BLACKWATTLE BAY CATCHMENT FLOOD STUDY MODEL UPDATE – ARR2019 HYDROLOGY

SEPTEMBER 2020

Level 2, 160 Clarence Street
Sydney, NSW, 2000

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

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Project **Blackwattle Bay Catchment – Flood Study Model Update ARR2019 Hydrology**	**Project Number** **119072**
Client City of Sydney	**Client's Representative** Shah Alam
Author Rhys Hardwick Jones Fabien Joly Richard Dewar	**Prepared by** Rhys Hardwick Jones
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Blackwattle Bay Catchment – Flood Study Model Update ARR2019 Hydrology

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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
ARR	Australian Rainfall and Runoff
ALS	Airborne Laser Scanning sometimes known as LiDAR
BoM	Bureau of Meteorology
DRAINS	Hydrologic computer model
DEM	Digital Elevation Model
FRMS	Floodplain Risk Management Study
FRMP	Floodplain Risk Management Plan
EY	Exceedances per Year
GIS	Geographic Information System
GPU	Graphical Processing Unit
HPC	Highly Parallelised Computing
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 Blackwattle Bay Catchment Flood Study Model Update has been prepared for the City of Sydney to provide a comprehensive catchment-wide flood model. The update is intended to ensure recent (and known upcoming) major developments are accurately accounted for, as well as incorporating current best practice data and methods for estimating design floods.

The Blackwattle Bay catchment has been the subject of previous flood modelling investigations. These models are effectively already out of date following development and infrastructure renewal throughout the catchment.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 catchment.

The model update included refinements to the model using more recent survey and aerial survey information, as well as increasing the detail of the stormwater network (with the addition of over 1,000 smaller stormwater pipes) and overland flow path resolution in the model (including changing the grid size from 2m to 1m). The model inputs were updated to use current rainfall data and design storm inputs (such as rainfall losses and temporal patterns) consistent with the 2019 version of Australian Rainfall and Runoff. Previous studies used the 1987 version of Australian Rainfall and Runoff which has now been superseded.

These updates have typically resulted in lower estimates of the flood risk throughout the catchment, with reductions in peak flood level in the order of 0.3 m to 0.4 m throughout the lower catchment for the 1% AEP event.

Estimates of tangible flood damages for the catchment were updated for this study. The updated estimates are slightly lower (by approximately 12%), with a reduction in Average Annual Damages from $7.8 million to $6.9 million compared to the estimates from the 2015 Floodplain Risk Management Study. This does not include damages to cars and intangible damages such as stress and disruption to economic activity. The primary contributing factors for this reduction are:

- 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.
- The revised modelling schematisation alters flood levels slightly, particularly by refining the modelling of narrow overland flow paths in the upper catchment. This reduces the affectation of some properties slightly, since there are fewer areas of artificially trapped flow in the upper catchment.
- The sampling locations for some properties were revised to accurately capture the highest flood level affecting the property, resulting in slightly increased affectation in some instances.

1. INTRODUCTION

1.1. Overview

This Flood Study for the Blackwattle Bay Catchment includes the following updates to the previously available flood modelling by WMAwater (Reference 1, September 2015):

- 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 approximately 1,900 additional pipes and connecting inlets/junction pits to improve the representation of the stormwater drainage network, by including pipes of 0.45 m diameter or greater (previously the model included pipes with a larger diameter than 0.45 m);
- Inclusion of building footprints changes from recent years.
- Inclusion of recent developments in the catchment;
- Refinement of the model cell size to more accurately represent narrow overland flow paths;
- Refinements to the model schematisation to reflect features identified during catchment inspections.

City of Sydney required an up-to-date flood model 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.

WMAwater has previously undertaken modelling of the catchment using ARR1987 hydrology. A catchment-wide Flood Study (Reference 4) and Floodplain Risk Management Study & Plan (References 1 and 5) were completed by WMAwater in the period from 2012 to 2015. This report documents further refinement of that model, and updates to use ARR2019 hydrology.

1.2. Scope of Work

The tasks undertaken were:

- to update hydrologic and hydraulic models of the Blackwattle Bay 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 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. 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. Blackwattle Bay Catchment

The Blackwattle Bay catchment is located in Sydney's inner city suburbs of Glebe, Chippendale, Ultimo, Darlington, Camperdown, Redfern, Pyrmont and Surry Hills (refer Figure 1). This region lies within the City of Sydney Local Government Area (LGA) and has been extensively developed for urban usage. Land use is predominantly medium to high-density housing as well as commercial and industrial developments. In addition, there are pockets of open space positioned throughout the catchment, such as Wentworth, Victoria, and Prince Alfred Parks. Large portions of the parkland and industrial areas in the lower catchment are on reclaimed land.

The catchment covers an area of approximately 329 hectares with some 50 hectares of land draining directly into Blackwattle Bay (the Bay) and the remaining portion draining to Sydney Water's major trunk drainage system (known as SWC 17) to route flows from the upper regions of the catchment. The trunk drainage system is linked to Council's feeder drainage system consisting of covered channels, in-ground pipes, culverts and kerb inlet pits.

A number of locations within the catchment are flood liable. This flood liability mainly relates to the nature of the topography within the study area as well as the capacity of service provided by drainage assets. The topography of the catchment is steep in the upper areas, steep and undulating in the middle sections, and then flat particularly in the lower regions close to the Bay. In the upper regions of the catchment the maximum elevation is approximately 60 mAHD. Urbanisation throughout the catchment occurred prior to the installation of road drainage systems in the 1900s and many buildings have been constructed on overland flow paths or in localised sag points (in some cases with contiguous terrace housing adjacent to the sag point). Due to these drainage restrictions, topographic depressions can cause localised flooding as excess flows have no opportunity to escape via overland flow paths. This creates a significant drainage/flooding problem in many areas throughout the catchment.

Future development in this area is most likely to be in the form of urban consolidation, with aggregation of individual lots creating high density high rise residential developments. One example is the Central Park development at the former Carlton and United Brewery site adjoining Parramatta Rd and Abercrombie St.

2.2. Drainage System

The catchment is serviced by a major-minor drainage system. Property drainage is directed to the kerb-gutter system where it is then able to enter the Council owned minor street drainage network. The Blackwattle Bay (SWC 17) Flood Study (Reference 6) determined that the minor drainage within the catchment services for approximately a 5 year ARI event. Flow is then routed into the Sydney Water Corporation (SWC) owned and maintained SWC17 trunk drainage system. This trunk drainage system is composed of eight large drains that run predominately south-north through the catchment. A list of these eight main branches is presented below:

- Wattle Street (Council) Branch,
- Wattle Street (Old Council) Branch,

- Brewery Sub-Branch,
- Prince Alfred Park Sub-Branch,
- Blackwattle Creek Branch,
- Mountain Street/Shepherd Street Branch,
- Bay Street Branch,
- Victoria Park Sub-Branch.

The upper branches collect runoff from a wide area in the south of the catchment, before converging to a narrow strip of parallel branches immediately south of Wentworth Park which then discharge into Blackwattle Bay near the Fish Markets on Pyrmont Bridge Road, Pyrmont.

When the capacity of the drainage system is exceeded there is the potential for velocities and/or flow depths combining to generate high hazard flooding conditions. Past events indicate that events as small as the 5 year ARI rainfall event can cause these conditions in several locations throughout the catchment (e.g. Wattle St and Blackwattle Lane).

2.3. Historical Floods

Historical records (photographs, reports) indicate that rainfall intensities as low as 2 to 5 year ARI events can cause flooding at many locations within the catchment. Consequently there have been many instances of flooding in the past with June 1949, November 1961, March 1975, November 1984, January 1991 and February 2001 being some of the most significant storm events causing extensive flooding throughout the catchment.

To highlight the potential magnitude of flooding in the region, Council has provided photographs (Photo 1 and Photo 2) at Macarthur Street, Glebe during the March 1975 flood event. Water depths in excess of one metre covered large areas during this event.

Photo 1: Macarthur Street at junction of Mountain Street, Glebe – March 1975

Photo 2: Macarthur Street at junction of Mountain Street, Glebe – March 1975

2.4. Previous Studies

A number of previous studies have been undertaken for the Blackwattle Bay catchment, as summarised below.

2.4.1. Blackwattle Bay (SWC 17) Flood Study, Sydney Water, September 1995 (Reference 6)

The aim of this flood study was to determine flooding behaviour for the 20% AEP to 1% AEP design floods as well as the Probable Maximum Flood (PMF). The study used the hydrologic model ILSAX, which utilises the pit and pipe survey data and other parameters to generate runoff hydrographs. These inflows represented the upstream boundary conditions and were then input into a MIKE-11 UD model which was used to predict flood depths and velocities. Due to limited computer memory capacity, pits in the 1D network were aggregated in some cases. Six major floodways were identified in this study including Wentworth Park Road, Blackwattle Lane, Wattle Street, Broadway between Mountain Street and Wattle Street, Buckland Street and Abercrombie Street. This study was superseded by more recent modelling studies due to improvements in modelling techniques and the availability of aerial survey data. The primary relevance of SWC study to the current modelling is the geometry information (culvert sizes, invert levels, etc.) for the trunk drainage network in the catchment.

2.4.2. South Sydney Stormwater Quality and Quantity Study, Blackwattle Bay and Johnstons Creek Catchments, Hughes Trueman & Perrens Consultants, September 2004 (Reference 7)

This report was commissioned by South Sydney Council (now known as City of Sydney) to assess the performance of the trunk drainage systems in the Johnstons Creek and Blackwattle Bay catchments. The two trunk drainage systems SWC17 and SWC55 (Blackwattle Bay and Johnston Creek respectively) lie within the City of Sydney LGA. The study aims were to provide stormwater management options. Key issues examined in the report are as follows:

- Analysis of the origin and causes of stormwater flows that contribute to stormwater flooding;
- Strategies for managing stormwater flooding;
- Options for reducing stormwater flooding;
- Water quantity and quality management opportunities; and
- Water quality improvement.

The study modelled stormwater flows using the DRAINS modelling package. The DRAINS model was then used to produce a summary of pipe flows estimates, estimates of potential overland flow paths and estimates of flood depths in sag points.

2.4.3. Draft Blackwattle Bay Catchment Flood Study, WMAwater, May 2012 (Reference 4)

This flood study was carried out as part of the NSW Flood Risk Management Program to define existing flood behaviour for the Blackwattle Bay catchment in terms of flood levels, depth, velocities, flows and extents. The mechanisms of flooding examined in this study include local overland flow as well as backwater flooding from receiving waters. A 1D/2D TUFLOW hydraulic model was established utilising the rainfall on grid approach and verified by a limited calibration exercise to historical data (26th January 1991 calibration event and 17th February 1993 verification event). The study investigated the 50%, 20%, 10%, 5%, 2%, 1% AEP design flood and PMF events. Preliminary hydraulic categories were determined for these events as was provisional hazard mapping. Several flooding hot spots were also identified in the study. A floor level survey and damages assessment identified 55 residential and 11 non-residential properties liable to over floor inundation in the 1% AEP event.

2.4.4. University of Sydney Flood Risk Management Stage 1 – Campus Flood Study Review, WMAwater, August 2013 (Reference 8)

The main objective of this study is to define the existing flood behaviour on the University of Sydney's Camperdown and Darlington campuses for a range of design events including the 20%, 5%, 1% AEP design flood and PMF events. The Darlington campus and parts of the Camperdown campus east of Eastern Avenue are located within the Blackwattle Bay catchment. This study utilised the hydraulic models from the Blackwattle Bay Catchment Flood Study (Reference 4), which were updated to reflect recent developments as well as improved definition of the stormwater drainage network and overland flow paths within the campuses. The flood affected areas within the University were identified and relevant information was provided to inform the University with regards to managing existing and future flood risk within the University.

2.4.5. Blackwattle Bay Floodplain Risk Management Study and Plan, WMAwater, References 1 and 5

The Draft Flood Study (Reference 4) described in Section 2.4.3 was reviewed and updated as part of the FRMS/P (References 1 and 5). Updates to the model included:

- Developments within the University of Sydney, i.e. Eastern Ave walkway, Cadigal Green, Darlington Walk, Faculty of Law building and Jane Foss Russell building; and
- The Central Park development adjacent to Parramatta Rd.

Where details were available they were used to revise the model definition for that particular development site. Some of these changes were incorporated into the model in the study for the University of Sydney (Reference 8).

The flood damages estimates were also updated as further flood prone properties were identified upon completion of the Flood Study and additional floor levels were surveyed and included in the damages assessment.

The study also considered the potential effects of climate change by modelling rainfall increases of 10%, 20% and 30% on the 1% AEP flood event. A 10% increase in design rainfall intensity resulted in approximately 0.1m increase in peak flood levels and a 20% increase in rainfall intensity lead to a 0.1m increase in flood level and 30% to 0.2m.

The main outcomes of the FRMS/P were:

- Identification of flooding hot spot areas;
- Delineation of hydraulic category and hazard categories;
- Identification of mitigation measures to address the adverse impacts of new developments; and
- Identification of risk management measures to reduce flood costs to properties within the catchment by either structural or non-structural measures.

A number of hot spots were identified including:

- Intersection of Cleveland St and Beaumount St;
- Intersection of Parramatta Rd and Buckland St;
- Wentworth Park Rd/William Henry St;
- Wattle St;
- Properties off Mitchell St and Talfourd St; and
- Bridge Rd.

The revised model from Reference 1 was used as the starting point for model updates documented in the current study (see following sections).

3. ADOPTED MODEL APPROACH

The overall guidelines for the modelling approach are taken from the 2005 NSW Government's Floodplain Development Manual (Reference 9) with technical details based on best practice from Reference 10. 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. Hydrologic Model Approach

Hydrologic modelling was undertaken by aggregating rainfall over micro sub-catchment areas and applying as an inflow to the hydraulic model. The sub-catchments were delineated with a small enough area that the catchment response is rainfall driven, and attenuation and lag effects on the flow are not significant over the timescales of the relevant design temporal patterns (i.e. less than 5 minutes). The sub-catchment layout is shown on Figure 2.

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 11).

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 update the existing 2D TUFLOW model, with channels and stormwater elements 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 2015 TUFLOW model from the FRMS (Reference 1) was previously validated using the January 1991 and February 1993 events. These historical events were the events where relatively reliable flood records were available for comparison with the modelling. There have not been additional flood events where suitable data was collected for calibration 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. The model DEM is shown on Figure 5.

3.4.2. Detail Survey

A range of datasets provided detailed survey information about existing and proposed development within the catchment, primarily within road reserves and the public domain. The datasets included works-as-executed survey plans and detail survey datasets provided by City of Sydney. The datasets were provided as 3D drawing files, which were triangulated to create localised digital elevation models for inclusion in TUFLOW. Table 1 lists the datasets incorporated into the model.

Table 1 is not a comprehensive summary of the locations where development has occurred in the catchment since 2013. WMAwater identified some localised changes in development and 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.

Table 1 Data Sources

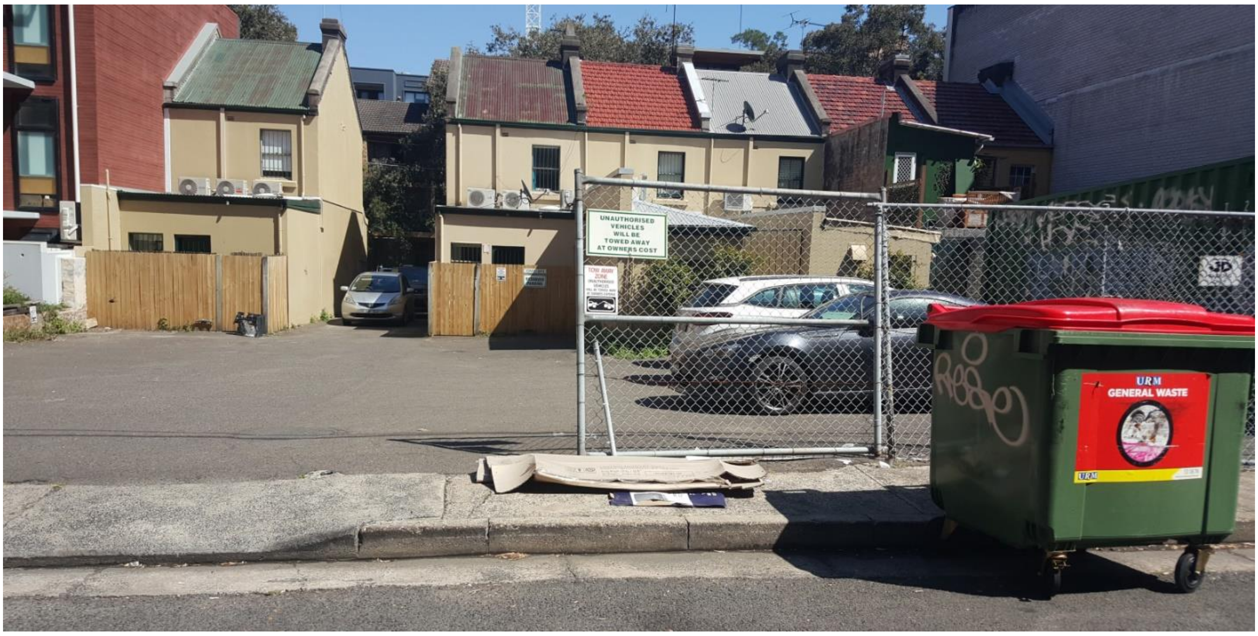
Location	Title / Description	Drawing No.	Author / Source	Date
Central Park Precinct	Plan showing grids, relative heights and physical features over Central Park, Sydney	Drawing Ref: 17847-1	Bee & Lethbridge Pty Ltd	Nov 2012
Wiley Street between Myrtle Street and Cleveland Street, Chippendale	Detail and level survey of Wiley Street Chippendale	Drawing Ref: 09-0009	Peter Bolan and Associates Pty Ltd	Mar 2009
Ada Place, Ultimo	Detail and levels of Ada Place between Fig Street and Quarry Street, Ultimo	Drawing Ref: S5-12/2015	City Infrastructure Technical Services – City of Sydney	Nov 2012
Seamer Street / Arundel Street / Catherine Street, Glebe	Detail and levels, Arundel St. No 59 to Seamer St, Seamer St to Catherine St, and Catherine St to mount Vernon Rd Intersection, Glebe	Drawing Ref: S5-12/1001	City Infrastructure Technical Services – City of Sydney	Oct 2012
Marry Ann Street Park, Ultimo	Detail and levels, Mary Ann Street Park from Jones St to Bulwara Road, Mary Ann Street Ultimo	Drawing Ref: S5-12/995	City Infrastructure Technical Services – City of Sydney	Sep 2012
Lyndhurst Street, Glebe	Detail and levels, Intersections of Lyndhurst Street with Bridge Road and Colbourne Avenue, Glebe	Drawing Ref: S5-13/1036	City Infrastructure Traffic Operations – City of Sydney	Mar 2013
Stewart Street, Glebe	Detail and levels, Stewart Street from Mary Street to Oxley Street, Glebe	Drawing Ref: S5-13/1037	City Infrastructure Traffic Operations – City of Sydney	Mar 2013
Westmoreland Street, Glebe	Detail and levels, Westmoreland Street between St. Johns Road and Mitchell Street, Glebe	Drawing Ref: S5-13/1043	City Infrastructure Technical Services – City of Sydney	May 2013
Prince Alfred Park, Surry Hills	Detail and levels, area adjacent western boundary, Prince Alfred Park Pool, Surry Hills	Drawing Ref: S5-13/1045	City Infrastructure Technical Services – City of Sydney	May 2013
Belvoir Street, Surry Hills	Detail and levels over part of Belvoir Street, Surry Hills	Drawing Ref: S5-11/869	City Infrastructure Traffic Operations – City of Sydney	Jul 2011
Hugo Reserve, Redfern	Detail and levels over Hugo Reserve, Redfern	Drawing Ref: S5-11/882	City Infrastructure Traffic Operations – City of Sydney	Sep 2011
Abercrombie St, Darlington	Detail and levels, intersection of Abercrombie St and Codrington St, Darlington	Drawing Ref: S5-11/895	City Infrastructure Traffic Operations – City of Sydney	Oct 2011
Myrtle Street, Chippendale	Detail and levels over the intersection of myrtle Street and Wiley Street, Chippendale	Drawing Ref: S5-12/1006	City Infrastructure Traffic Operations – City of Sydney	Oct 2012
Bartley Street, Chippendale	Detail and levels over Bartley Street, Chippendale between Abercrombie Street and Balfour Street	Drawing Ref: S5-13/1050	City Infrastructure Traffic Operations – City of Sydney	Jun 2013
Lower Avon Street, Glebe	Detail and levels over Lower Avon Street between Bayview Street and Palmerston Avenue, Glebe	Drawing Ref: S5-15/1230	City Infrastructure Traffic Operations – City of Sydney	Sep 2015
Regent St / Meagher St, Chippendale	Regent Street and Meagher Street, Chippendale – Detail and levels	Drawing Ref: S5-587/311	Public Works & Services, City of South Sydney	

3.4.3. Aerial Photograph

Updated aerial photography for the catchment was used to inform modelling revisions to building footprints and other development changes. 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 December 2019, as displayed on Figure 1).

3.4.4. Site Inspection

Photo 3: Overland flow path from Little Buckingham Street to Buckingham Street



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. Generally the ground levels were estimated by interpolating between adjacent streets, and incorporating observations for the site visit. These modifications included:

a) Inclusion of the flow path through the car park and between buildings from Little Buckingham Street to Buckingham Street (see Photo 3).
b) Inclusion of flow through a building walkway between sag points in Buckingham Street and Pembroke Street (see Photo 4). Previous modelling did not allow flow through the building, leading to accumulation of significant depths of water in the street. Gaps were introduced in the model schematisation between the buildings to mimic the observed conditions. There is an obstruction in the sag point in Pembroke Street (Photo 5) resulting in water ponding at this location until it can be drained through the stormwater system under the building.

Photo 4: Overland flow path through building from Buckingham Street to Pembroke Street

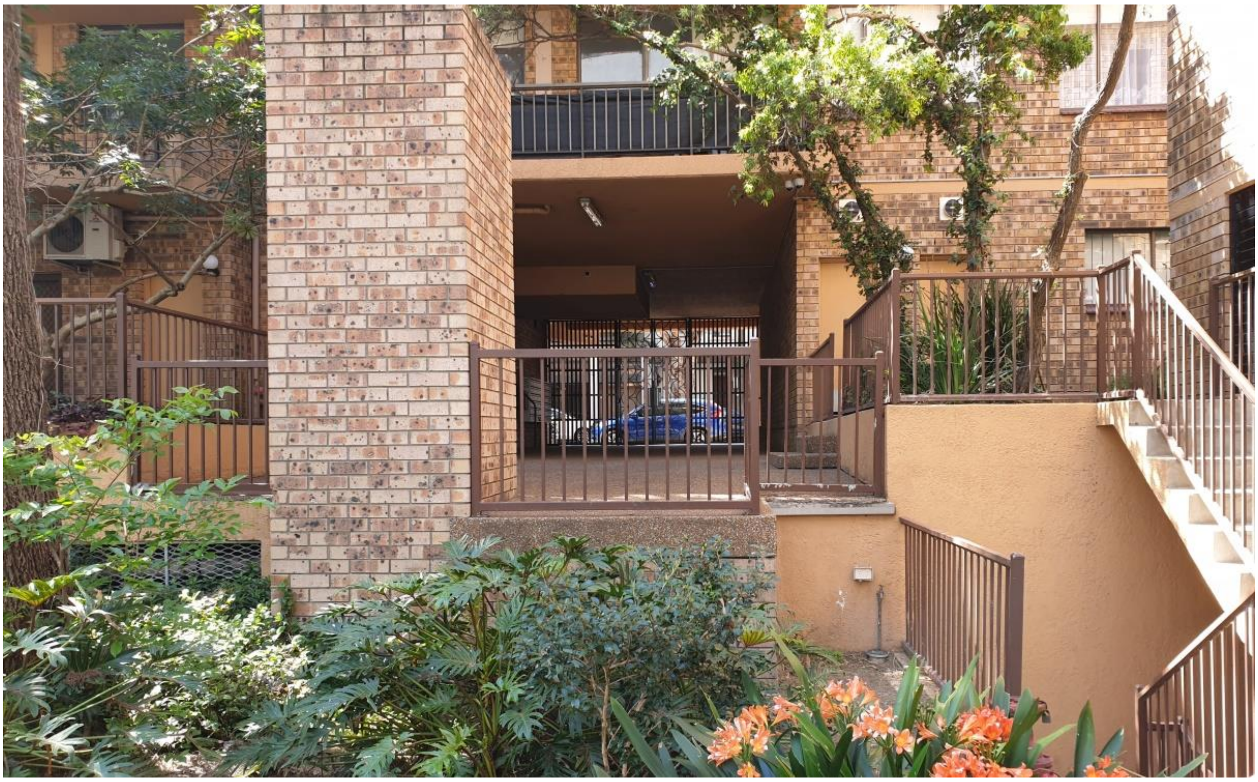
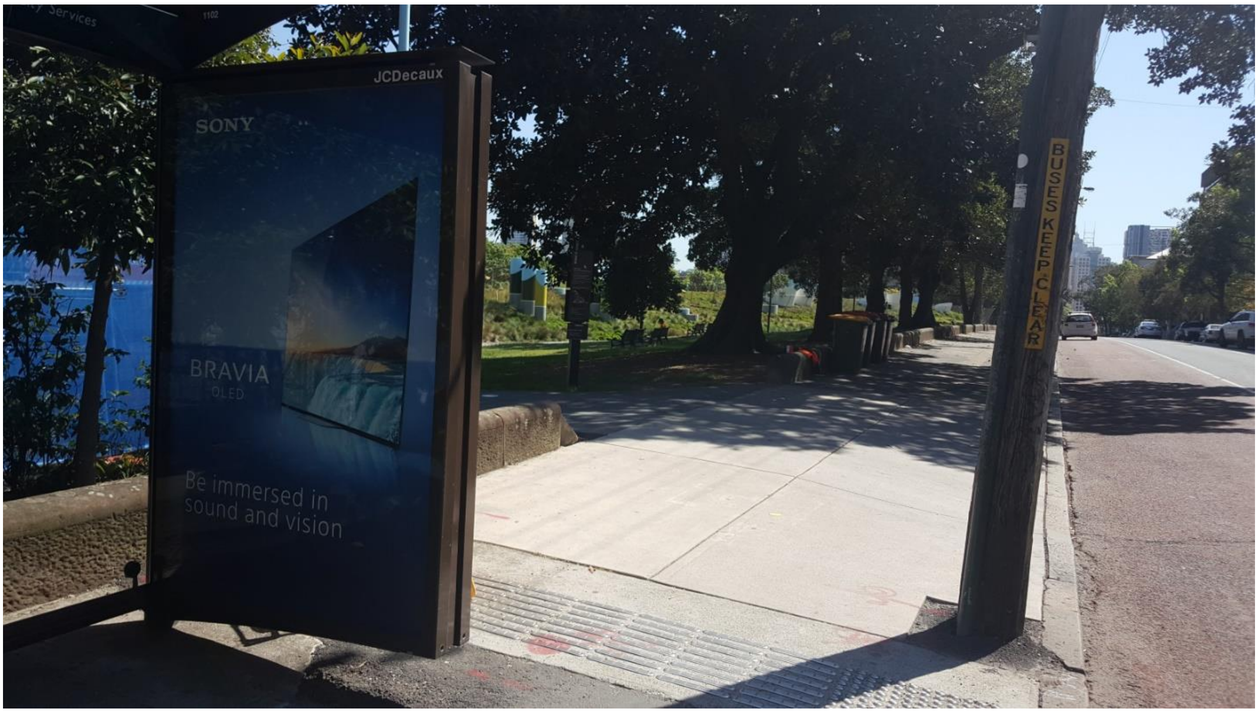


Photo 5: Sag point and obstruction from building in Pembroke Street

c) Refinement of the building footprints, walls and relief flow path from Chalmers Street into Prince Alfred Park (Photo 6 and Photo 7).

Photo 6: Buildings at sag point on Chalmers Street

Photo 7: Overland flow relief point from Chalmers Street into Prince Alfred Park



d) Vine Grove in Redfern grades downwards towards a brick garage that obstructs flow from Vine Grove to Boundary Street. This creates a trapped low area in Vine Grove, where water will pond until the level is high enough to flow out via Shepherd Lane (Photo 8). The model was refined to allow flow down this laneway. There is a narrow gap between the buildings allowing some flow to discharge through to Boundary Street, visible in Photo 9 (from Vine Grove), and Photo 10 (from Boundary Street).

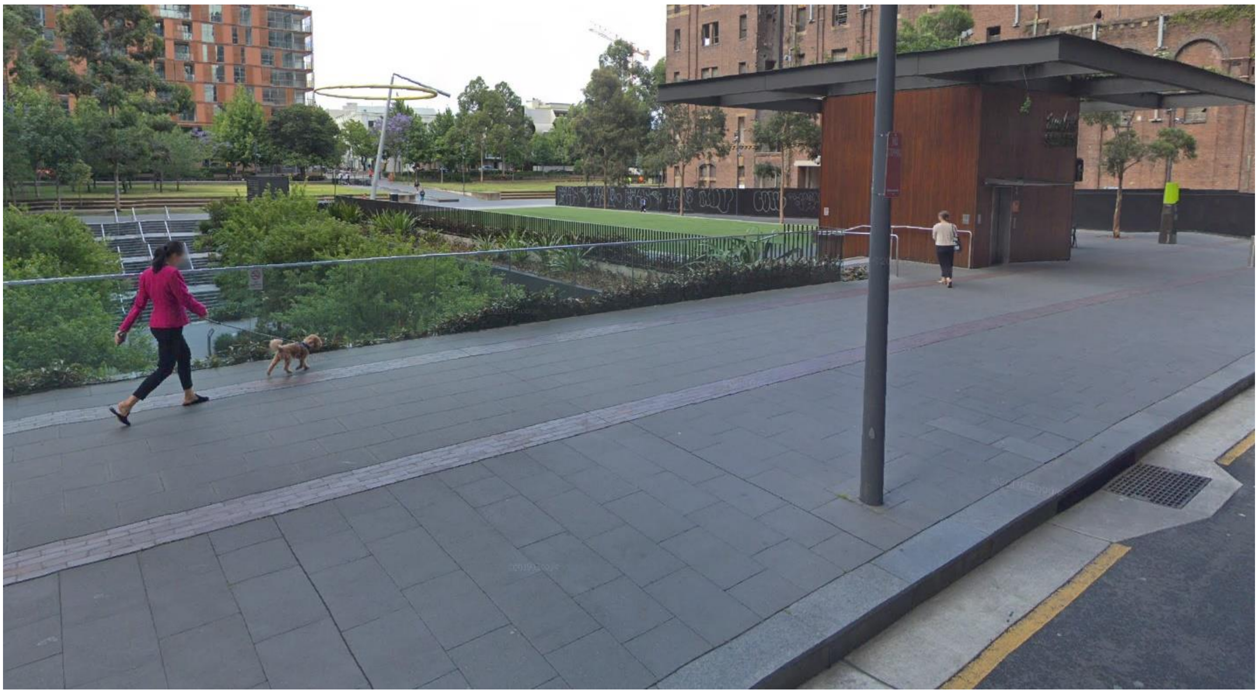
Photo 8: Shepherd Lane overland flow relief point from sag point in Vine Grove

Photo 9: Vine Grove, showing obstruction from garage of flow path to Boundary Street

Photo 10: Gap between buildings allowing some flow from Vine Grove to Boundary Street

e) There is a large lower ground entry staircase and plaza in Central Park. The northern side of this plaza has a glass safety barrier along the street that will limit overland flow falling into the plaza (Photo 11). The glass safety barrier was included as an obstruction in the model.

Photo 11: Sag point in Central Park Avenue and glass safety barrier around lower ground entry



f) There is a sag point in Broadway (Parramatta Road) between Wattle Street and Mountain Street. When overland flow exceeds the pipe network capacity, water will collect in the sag point. Outflow to Blackwattle Lane to the north is obstructed by buildings and hoarding across the laneway linking the streets. There is a gap under the hoarding that allows some flow (Photo 12 and Photo 13), and a higher relief flow path through a walkway between buildings further to the west (Photo 14).

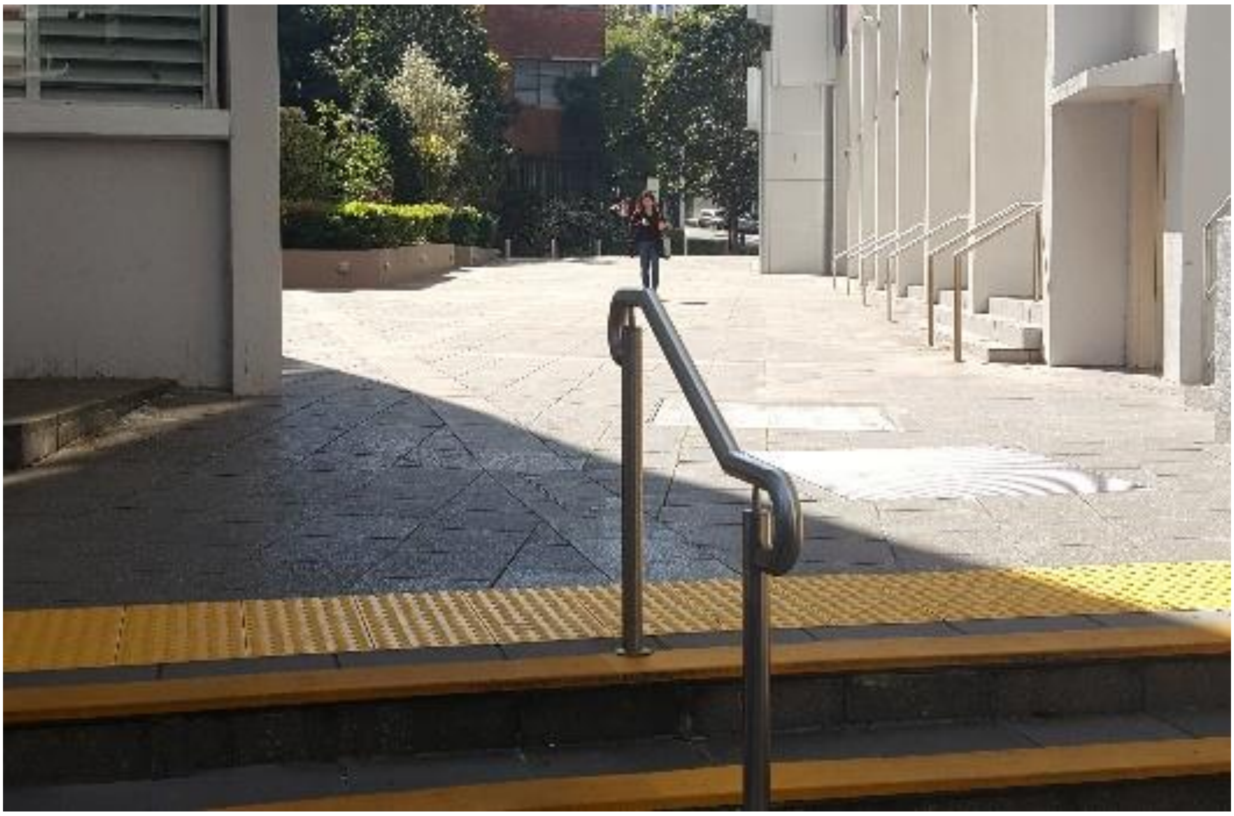
Photo 12: Gap under hoarding to allow overland flow from Broadway sag point to Blackwattle Lane

Photo 13: Gap under hoarding viewed from downstream at Blackwattle Lane

Photo 14: Overland flow path from Broadway sag point through buildings towards Blackwattle Lane

g) The DEM was adjusted to better represent the pedestrian plaza between Wattle Street and Blackwattle Lane (Photo 15).

Photo 15: Overland flow path through plaza from Wattle Street to Blackwattle Lane

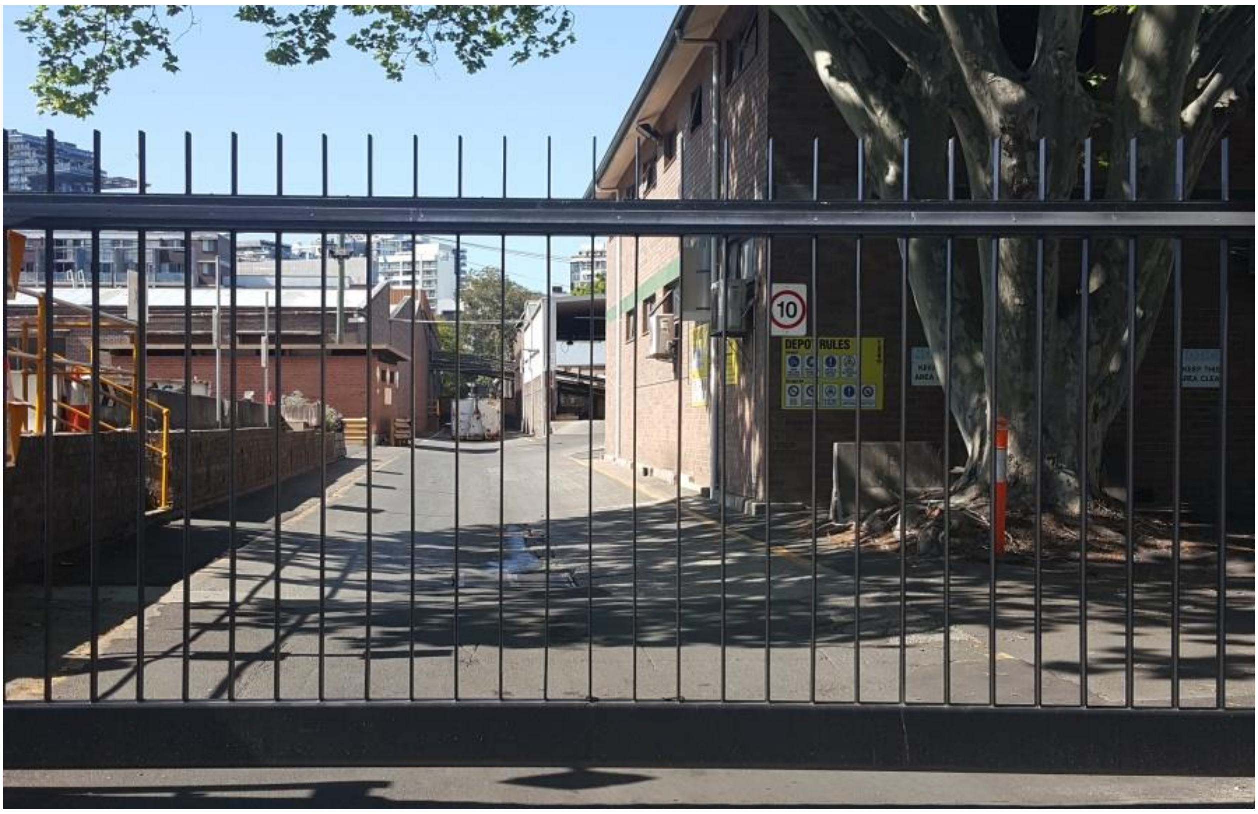


h) The schematisation was refined for the flow path along Blackwattle Lane (Photo 16) and through the Council depot from Macarthur St to William Henry St (Photo 17 and Photo 18).

Photo 16: Overland flow path above trunk drainage line in Blackwattle Line

Photo 17: Overland flow path through depot from Macarthur St to William Henry St (upstream)

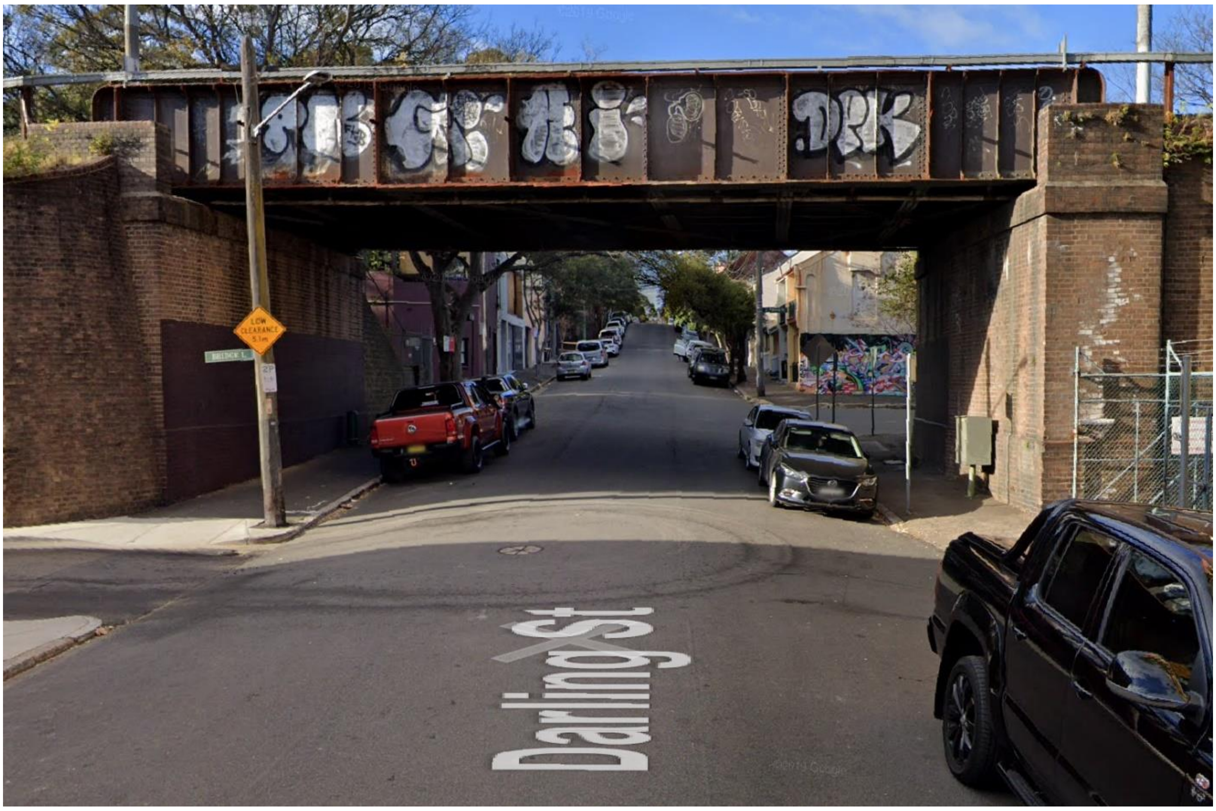
Photo 18: Overland flow path through depot from Macarthur St to William Henry St (downstream)



i) The road underpasses through the light rail viaduct at Bellevue Street (Photo 19) and Darling Street (Photo 20) were not captured by the LIDAR, and the DEM was adjusted to represent these flow paths.

Photo 19: Light rail underpass as Bellevue Street, Glebe

Photo 20: Light rail underpass at Darling St, Glebe



4. HYDROLOGIC MODEL SETUP

4.1. Sub-catchment Delineation

The catchment was represented by a total of 831 sub-catchments (shown in Figure 2), with an average sub-catchment size of approximately 0.4 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.

Flows from each subcatchment are input into the TUFLOW model at the downstream end of each subcatchment at an appropriate location as relevant for each subcatchment, either:

- at inlet pits to the stormwater system; or
- within the road reserve or overland flow path where there are no inlet pits within the subcatchment.
-

4.2. 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 12).

Table 2: Probability Neutral Initial Losses for Rural Pervious Areas (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

The adopted initial loss values (accounting for pre-burst rainfalls) are summarised in Table 2. 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 0.72 mm/hr was adopted for impervious surfaces, obtained by using 40% of the value specified on the ARR Datahub (as per Reference 12).

4.3. Impervious Surface Area

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occurs differently than from vegetated surfaces. It is therefore necessary to estimate the proportion of the catchment area that is covered by such surfaces.

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 area percentage of the chosen zoning classifications is summarised in Table 3.

Table 3: Impervious Percentage for Land-use types

Development Description	Effective Impervious Area	Indirectly Connected Impervious Area	Rural Pervious Area
Urban (Typical)	70%	25%	5%
Parkland	5%	30%	65%
Industrial-Commercial / Full urbanised	100%	0%	0%

The development categories above were allocated based on land use zoning, as per Table 4.

Table 4: Land-use category based on zoning

Land Use Type	Zoning	Land Use Category
Commercial / Industrial	B1	Full urbanised
Commercial / Industrial	B2	Full urbanised
Fish Market	B3	Full urbanised
Highly industrialized	B4	Full urbanised
Wentworth Park	CW	Parkland
New development	GAHP	Full urbanised
Railway+ the block	MD	Urbanised (typical)
Light residential (terrace houses)	R1	Urbanised (typical)
Parks	RE1	Parkland
Central Park	SLEP	Urbanised (typical)
Railway/highway/school/university	SP2	Urbanised (typical)
Sydney University	SYDU	Urbanised (typical)

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-w64 (using the finite volume HPC solver), and further details regarding TUFLOW software can be found in the User Manual (Reference 11). 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. Refined Model Grid Resolution

The TUFLOW model from the FRMS (Reference 1) used a 2 m by 2 m grid resolution. This model resolution was refined to 1 m by 1 m, which significantly increases the detail of urban flow paths such as roadways, lanes, and overland flow paths between buildings. This increase in the model detail was made feasible by increases in computing power since the previous modelling was undertaken, as well as the availability of the HPC finite volume formulation of TUFLOW using GPU hardware.

5.3. Stormwater Network – Increased Modelling Detail

The detail of the stormwater network in the model was significantly increased by including pipes of 450 mm diameter and smaller, which had not previously been modelled. This involved the addition of approximately 1,900 pipes into the model, using information from Council's asset database, as well as the relevant inlet and junction pits to connect these pipes to the surface and larger pipe 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 or Councils database and revised based on detailed survey where available. If no invert information was available, levels were estimated based on an assumed depth below the local ground levels.

5.4. Boundary Conditions

5.4.1. Runoff 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.

5.4.2. Downstream Boundary

The primary mechanism for flooding for the catchment is from storm runoff, but within the lower catchment flooding can be exacerbated by elevated water levels within Blackwattle Bay.

Table 5 summarises the adopted tailwater levels for the design events, using a joint probability assumption consistent with Reference 12.

Table 5: Adopted tailwater levels for design event modelling

Design Rainfall Event (AEP)	Ocean Level (AEP)	Tailwater Level in Blackwattle Bay (mAHD)
50%	50%	1.2
20%	20%	1.2
10%	10%	1.2
5%	5%	1.4
2%	5%	1.4
1%	5%	1.4
0.5%	1%	1.43
0.2%	1%	1.43
PMF	1%	1.43

Sensitivity analysis of tailwater levels was undertaken and is reported in Section 6.8.

5.5. 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 1, with updates as follows:

- The separate, formerly overlapping materials layers from previous models were merged into one layer and simplified;
- Building footprints were nulled out of the model (see Section 5.6 for treatment of buildings); and
- The delineation of the roughness zones was refined based on current available aerial photography.

The adopted roughness values for different land use types are presented in Table 6. A map of the adopted land use types for the 2D TUFLOW domain is shown on Figure 4.

Table 6: Adopted Manning's "n" Roughness Values

Elements	Manning's *n* value
Roads	0.015
Urban Development (default)	0.05
Parks	0.03
Open car parking / hardstand	0.02
Ponds / lakes	0.02
Vegetation	0.08
Railway Corridor	0.06

5.6. 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. 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 10). 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.*"

5.7. Blockage Assumptions

5.7.1. Stormwater Inlet Pits

For the design modelling undertaken in this current study, each inlet pit was 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 6.8.

5.7.2. Stormwater Pipes, Open Channel Bridges and Culverts

The trunk drainage network of the Blackwattle Bay catchment is almost entirely below ground, with very few sections of open channel. This means that the potential for blockage within the pipe network is reduced, since any debris able to enter the system through inlet pits will generally be small enough to travel through the pipe network without causing an obstruction.

The stormwater pipes, bridges and culverts were assumed to be unaffected by debris blockage for the design flood modelling. This is a change from Reference 1, but 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 11), 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 2015 Modelling 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

- It was assumed that there would be no blockages within the underground stormwater pipes, removing the blockage assumption used in Reference 1. The peak flood level changes resulting from this update are shown on Figure B1, with a slight reduction (typically 0.05 m to 0.1 m) along the main trunk drainage line.
- The base DEM was updated to use the 2013 LIDAR survey across the entire study area. This primarily affected the Central Park precinct, Sydney University, Prince Alfred Park, and Victoria Park. 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 Buckingham/Pembroke/Chalmers Streets in Surry Hills, Shepherd Lane/Vine Grove in

Redfern, and Broadway/Blackwattle Lane in Ultimo. The peak flood level changes resulting from this update are shown on Figure B3.

- Mannings 'n' Roughness values were updated based on current aerial photography (see Section 5.5). The peak flood level changes resulting from this update were minor and are shown on Figure B4.
- The stormwater network was refined to include smaller pipes as discussed in Section 5.3. The peak flood level changes resulting from this update were relatively minor and are shown on Figure B5.
- The schematisation of the kerb/gutter system and road centrelines was revised to be consistent across the model and consistent with other City of Sydney Flood Study models. The peak flood level changes resulting from this update were relatively minor and are shown on Figure B6.
- 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 B7.
- The model grid resolution was refined from 2 m to 1 m. The primary effect of this change was to improve the schematisation of narrow flow paths such as laneways, smaller streets and between buildings, reducing the amount of water artificially trapped in the upper catchment, and slightly increasing flood levels along major flow paths and the lower catchment. The peak flood level changes resulting from this update were relatively minor and are shown on Figure B8.
- The combined changes resulting from the changes above are shown on Figure B9. These changes were all assessed for the 1% AEP event using the previous hydrology from the 2015 modelling for the FRMS (Reference 1). 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 13) 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 7.

Table 7: Catchment average design rainfall depths (mm)

Duration	AEP					
(min)	20%	10%	5%	2%	1%	0.5%	0.2%
20	18.4	20.6	27.6	32.3	36.9	51.3	58.1
25	20.3	22.8	30.4	35.6	40.6	56.7	64.1
30	21.9	24.5	32.8	38.3	43.7	61.1	69.2
45	25.6	28.6	38.1	44.6	50.9	71.6	81.1
60	28.4	31.7	42.2	49.4	56.4	79.6	90.2
90	32.8	36.5	48.6	56.8	65	92.4	105
120	36.2	40.4	53.7	63	72.2	103	116
180	41.9	46.7	62.3	73.3	84.3	121	136
270	48.9	54.5	73.1	86.3	99.7	143	162
360	54.7	61.2	82.4	97.6	113	163	184
540	64.5	72.4	98.4	117	137	198	224
720	72.8	81.9	112	134	157	228	258
1080	86.2	97.4	135	162	190	279	316
1440	96.9	110	153	185	218	321	364

No areal reduction factors were applied to these rainfalls.

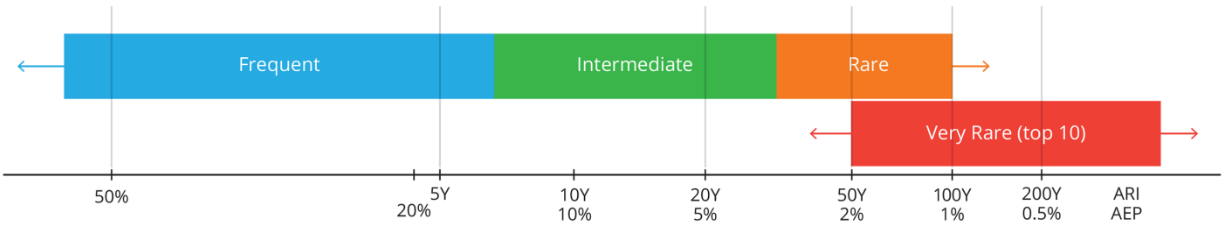
6.3. Temporal Patterns

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 Blackwattle Bay 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 13).

6.4. Critical Duration Analysis

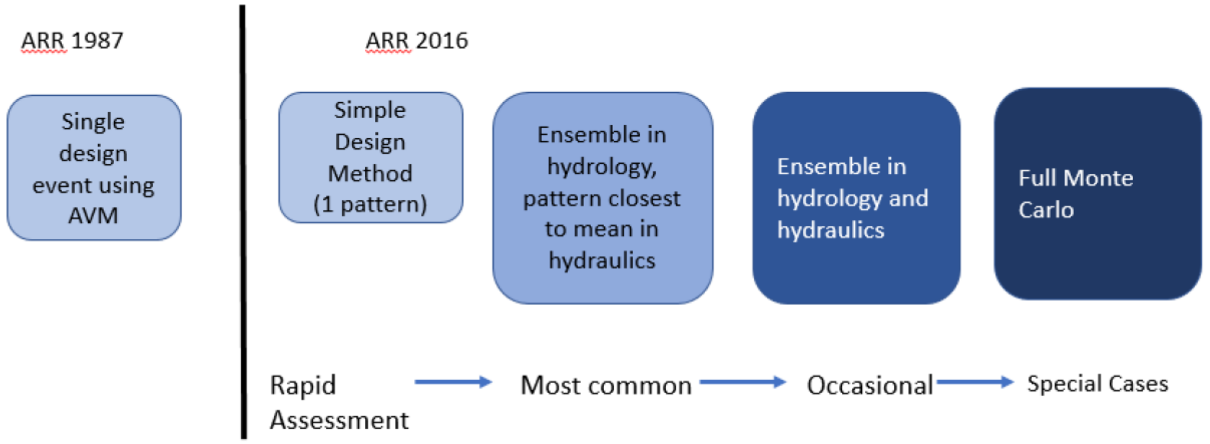
The critical duration is the temporal pattern and duration that best represents the flood behaviour (e.g. flow, level) for a specific design magnitude. It is generally related to the catchment size, as flow takes longer to concentrate at the outlet from a larger catchment, as well as other considerations 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 12, 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 representative storm patterns selected for the design event modelling are summarised in Table 8:

Table 8: Selected Representative Design Storm Temporal Patterns

Design Storm AEP	30 minute Temporal Pattern ID	60 minute Temporal Pattern ID
Frequent **50% and 20%**	4524	4578
Intermediate **10% and 5%**	4511	4573
Rare **2%, 1%, 0.5% and 0.2%**	4504	4463

For the PMF, the 30 minute storm generally produced peak flood levels within 0.1 m of the peak depths obtained from the envelope of multiple storm durations, and this duration was adopted as the critical PMF duration.

6.5. Results

Maps of estimated peak flood depths and flood level contours from the updated design modelling are presented in Appendix C:

- 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 9 and Table 10. See Figure 6 for the locations referred to in the tables.

Table 9 Peak Flood Level Results at Key Locations (mAHD)

Location	50% AEP	20% AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP	0.2 % AEP	PMF
1	29.9	29.9	29.9	30.0	30.0	30.0	30.0	30.0	30.0
2	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.1	31.1
3	23.7	23.7	23.8	23.8	23.9	23.9	23.9	24.0	24.1
4	18.2	18.3	18.3	18.3	18.4	18.4	18.4	18.4	18.5
5	13.9	14.0	14.0	14.1	14.2	14.2	14.2	14.3	14.4
6	11.3	11.5	11.5	11.6	11.7	11.7	11.7	11.8	12.0
7	11.5	11.5	11.5	11.6	11.6	11.6	11.6	11.6	11.7
8	7.4	7.7	7.9	8.1	8.3	8.4	8.5	8.6	9.1
9	4.7	5.1	5.4	5.5	5.6	5.6	5.7	5.7	6.1
10	4.3	4.4	4.5	4.6	4.7	4.8	4.8	4.9	5.4
11	4.0	4.2	4.3	4.4	4.5	4.6	4.7	4.8	5.4
12	2.7	2.9	2.9	3.0	3.1	3.2	3.2	3.3	3.8
13	3.4	3.4	3.4	3.5	3.6	3.6	3.7	3.7	4.0
14	0.0	0.0	2.3	2.4	2.5	2.6	2.6	2.7	3.4
15	2.1	2.3	2.3	2.4	2.5	2.6	2.6	2.7	3.4
16	13.0	13.0	13.0	13.1	13.2	13.3	13.3	13.4	13.5
17	3.2	3.3	3.3	3.4	3.4	3.5	3.5	3.5	3.9
18	2.5	2.6	2.7	2.7	2.8	2.9	3.0	3.1	3.7
19	2.3	2.4	2.5	2.6	2.7	2.7	2.8	2.8	3.4
20	15.6	16.0	16.2	16.4	16.6	16.6	16.7	16.7	16.9
21	2.9	2.9	2.9	2.9	3.0	3.0	3.0	3.0	3.1
22	1.9	2.0	2.1	2.2	2.3	2.3	2.4	2.4	2.9

Table 10 Peak Flow Results at Key Locations (m^3/s)

Location	50% AEP	20% AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP	0.2 % AEP	PMF
P1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P2	4.0	4.1	4.2	4.3	4.4	4.4	4.5	4.5	4.7
P3	4.8	5.7	5.9	6.0	6.2	6.3	6.3	6.4	6.9
P4	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1
P5	0.2	0.2	0.2	0.4	0.5	0.6	0.6	0.7	1.3
P6	12.1	13.1	13.4	14.5	14.7	14.7	14.8	14.7	15.3
P7	2.5	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
P8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1
P9	1.4	1.4	1.5	1.4	1.4	1.5	1.5	1.5	1.9
P10	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.4
P11	3.0	3.5	3.6	4.0	4.1	4.2	3.9	4.0	4.3
P12	3.2	3.6	3.8	3.8	4.1	4.1	4.2	4.1	4.4
P13	5.6	6.5	6.7	6.7	7.1	7.2	7.4	7.5	8.1
P14	4.7	4.9	5.0	4.8	4.9	5.0	5.0	5.1	5.6
OF1	1.0	1.5	2.1	2.7	3.7	4.2	4.6	5.1	8.2
OF2	1.1	4.8	7.5	9.9	14.2	16.8	19.2	23.1	47.7
OF3	0.6	0.8	0.9	1.0	1.1	1.3	1.5	1.9	3.1
OF4	0.5	0.5	0.6	0.6	2.4	4.2	5.9	9.0	31.0
OF5	1.8	5.4	8.0	10.2	11.7	12.9	13.8	15.0	22.2
OF6	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	5.1
OF7	0.7	1.0	1.1	1.3	1.6	1.7	1.8	2.0	3.6
OF8	0.4	0.6	2.1	3.9	6.0	8.0	9.9	13.3	43.2
OF9	0.4	1.1	1.4	1.9	2.7	4.6	6.3	9.0	36.7
OF10	0.1	0.4	0.8	1.1	1.6	2.1	2.6	3.4	10.1
OF11	1.6	2.3	2.9	3.5	3.9	4.3	4.7	5.3	8.0
OF12	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	3.6
OF13	0.3	0.5	0.8	0.9	1.5	2.1	3.1	4.9	45.3
OF14	1.4	4.5	6.6	9.0	12.3	15.7	18.3	22.0	55.9
OF15	0.7	1.3	1.6	1.9	2.8	3.2	3.8	4.9	10.5

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 9) 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 14). This was the categorisation methodology used for this study.

The classification is divided into 6 categories which indicate the restrictions on people, buildings and vehicles:

- H1 – No constraints, generally safe for vehicles, people and buildings;
- 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. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure. Buildings require special engineering design and construction; and
- H6 – Unsafe for all people and all vehicles. All building types considered vulnerable to failure.

The classifications are based on the relationship between flood velocity and depth as shown on Diagram 3.

Diagram 3: Hazard Classifications

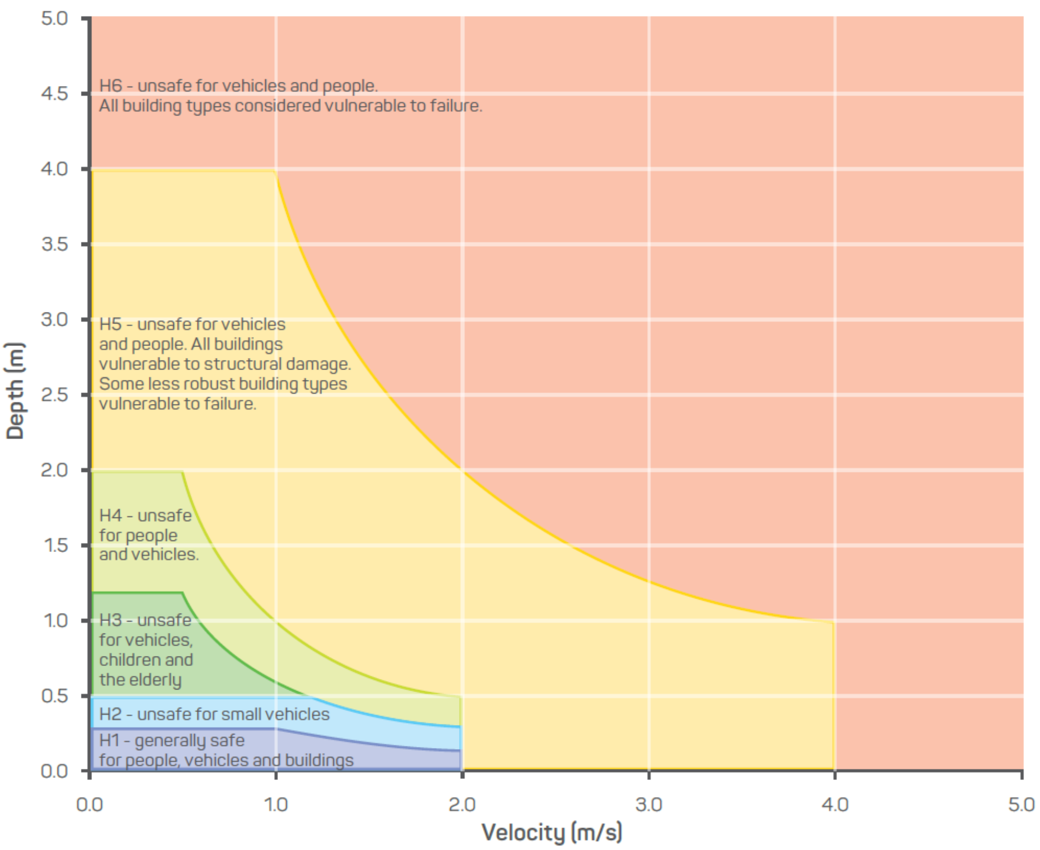


Figure C28 to Figure C36 provide the hazard classification for the full range of design storm events, according to the above classification. Under this classification, the most hazardous areas of the floodplain are generally constrained to the non-habitable areas, the parks, reserves, golf courses etc.,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

6.7. Provisional Hydraulic Categorisation

The 2005 NSW Government's Floodplain Development Manual (Reference 9) 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 15), 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*:

- <u>Floodway</u> 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,

- <u>Flood Storage</u> comprises areas outside the floodway where peak depth > 0.2 m; and
- <u>Flood Fringe</u> 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 shows the results of the pipe capacity assessment for the modelled range of design events. A large proportion of the pipes are full in the 50% AEP event. Some sections of the main trunk drainage lines have larger capacity, in the order of 20% to 5% AEP.

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;
- Pipe blockage; The effect of trunk drain pipe blockages of 10% and 25% 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 16 and 17.

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 11. Pipe blockages would generally cause localised increases in flood level upstream of the blockage up to 0.05 m for 10% blockage, and up to 0.1 m for 25% blockage. These impacts are relatively small.

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 12 there is limited sensitivity to the modelled scenario which assumes 0% blockage for both on-grade and sag pits. Modelled peak flood levels increase in the order of 0.05 m up to 0.1 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 11: 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
1	30.0	30.0	0.00	0.00	0.00	0.00
2	31.0	31.0	0.00	0.00	0.00	0.00
3	23.8	23.9	0.00	0.00	0.01	0.01
4	18.3	18.4	0.00	0.00	0.00	0.00
5	14.1	14.2	0.02	0.01	0.05	0.04
6	11.6	11.7	0.01	0.01	0.04	0.03
7	11.6	11.6	0.00	0.00	0.01	0.00
8	8.1	8.4	0.04	0.03	0.11	0.07
9	5.5	5.6	0.02	0.01	0.06	0.04
10	4.6	4.8	0.02	0.02	0.06	0.06
11	4.4	4.6	0.02	0.02	0.07	0.06
12	3.0	3.2	0.03	0.02	0.07	0.05
13	3.5	3.6	0.02	0.02	0.05	0.04
14	2.4	2.6	0.01	0.02	0.04	0.05
15	2.4	2.6	0.01	0.02	0.04	0.05
16	13.1	13.3	0.00	0.00	0.01	0.00
17	3.4	3.5	0.01	0.01	0.02	0.01
18	2.7	2.9	0.02	0.03	0.07	0.08
19	2.6	2.7	0.02	0.02	0.05	0.05
20	16.4	16.6	0.00	0.00	0.00	0.00
21	2.9	3.0	0.00	0.00	0.00	0.00
22	2.2	2.3	0.02	0.02	0.05	0.05

Table 12: Peak Flood Level Changes for Blockage Sensitivity Tests - Pits

ID	Peak flood Level (mAHD)		Change (m) Pit Inlets 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
1	30.0	30.0	0.00	0.00	-0.01	-0.01
2	31.0	31.0	0.00	0.00	0.00	0.00
3	23.8	23.9	0.00	0.00	0.01	0.01
4	18.3	18.4	0.00	0.00	0.00	0.00
5	14.1	14.2	0.00	0.00	0.00	0.00
6	11.6	11.7	0.00	0.00	0.00	0.00
7	11.6	11.6	0.00	0.00	0.01	0.00
8	8.1	8.4	0.00	0.00	0.04	0.02
9	5.5	5.6	0.00	0.00	0.02	0.01
10	4.6	4.8	0.00	0.00	0.03	0.02
11	4.4	4.6	0.00	0.00	0.04	0.03
12	3.0	3.2	-0.02	-0.01	0.07	0.03
13	3.5	3.6	0.00	0.00	0.03	0.02
14	2.4	2.6	0.00	0.00	0.07	0.03
15	2.4	2.6	0.00	0.00	0.07	0.04
16	13.1	13.3	0.00	0.00	0.04	-0.01
17	3.4	3.5	0.00	0.00	0.02	0.00
18	2.7	2.9	-0.01	-0.01	0.06	0.02
19	2.6	2.7	-0.01	-0.01	0.05	0.01
20	16.4	16.6	0.00	0.00	0.01	0.00
21	2.9	3.0	0.00	0.00	0.00	0.00
22	2.2	2.3	-0.01	-0.01	0.06	0.01

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 13, 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 13: 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
1	30.0	30.0	0.00	0.00	0.00	0.00
2	31.0	31.0	0.00	0.00	0.00	0.00
3	23.8	23.9	0.00	0.00	0.00	0.00
4	18.3	18.4	0.00	0.00	0.00	0.00
5	14.1	14.2	0.01	0.00	0.00	0.00
6	11.6	11.7	0.00	0.00	0.00	0.00
7	11.6	11.6	0.00	0.00	0.00	0.00
8	8.1	8.4	0.02	0.01	-0.02	-0.01
9	5.5	5.6	0.01	0.00	-0.01	-0.01
10	4.6	4.8	0.01	0.01	-0.01	-0.01
11	4.4	4.6	0.01	0.01	-0.01	-0.01
12	3.0	3.2	0.02	0.01	-0.01	0.00
13	3.5	3.6	0.01	0.01	-0.01	-0.01
14	2.4	2.6	0.01	0.00	-0.01	0.00
15	2.4	2.6	0.01	0.00	-0.01	0.00
16	13.1	13.3	0.00	0.00	0.00	0.00
17	3.4	3.5	0.00	0.00	0.00	0.00
18	2.7	2.9	0.00	0.00	-0.01	0.00
19	2.6	2.7	0.00	0.00	-0.01	0.00
20	16.4	16.6	0.01	0.00	-0.01	0.00
21	2.9	3.0	0.00	0.00	0.00	0.00
22	2.2	2.3	0.01	0.00	-0.01	0.00

7.3. Downstream Tailwater Boundary

Table 14: 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
1	30.0	30.0	0.00	0.00	0.00	0.00
2	31.0	31.0	0.00	0.00	0.00	0.00
3	23.8	23.9	0.00	0.00	0.00	0.00
4	18.3	18.4	0.00	0.00	0.00	0.00
5	14.1	14.2	0.00	0.00	0.00	0.01
6	11.6	11.7	0.00	0.00	0.00	0.00
7	11.6	11.6	0.00	0.00	0.00	0.00
8	8.1	8.4	0.00	0.00	0.00	0.00
9	5.5	5.6	0.00	0.00	0.00	0.00
10	4.6	4.8	0.00	0.00	0.01	0.01
11	4.4	4.6	0.00	0.00	0.01	0.01
12	3.0	3.2	0.00	0.00	0.02	0.01
13	3.5	3.6	0.00	0.00	0.01	0.01
14	2.4	2.6	-0.06	-0.05	0.10	0.06
15	2.4	2.6	-0.06	-0.05	0.10	0.06
16	13.1	13.3	0.00	0.00	0.00	0.00
17	3.4	3.5	0.00	-0.01	0.01	0.00
18	2.7	2.9	-0.02	-0.01	0.02	0.03
19	2.6	2.7	-0.02	-0.01	0.02	0.02
20	16.4	16.6	0.00	0.00	0.00	0.00
21	2.9	3.0	0.00	0.00	0.00	0.00
22	2.2	2.3	-0.02	-0.01	0.04	0.02

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 5.4.2. The change in peak flood level for these scenarios is shown on Figure D13 to Figure D16. The impacts on peak flood level from this assumption are confined generally to Pyrmont Bridge Road, Wattle Street and Wentworth Park Road (i.e. the roads surrounding Wentworth Park). Changes to peak flood levels for these scenarios are generally between -0.1 m and 0.2 m.

7.4. 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 D17 to Figure D20. The impacts on peak flood level estimates in the 1% AEP event are generally not significant and are within ±0.05m, as shown in Table 15.

Table 15: 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
1	30.0	30.0	0.00	0.00	0.00	0.00
2	31.0	31.0	0.00	0.00	0.00	0.00
3	23.8	23.9	0.00	-0.01	0.00	0.01
4	18.3	18.4	0.00	0.00	0.00	0.00
5	14.1	14.2	0.02	0.03	-0.01	-0.02
6	11.6	11.7	-0.01	-0.03	0.01	0.02
7	11.6	11.6	-0.01	-0.02	0.01	0.02
8	8.1	8.4	0.03	0.03	-0.03	-0.03
9	5.5	5.6	0.00	-0.01	-0.01	0.00
10	4.6	4.8	0.00	0.00	0.00	0.00
11	4.4	4.6	0.00	0.01	-0.01	0.00
12	3.0	3.2	0.00	0.01	0.00	0.00
13	3.5	3.6	0.00	0.01	-0.01	-0.01
14	2.4	2.6	0.00	0.01	0.00	0.00
15	2.4	2.6	0.00	0.00	0.00	0.00
16	13.1	13.3	0.00	0.00	0.00	0.00
17	3.4	3.5	-0.01	-0.01	0.02	0.01
18	2.7	2.9	0.00	0.00	0.00	0.01
19	2.6	2.7	0.00	-0.02	0.00	0.01
20	16.4	16.6	0.01	0.00	-0.01	0.00
21	2.9	3.0	0.00	0.00	0.00	0.00
22	2.2	2.3	0.01	0.01	-0.01	-0.01

7.5. 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 12). The change in peak flood level is shown on Figure D21 and Figure D22 for the 0.5% AEP and 0.2% AEP events respectively. Results at key locations are presented in Table 16.

Increases would be generally between 0.05 m to 0.1 m for the 0.5% AEP event, and broad increases up to 0.2 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 16: 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
1	30.0	0.01	0.02
2	31.0	0.00	0.01
3	23.9	0.02	0.04
4	18.4	0.02	0.04
5	14.2	0.03	0.07
6	11.7	0.03	0.07
7	11.6	0.01	0.02
8	8.4	0.08	0.20
9	5.6	0.04	0.09
10	4.8	0.06	0.14
11	4.6	0.06	0.15
12	3.2	0.05	0.12
13	3.6	0.04	0.11
14	2.6	0.05	0.12
15	2.6	0.05	0.11
16	13.3	0.04	0.09
17	3.5	0.02	0.07
18	2.9	0.08	0.17
19	2.7	0.05	0.11
20	16.6	0.05	0.10
21	3.0	0.01	0.03
22	2.3	0.05	0.12

7.6. Climate Change: Sea Level Rise

Design ocean boundary conditions were raised by 0.4 m and 0.9 m in line with References 16 and 17 to assess the potential impact of sea level rise on flood behaviour in the catchment for the year 2050 and 2100 respectively. There are locations in the lower floodplain that would be more sensitive to sea level rise, which can be identified from Table 17 and Figure D23 and Figure D24.

Table 17: Sensitivity Analysis Results: Sea Level Rise

ID	Peak flood Level (mAHD)	Change (m) Sea Level Rise Scenario	
	1% AEP event	2050 SLR	2100 SLR
1	30.0	0.00	0.00
2	31.0	0.00	0.00
3	23.9	0.00	0.00
4	18.4	0.00	0.00
5	14.2	0.00	0.00
6	11.7	0.00	0.00
7	11.6	0.00	0.00
8	8.4	0.00	0.00
9	5.6	0.00	0.00
10	4.8	0.01	0.02
11	4.6	0.01	0.02
12	3.2	0.01	0.03
13	3.6	0.00	0.01
14	2.6	0.05	0.12
15	2.6	0.05	0.12
16	13.3	0.00	0.00
17	3.5	0.00	0.01
18	2.9	0.02	0.06
19	2.7	0.01	0.04
20	16.6	0.00	0.00
21	3.0	0.00	0.00
22	2.3	0.02	0.14

8. COMPARISON OF RESULTS

The current study update provided an opportunity to:

- Update the modelling software to more recent versions, improving the model 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 modelling 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 18 and Table 19. Maps of the change to peak flood levels from the hydrology updates are shown on Figure B10, Figure B11 and Figure B12 for the 1% AEP, 5% AEP and 20% AEP events respectively.

Table 18: Comparison of ARR1987 and ARR2019 hydrology results (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)
	ARR 1987	ARR 2019		ARR 1987	ARR 2019		ARR 1987	ARR 2019	
1	30.0	29.9	-0.03	30.0	30.0	-0.04	30.0	30.0	-0.02
2	31.0	31.0	-0.01	31.0	31.0	-0.01	31.1	31.0	-0.01
3	23.9	23.7	-0.11	23.9	23.8	-0.08	24.0	23.9	-0.05
4	18.3	18.3	-0.05	18.4	18.3	-0.07	18.4	18.4	-0.05
5	14.1	14.0	-0.11	14.2	14.1	-0.13	14.3	14.2	-0.08
6	11.6	11.5	-0.11	11.7	11.6	-0.11	11.8	11.7	-0.08
7	11.6	11.5	-0.05	11.6	11.6	-0.03	11.6	11.6	-0.03
8	8.1	7.7	-0.40	8.4	8.1	-0.32	8.6	8.4	-0.22
9	5.5	5.1	-0.37	5.7	5.5	-0.16	5.8	5.6	-0.12
10	4.6	4.4	-0.21	4.8	4.6	-0.20	4.9	4.8	-0.18
11	4.5	4.2	-0.24	4.6	4.4	-0.20	4.8	4.6	-0.20
12	3.1	2.9	-0.21	3.2	3.0	-0.20	3.4	3.2	-0.17
13	3.5	3.4	-0.13	3.7	3.5	-0.15	3.8	3.6	-0.14
14	2.4	-	-	2.6	2.4	-0.14	2.7	2.6	-0.13
15	2.4	2.3	-0.17	2.6	2.4	-0.13	2.7	2.6	-0.13
16	13.1	13.0	-0.17	13.3	13.1	-0.18	13.4	13.3	-0.12
17	3.4	3.3	-0.07	3.5	3.4	-0.08	3.5	3.5	-0.07
18	2.7	2.6	-0.14	3.0	2.7	-0.24	3.2	2.9	-0.23
19	2.6	2.4	-0.16	2.8	2.6	-0.18	2.9	2.7	-0.15
20	16.4	16.0	-0.39	16.6	16.4	-0.17	16.7	16.6	-0.10
21	2.9	2.9	-0.02	3.0	2.9	-0.06	3.0	3.0	-0.02
22	2.2	2.0	-0.19	2.4	2.2	-0.18	2.5	2.3	-0.16

Table 19: 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)
	ARR 1987	ARR 2019		ARR 1987	ARR 2019		ARR 1987	ARR 2019	
P1	1.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0	0.0
P2	4.3	4.1	-0.1	4.4	4.3	-0.1	4.5	4.4	-0.1
P3	6.0	5.7	-0.4	6.3	6.0	-0.3	6.4	6.3	-0.1
P4	0.8	0.9	0.1	0.9	0.9	0.1	1.0	1.0	0.0
P5	0.5	0.2	-0.3	0.6	0.4	-0.2	0.7	0.6	-0.2
P6	13.8	13.1	-0.7	14.7	14.5	-0.2	14.6	14.7	0.1
P7	2.6	2.6	0.0	2.6	2.6	0.0	2.6	2.6	0.0
P8	2.0	2.0	0.1	1.9	2.0	0.0	2.0	2.0	0.0
P9	1.4	1.4	0.0	1.5	1.4	-0.1	1.6	1.5	-0.1
P10	1.1	1.0	-0.1	1.2	1.1	-0.1	1.2	1.2	-0.1
P11	3.9	3.5	-0.4	4.2	4.0	-0.2	4.2	4.2	-0.1
P12	3.8	3.6	-0.2	4.1	3.8	-0.3	4.3	4.1	-0.2
P13	6.7	6.5	-0.2	7.2	6.7	-0.5	7.5	7.2	-0.3
P14	4.8	4.9	0.1	5.0	4.8	-0.2	5.2	5.0	-0.2
OF1	2.9	1.5	-1.4	4.4	2.7	-1.8	5.5	4.2	-1.3
OF2	10.1	4.8	-5.3	16.9	9.9	-7.0	24.3	16.8	-7.5
OF3	0.9	0.8	-0.2	1.5	1.0	-0.5	1.8	1.3	-0.5
OF4	0.7	0.5	-0.2	4.4	0.6	-3.8	9.6	4.2	-5.4
OF5	10.4	5.4	-5.0	13.1	10.2	-2.8	15.3	12.9	-2.5
OF6	0.5	0.3	-0.1	0.6	0.4	-0.2	0.9	0.6	-0.3
OF7	1.4	1.0	-0.4	1.8	1.3	-0.5	2.1	1.7	-0.4
OF8	4.7	0.6	-4.1	9.4	3.9	-5.5	15.4	8.0	-7.4
OF9	1.9	1.1	-0.8	5.7	1.9	-3.8	11.1	4.6	-6.5
OF10	0.9	0.4	-0.5	2.2	1.1	-1.1	3.8	2.1	-1.7
OF11	3.4	2.3	-1.0	4.5	3.5	-1.0	5.4	4.3	-1.1
OF12	0.4	0.2	-0.1	0.5	0.3	-0.2	0.7	0.5	-0.2
OF13	1.0	0.5	-0.6	2.3	0.9	-1.5	5.8	2.1	-3.8
OF14	9.3	4.5	-4.8	17.8	9.0	-8.8	24.6	15.7	-9.0
OF15	2.0	1.3	-0.7	3.3	1.9	-1.4	4.8	3.2	-1.6

8.1. Comparison with Previous Study Results

The changes in peak flood level results from this study compared to the 2015 FRMS model (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 from ARR1987 to ARR2019.

Table 20: Comparison against 2015 Flood Study (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)
	2015	Update		2015	Update		2015	Update	
1	30.0	29.9	-0.10	30.1	30.0	-0.17	30.2	30.0	-0.21
2	31.2	31.0	-0.19	31.2	31.0	-0.19	31.2	31.0	-0.19
3	23.9	23.7	-0.17	24.0	23.8	-0.13	24.0	23.9	-0.12
4	18.4	18.3	-0.17	18.5	18.3	-0.19	18.5	18.4	-0.17
5	14.3	14.0	-0.29	14.4	14.1	-0.26	14.4	14.2	-0.22
6	11.7	11.5	-0.21	11.8	11.6	-0.22	11.9	11.7	-0.23
7	11.5	11.5	-0.02	11.6	11.6	0.01	11.6	11.6	0.03
8	8.7	7.7	-0.93	8.9	8.1	-0.76	9.0	8.4	-0.60
9	5.5	5.1	-0.40	5.7	5.5	-0.17	5.8	5.6	-0.13
10	4.7	4.4	-0.28	4.9	4.6	-0.29	5.0	4.8	-0.28
11	4.5	4.2	-0.31	4.7	4.4	-0.30	4.9	4.6	-0.31
12	3.1	2.9	-0.22	3.3	3.0	-0.24	3.4	3.2	-0.25
13	3.6	3.4	-0.19	3.7	3.5	-0.15	3.7	3.6	-0.12
14	2.7	-	-	2.8	2.4	-0.31	2.9	2.6	-0.29
15	2.7	2.3	-0.40	2.8	2.4	-0.31	2.9	2.6	-0.29
16	13.6	13.0	-0.63	13.7	13.1	-0.59	13.8	13.3	-0.53
17	3.8	3.3	-0.51	3.9	3.4	-0.50	4.0	3.5	-0.49
18	2.8	2.6	-0.21	3.0	2.7	-0.29	3.2	2.9	-0.30
19	2.6	2.4	-0.18	2.8	2.6	-0.22	2.9	2.7	-0.21
20	17.0	16.0	-0.97	17.0	16.4	-0.57	17.1	16.6	-0.45
21	3.2	2.9	-0.25	3.2	2.9	-0.29	3.3	3.0	-0.32
22	2.3	2.0	-0.27	2.4	2.2	-0.24	2.5	2.3	-0.22

Table 21: Comparison against 2015 Flood Study (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		Change (m^3/s)
	2015	Update		2015	Update		2015	Update	
P1	0.6	1.0	0.4	0.8	1.0	0.2	1.1	1.0	-0.1
P2	2.3	4.1	1.8	2.5	4.3	1.8	2.5	4.4	1.9
P3	3.4	5.7	2.3	3.8	6.0	2.2	4.0	6.3	2.3
P4	0.4	0.9	0.5	0.4	0.9	0.5	0.5	1.0	0.5
P5	0.7	0.2	-0.5	1.2	0.4	-0.8	1.2	0.6	-0.6
P6	9.9	13.1	3.2	9.9	14.5	4.5	9.8	14.7	4.9
P7	1.4	2.6	1.2	1.6	2.6	1.0	1.6	2.6	1.0
P8	1.4	2.0	0.6	1.4	2.0	0.5	1.4	2.0	0.6
P9	0.9	1.4	0.5	0.9	1.4	0.5	1.0	1.5	0.5
P10	0.7	1.0	0.3	1.2	1.1	-0.1	1.2	1.2	0.0
P11	3.3	3.5	0.2	3.6	4.0	0.4	3.8	4.2	0.4
P12	3.4	3.6	0.3	3.7	3.8	0.2	3.9	4.1	0.3
P13	5.8	6.5	0.7	6.5	6.7	0.2	6.7	7.2	0.5
P14	2.9	4.9	2.0	3.1	4.8	1.8	3.1	5.0	1.9
OF1	4.9	1.5	-3.4	6.9	2.7	-4.2	8.8	4.2	-4.6
OF2	10.5	4.8	-5.7	17.3	9.9	-7.4	24.5	16.8	-7.8
OF3	1.4	0.8	-0.6	0.6	1.0	0.4	0.7	1.3	0.6
OF4	5.7	0.5	-5.2	12.9	0.6	-12.3	19.6	4.2	-15.4
OF5	8.8	5.4	-3.4	9.7	10.2	0.5	10.8	12.9	2.1
OF6	0.5	0.3	-0.2	1.6	0.4	-1.2	3.7	0.6	-3.1
OF7	0.6	1.0	0.4	0.6	1.3	0.7	0.6	1.7	1.1
OF8	2.9	0.6	-2.3	6.8	3.9	-2.9	12.2	8.0	-4.2
OF9	1.8	1.1	-0.7	5.6	1.9	-3.7	10.8	4.6	-6.2
OF10	1.9	0.4	-1.5	3.4	1.1	-2.4	5.2	2.1	-3.1
OF11	2.8	2.3	-0.4	3.5	3.5	0.0	4.1	4.3	0.2
OF12	0.4	0.2	-0.2	0.6	0.3	-0.3	0.8	0.5	-0.3
OF13	0.9	0.5	-0.4	2.4	0.9	-1.6	5.2	2.1	-3.2
OF14	7.6	4.5	-3.1	14.6	9.0	-5.6	21.9	15.7	-6.2
OF15	2.5	1.3	-1.2	4.2	1.9	-2.3	5.7	3.2	-2.5

9. FLOOD DAMAGES UPDATE

A flood damages assessment was completed as part of the 2015 FRMS (Reference 1). An update to the damages assessment was undertaken for this study. Table 22 shows the original outcomes of the flood damages assessment from the FRMS.

Table 22: Previous Flood Damage Assessment Summary (from 2015 FRMS)

Event	No. Properties Affected	No. Flooded Above Floor Level	Residential	Non-Residential	Total Damages for Event
50% AEP	202	94	71	23	$ 8,851,000
20% AEP	236	112	82	30	$ 11,011,000
10% AEP	246	131	96	35	$ 12,259,000
5% AEP	259	141	102	39	$ 13,526,000
2% AEP	268	163	120	43	$ 14,628,000
1% AEP	283	171	127	44	$ 16,230,000
PMF	307	255	202	53	$ 25,050,000
				Average Annual Damages (AAD)	**$ 7,783,000**

In undertaking the updated assessment, it was observed that the sampling location for some properties could be improved to better reflect the primary flood risk to the property (for example, a higher flood level at the rear of the building, where the previous assessment had used the flood level at the front of the building). Furthermore, the updated assessment includes additional design events (the 0.5% and 0.2% AEP events) that were not included in the previous assessment.

Table 23 shows the updated property affectation and damage estimates for various design storms, comparable with Table 23.

Table 23: Revised Flood Damage Assessment Summary

Event	No. Properties Affected	No. Flooded Above Floor Level	Residential	Non-Residential	Total Damages for Event
50% AEP	139	75	62	13	$7,586,000
20% AEP	191	89	69	20	$10,012,000
10% AEP	214	93	73	20	$10,815,000
5% AEP	218	106	82	24	$13,460,000
2% AEP	233	127	102	25	$14,875,000
1% AEP	239	134	109	25	$15,651,000
0.5% AEP	248	148	118	30	$16,270,000
0.2% AEP	261	165	132	33	$18,287,000
PMF	286	232	182	50	$26,298,000
				Average Annual Damages (AAD)	**$6,938,000**

Table 24 shows the change in the affected property numbers, flood depths and damage estimates, comparing Table 23 and Table 22.

Table 24: Comparison of Flood Damage Summary with FRMS

Event	Change Flooded Above Floor Level	Residential Change	Non-Residential Change	Damages Change ($)	Damages Change (%)
50% AEP	-19	-9	-10	-$1,265,000	-17%
20% AEP	-23	-13	-10	-$999,000	-10%
10% AEP	-38	-23	-15	-$1,444,000	-13%
5% AEP	-35	-20	-15	-$66,000	0%
2% AEP	-36	-18	-18	$247,000	2%
1% AEP	-37	-18	-19	-$579,000	-4%
0.5% AEP	-	-	-	-	-
0.2% AEP	-	-	-	-	-
PMF	-23	-20	-3	$1,248,000	5%
Average Annual Damages (AAD)				**-$845,000**	**-12%**

The updated estimates are slightly lower than the estimates from the 2015 FRMS estimates. The primary contributing factors for this reduction are:

- 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.
- The revised modelling schematisation alters flood levels slightly, particularly by refining the modelling of narrow overland flow paths in the upper catchment. This reduces the affectation of some properties slightly, since there are fewer areas of artificially trapped flow in the upper catchment.
- The sampling locations for some properties were revised to accurately capture the highest flood level affecting the property, resulting in slightly increased affectation in some instances.

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 2015 FRMS, prepared by WMAwater. The calculation assumptions, damage curves, and economic assumptions were not modified, apart from updating the inflation figures from 2015 dollars to 2019 dollars.
- The update used the same floor level database obtained for the 2015 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 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 Blackwattle Bay catchment are slightly lower than previously estimated, primarily due to reductions in the estimated flood risk from changes to the design storm methodology.

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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
BLACKWATTLE BAY CATCHMENT STUDY AREA

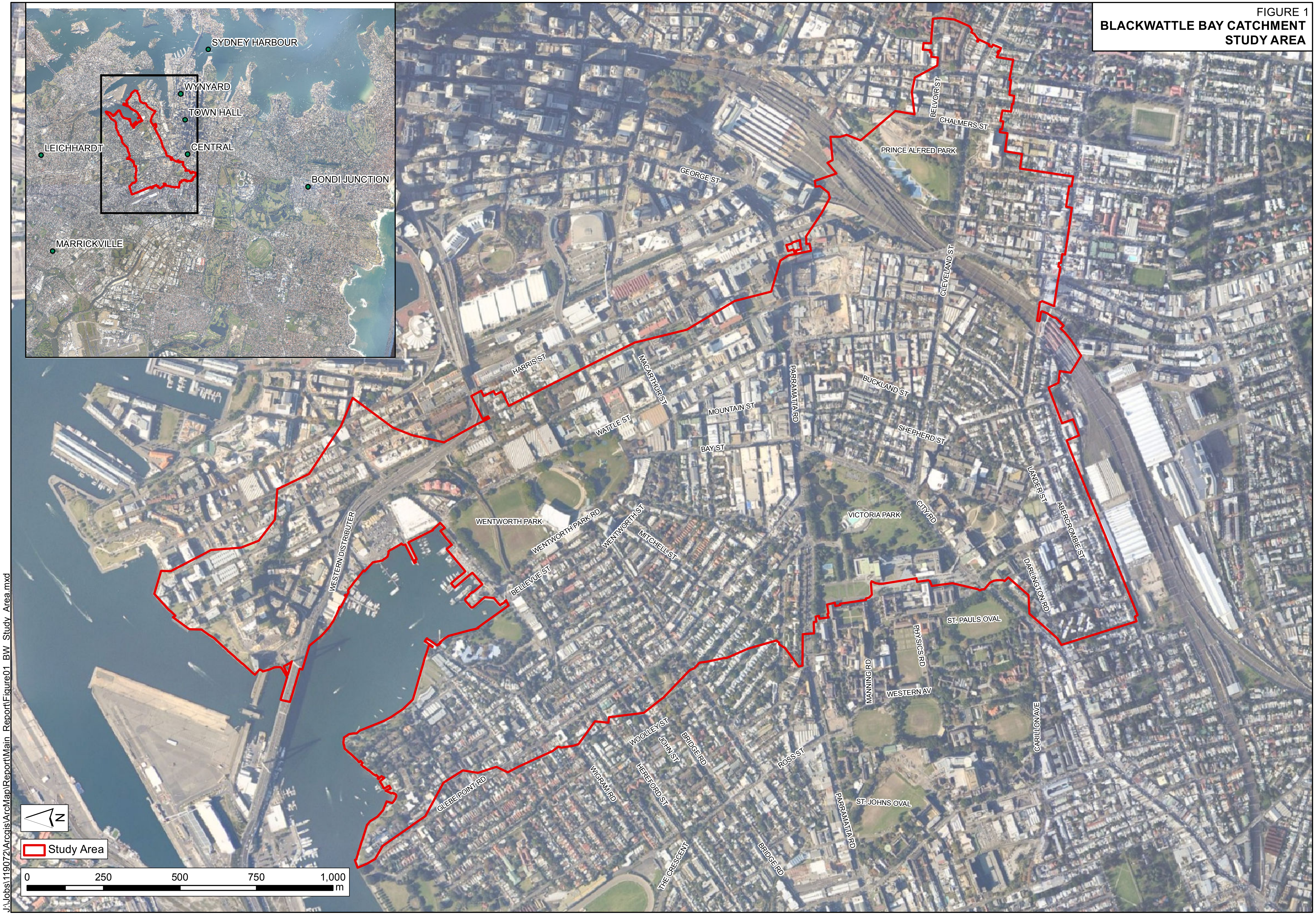

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FIGURE 2
BLACKWATTLE BAY CATCHMENT
HYDROLOGICAL SUBCATCHMENTS

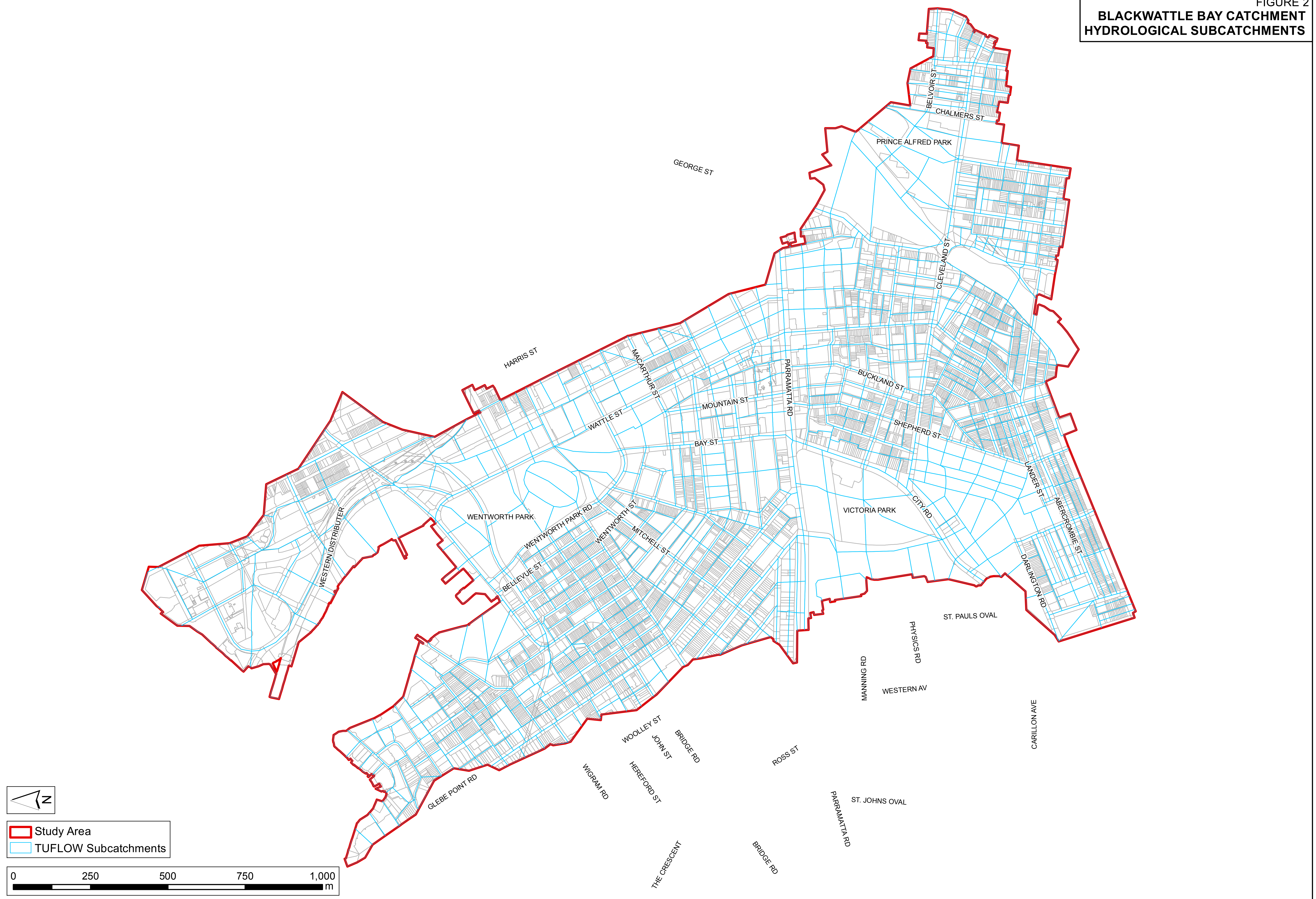

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FIGURE 3
BLACKWATTLE BAY CATCHMENT HYDRAULIC MODEL LAYOUT

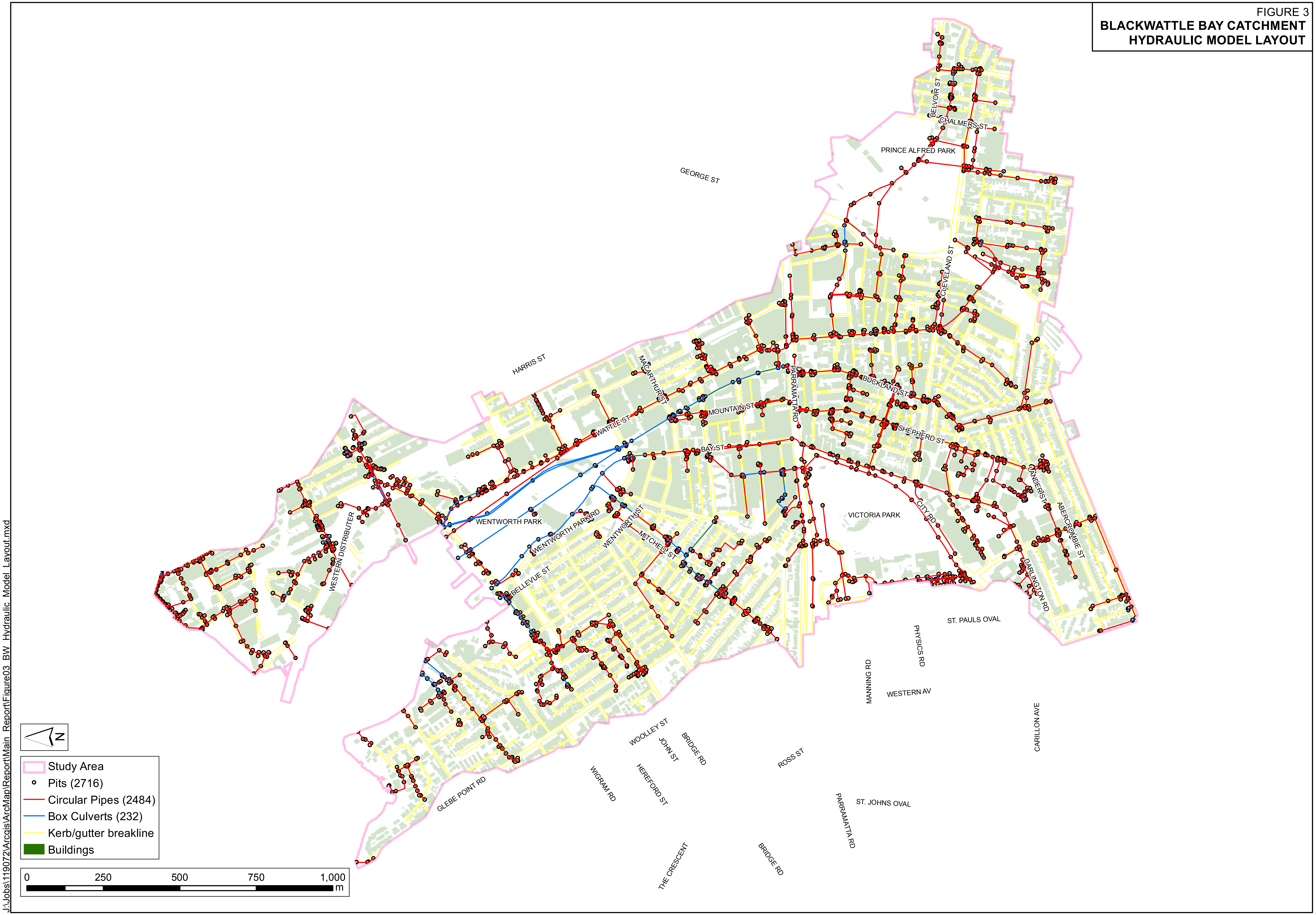

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FIGURE 4
BLACKWATTLE BAY CATCHMENT
HYDRAULIC MODEL ROUGHNESS

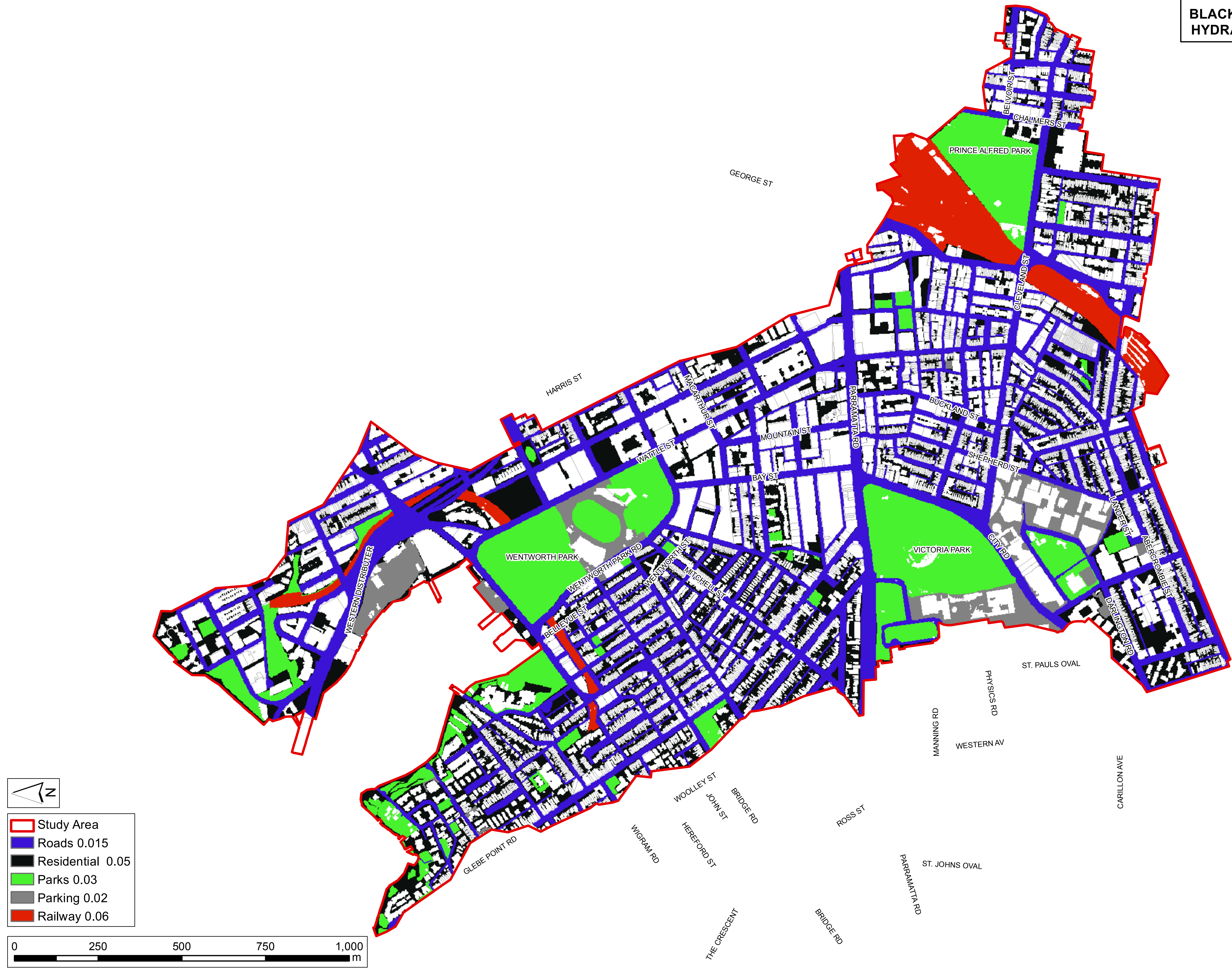

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FIGURE 5
BLACKWATTLE BAY CATCHMENT DIGITAL ELEVATION MODEL

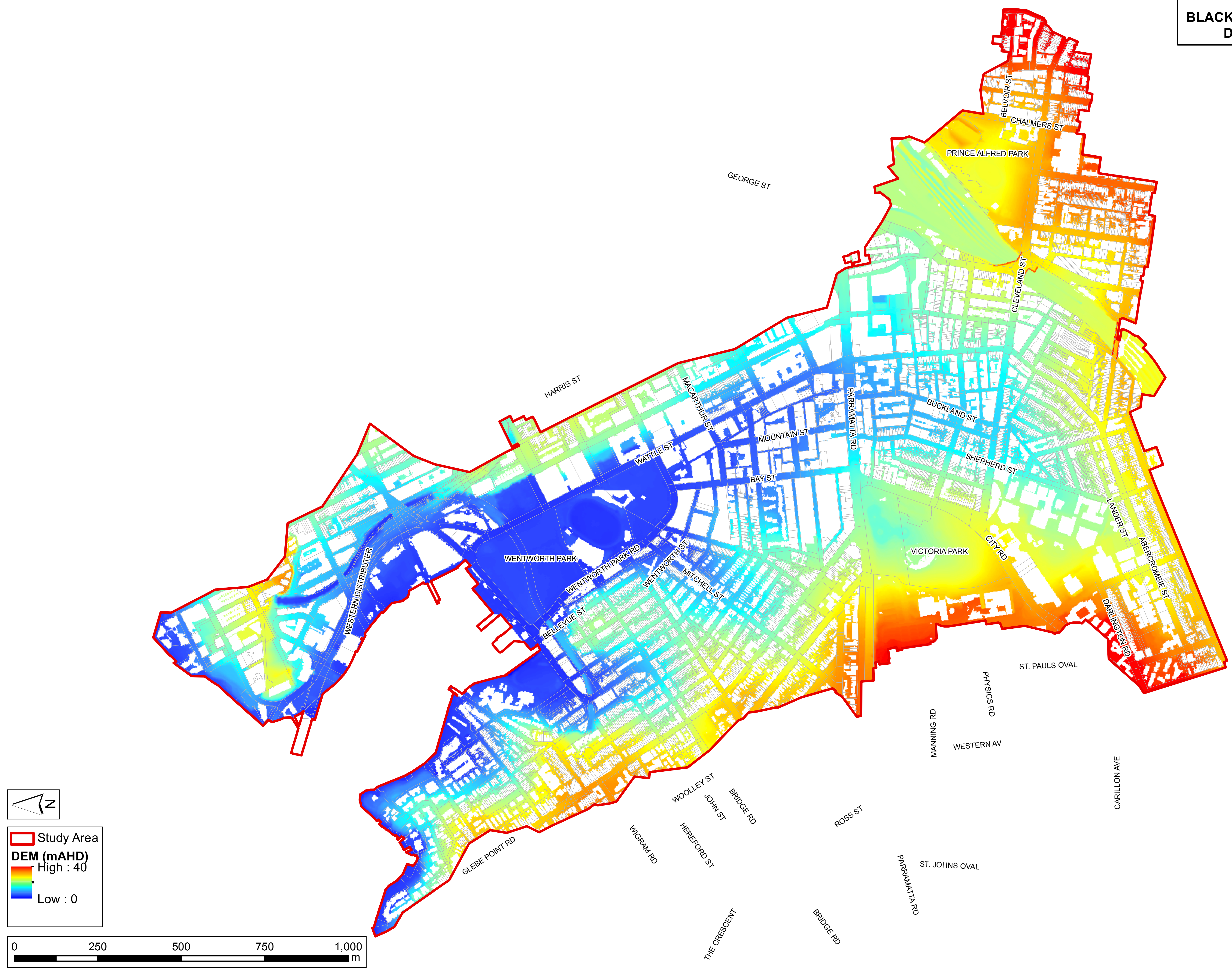

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FIGURE 6
BLACKWATTLE BAY CATCHMENT
REPORTING LOCATIONS FOR FLOOD LEVELS AND FLOW

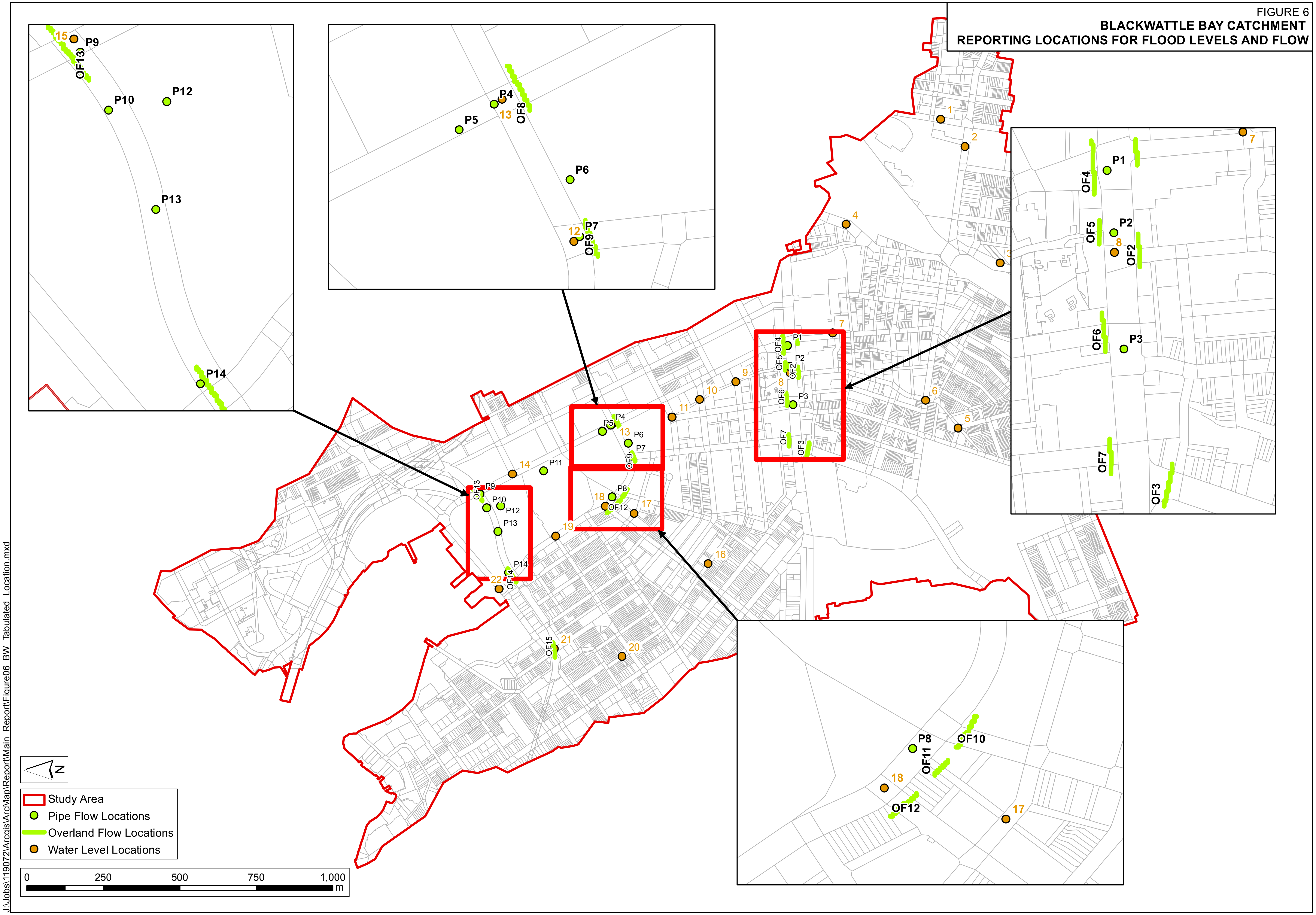

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FIGURE 7
BLACKWATTLE BAY CATCHMENT
CRITICAL DURATION
1% AEP EVENT, 2019 AR&R

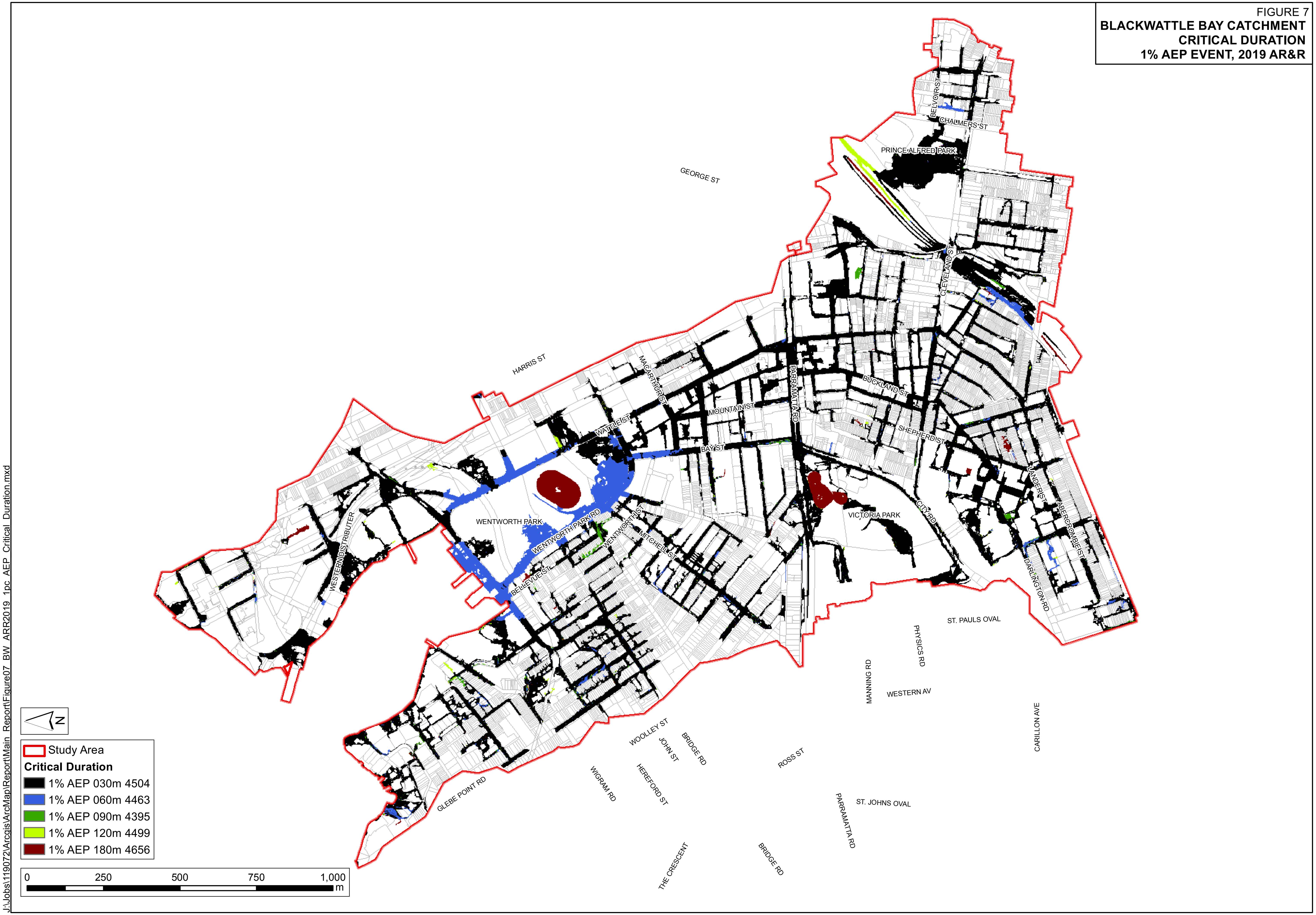

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FIGURE 8
BLACKWATTLE BAY CATCHMENT
CHANGE IN PEAK FLOOD LEVEL
30&60 MINUTE ENVELOPE VS CRITICAL DURATION
1% AEP EVENT, 2019 AR&R

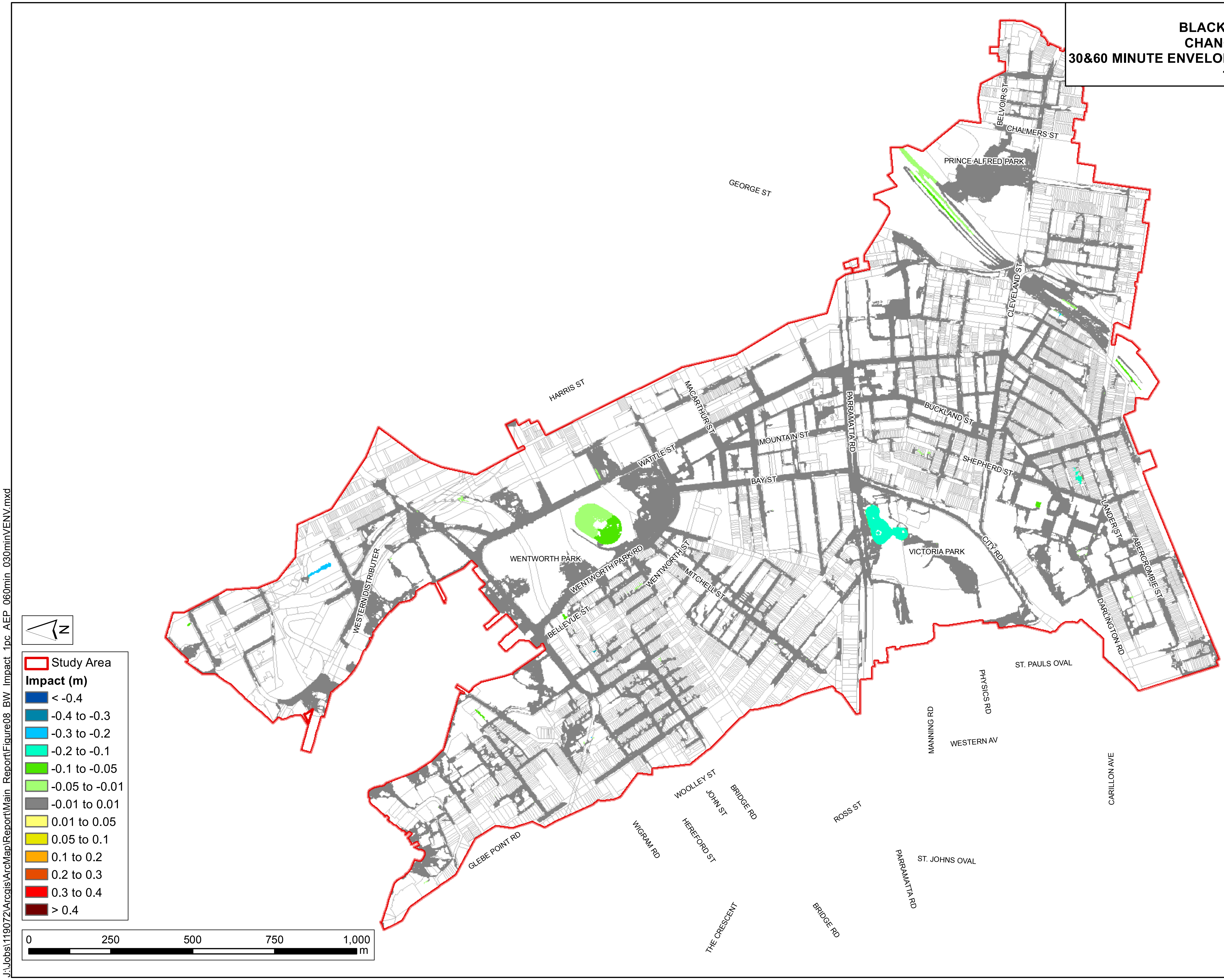

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FIGURE 9
BLACKWATTLE BAY CATCHMENT
CHANGE IN PEAK FLOOD LEVEL
REVISED MODEL AR&R 2019 V 2015 FRMS
20% AEP EVENT

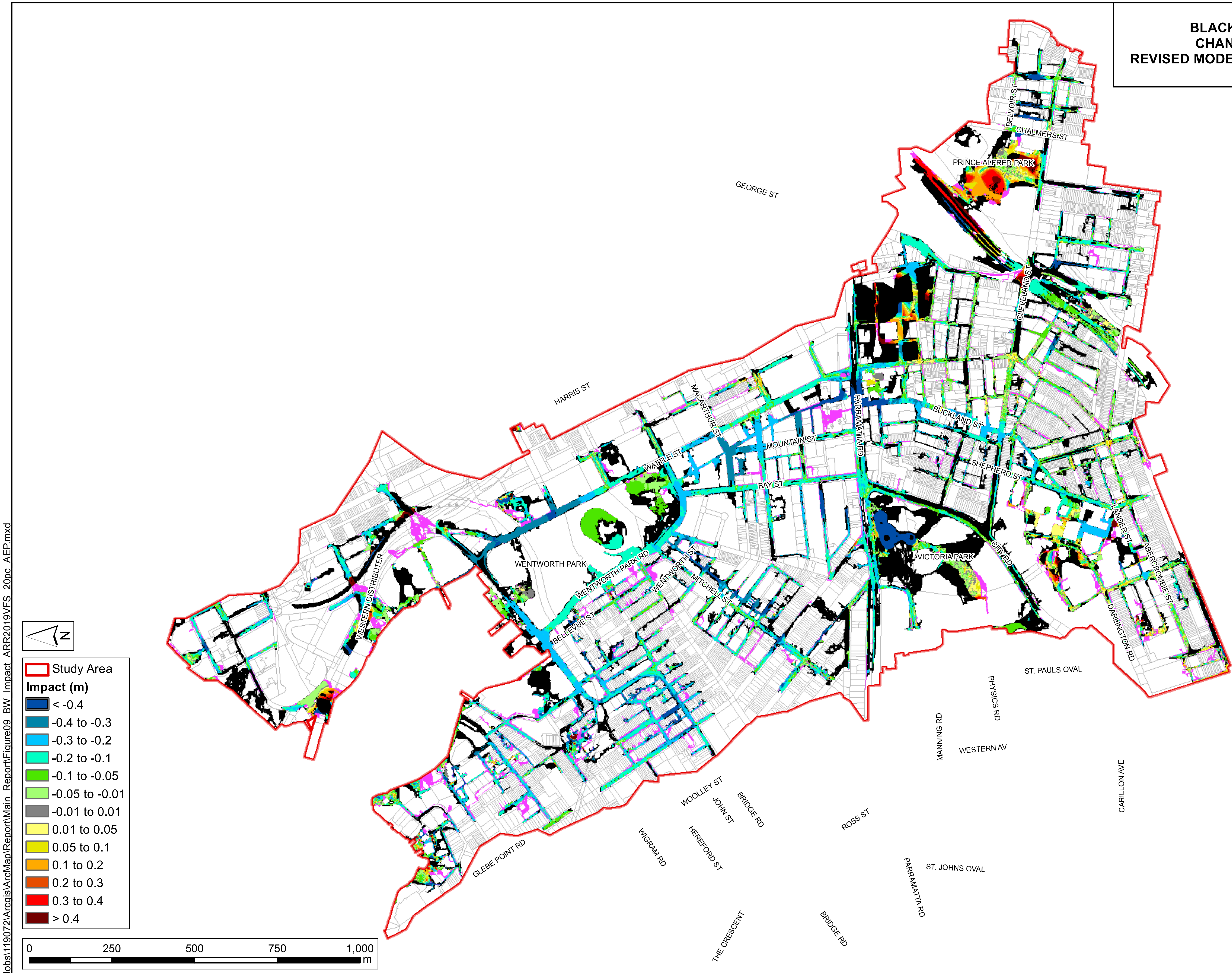

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FIGURE 10
BLACKWATTLE BAY CATCHMENT
CHANGE IN PEAK FLOOD LEVEL
REVISED MODEL AR&R 2019 V 2015 FRMS
5% AEP EVENT

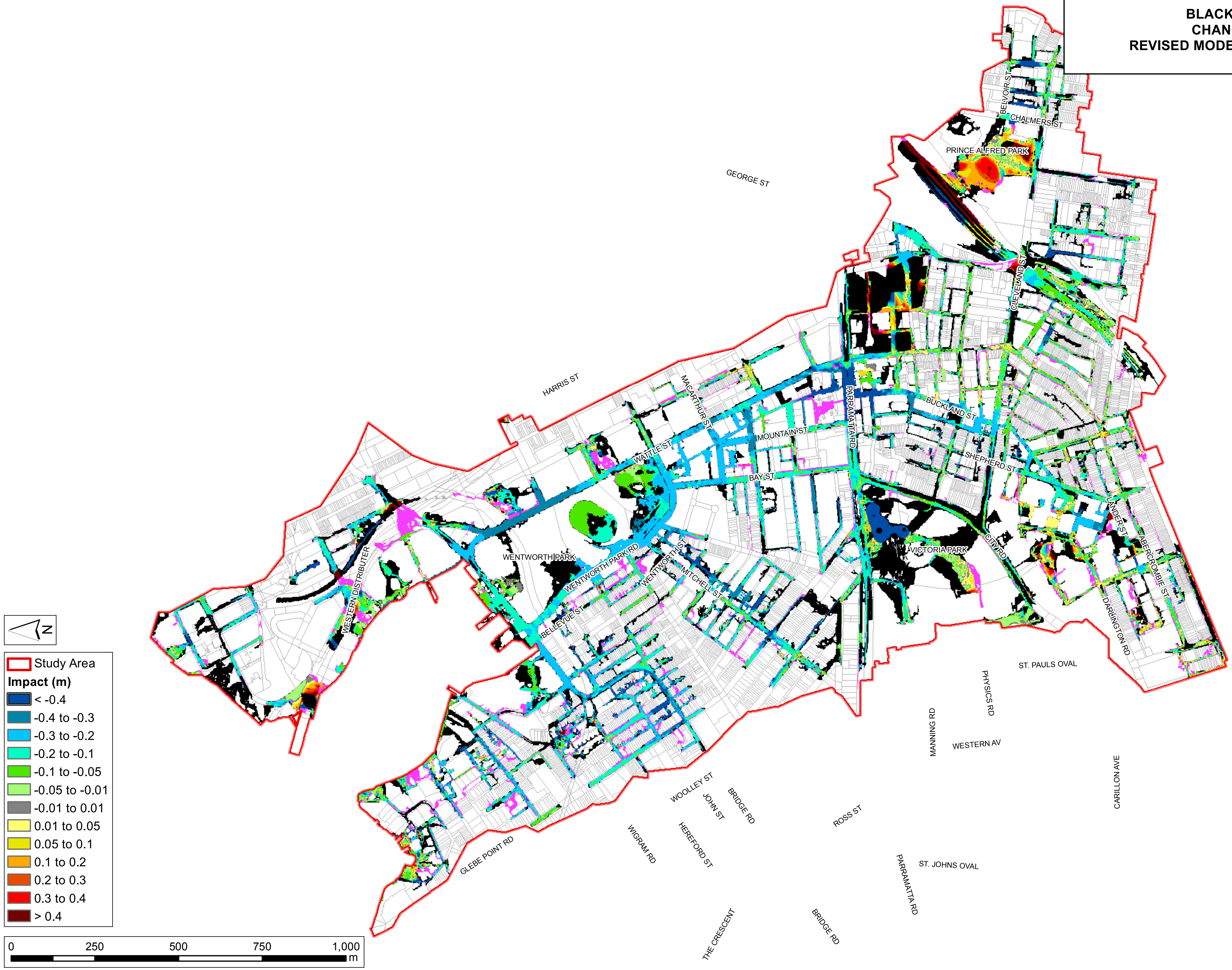

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FIGURE 11

BLACKWATTLE BAY CATCHMENT
CHANGE IN PEAK FLOOD LEVEL
REVISED MODEL AR&R 2019 V 2015 FRMS
1% AEP EVENT

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FIGURE 12
BLACKWATTLE BAY CATCHMENT STORMWATER CAPACITY 2019 AR&R