indication of the average flood damage across a catchment. The accuracy of the results at individual properties can be affected by vagaries such as the variability in the flood level across the property, the location of the sampled flood level for the property, whether the floor level is consistent or various through the building.

This variability tends to average out across the catchment, particularly if a large number of properties are considered.

The updated estimates indicate that tangible flood damages across the Alexandra Canal catchment have been substantially reduced in the last decade, by at least 40%, with an average annual damages savings in the order of $6 million per year. This does not include damages to cars and intangible damages such as stress and disruption to economic activity, which have also been substantially reduced due to reductions in flood risk as Botany Road, O'Riordan Street, Joynton Avenue and O'Dea Avenue. This indicates that the investments in trunk drainage infrastructure upgrades by City of Sydney and Sydney Water Corporation, and the application of flood-related development controls such as minimum floor heights for new buildings, have been very successful measures for mitigating flood risks and damages throughout the catchment.

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Appendix A

APPENDIX A: GLOSSARY OF TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

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.
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).
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 and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
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.

Figures

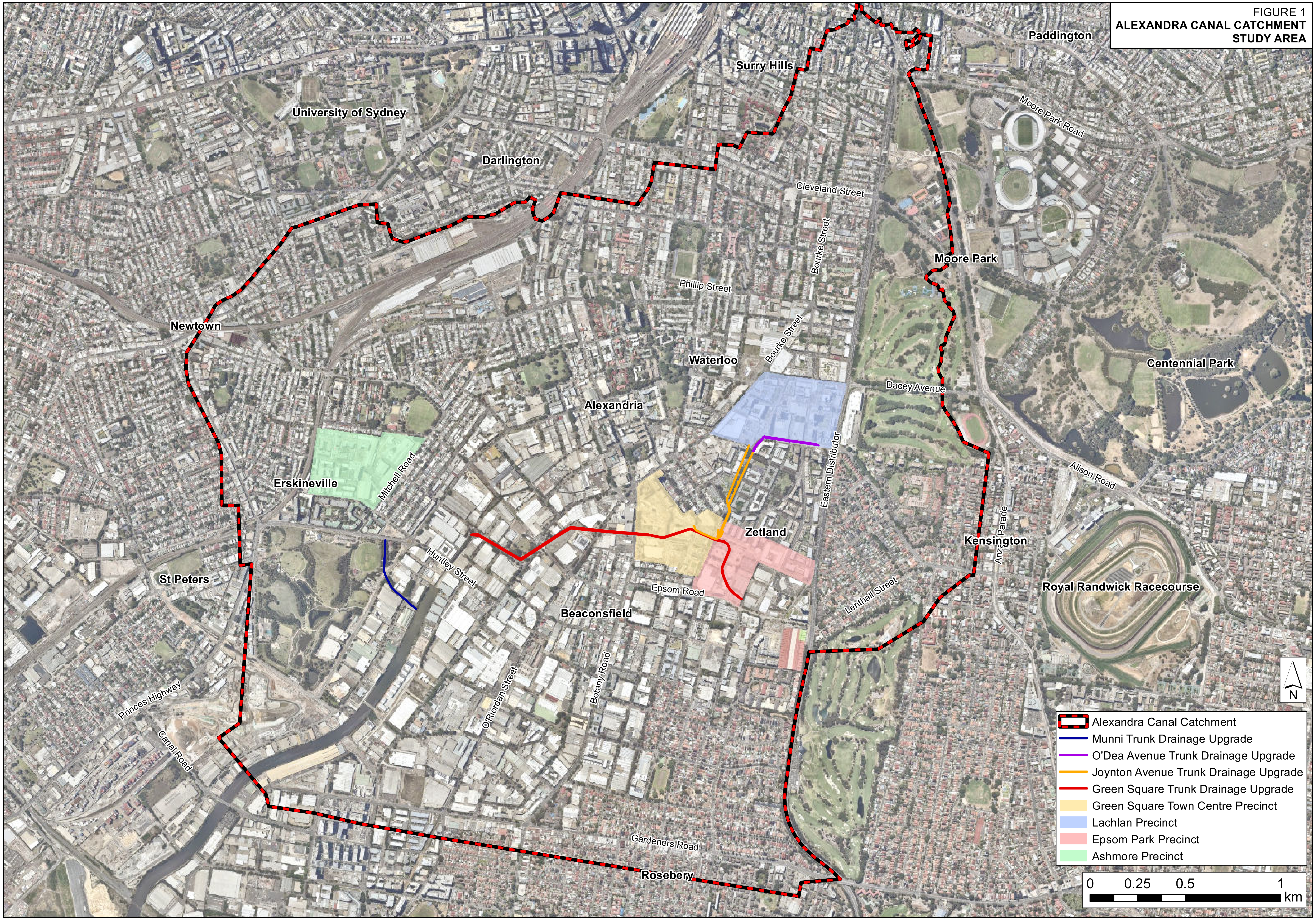

FIGURE 1
ALEXANDRA CANAL CATCHMENT STUDY AREA

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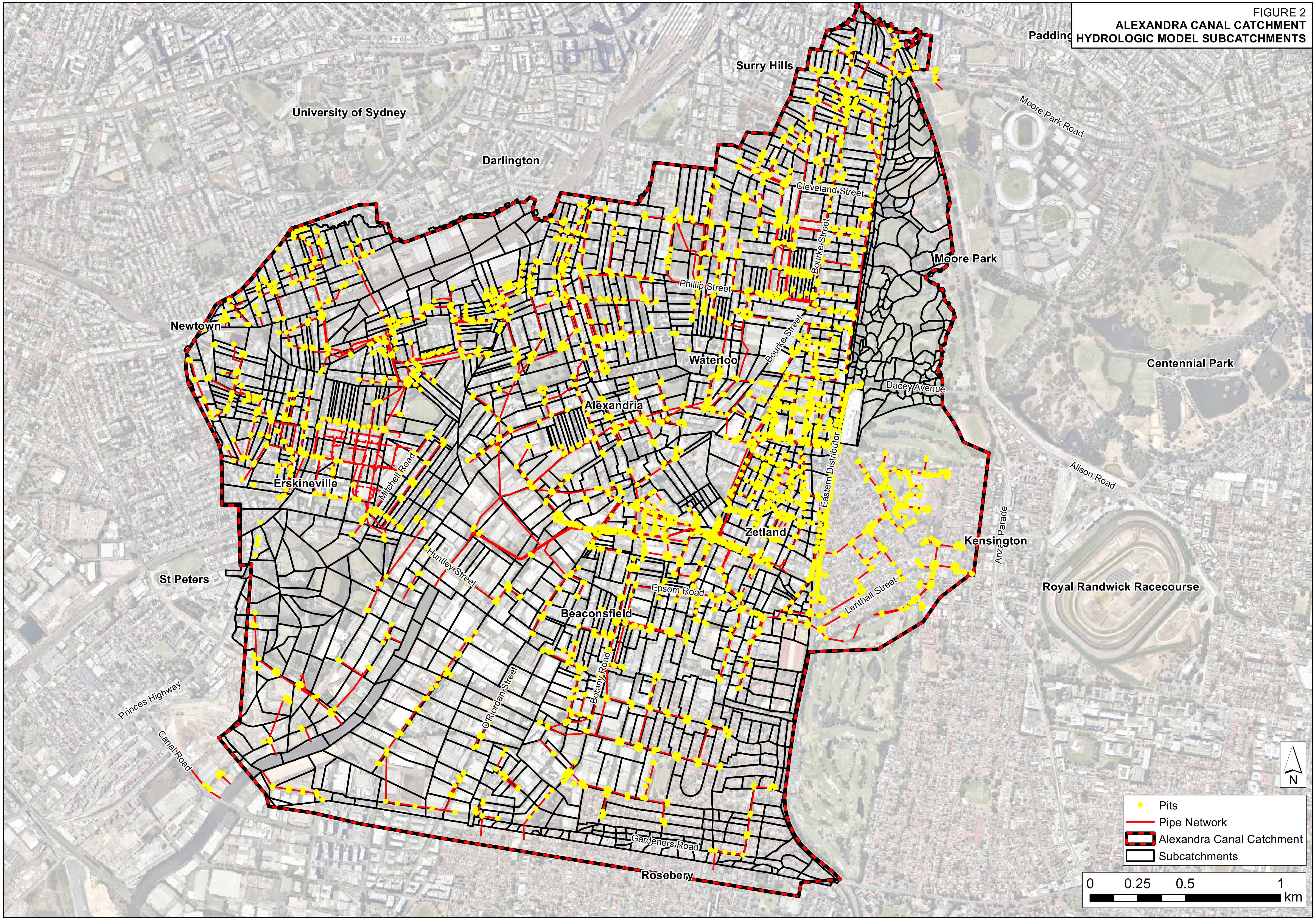

FIGURE 2
ALEXANDRA CANAL CATCHMENT HYDROLOGIC MODEL SUBCATCHMENTS

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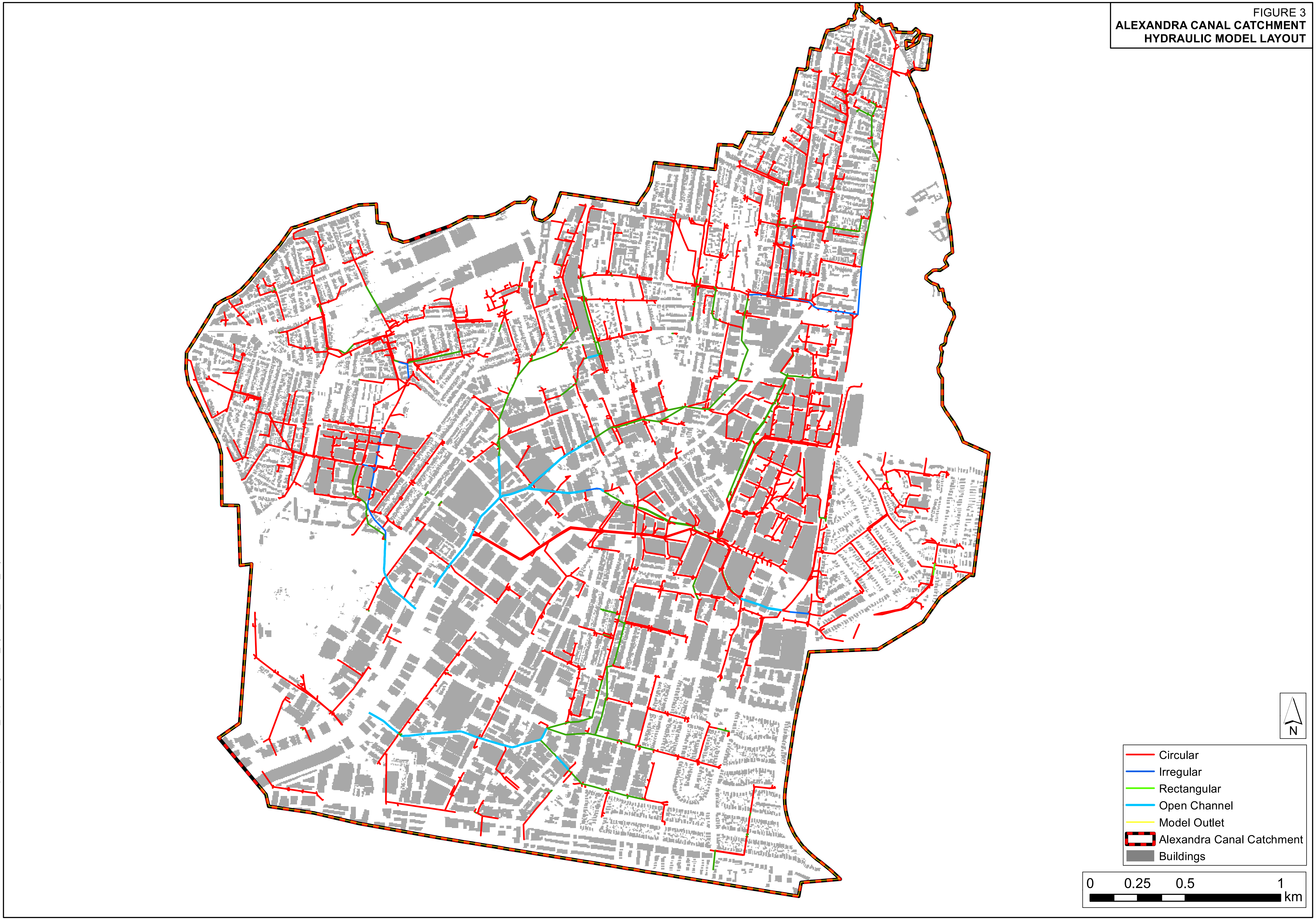

FIGURE 3
ALEXANDRA CANAL CATCHMENT HYDRAULIC MODEL LAYOUT

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FIGURE 4
ALEXANDRA CANAL CATCHMENT
HYDRAULIC MODEL ROUGHNESS

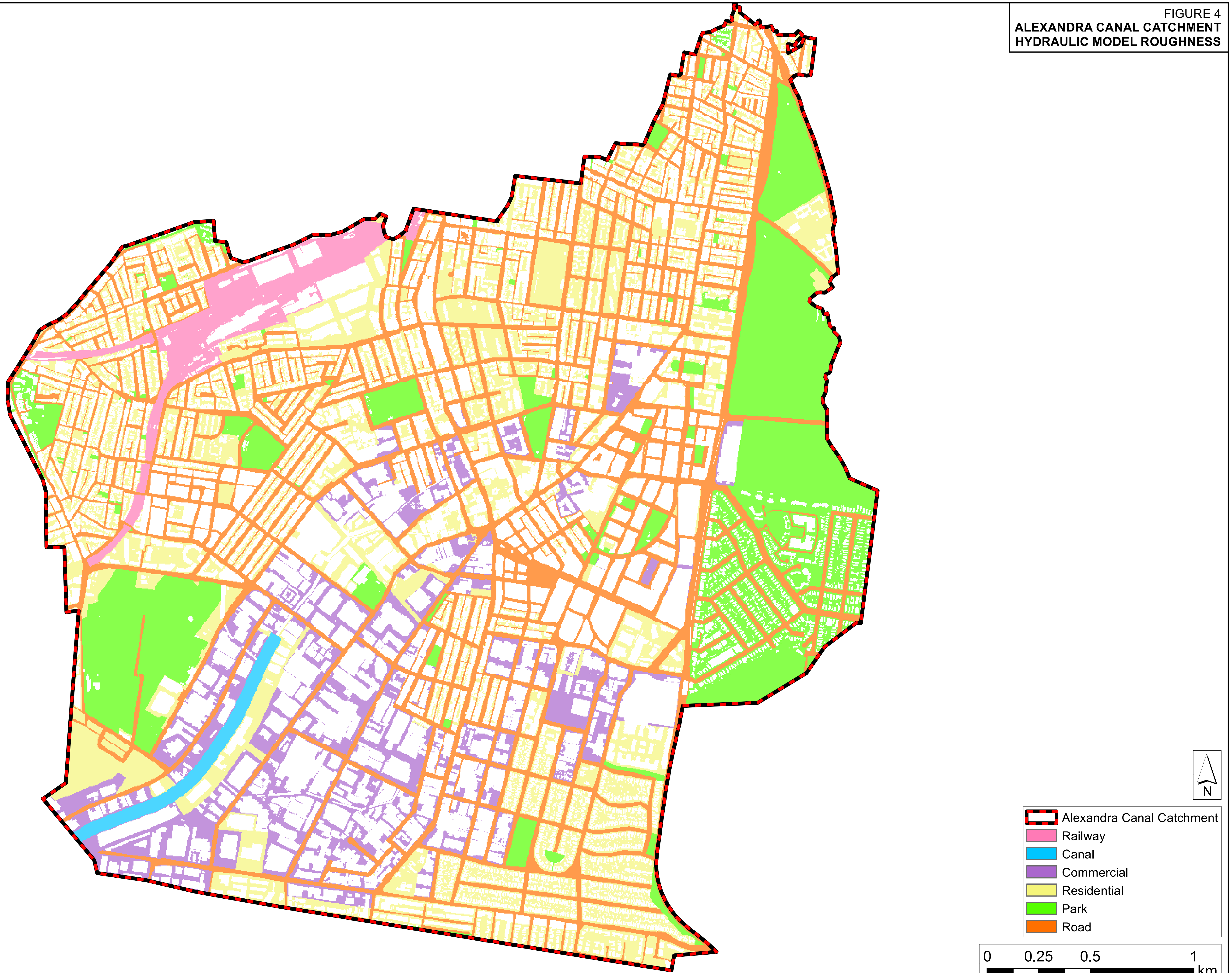

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FIGURE 5
ALEXANDRA CANAL CATCHMENT
DIGITAL ELEVATION MODEL

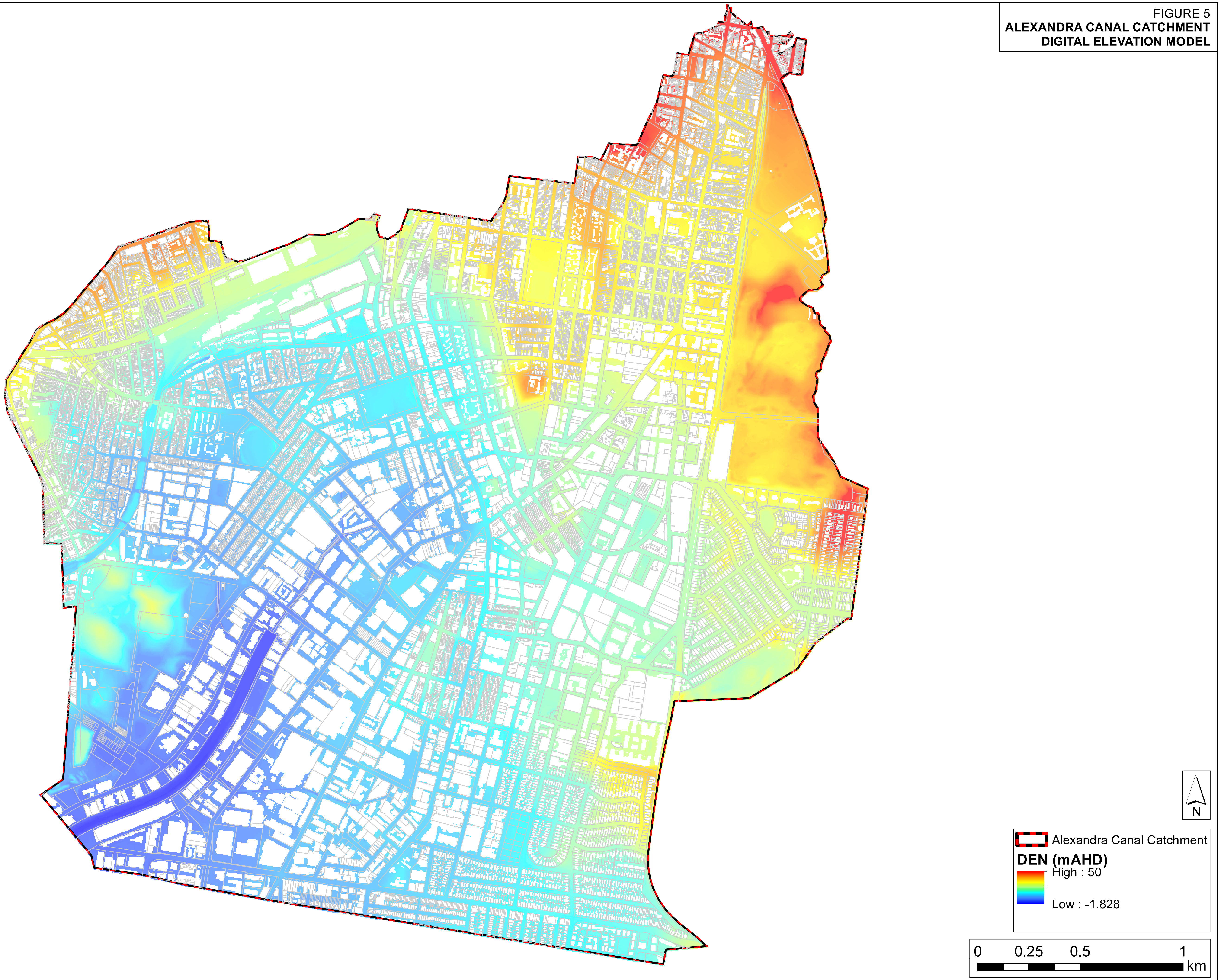

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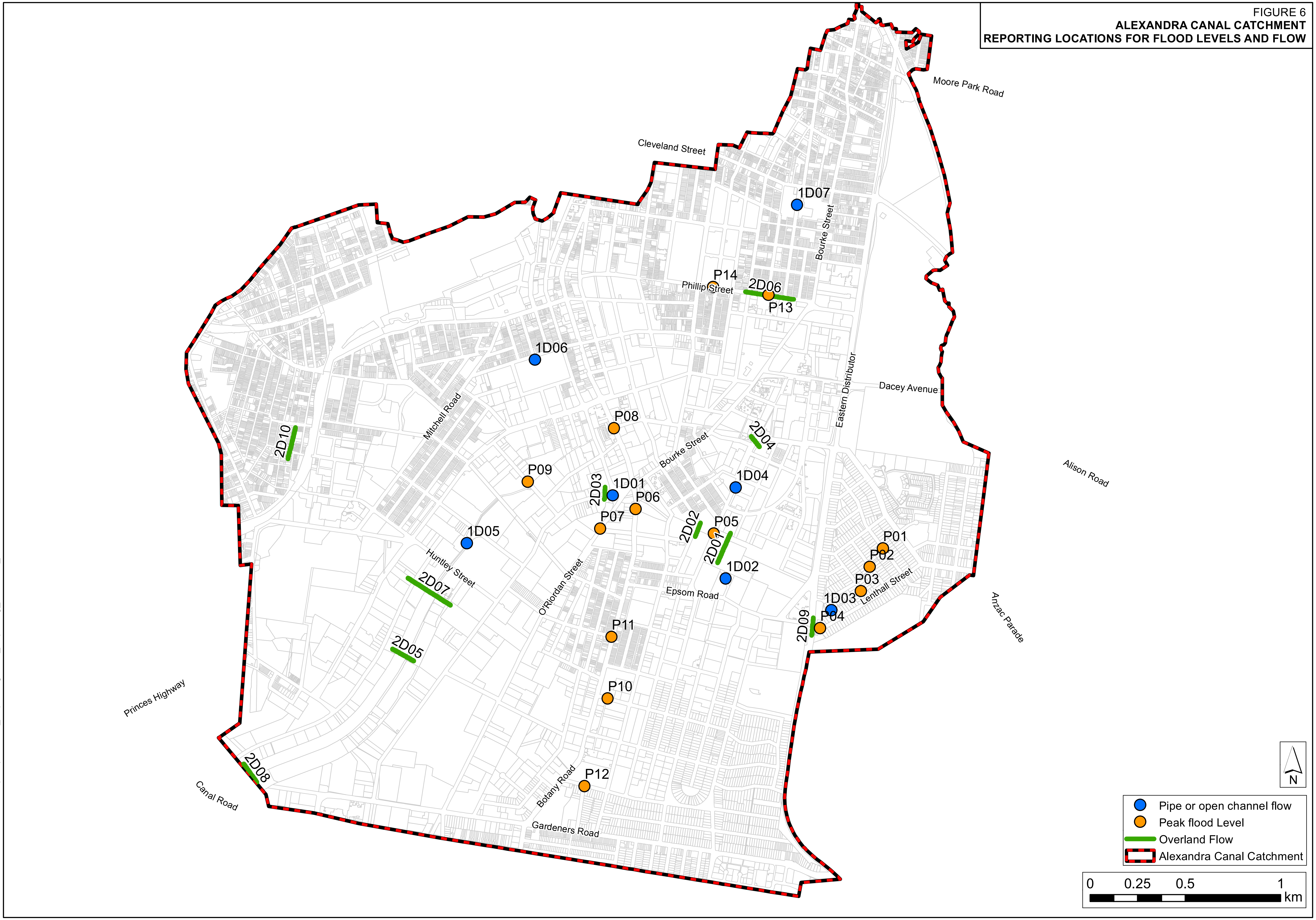
FIGURE 6
ALEXANDRA CANAL CATCHMENT
REPORTING LOCATIONS FOR FLOOD LEVELS AND FLOW



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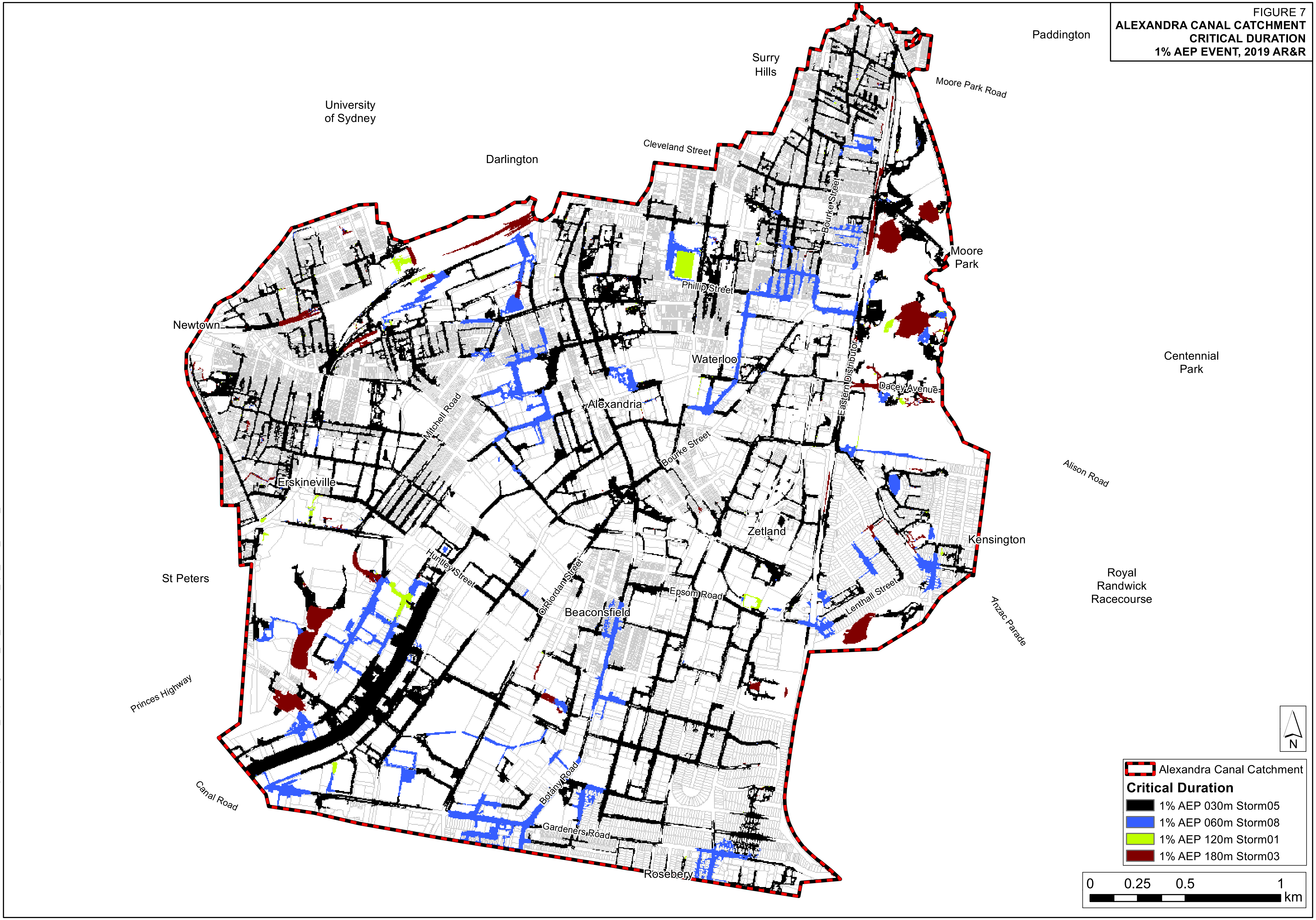

FIGURE 7
ALEXANDRA CANAL CATCHMENT CRITICAL DURATION 1% AEP EVENT, 2019 AR&R

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FIGURE 8
ALEXANDRA CANAL CATCHMENT CHANGE IN PEAK FLOOD LEVEL 30&60 MINUTE V ENVELOPE 1% AEP EVENT, 2019 AR&R

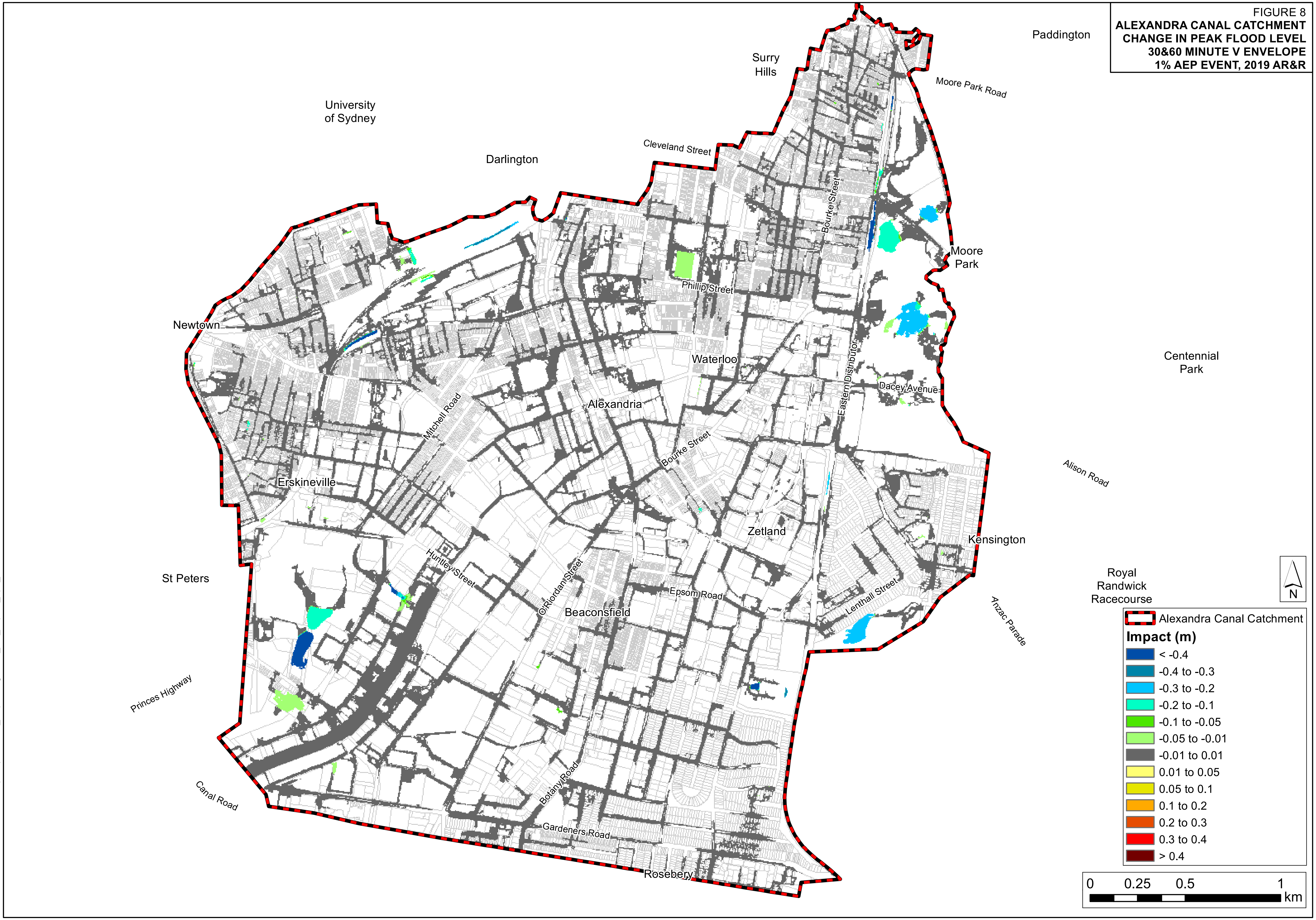

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FIGURE 9
ALEXANDRA CANAL CATCHMENT
CHANGE IN PEAK FLOOD LEVEL
REVISED MODEL AR&R 2019 VS 2017 MODEL UPDATE
20% AEP EVENT

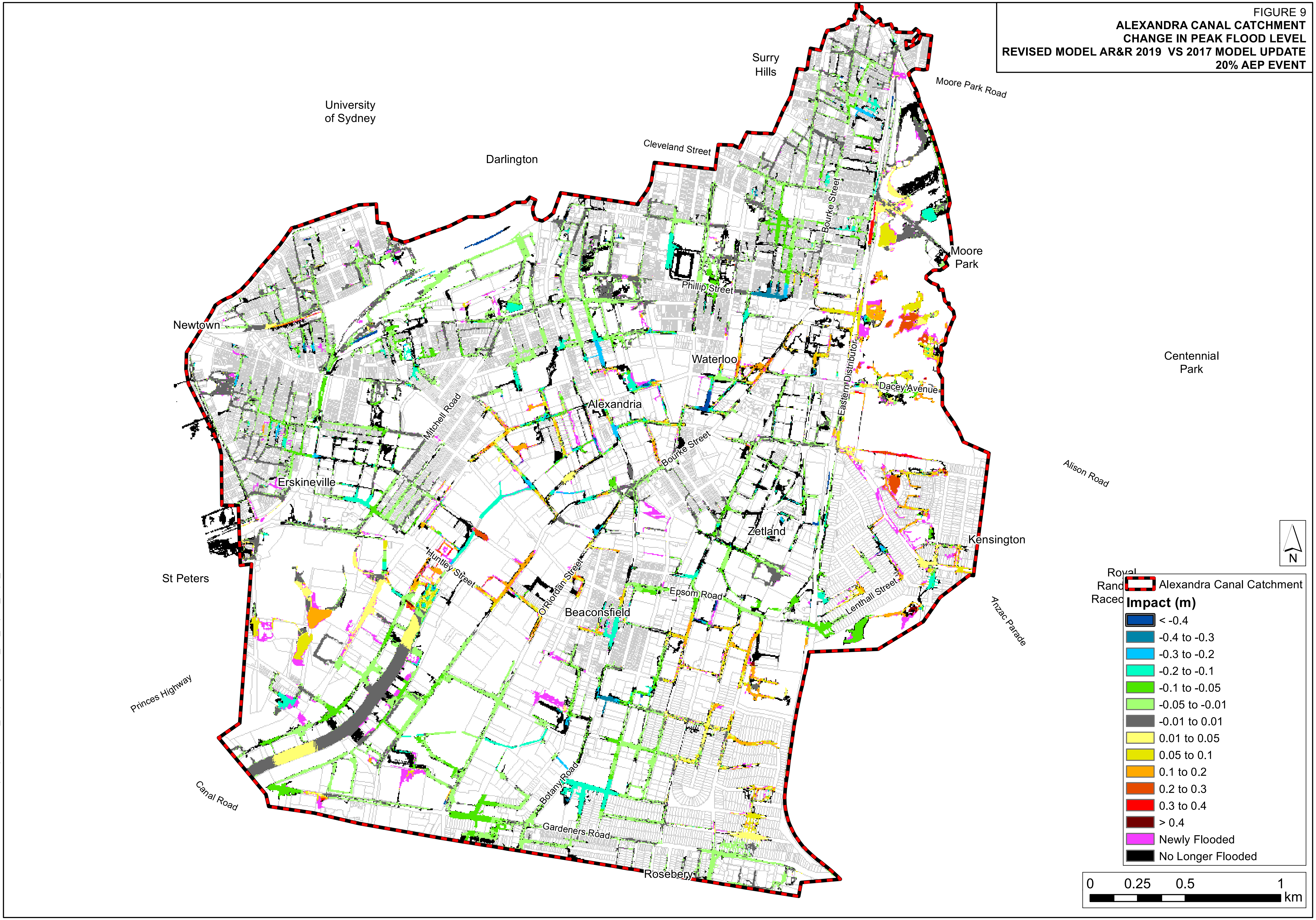

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FIGURE 10
ALEXANDRA CANAL CATCHMENT
CHANGE IN PEAK FLOOD LEVEL
REVISED MODEL AR&R 2019 VS 2017 MODEL UPDATE
5% AEP EVENT

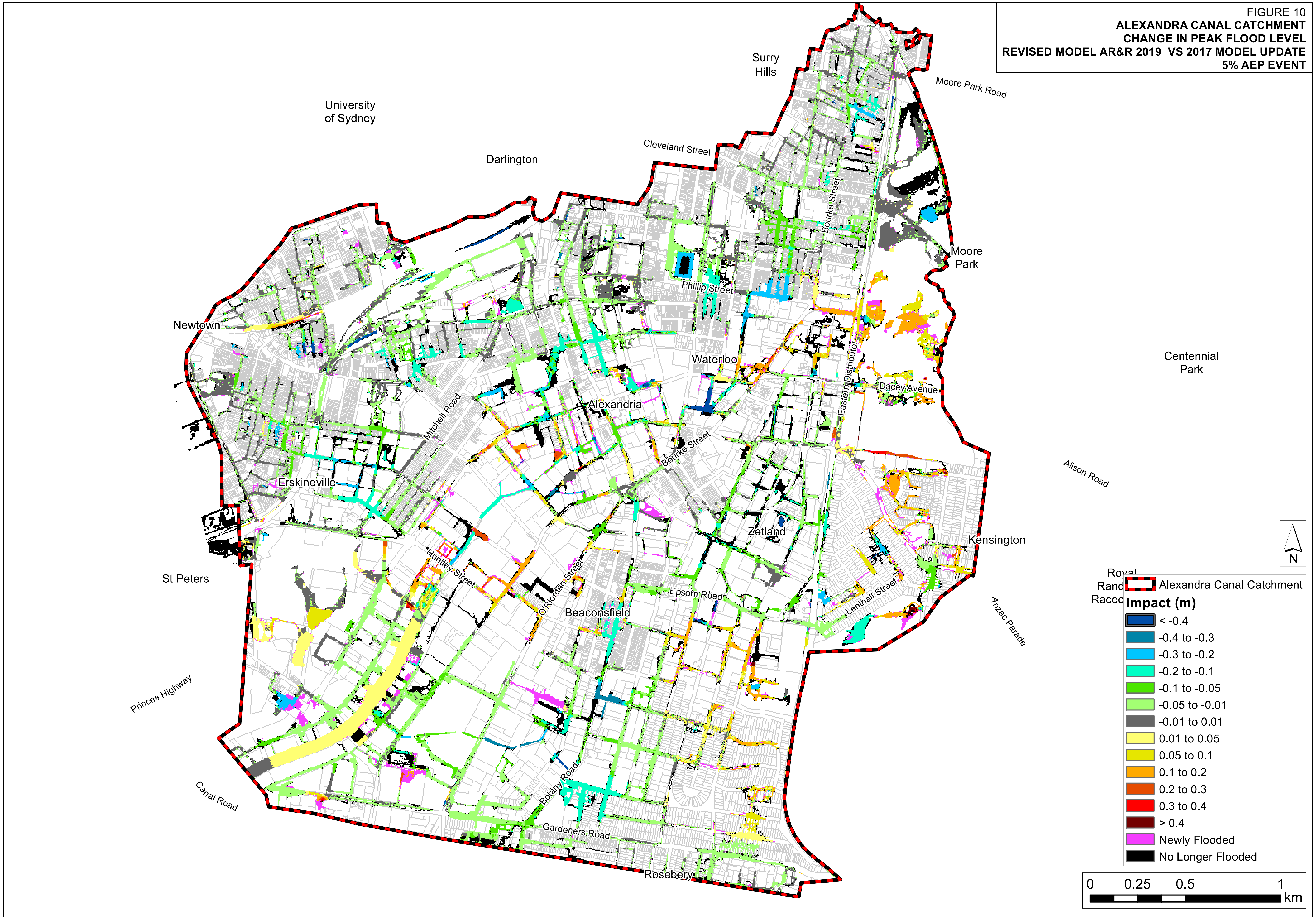

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FIGURE 11
ALEXANDRA CANAL CATCHMENT
CHANGE IN PEAK FLOOD LEVEL
REVISED MODEL AR&R 2019 VS 2017 MODEL UPDATE
1% AEP EVENT

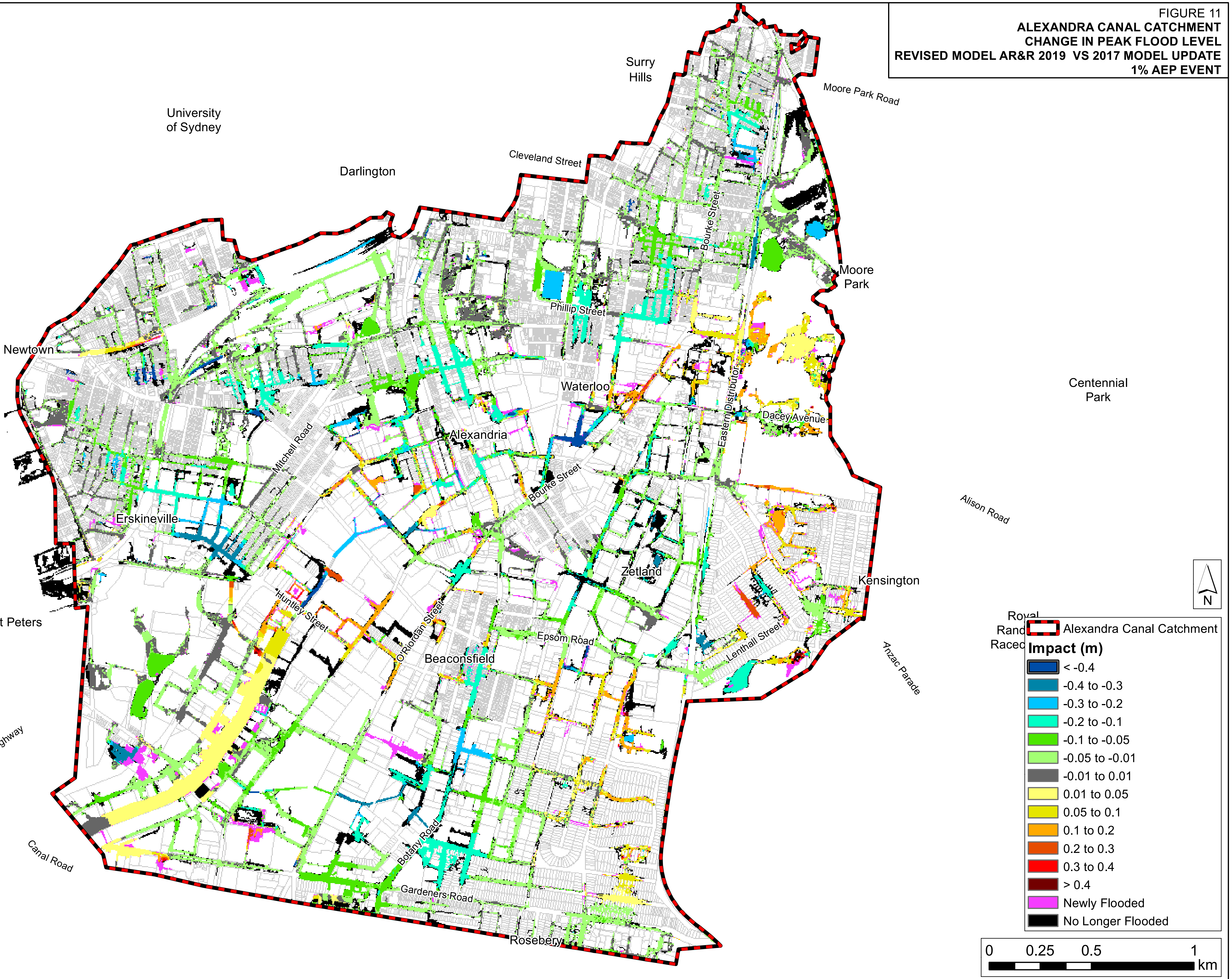

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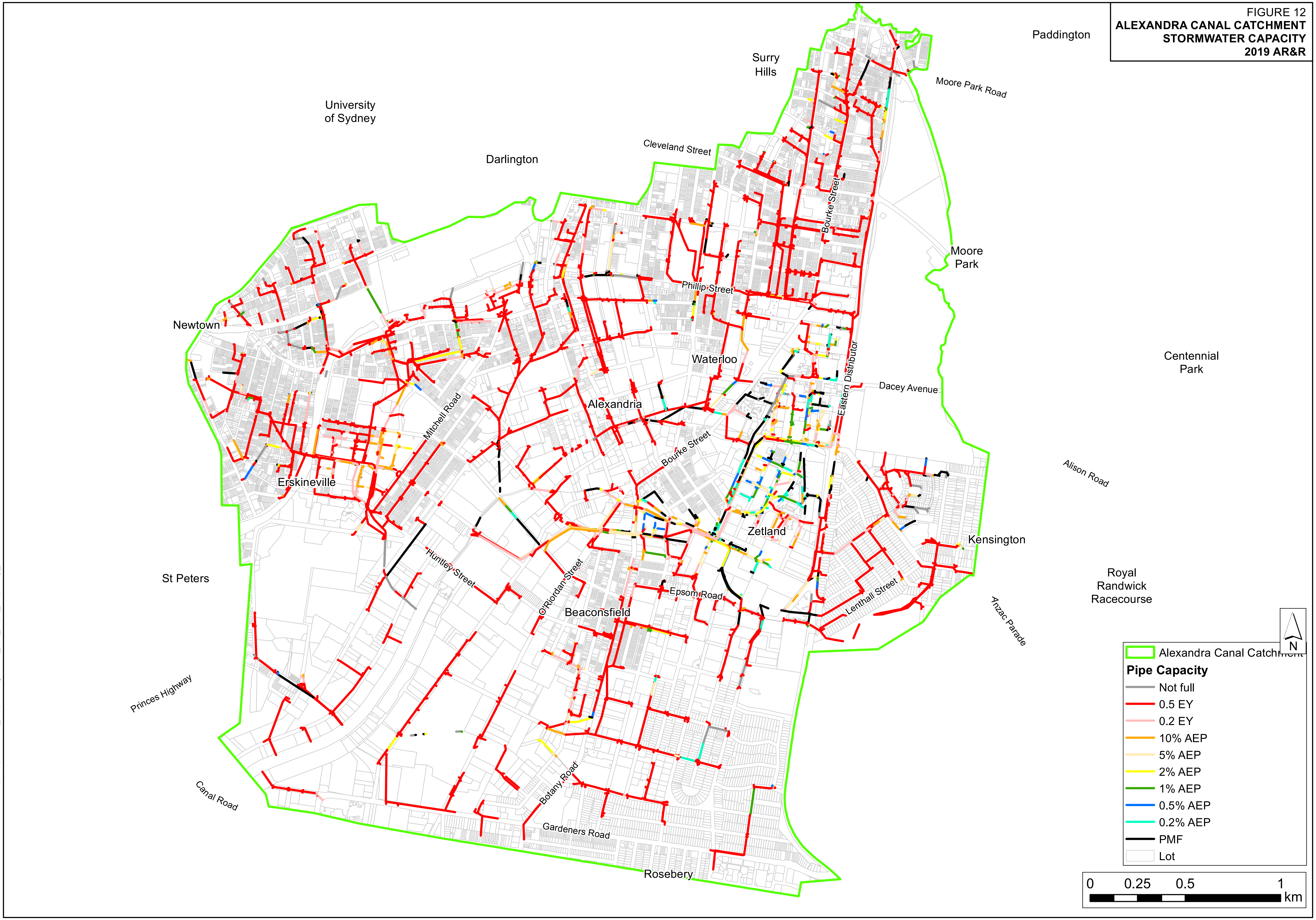
FIGURE 12
ALEXANDRA CANAL CATCHMENT STORMWATER CAPACITY 2019 AR&R



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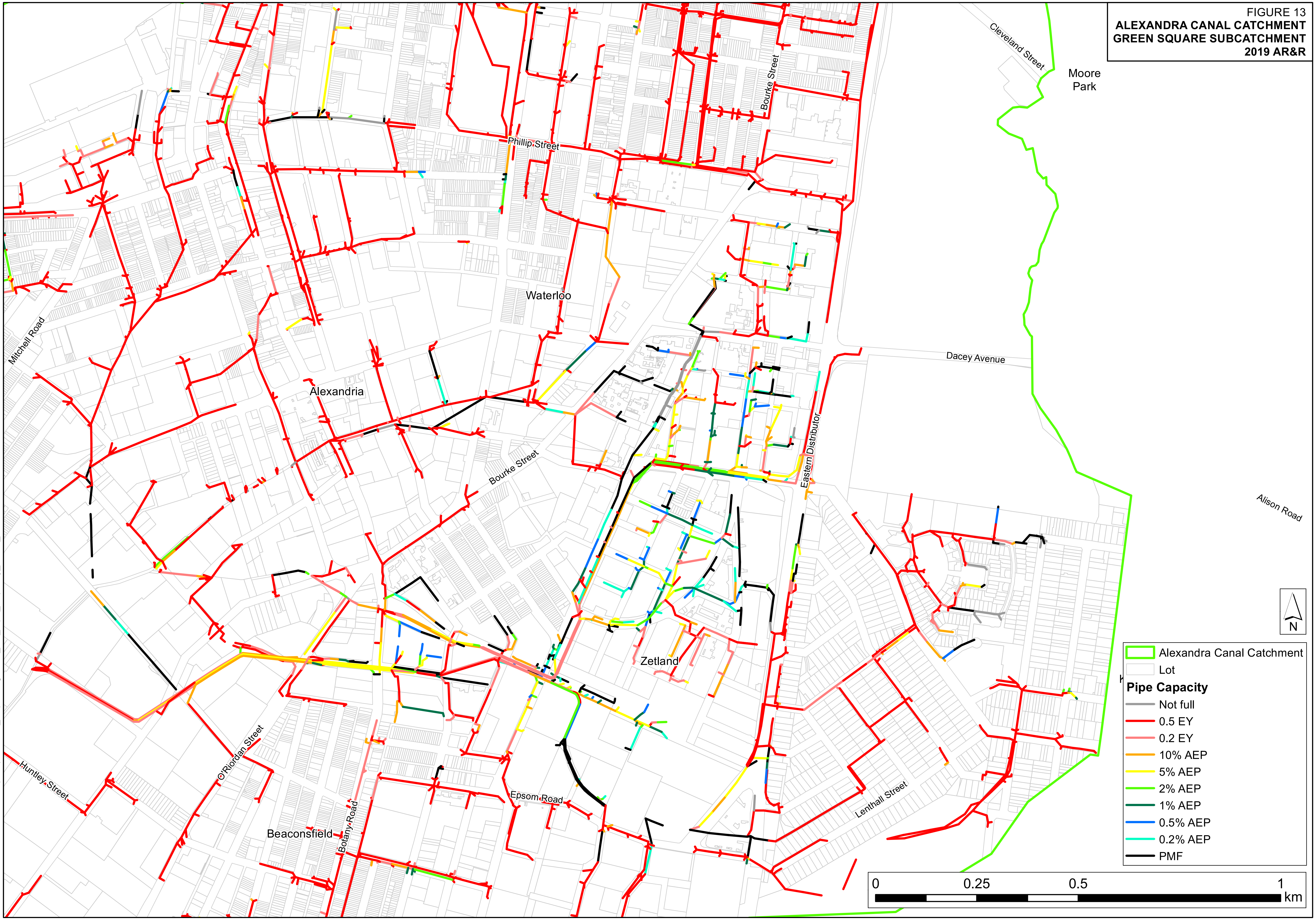

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