Leichhardt Floodplain Risk Management Study and Plan

APPENDICES

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Leichhardt Floodplain Risk Management Study and Plan

APPENDIX A
FLOOD STUDY ADDENDUM

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Version	Effective Date	Description of Revision	Prepared by:	Reviewed by:
1	8 September 2016	Draft for Council Review	Matthew Prumm Bala Kilaparty	Emma Maratea
2	17 March 2017	Updated Draft (included in preliminary draft FRMS)	Bala Kilaparty	Emma Maratea
3	22 May 2017	Draft for Public Exhibition	Bala Kilaparty	Emma Maratea
4	01 August 2017	Public Exhibition	Bala Kilaparty Scott Mortimer	Emma Maratea
5	November 2017	Final	Bala Kilaparty	David Whyte

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Attachment

1 Introduction

Since the modelling undertaken in 2010 – 2014 as part of the Leichhardt LGA Flood Study (Cardno, 2014) there have been several upgrades to drainage infrastructure and confirmation of drainage infrastructure connections, sizes and location that were previously uncertain. This addendum report provides the outcomes of the updated modelling undertaken to incorporate these upgrades.

Modifications to the hydraulic model were only required in four of the nine model zones. The model zones are shown in **Figure 5-1** of the FRMS (also see Figure 6.2 in the Flood Study).

This Addendum presents the outcomes of additional flood modelling undertaken within the following model zones:

- Rozelle Bay Catchment;
- Whites Creek Catchment;
- White Bay Catchment; and
- Mort Bay Catchment.

The impacts on the flood levels as a result of this modelling are provided in **Section 2** and the updated model results are presented in **Section 3**, with the replacement figures for the Flood Study provided in **Attachment A**.

As an outcome of the revised modelling, the flood control lots were also reviewed. The changes to flood control lots are described in **Section 4**, with the updated mapping provided in **Attachment A**.

This document should be read in conjunction with the Leichhardt LGA Flood Study (Cardno, 2014).

2 Updated Modelling

2.1 Rozelle Bay Catchment

2.1.1 Model Updates

The following drainage infrastructure details were updated as a result of additional information becoming available:

- Updated details of the drainage system within the Railyards between Lilyfield Road and Brennan Street became available to Council.
- Updated details of the drainage system between Pritchard Street and Railway Parade became available to Council.

A significant stormwater culvert was identified running from the Rozelle Railyards into Whites Creek. This culvert was previously not surveyed and was not included in the Flood Study. The flood model was updated to include this. This update impacted both the Rozelle Bay Catchment and the Whites Creek Catchment.

2.1.2 Impacts on Peak Flood Levels

The impacts of the revised modelling on peak flood levels on the 5 and 100 Year ARI and PMF events in the Rozelle Bay Catchment are shown in **Figures 2-1** to **2-3**.

The most significant impact on the flood behaviour was as a result of the inclusion of the major drainage culvert from Rozelle, under the railyards and into Whites Creek. When the Flood Study was undertaken, the presence of this culvert was unknown and as a result of the updated flood model a significant volume of flow is conveyed from the north of the railyards into Whites Creek resulting in a reduction of flood levels to the south of Lilyfield Road and an increase of flood levels in Whites Creek. The impacts become more significant and widespread in the larger events.

2.2 Whites Creek Catchment

2.2.1 Model Updates

Drainage works were recently completed at Young Street and Parramatta Road. The details of the upgraded pipe system were incorporated into the flood model.

Council stormwater database did not show a pipe between 28 Alfred Street and Whites Creek. Due to the fact that a pipe must exist at this location, the Flood Study made assumptions on the pipe locations and diameter. Council provided surveyed details of this pipe, which were incorporated into the flood model.

A significant stormwater culvert was identified running from the Rozelle Railyards into Whites Creek as discussed further in Section 2.1. This culvert was previously not surveyed and was not included in the Flood Study. The flood model was updated to include this.

2.2.2 Impacts on Peak Flood Levels

The impacts of the revised modelling on peak flood levels on the 5 and 100 Year ARI and PMF events in the Whites Creek Catchment are shown in **Figure 2-4** to **2-6**.

The impacts of the culvert through the railyards is discussed in **Section 2.1.2**. In addition to the increases in flood levels in Whites Creek at the downstream end, near Railway Parade, flood levels can also be seen to have increased further up Whites Creek, especially in the larger events.

The inclusion of the completed works at Parramatta Road result in a minor reduction in the flood level in this area in the 5 and 100 Year ARI events.

2.3 White Bay Catchment

2.3.1 Model Updates

The following drainage infrastructure details were updated as a result of additional information becoming available:

- Updated pipe details within the drainage easement at 7 Rosebery Place became available to Council.
- Inclusion of the Sydney Water pipeline located in Evans Street, Goodsir Street, Moore Street and the laneway between Mansfield Street and Parsons Street.

2.3.2 Impacts on Peak Flood Levels

The impacts of the revised modelling on peak flood levels on the 5 and 100 Year ARI and PMF events in the White Bay Catchment are shown in **Figure 2-7** to **2-9**.

The updated drainage details result in a reduction in flooding on Beattie Street and a subsequent minor increase in flood levels downstream of this location.

2.4 Mort Bay Catchment

2.4.1 Model Updates

Upgrade works to the drainage system at Curtis Road were recently completed. The details of these works were included in the flood model.

Council undertook detailed survey of the piped drainage network in the vicinity of Cameron Street between Church Street and College Street. The details varied slightly from those in the Flood Study model and the updated details were included in the flood model.

2.4.2 Impacts on Peak Flood Levels

The impacts of the revised modelling on peak flood levels on the 5 and 100 Year ARI and PMF events in the Mort Bay Catchment are shown in **Figure 2-10** to **2-12**.

The upgraded drainage system at Curtis Road resulted in a minor decrease in flooding in the area, primarily along Clayton Street.

3 Updated Modelling Results

3.1 Flood Extents, Depths and Velocities

The results for the 5 and 100 year ARI and Probable Maximum Flood (PMF) events are presented in the following Figures in **Attachment A**.

> Flood extents and depths are shown in **Figures 8.1 to 8.3.**

> Flood velocities are shown in **Figures 8.4 to 8.6.**

3.2 Provisional Flood Hazard

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters (Figure L2, NSW Government, 2005). The Floodplain Development Manual (2005) defines two categories for provisional hazard - High and Low.

The model results were processed using an in-house developed program, which utilises the model results of flood level and velocity to determine hazard. Provisional flood hazard was prepared for four design events, namely 5 and 100 year ARI and PMF design events. The provisional hazard is based on the envelope of the hazard at each location for each ARI.

Flood hazard for the 5 year ARI, 100 year ARI and PMF events is shown in **Attachment A** as **Figures 9.1 to 9.3.**

3.3 Major Road Flooding

The analysis of road flooding provided in the Floodplain Risk Management Study (**Section 8.6** of the FRMS document) supersedes the data presented in the Flood Study (Cardno, 2014). This discussion includes the revised flood modelling results.

4 Flood Control Lots

Flood control lots are those properties within the LGA that should be referred to Council's development controls because of their potential to be flood affected. This does not necessarily mean that the properties are flood affected, simply that they have the potential to be flood affected.

Typically, flood control lots may experience one or more of the following types of flooding:

> Mainstream flooding;

> Flooding by overland flows; and/ or,

> Estuarine inundation and wave impact.

Mainstream flooding is generally defined as overflow along Whites Creek and Johnstons Creek in Annandale and Hawthorne Canal in Leichhardt. Flooding by overland flows generates the majority of the flood control lots within the Leichhardt Local Government Area and is generally defined as flooding that occurs within natural depressions and along surface flowpaths along the streets or through properties.

Estuarine inundation and wave impact is associated storm tide, wave run-up and overtopping effects on water level for the foreshore areas of the Leichhardt Council LGA.

The flood control lot mapping was reviewed for all areas where the revised flood modelling resulted in altered flood levels. The revision of flood control lots was undertaken in accordance with the criteria outlined in **Section 12** of the Flood Study (Cardno, 2014).

This review resulted in some minor amendments to the flood control lot mapping presented in the Flood Study (Cardno, 2014). The updated flood control lot mapping is provided in **Attachment A in Figures 12.1 to 12.5.**

5 Conclusions

This Addendum report was prepared based on modelling undertaken in 2016 using the Sobek model originally developed in 2010 for the purpose of the Leichhardt LGA Flood Study (Cardno, 2014).

The information presented in this Addendum Report supersedes the equivalent data presented in the Leichhardt LGA Flood Study (Cardno, 2014).

This Addendum report should be read in conjunction with the Leichhardt LGA Flood Study (Cardno, 2014).

FIGURES

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Figure 2-1 - 5yr ARI WLDifference
2016 Less 2014 results
Rozelle Bay

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Figure 2-2 - 100yr ARI WLDifference
2016 Less 2014 results
Rozelle Bay

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Figure 2-3 - PMF WLDifference
2016 Less 2014 results
Rozelle Bay

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Figure 2-4 - 5yr ARI WLDifference
2016 Less 2014 results
Whites Creek

Figure 2-5 - 100yr ARI WLDifference
2016 Less 2014 results
Whites Creek

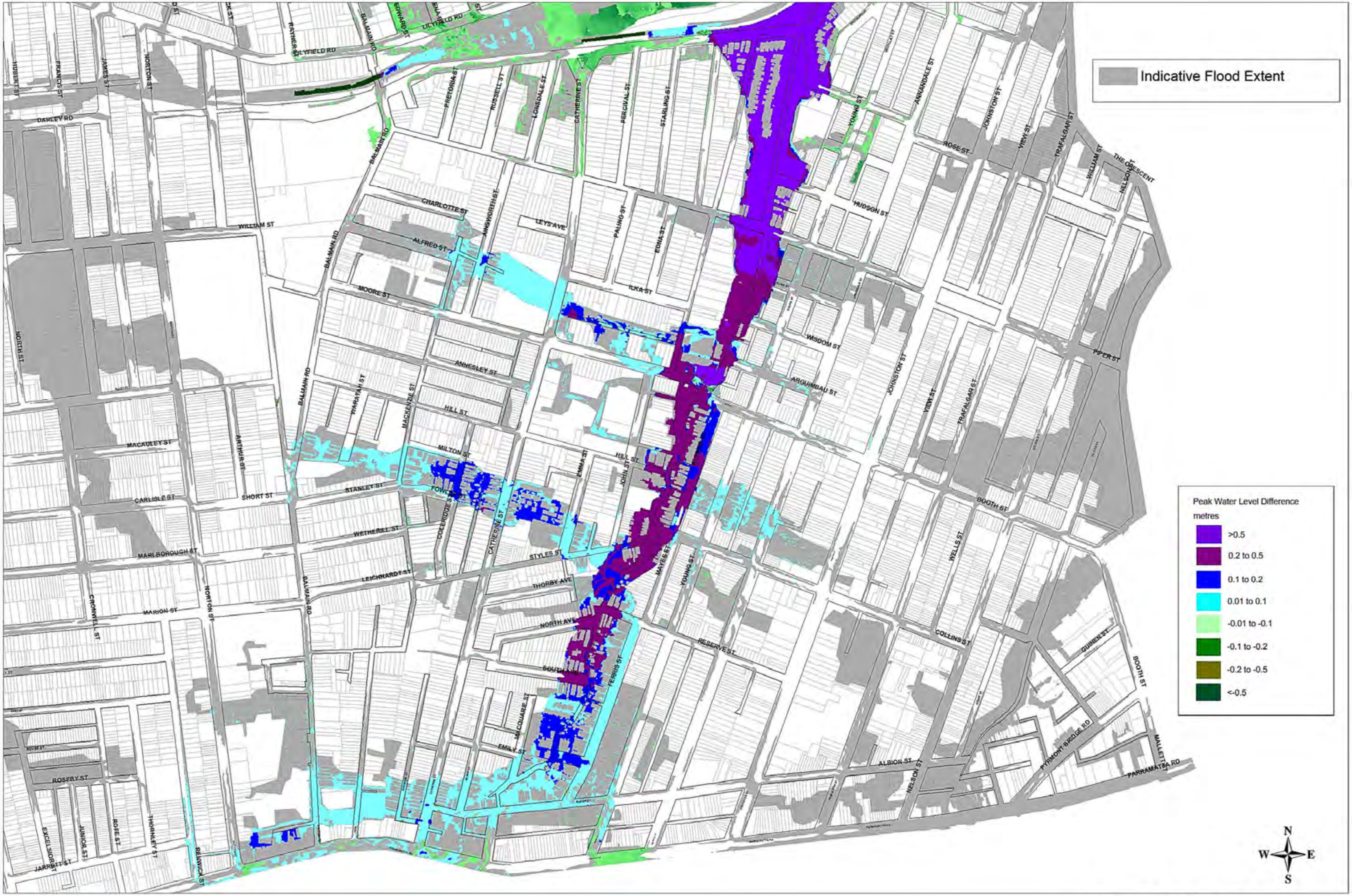

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Figure 2-6 - PMF WLDifference
2016 Less 2014 results
Whites Creek

Figure 2-7 - 5yr ARI WLDifference
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Figure 2-8 - 100yr ARI WLDifference
2016 Less 2014 results
Whites Bay

Figure 2-9 - PMF WLDifference
2016 Less 2014 results
Whites Bay

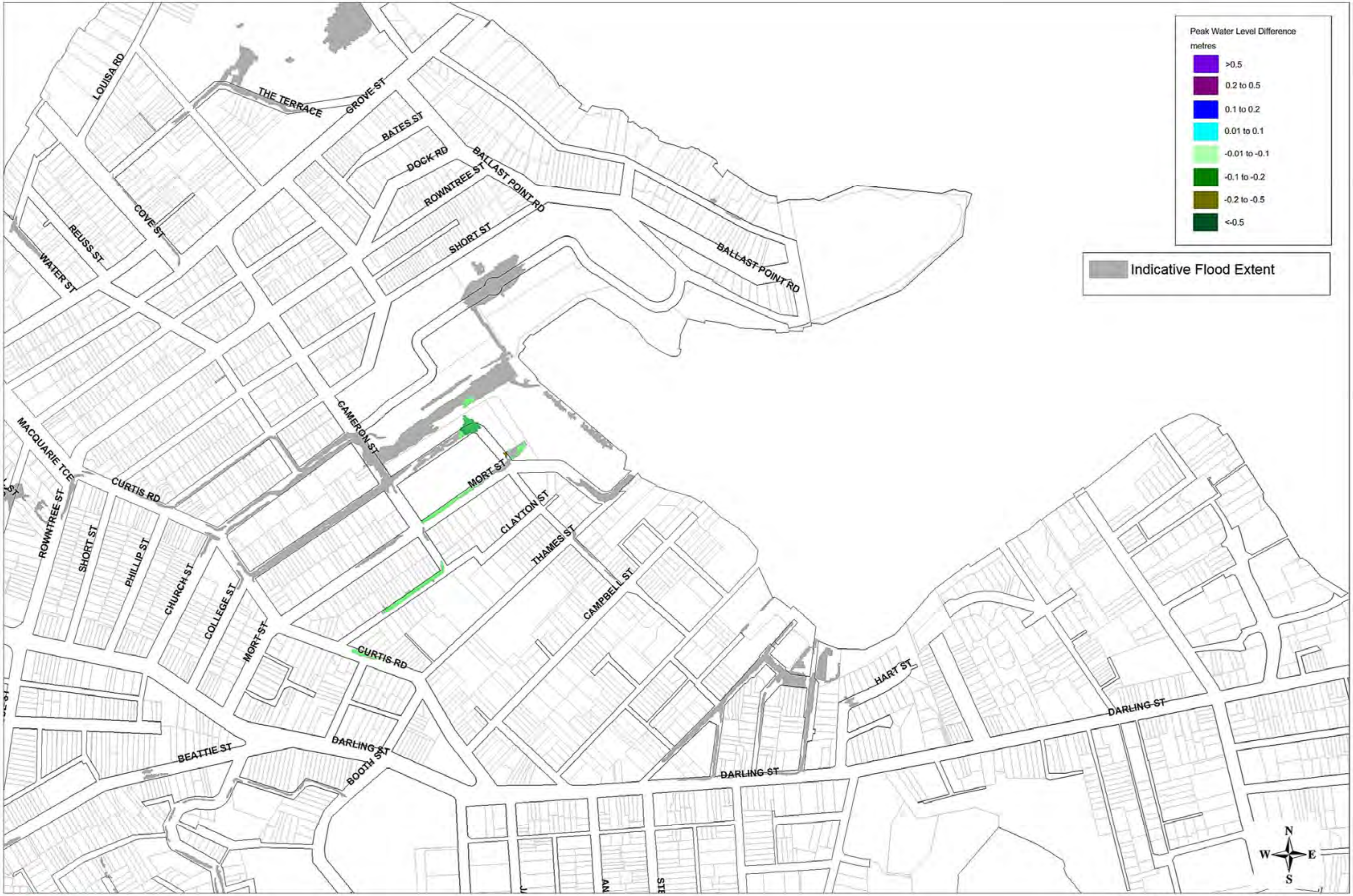

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Figure 2-10 - 5yr ARI WLDifference
2016 Less 2014 results
Mort Bay

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Figure 2-11 - 100yr ARI WLDifference
2016 Less 2014 results
Mort Bay

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Figure 2-12 - PMF WLDifference
2016 Less 2014 results
Mort Bay

APPENDIX A
REVISED FLOOD STUDY FIGURES

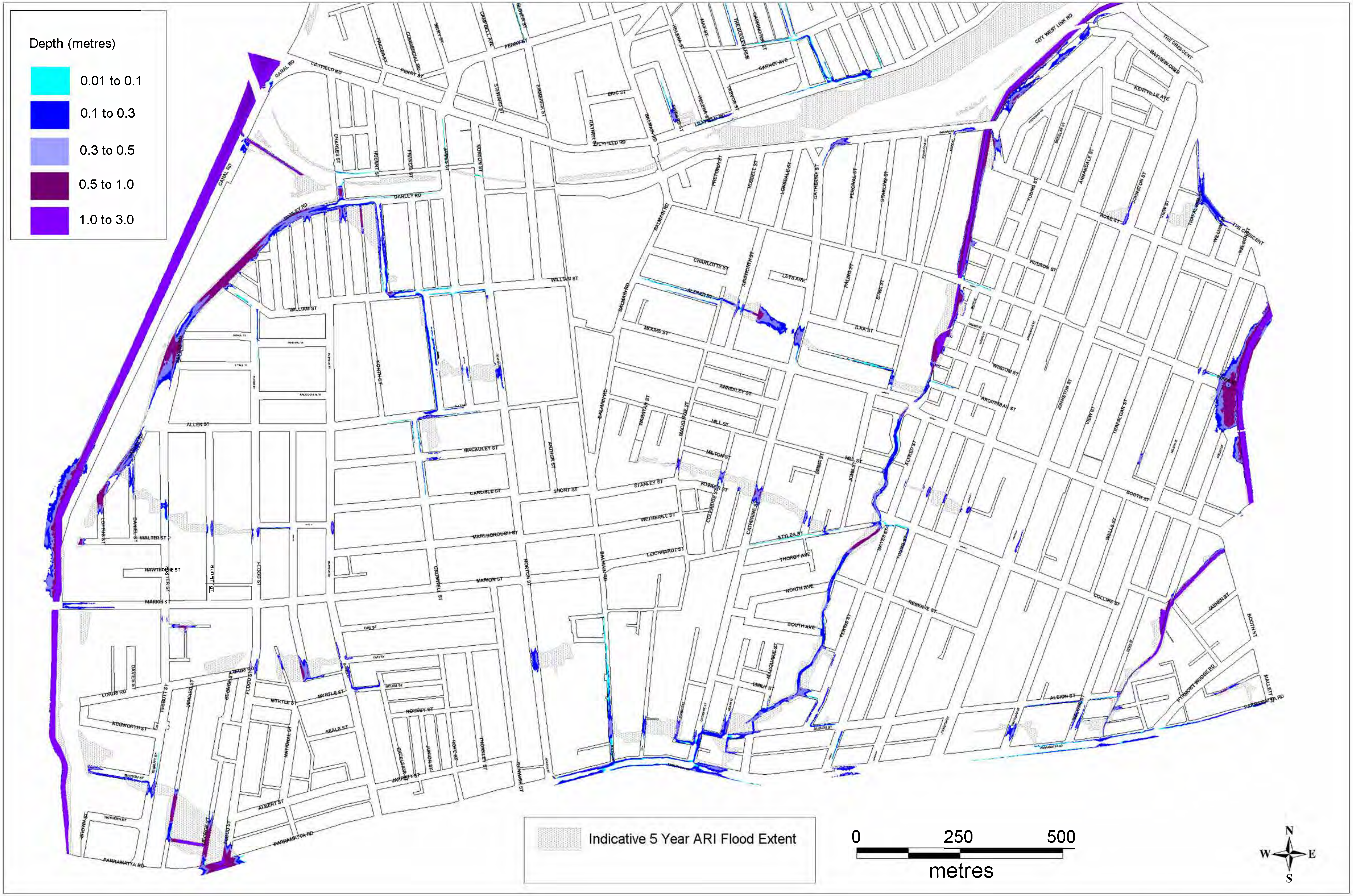

Figure 8.1- 5yr ARI Peak Depth
Sheet1

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Figure 8.1- 5yr ARI Peak Depth
Sheet2

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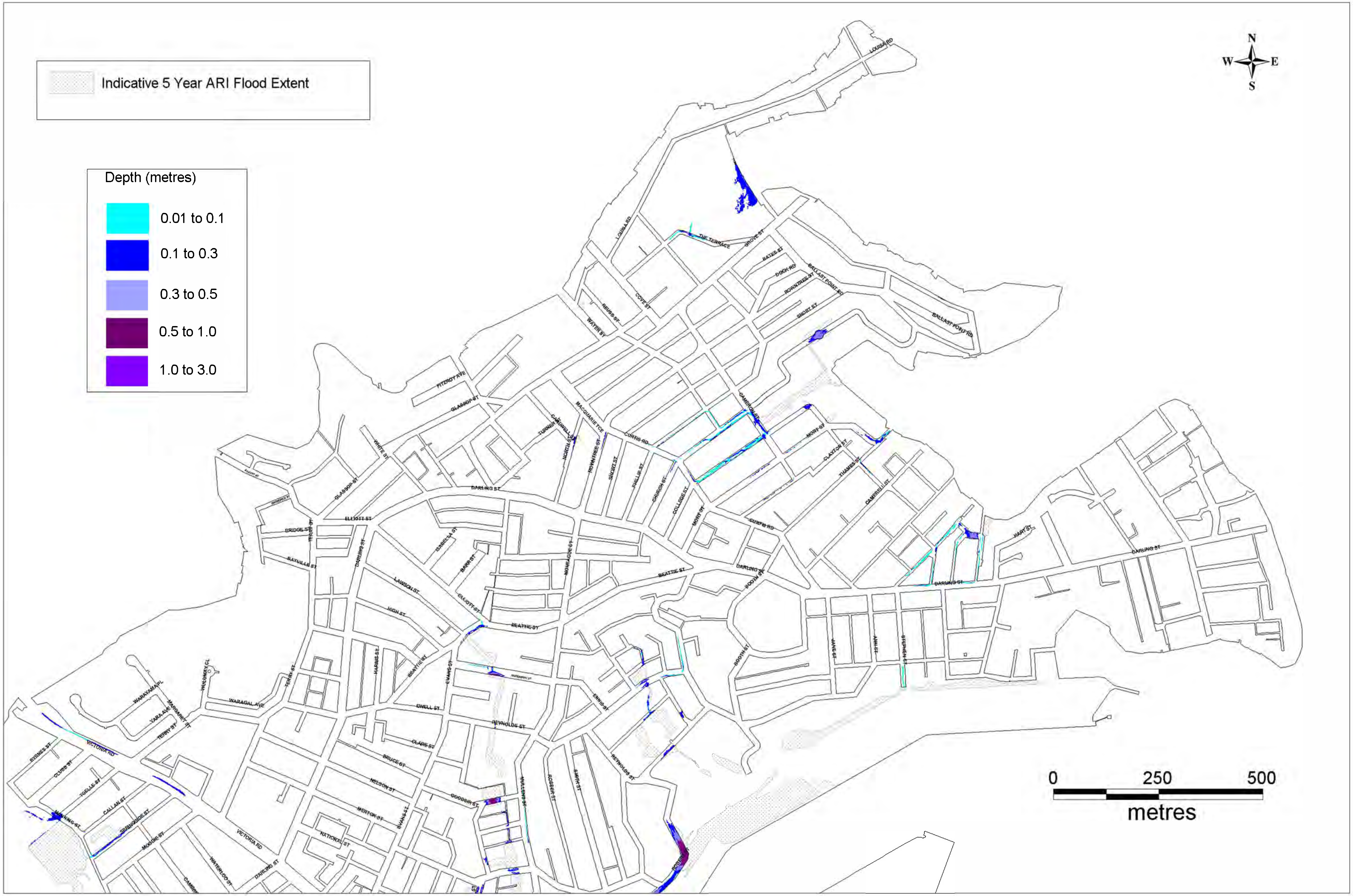

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Figure 8.1 - 5yr ARI Peak Depth
Sheet3

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Figure 8.2- 100yr ARI Peak Depth
Sheet1

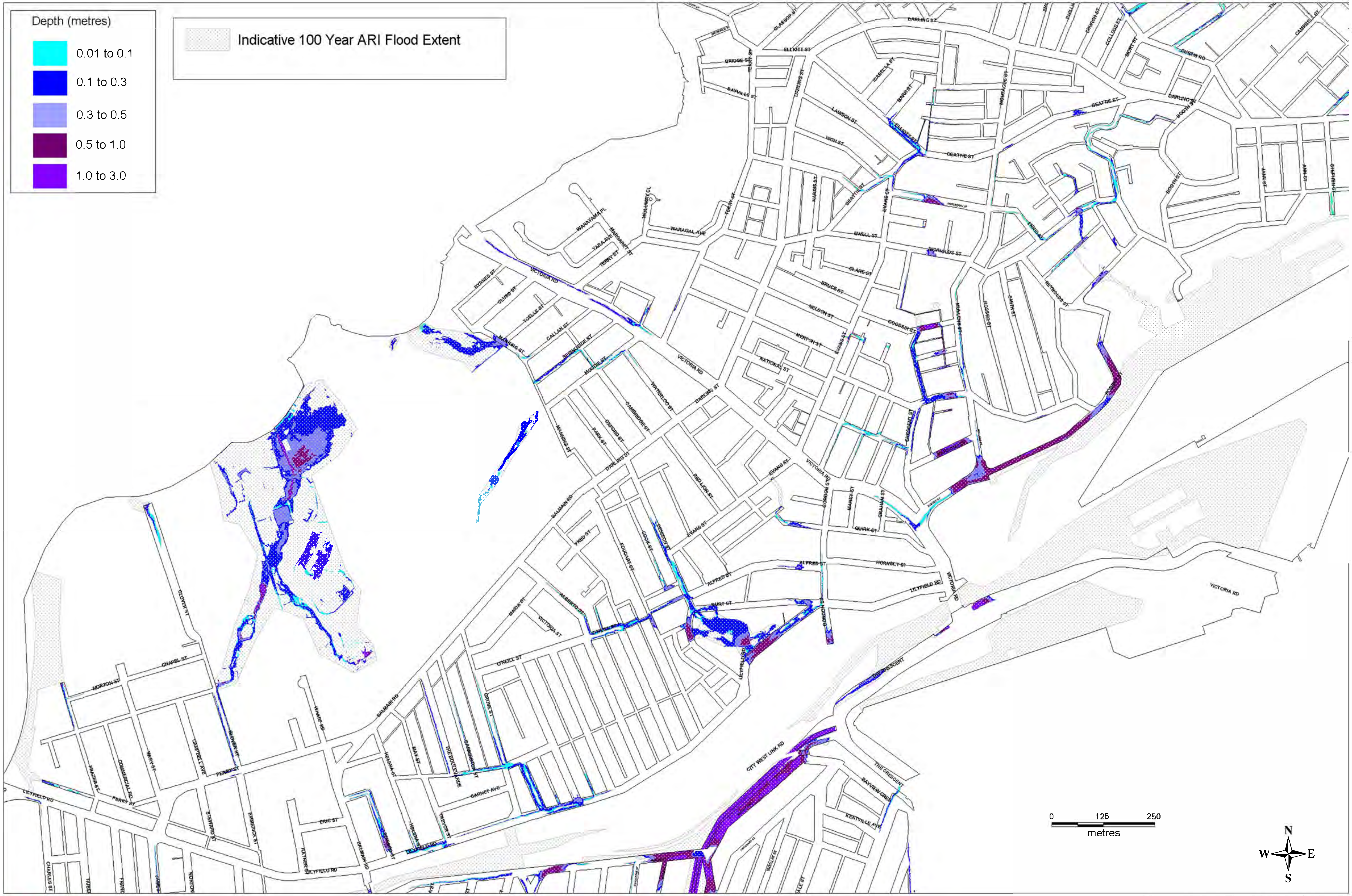

Figure 8.2- 100yr ARI Peak Depth
Sheet2

Figure 8.2 - 100yr ARI Peak Depth
Sheet3

Figure 8.3- PMF Peak Depth Sheet1

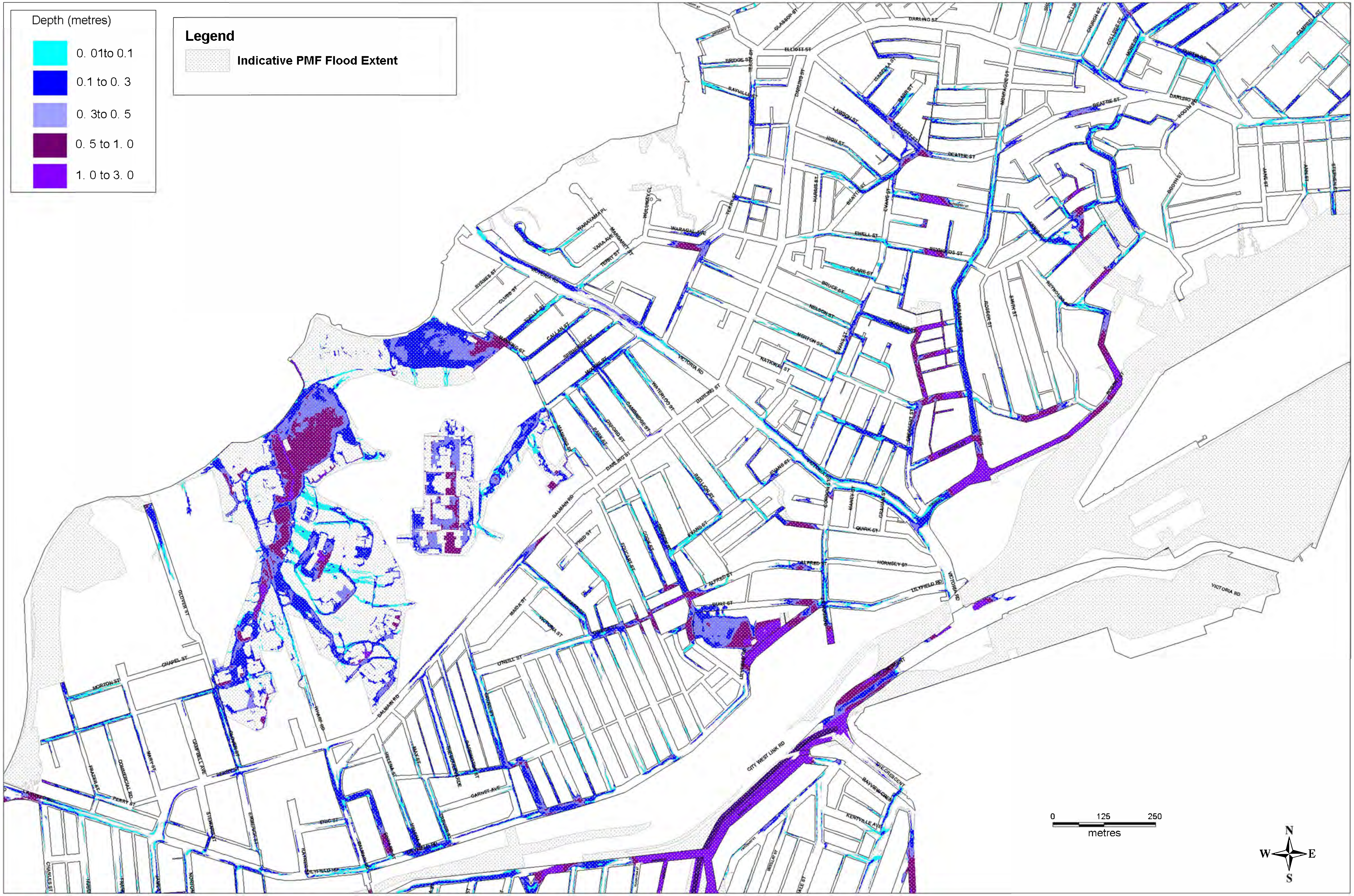

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Figure 8.3- PMF Peak Depth
Sheet2

Figure 8.3 - PMF Peak Depth
Sheet3

Figure 8.4- 5yr ARI Peak Velocity
Sheet1

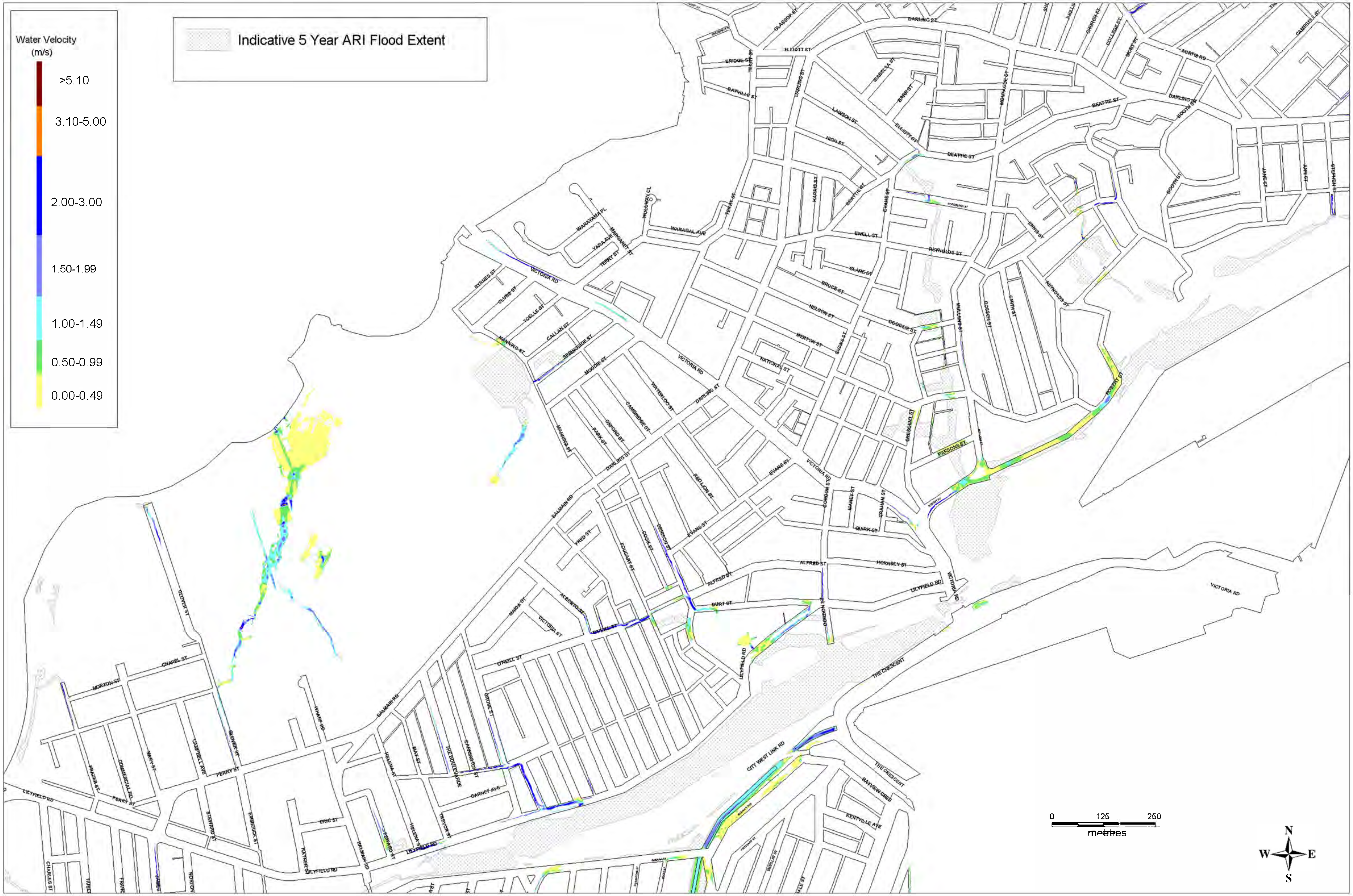

Figure 8.4- 5yr ARI Peak Velocity
Sheet2

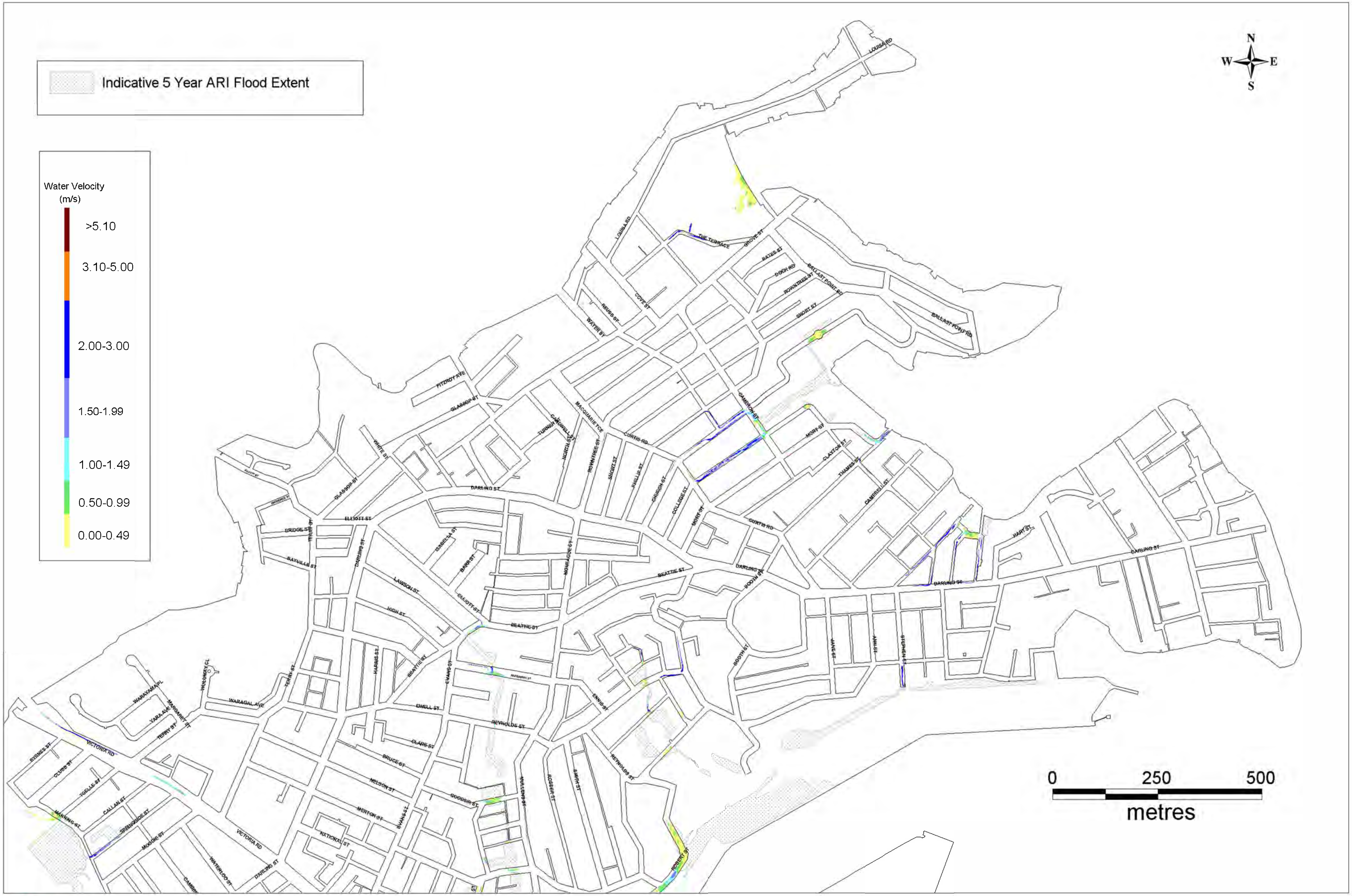

Figure 8.4 - 5yr ARI Peak Velocity
Sheet3

Figure 8.5- 100yr ARI Peak Velocity
Sheet1

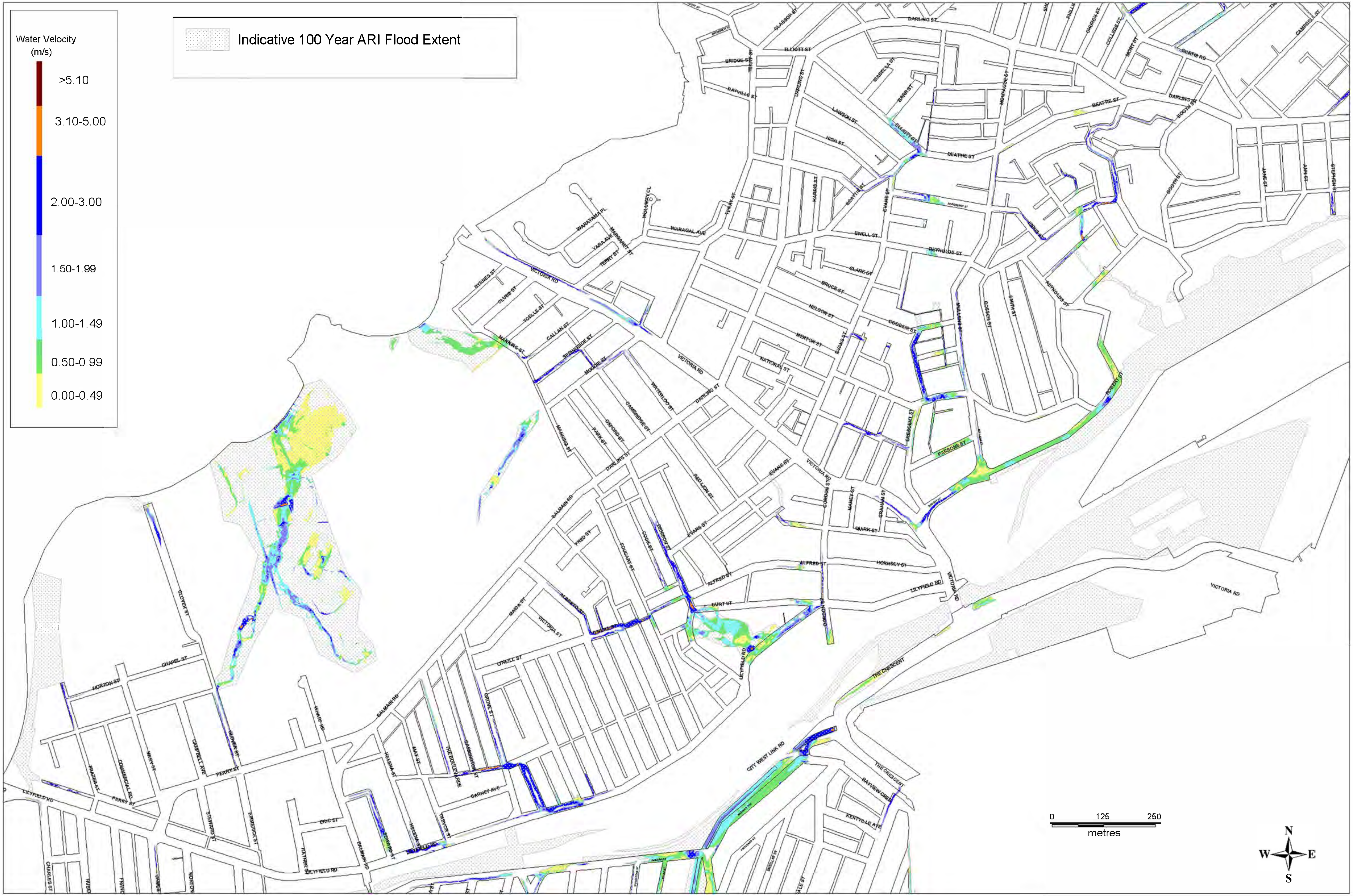

Figure 8.5- 100yr ARI Peak Velocity
Sheet2

Figure 8.5 - 100yr ARI Peak Velocity
Sheet3

Figure 8.6- PMF Peak Velocity
Sheet1

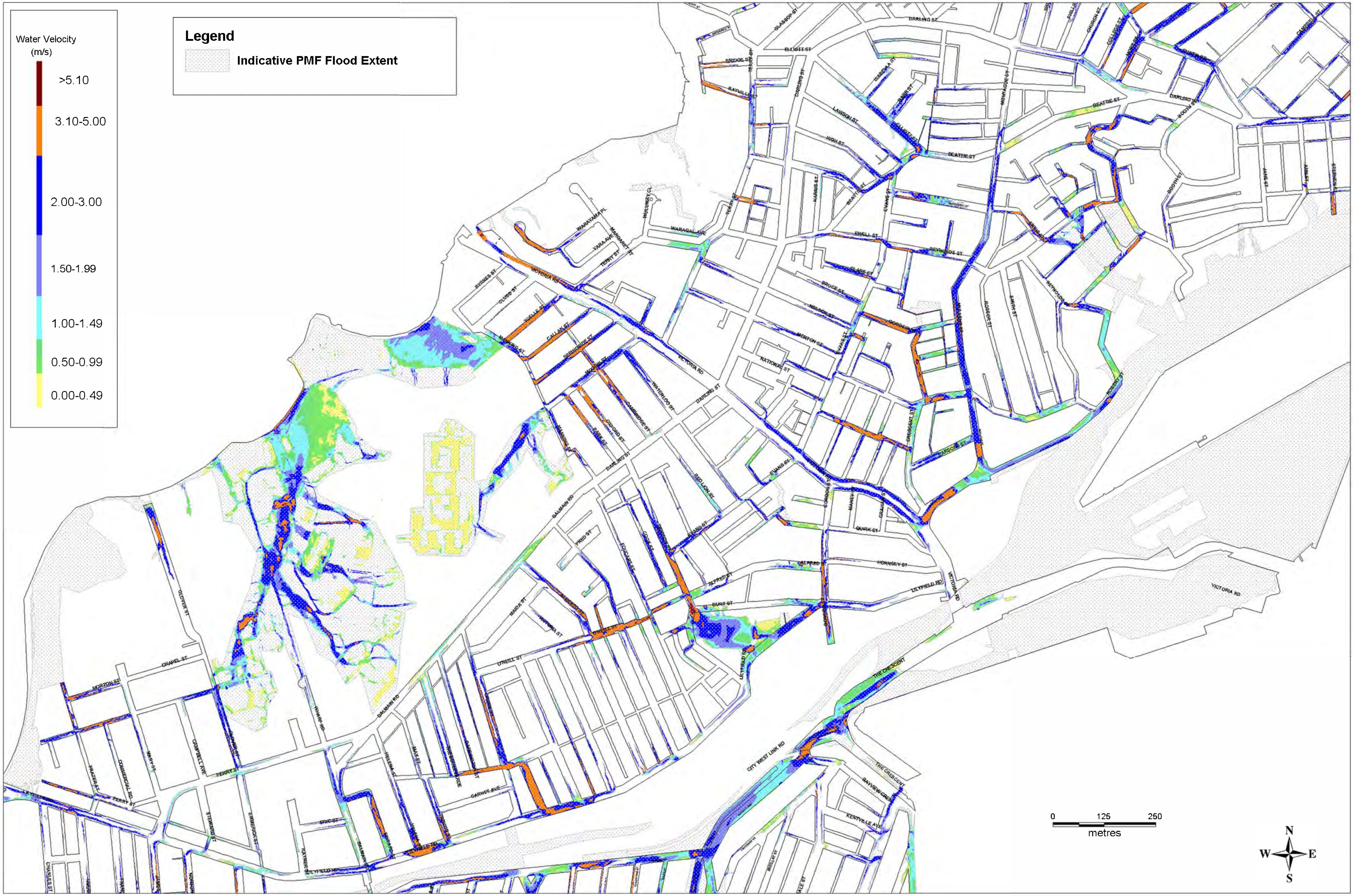

Figure 8.6- PMF Peak Velocity
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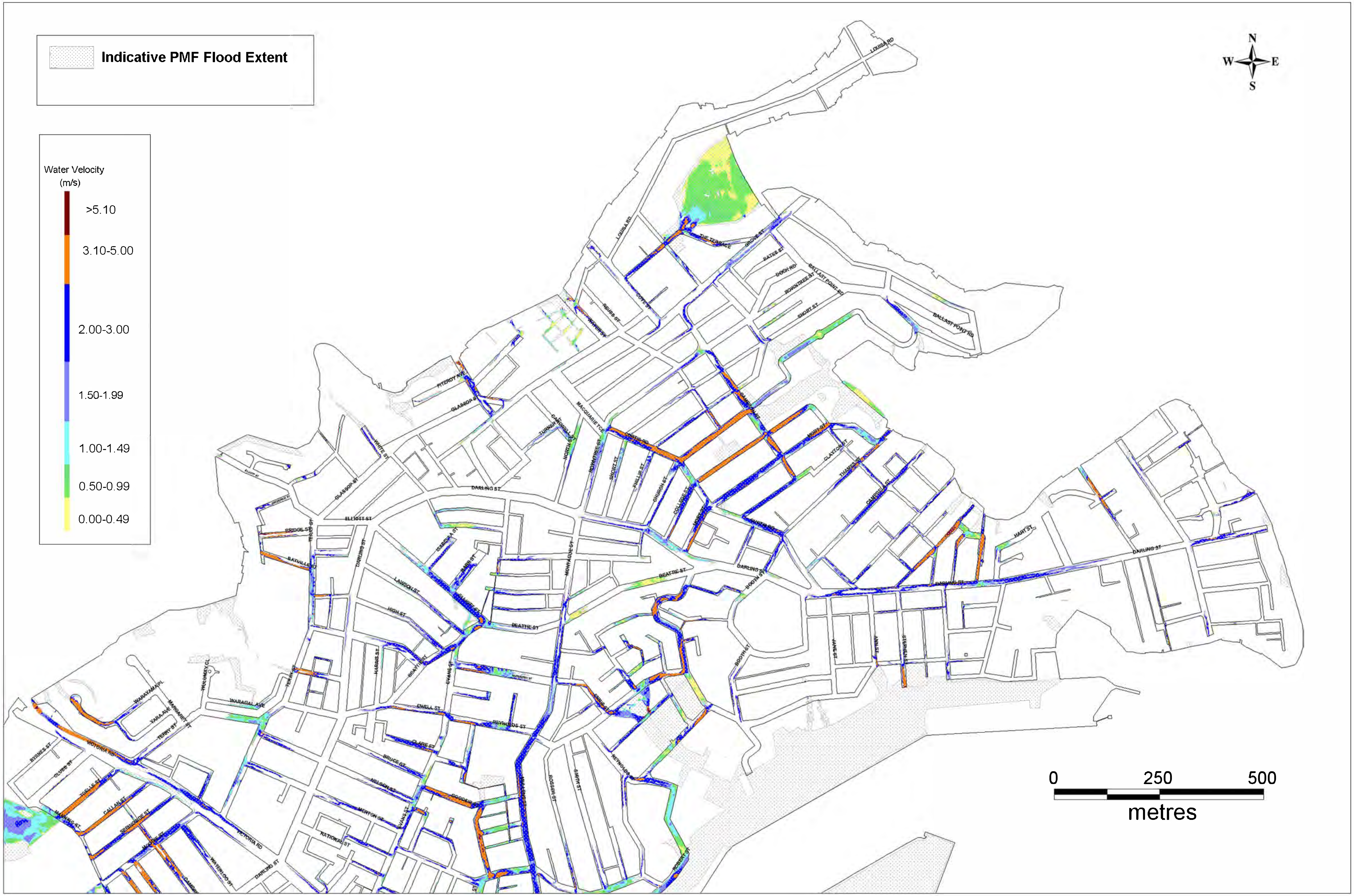

Figure 8.6 - PMF Peak Velocity
Sheet3

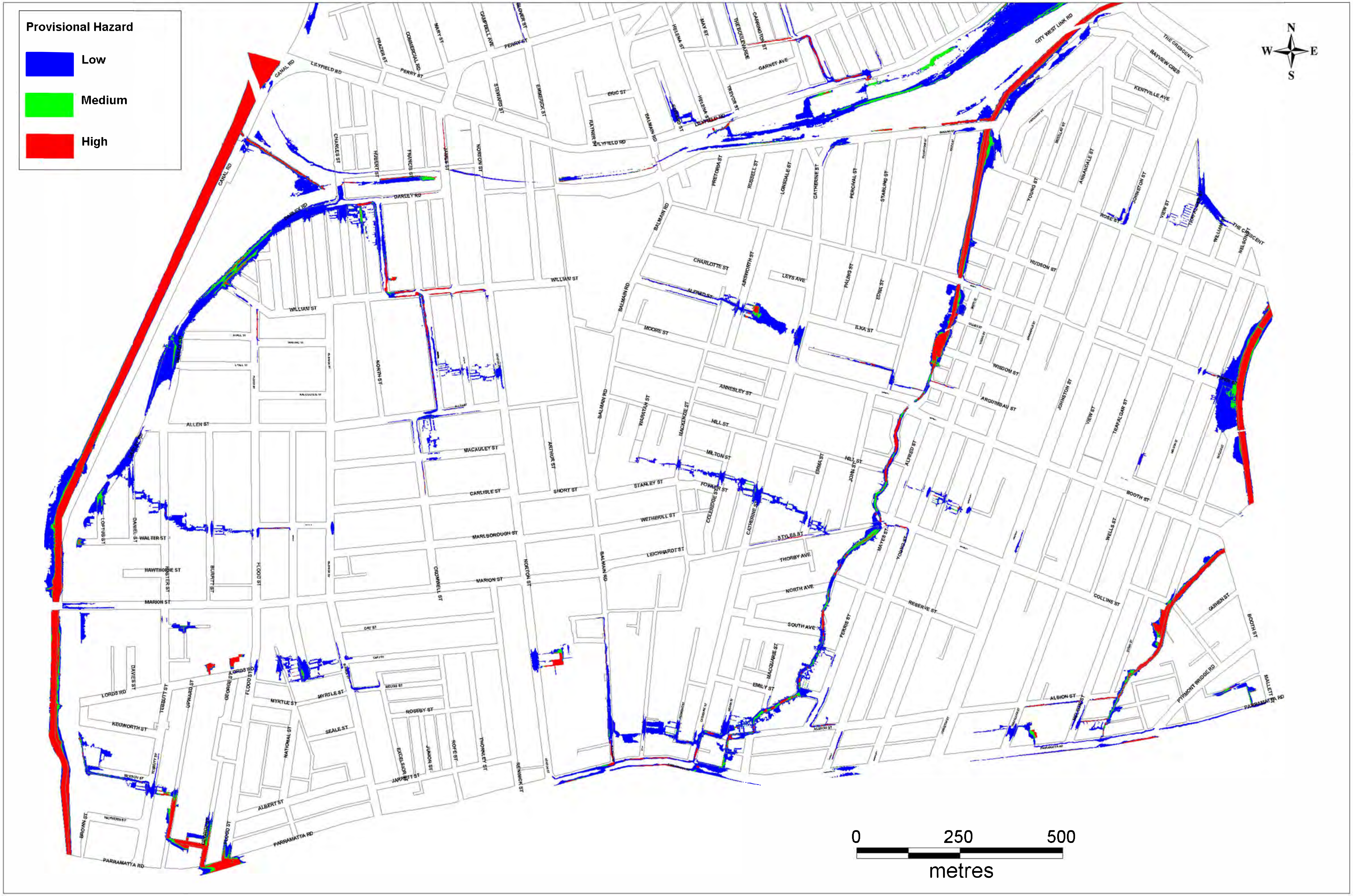

Figure 9.1 - 5yr ARI - Hazard
Sheet1

Figure 9.1 - 5yr ARI - Hazard
Sheet2

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Figure 9.1 - 5yr ARI - Hazard
Sheet3

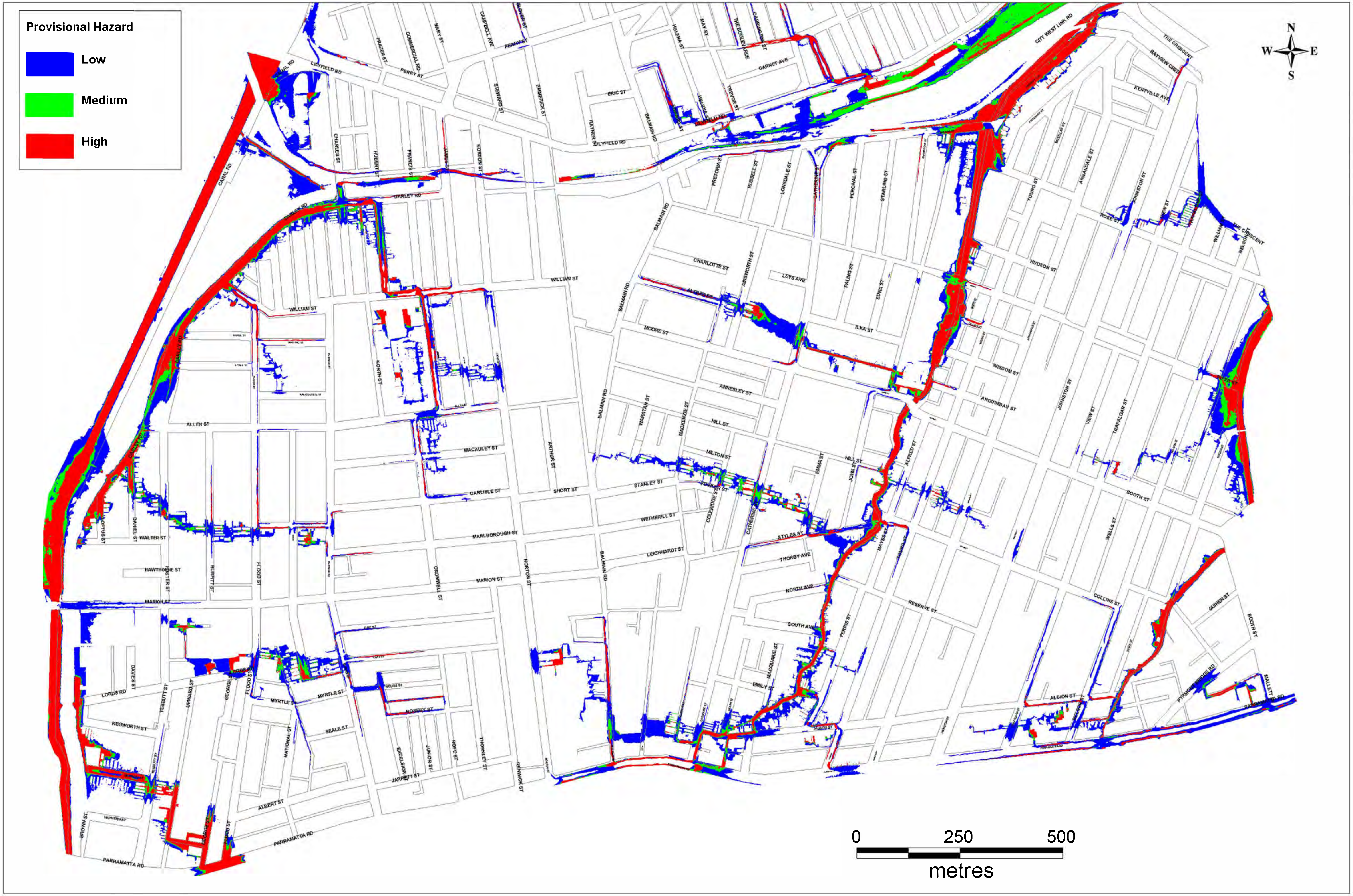

Figure 9.2 - 100yr ARI - Hazard
Sheet1

Figure 9.2 - 100yr ARI - Hazard
Sheet2

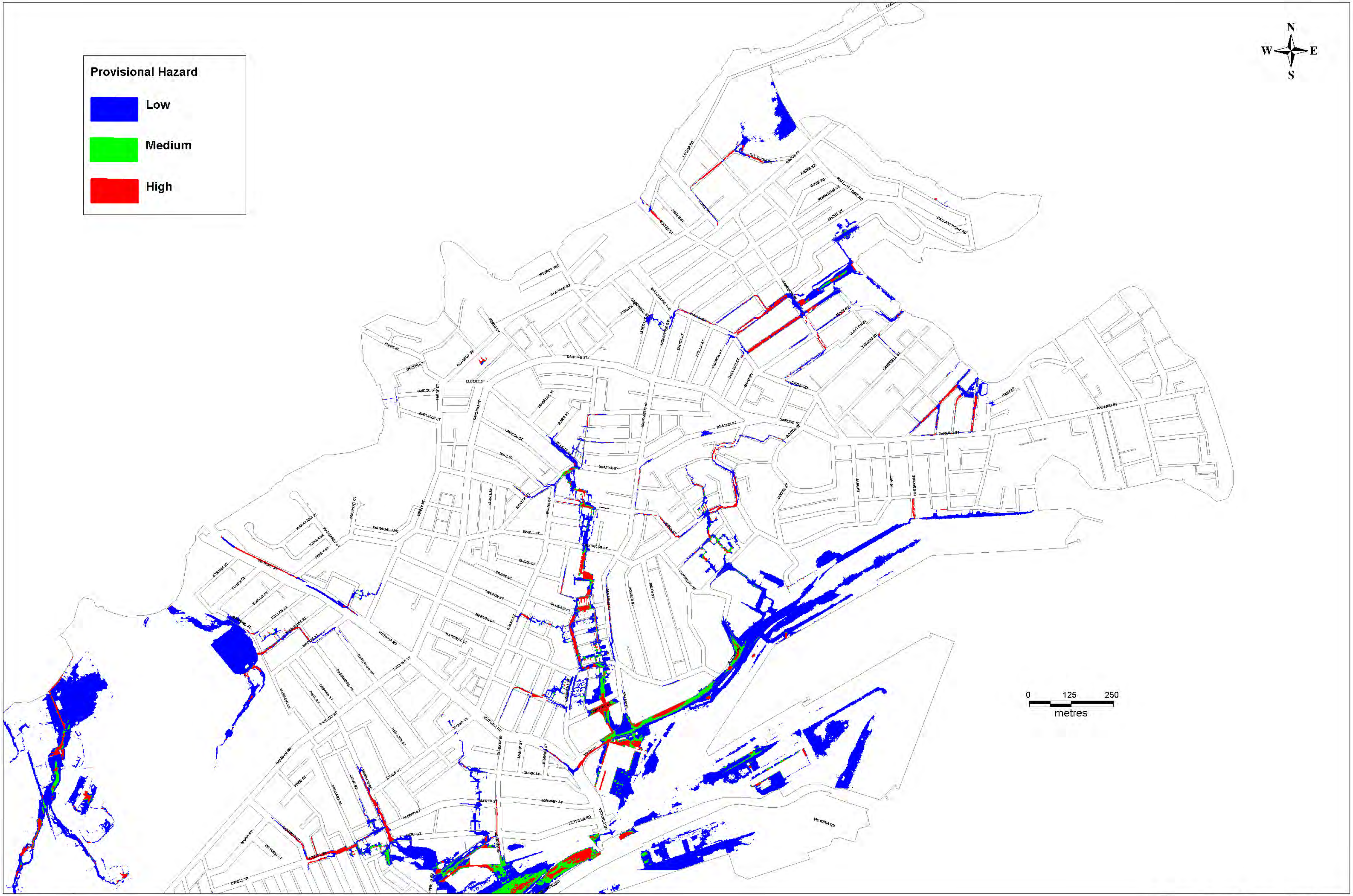

Figure 9.2 - 100yr ARI - Hazard
Sheet3

Figure 9.3 - PMF - Hazard
Sheet1

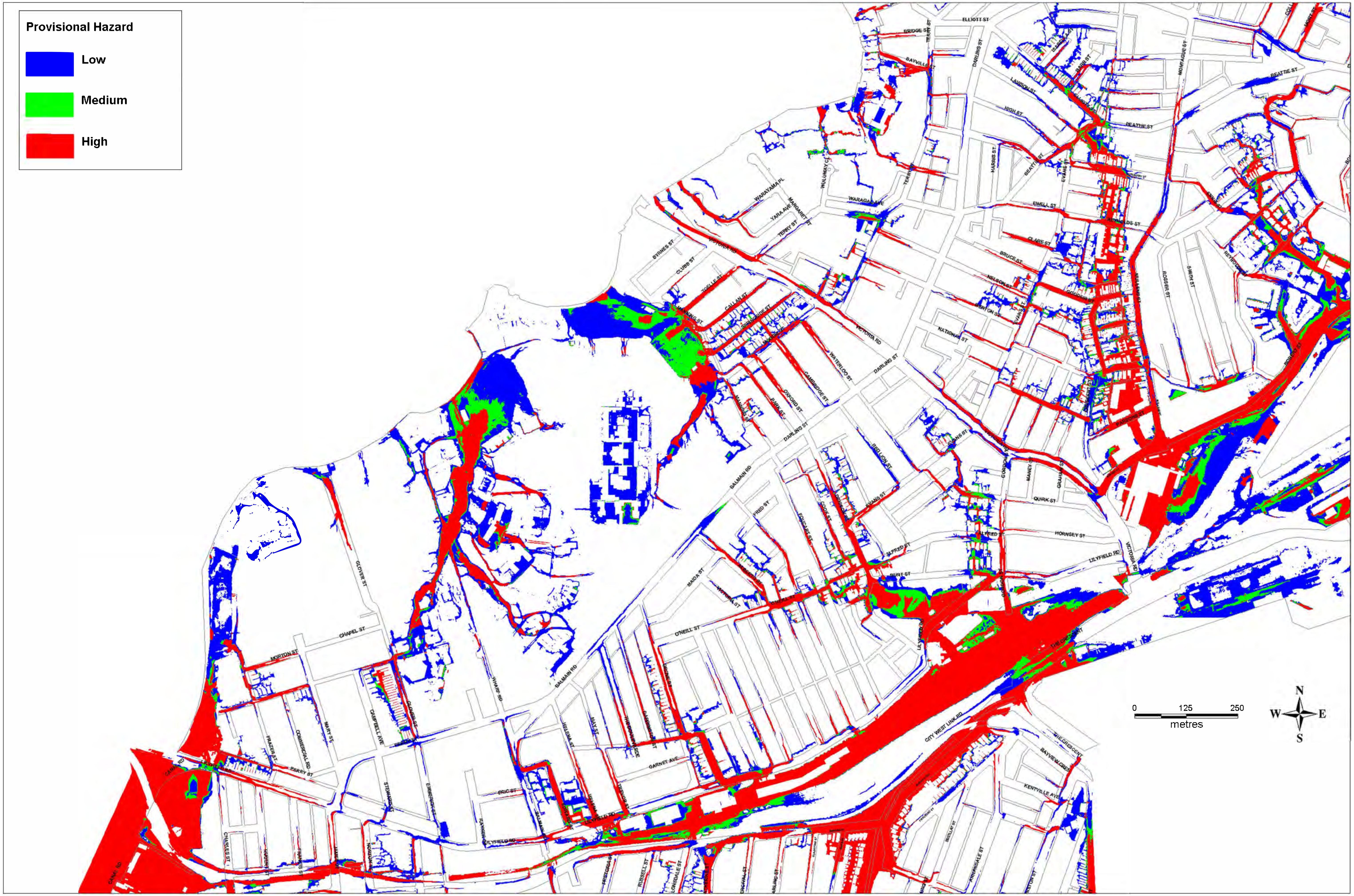

Figure 9.3 - PMF - Hazard
Sheet2

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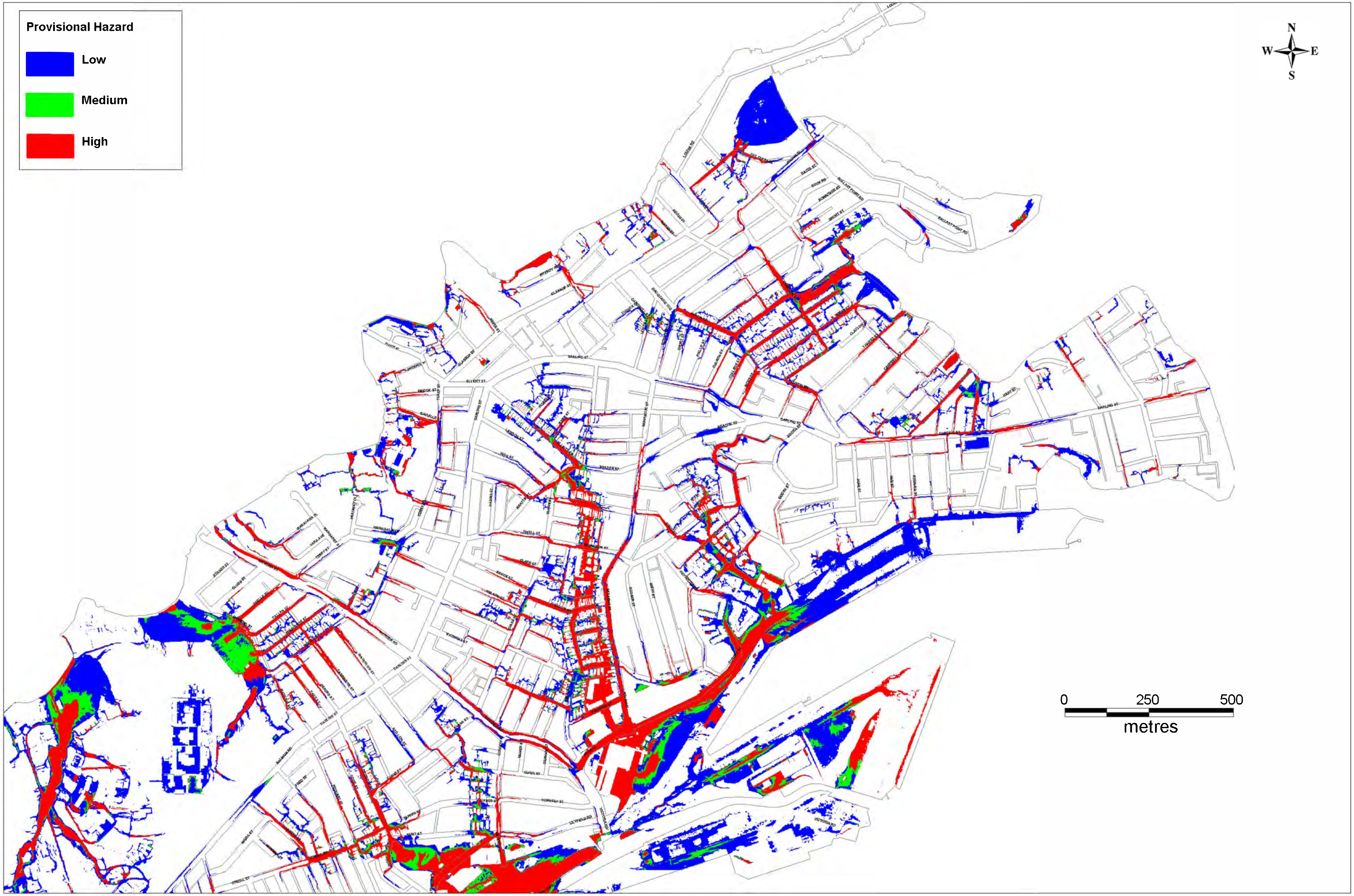

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Figure 9.3 - PMF - Hazard
Sheet3

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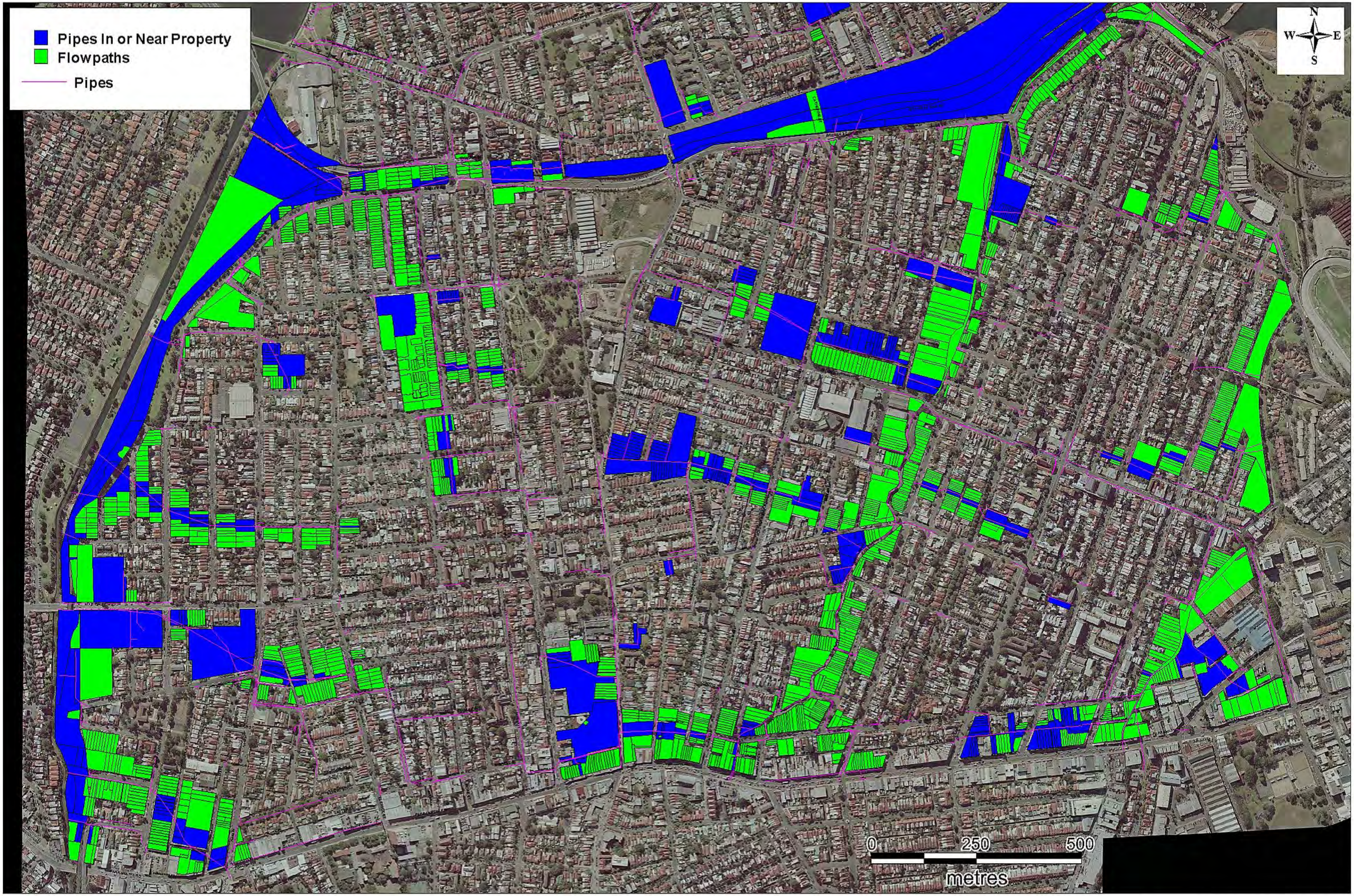

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Figure 12.1 - Flood Control Lots
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Figure 12.2 - Flood Control Lots
Sheet 2

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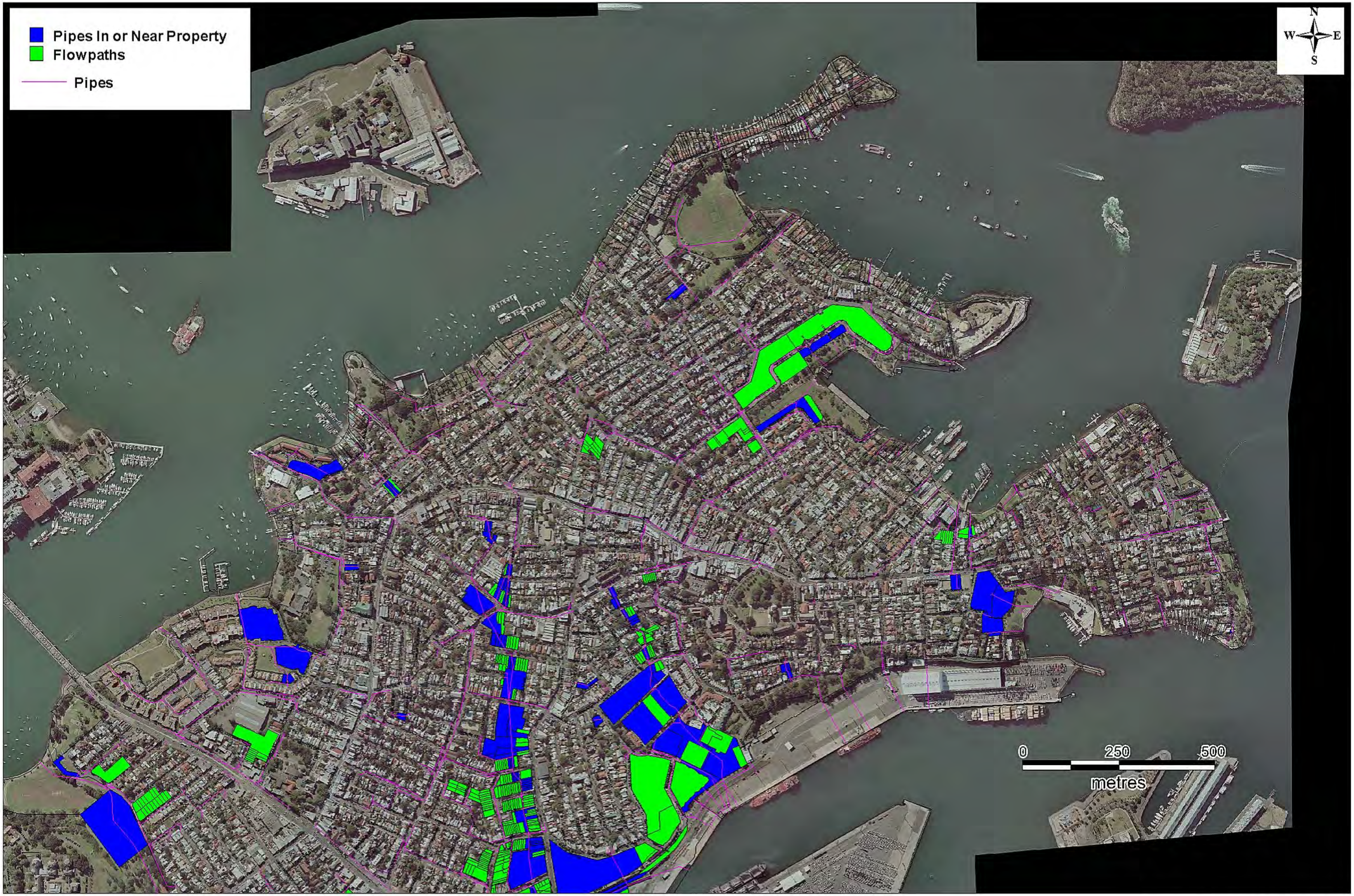

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Figure 12.3 - Flood Control Lots
Sheet 3

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Figure 12.4 - Foreshore Mapping
Sheet 2

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Figure 12.5 - Foreshore Mapping
Sheet 3

Leichhardt Floodplain Risk Management Study and Plan

APPENDIX B
ENVIRONMENTAL AND SOCIAL CHARACTERISTICS

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1 Introduction

Floodplain management can impose a variety of social and environmental costs on flood affected communities and areas. For example the relocation or disruption of a community, the clearing of vegetation or reshaping of a waterway to improve hydraulic efficiency and lower flood levels or the construction of levees can all have various social and environmental implications. Further, the implementation of risk management measures may disadvantage some groups of the community, but advantage others. In some cases, floodplain management can be used to enhance environmental or social aspects of a community. For example creek rehabilitation in conjunction with improved hydraulic efficiency.

In order to objectively compare issues and management measures, it is necessary to gather a variety of social and environmental data. The following discussion provides the details of the base line assessment undertaken to inform the floodplain management option identification and assessment process.

The following data has been collected:

- Demographic, ethnic and socio-economic data.
- Topography, geology and soils.
- Flora and Fauna.
- Aboriginal and Non-Aboriginal Heritage.

2 Social Assessment

The demographic characteristics of the study area presented in this report includes the suburbs of Annandale, Balmain, Balmain East, Birchgrove, Leichhardt, Lilyfield and Rozelle. Population data was sourced primarily from the Australian Bureau of Statistics (ABS) 2011 Census. The data was then aggregated to produce an overall summary for the region of interest.

In summary, the data revealed that:

- The median age of people in the study area is 37 years as of 2011 census, which is a similar figure to Australia's median age. In fact almost 40% of people living in the study area are within 25-44 age group, only 4% are above 75 year age and children under 14 year age comprise 16.8%. This results is a community which may be primarily able-bodied, able to evacuate effectively and/or assist with evacuation procedures.
- In the study area, 79.4% of people only speak English at home. The most common languages spoken at home other than English include Italian 3.0%, Greek 1.4%, Spanish 1.0%, Cantonese 0.8% and Mandarin 0.7%. Flood information provided to the community should consider the range of languages spoken.
- The median weekly personal income for people aged 15 years and over in the study area was $1,086 as of 2011 Census, compared to the NSW average of $561. This trend of well above average income for the region compared to the NSW average was also evident for family and household incomes. This may have implications for the economic damages incurred on property contents during a flood event.
- When the social assessment was undertaken in 2013, the median house price in the study area was $805,000, and the median unit price was $612,500. In NSW, the median house price was $440,000, and median unit price was $445,000 (APM, 2012). This information has implications for the economic damages incurred during a flood event.

An overview of the demographic data is provided in **Tables 2.1 to 2.4**.

Table 2.1 Age Structure of the Study Area (the former Leichhardt LGA) (ABS, 2011)

Age Group (Years)	Persons in the study area	% of total persons in the study area	% of total persons in NSW
0-4 years	4,299	8.34	6.6
5-14 years	4,486	8.70	12.6
15-19 years	1,642	3.18	6.4
20-24 years	2,592	5.03	6.5
25-34 years	9,801	19.01	13.6
35-44 years	10,988	21.31	14.1
45-54 years	7,109	13.79	13.8
55-64 years	5,893	11.43	11.7
65-74	3,111	6.03	7.8
75-84	1,645	3.19	4.9
85 years and over	631	1.22	2
Total	51,566		

Table 2.2 Languages Spoken at Home in the Study Area (former Leichhardt) LGA (ABS, 2011)

Languages Spoken at Home	Persons in the study area	%of total persons in the study area	% of total persons in NSW
English Only	41,457	79.4	72.5
Greek	729	1.4	1.3
Italian	1,586	3	1.2
Spanish	534	1.0	0.8
Cantonese	431	0.8	2
Mandarin	377	0.7	2
Total	52,197		

Table 2.3 Average Median Income in the Study Area (former Leichhardt LGA) (ABS, 2011)

Income (For Population Aged 15 Years and Over)	Study Area ($)	New South Wales ($)
Average Median Individual Income (weekly)	1,086	561
Average Median Family Income (weekly)	2,738	1,477
Average Median Household Income (weekly)	2,234	1,237

Table 2.4 Median House and Unit Prices within the Study Area (former Leichhardt LGA) (realestate.com.au, 2013)

Suburb	Median House Price ($)	Median Unit Price ($)
Annandale	950,000	542,500
Balmain	1,047,500	730,000
Balmain East	1,600,000	590,000
Birchgrove	1,182,500	661,500
Leichhardt	815,000	612,500
Lilyfield	910,000	527,500
Rozelle	947,000	667,000

3 Environmental Issues

3.1 Topography, Geology and Soils

3.1.1 Topography

The study area partly lies over the Cumberland Plain region, a relatively flat region which lies to the south and west of Sydney Harbour. The topography of the study area reflects rolling hills intersected by shallow valleys through which waterways including Hawthorne Canal, Whites Creek and Johnsons Creek flow.

3.1.2 Geology

When developing floodplain management options it is important to understand the geology of the study area to ensure appropriate locations for management options are selected and to assist with the planning of suitable foundations and other constructions to cope with the geology present.

The study area is comprised of the shale and sandstone layers of The Wianamatta Group and Hawkesbury Sandstone. The Wianamatta Group directly overlies the older (but still Triassic in age) Hawkesbury sandstone.

The Wianamatta Group comprises siltstones, interbedded siltstones and fine-grained sandstone, and fine grained lithic sandstone. Weathering of the shale units produces a rich clayey soil, often with poor drainage. These clay soils are recognised as being reactive with appreciable Shrink-Swell Capacity. Low lying areas where groundwater is close to the surface are also susceptible to dryland salinity. Groundwater quality can range from fresh to highly saline, with the deeper groundwater generally less saline.

Hawkesbury Sandstone is a fine to medium and course grained quartz sandstone with some interbeds of laminated siltstone and very fine sandstones. It is a conspicuous rock unit in the Sydney region. It has occurred as exposures in sea-cliff and quarries took place throughout the suburban areas of Sydney. Hawkesbury sandstone is generally some 200 metres thick, with shale lenses and fossil riverbeds dotted throughout it. Hawkesbury Sandstone is considered a safer bedrock than the (less stable and laminated) Wianamatta Group for building construction

3.1.3 Soil Landscapes

According to the Soil Landscape Map of Sydney (Scale 1:100,000), the study area occurs within the Birrong (bg), Blacktown (bt), Gymea (gy), and Hawkesbury (ha) soil landscape groups.

The Birrong soil landscape group is dominated by silt and clay sized alluvial materials derived from the Wianamatta Group. Deep yellow podzolic soils and yellow solodic soils occur on older alluvial (terraces); deep solodic soils and yellow solonetzic soils occur on the current floodplain.

The Blacktown soil landscape group has been formed by residual geomorphic processes. It usually occurs on gently undulating rises over Wianamatta Group shales. The ground slopes are usually less than 5% and the vegetation typically comprises partly cleared eucalypt, woodlands and tall open forests. The soils depths range from shallow to moderately deep (less than 1m thick) and are hard setting mottled textured clay soils. The soils are typically moderately reactive with highly plastic subsoil, have a low soil fertility and poor soil drainage.

The Gymea soil landscape is present on broad, convex ridge-tops on Hawkesbury Sandstone with little outcropping rock (less than 25%). Slopes are mostly 10-25%. The soils are yellow earths and earthy sands and are shallow stony, moderately acidic and highly permeable, with very low nutrient levels. The soil is subject to high erosion risk when exposed.

The Hawkesbury soil landscape occurs on Hawkesbury Sandstone where slopes are mostly greater than 25%. It consists of narrow ridges, deep, narrow valleys, and steep slopes with a characteristic sequence of benches and rocky scarps, like a staircase. The deeper soils are earthy sands, yellow earths and some yellow podzolic soils. The shallow, discontinuous soils associated with the extensive rock outcrops are lithosols and siliceous sands. Localised yellow and red podzolic soils occur on shale lenses, and siliceous sands and secondary yellow earths occur along drainage lines.

3.1.4 Acid Sulfate Soils

Along the NSW coast, Acid Sulfate Soils (ASS) are widespread in estuarine flood plains and coastal lowlands. ASS distribution is diverse and includes urban areas, farmlands, mangrove tidal flats, salt marshes and tea-tree swamps These types of soils contain iron sulfides (actual ASS), and soils that can potentially become acid producing are known as Potential Acid Sulfate Soils (PASS).

Acid Sulfate Soils (ASS) occur when soils containing iron sulfides are exposed to air and the sulfides oxidise producing sulphuric acid (DECC, 2008). This usually occurs when soils are disturbed through excavation of drainage works. The production of sulfuric acid results in numerous environmental problems. It is therefore important to be aware of the distribution of ASS within the study area, so that potential management options are developed and assessed in a manner that is sensitive to the problem of ASS (potential and actual acid sulfate soils).

The Parramatta River, which surrounds much of the study area, and Hawthorne Canal have a high probability of ASS, within 1m of the ground surface (severe environmental risk if ASS materials are disturbed by activities such as shallow drainage, excavation or clearing). If high risk materials were to be disturbed there may be a severe environmental risk and any structure would need to be designed to ensure integrity of the structure against acid sulfate soils. Soil investigations would be necessary to assess these areas for acid sulfate potential should any flood management actions be proposed in these locations.

3.1.5 Contaminated Land and Licensed Discharges

Contaminated land refers to any land which contains a substance at such concentrations as to present a risk of harm to human or environmental health, as defined in the Contaminated Land Management Act 1997. The Office of Environment and Heritage (OEH) is authorised to regulate contaminated land sites and maintains a record of written notices issued by the Environment Protection Authority (EPA) in relation to the investigation or remediation of site contamination. A search of the OEH Contaminated Land Record on 11 February 2013 showed 7 known contaminated sites within the study area as shown in **Table 3.1**. Flood modification works within the study area should consider the impacts that may be caused due to these contaminated sites and further investigation may be necessary.

Table 3.1 Items listed on the OEH Contaminated Land Record (OEH, 2013)

Suburb/City	Site Description and address	Activity that caused contamination
Annandale	Mobil Service State, 198 Parramatta Road	Service Station
Annandale	Shell Coles Express Service Station, 124-126 Johnston Street	Service Station
Leichhardt	7 Darley Road	Other Industry
Leichhardt	Bus Depot (Area E), Cnr Balmain Rd and City West Link	Other Industry
Leichhardt	SRA Land, 10-11 Balmain Road	Other Industry
Rozelle	BP Service Station, cnr Darling Street and Thornton Street	Service Station
Rozelle	Caltex Service Stations, 121 Victoria Rd	Service Station
Rozelle	Kennards Rozelle, 15-39 Wellington street	Other Petroleum
Rozelle	Mobil Service Station, 178-180 Victoria Road	Service Station
Rozelle	White Bay Power Station, Robert Street	Other Industry

A search of the PoEO licensed premises public register on 25 January 2013 identified three licensed premises within the LGA as shown in **Table 3.2**.

Table 3.2 Items listed on the PoEO Licensed Premises Register (OEH, 2013)

Suburb/City	Organisation name and address	Location	Type of License
Leichhardt	APPAREL FITTINGS AUSTRALASIA PTY LTD C/- STAR DEAN-WILLCOCKS	67 John Street	POEO licence no longer in force; S 58 Licence Variation issued on 08 Feb 2005
Leichhardt	STATE TRANSIT AUTHORITY OF NSW	Corner William & Derbyshire Streets	POEO licence no longer in force; S 58 Licence Variation issued on 05 Jul 2004
Leichhardt	SYDNEY SOUTH WEST AREA HEALTH SERVICE	Corner Glover & Church Streets	POEO licence no longer in force; S 58 Licence Variation issued on 25 Jul 2002 and 21 Sep 2005

Any flood modification works within Leichhardt suburb should both consider the protection of these facilities from flood damages and the compatibility of the flood works with the operations of the facilities.

3.2 Flora and Fauna

Due to the highly urbanised nature of the study area, most of the original native vegetation has been cleared and modified and no substantial natural areas remain. Many of the plant and animal species that used to occur in this area are no longer present.

A search of the NPWS Atlas of Wildlife database (OEH, 2012a) on 12 February 2013 for threatened flora species recorded since 1980 showed no known threatened flora species with a 10km by 10km search area surrounding the study area.

A search of the NPWS Atlas of Wildlife database (OEH, 2012a) on 12 February 2013 for threatened fauna species recorded since 1980 showed no known threatened fauna species with a 10km by 10km search area surrounding the study area.

A search of the Environment Protection and Biodiversity Conservation (EPBC) Protected Matters database identified 33 threatened species known to occur within the study area. The results of this search can be found in main report. There is very limited habitat for threatened species in the study area, and the Grey-headed Flying-fox is the only listed threatened species that is seen regularly around Iron Cove. A range of visiting shore birds has also been seen wading and feeding on Iron Cove’s mudflats.

Any proposed flood modification options or flood protection works should consider the number and type of species the modification may affect.

3.3 Heritage

3.3.1 Aboriginal Heritage

The study area was once the area inhabited by the Wangal band of the Dharug (Eora) language group. Wangal country was known as wanne and it originally extended from the suburbs of Balmain and Birchgrove in the east to Silverwater and Auburn in the west. The northern boundary was the Parramatta River. Neighbouring Darug bands were the Cadigal to the east, the Wallumattagal on the northern shore of the Parramatta River and the Bediagal to the south.

A preliminary investigation of indigenous heritage was undertaken by searching the Aboriginal Heritage Information Management System (AHIMS) (2012b) in January 2013 for known or potential indigenous archaeological or cultural heritage sites within the study area. The relevant AHIMS search results are presented in **Table 3.3**. This information is useful in the development and feasibility assessment of floodplain management options. However, a more detailed heritage assessment should be undertaken prior to implementation of any management actions to ensure that any proposed flood mitigation works will not impact heritage items or places.

Table 3.3 Items Identified under the NPWS Aboriginal Heritage Information Management System for the Study Area (OEH, 2012b)

Site ID	Site Name	Site Type
45-6-2278	Lilyfield Cave	Shelter with midden
45-6-0283	Rozelle Hospital 1	Shelter with midden
45-6-1900	White Horse Pt.	Midden
45-6-0618	Rozelle Hospital 2, Rozelle Hospital 1	Midden
45-6-1481	Rozelle Hospital 3	Midden
45-6-1971	Rozelle Hospital 5, Rozelle Hospital 3	Shelter with midden
45-6-1972	Rozelle Hospital 4	Shelter with midden
45-6-2676	Johnstons Creek	Art (pigment or engraved), artefact
45-6-1809	Birchgrove	Midden, Shelter with Art

The following qualifications apply to an AHIMS search:

- AHIMS only includes information on Aboriginal objects and Aboriginal places that have been provided to OEH;
- Large areas of New South Wales have not been the subject of systematic survey or recording of Aboriginal history. These areas may contain Aboriginal objects and other heritage values which are not recorded on AHIMS;
- Recordings are provided from a variety of sources and may be variable in their accuracy. When an AHIMS search identifies Aboriginal objects in or near the area it is recommended that the exact location of the Aboriginal object be determined by re-location on the ground; and
- The criteria used to search AHIMS are derived from the information provided by the client and OEH assumes that this information is accurate.

Middens that are composed predominantly of shells are essentially the remains of shellfish meals eaten on the spot by Aboriginal people over a long period of time. Fish and shellfish were the main foods of Aboriginal people living around the harbour, with fishing being an important activity of daily life for both men and women.

The middens that can be found in the study area are dated at approximately 4, 500 years old, and are recognised as significant by the Metropolitan Local Aboriginal Land Council and archaeologists. A series of interpretive signs can be found at these sites recognising the traditional owners of the study area.

All Aboriginal sites are protected under the National Parks and Wildlife Act 1974 and therefore any management considerations that impact upon Aboriginal sites must include this in their design. Known Aboriginal sites should be left undisturbed if possible, however if a management option requires their destruction, an Aboriginal Heritage Impact Permit (AHIP) must be sought from OEH. Under the National Parks and Wildlife Act 1974 it is a requirement that any developments show “due diligence” with regard to Aboriginal heritage in the area

Land Rights and Native Title Claims

Land rights and Native Title are two different forms in which traditional land owners can gain access to land or claim compensation for previous dispossession of their land.

Under the Aboriginal Land Rights Act 1983, local Aboriginal land councils can claim Crown lands provided the lands are vacant and not otherwise required for an essential public purpose. A search on the Land Claims

Register maintained by the Office of the Registrar, Aboriginal Land Rights Act 1983 (ORALRA), on 4 February 2013 found no Native Title claims in the study area.

3.3.2 Non-Aboriginal Heritage

There are three different types of statutory heritage listings of Non-Aboriginal origin; local, state and national heritage items. A property, item or place is a heritage item if it falls into a listings category. The category an item falls into depends on whether it is considered to be significant to the nation, state or a local area. The significance of an item is a status determined by assessing its historical, scientific, cultural, social, archaeological, architectural, natural or aesthetic value.

A desktop review of Non-Aboriginal heritage was undertaken for the study area. Searches were undertaken on a number of databases to determine the cultural heritage within this area. Databases searched include:

- Australian Heritage Database (incorporates World Heritage List; National Heritage List; Commonwealth Heritage List);
- NSW Heritage Office – State Heritage Register; and
- Leichhardt Local Environment Plan (LEP) 2000 Heritage Listings.

Table 3.4 contains 21 items that are found within the study area which have been listed by the Heritage Council under the NSW Heritage Act. This includes listing on the state heritage register, an interim heritage order or protected under Section 136 of the NSW Heritage Act. This information has been provided by the NSW Heritage Branch. No items were found to be included on the World Heritage List, Commonwealth Heritage List, or National Heritage List.

The Leichhardt LEP 2000 lists 669 heritage items of significance that are found within the study area under Schedule 2 of the LEP. There are also numerous heritage conservation areas with the study area. Part 3, Clause 16 of the Leichhardt LEP 2000 outlines the provisions which must be followed in relation to heritage items and Part 3, Clause 16 (8) outlines the provisions which must be followed in relation to conservation areas within the study area.

Table 3.4 Items listed under the NSW Heritage Act (OEH, 2012c)

Item name	Address	Suburb
Balmain Hospital - Main Building	Booth Street	Balmain
Callan Park Conservation Area & Buildings	Balmain Road	Lilyfield
Callan Park House - Rozelle Hospital	Balmain Road	Lilyfield
Dawn Fraser Swimming Pool	Glassop Street	Balmain
Ewenton	6 Ewenton Street	Balmain
Fenwick & Co Boat Store	2-8 Weston Street	Balmain
Goodman's Buildings	2-12 Johnston Street	Annandale
Hampton Villa	12B Grafton Street	Balmain
Hunter Baillie Memorial Presbyterian Church	Johnston Street	Annandale
Johnston's Creek Sewer Aqueduct	Taylor Street (Off), Hogan Park	Annandale
Louisaville	2 Wells Street	Balmain
Mort's Dock	Thames, Mort, College, McKell, Cameron, Yeend Streets	Balmain

Item name	Address	Suburb
Railway electricity tunnel under Sydney Harbour		Birchgrove / Greenwich
Raywell	144 Louisa Road	Birchgrove
Rozelle Hospital - Broughton Hall	Balmain Road	Lilyfield
Sewage Pumping Station 27	Callan Park	Rozelle
Substation	182 Johnston Street	Annandale
Waterview Wharf Workshops	37 Nicholson Street	Balmain
White Bay Power Station	Victoria Road	Rozelle
White's Creek Aqueduct	Piper Street	Lilyfield
Wyoming	25 Wharf Road	Birchgrove

The information contained within this Appendix has been used in the development and feasibility assessment of Floodplain Management Options. However, due to the extensive heritage found with the study area, a detailed heritage assessment should be undertaken prior to detailed design or implementation of any management options, as there are development restrictions and procedures which need to be followed.

4 Conclusions

The study area is a highly urbanised environment resulting in some key urban related constraints to floodplain management. However, there are also several environmental constraints that need to be considered in the preparation of a Floodplain Risk Management Plan. The key environmental and social constraints identified in this assessment include:

- The high probability of Acid Sulfate Soils in the Parramatta River and Hawthorne Canal, which if disturbed could cause serious environmental risk;
- 7 known contaminated sites which may require further investigation;
- Potential for the grey-headed flying fox to be disturbed; and
- 9 Aboriginal sites listed under the National Parks and Wildlife Act 1974, 21 non-Aboriginal heritage sites found on the State Heritage Register and 669 heritage items of significance under the Leichhardt LEP.

5 References

ABS (2011) *2011 Census*. Australian Government.

APM (2012) Australian Property Monitors. [online] URL: http://apm.com.au/

OEH (2012a) *NPWS Atlas of NSW Wildlife*, NSW Government.

OEH (2012b) *Aboriginal Heritage Information Management System*, NSW Government.

OEH (2012c) *State Heritage Register*, NSW Government.

Leichhardt Floodplain Risk Management Study and Plan

APPENDIX C
ONSITE DETENTION ASSESSMENT

1 Introduction

On-site detention (OSD) is the temporary storage of site stormwater so as to restrict the discharge leaving the site to a predetermined rate. The purpose of OSD is to either ensure no worsening of downstream flooding issues as a result of a development or it can also be used to decrease flooding downstream.

Leichhardt Council has Requirements for OSD within the former Leichhardt Local Government Area (study area) are set out in the Leichhardt Development Control Plan DCP 2013. These requirements currently aim to reduce flooding within the study area by applying OSD to significant proposed developments.

A review has been undertaken as part of the Leichhardt Floodplain Risk Management Study to incorporate the findings of Leichhardt LGA Flood Study into Council's OSD Policy and to review Council's Policy against current best practice. Catchment based analysis has been undertaken to determine the effectiveness of the current OSD policies as a flood mitigation / management tool. The purpose of the assessment is to identify:

- Site storage requirements (SSR);
- Permissible site discharge (PSD);
- Appropriate on-site detention offsets using on-site retention (rainwater tanks);
- Appropriate requirements for properties drainage against grade to the street above; and
- An OSD calculation sheet (provided to Council separately).

2 Desktop Review of Current OSD Policies

2.1 Leichhardt Council OSD Policy

2.1.1 Current Guidelines

Leichhardt DCP 2013 requires that residential and non-residential developments incorporate OSD in accordance with Council's Stormwater Management Policy (outlined in the Draft Drainage Code, 1995).

On-site detention is required for the following development types:

- Single residential (except for cases where increased roof and paved areas is less than 40m2).
- Dual occupancy.
- Villa, flats, town houses etc.
- Commercial, industrial and institutional.
- Tennis courts,
- Some paving (depending on the details of the development).

Design Values and Calculation Methods

Hydraulic calculations are required to demonstrate the 100 Year Average Recurrence Interval (ARI) post development site run-off does not exceed the 5 year ARI pre-development site runoff.

Calculation methods considered acceptable for this demonstration are:

- Triangular Hydrographs.
- Swinburne.
- Time Area models such as Ilsax.
- Other methods may be accepted at the discretion of Council's Engineer.

Times of concentration are to be calculated using the kinematic wave equation from p300 of Australian Rainfall and Runoff (1987).

Other Design Requirements

Council's Draft Drainage Code (1995) outlines the following design requirements:

- The outflow control structure is to be designed to control variable outflow rate in accordance with the storage discharge relationship (calculated as above).
- All roof and paved areas are to drain through the storage.
- Storages are to be located separate from any external surface flow paths.
- Finished ground levels are to be constructed so that impervious area runoff, in excess of the pipe system capacity, drains to the storages.
- The maximum storage level is to be such that habitable floor levels are at least 0.3m above the maximum water level, and garages 0.15m above.
- An emergency overflow with flowpath is to be provided, and is to be free of obstructions such as fences.
- Maximum ponding depths for above ground storages are to be 0.15m in parking areas, 0.3m in landscaping and 1m in a fenced off area.
- Storage volumes in landscaping areas are to be doubled to allow for vegetation growth.
- Surface storage areas in strata or community title development are not be in privately controlled areas such as courtyards.
- Hydraulic control devices are to be constructed to be non-removable.
- Existing stormwater storages can be incorporated into the new design.

2.1.2 On-Site Retention

DCP 2013 allows for the volume of OSD to be reduced where on-site retention (OSR) facilities for rainwater reuse and/or stormwater reuse are proposed to service all toilets, laundries and outdoor usage. Where OSR is proposed in lieu of OSD, Council requires the offset to be calculated at a rate of $1m^3$ from the OSD storage volume, for every $2.5m^3$ of OSR storage provided (up to a maximum OSD offset of $10m^3$).

2.1.3 Areas not Draining to OSD

Whilst Council's Policy requires "all roof and paved areas are to drain through the storage", it is acknowledged that this is not always possible. Council does not have a formal policy regarding properties which cannot completely or at all discharge to OSD (e.g. properties which discharge against the grade to the street and have no free discharge from the OSD orifice). However, it is understood that Council assesses application relating to properties of this type on a merits based approach. Council accepts that in many cases, new developments on the low side of the road will not be able to obtain easements, and consequently will need to drain against the grade to the street above. Council currently looks at the context of the nature and scale of the proposed development and its position within the catchment to determine an appropriate approach to OSD. Typically, an existing building that is to the replaced or renovated already has a portion of the front roof area that drains out to the street. In these cases, Council generally applies OSD on the principal of limiting the site discharge rate to at least the existing rate. Where no existing surfaces currently drain to the street, the criteria are often based on a typical area.

2.2 OSD Guidelines in Similar Governance Areas

The following OSD guidelines have been summarised for comparison and use in this review:

- Upper Parramatta River Catchment Trust;
- Auburn City Council (former); and
- Kogarah Council.

The relevant components of these guidelines have been summarised in the table below.

	Upper Parramatta River Trust	Auburn City Council (former)	Kogarah Council (former)
Source Document	On-site Stormwater Detention Handbook – Fourth Edition (Upper Parramatta River Catchment Trust, 2005)	Auburn Development Control Plan 2010 (Auburn City Council, 2012)	Water Management Policy: Site Drainage and Flood Management – Practice Note #1 (Kogarah Council, 2006)
Purpose of the Guidelines	To ensure that new developments and redevelopments do not increase peak stormwater flows in any downstream area during major storms up to and including 100 year ARI events. The secondary aims of the policy are to reduce post development peaks throughout the catchment in the 1.5 year ARI event to be as close to natural levels as practical and to encourage the integration of OSD with other water quality measures.	To ensure that through the OSD of stormwater, discharge is controlled thereby ensuring the development does not increase the risk of downstream flooding of roads and properties, or erosion of unstable waterways. Sufficient storage is provided to ensure peak flow rates at any point within the downstream drainage system do not increase as a result of the development during all storm events up to the 100 year ARI.	To ensure that a development does not increase the risk of flooding on downstream properties.
Development to which OSD Applies	OSD requirements generally apply to all types of development and redevelopment on both flood liable and flood-free sites. These include the following: • subdivisions (including residential) approved after 1991; • single dwellings on lots created by a subdivision approved after 1991, unless a communal OSD system was constructed as part of the subdivision; • all commercial, industrial and special-use developments and buildings; • town houses, villas, home units, duplexes and dual occupancies; • semi-detached residential/commercial and residential/industrial properties; • buildings, car parks and other sealed areas of public sport and recreational facilities; • single dwellings, extensions and additions (In the Parramatta City Council area only where the proposed development involves an increase in impervious area greater than 150 m2 and the land is within a designated catchment area which drains to a location of a known drainage problem area); • sites that include WSUD and water re-use. • tennis courts; • roads, car parks, paths and other sealed areas; and • public buildings.	All development except those noted below.	All development except those noted below.
Development to which OSD does not apply	OSD policy does not apply to: • most development types on subdivisions and lots created prior to 1991. Exceptions apply; • dual occupancy residences on a lot with an existing residence involving less than 150 m2 of development area; • sub-divisions of existing dual occupancies where no changes to the buildings or site are proposed; • boundary adjustments and consolidations of allotments where no a additional lots are created; • one-off minor developments, minor additions and repairs where the proposed development area is less than 150 m2 (subsequent minor developments or additions shall require OSD). This exclusion is aimed principally at small areas within large commercial or industrial sites. It does not apply to any developments	OSD is not required where: • The proposal is a one-off extension up to: o 50m2 of impervious area for a single dwelling or an outbuilding; or o 150 m2 impervious area for industrial development. Note: Subsequent extensions require OSD facility. • The proposal is a single dwelling where the site coverage exceeds Section 2.2 Development Control D1 in the Dwellings and Dual Occupancies DCP; • The applicant can demonstrate to Council's satisfaction, the development is subject to mainstream flooding or is subjected to major overland flow. A flood report	OSD will not be required when: • The Water Management Policy only applies to the proposed development instead of the whole site. • The discharge from the property does not pass through any drainage structure before reaching the receiving bays. These drainage structures include any pipe, culvert, lined channel or other restrictive structure. • When the property is wholly within a flood-affected area. For properties which are partly flood affected by the 100 year design flood, the area of the floodway and the area of the site discharging to the floodway would be exempted from the provision of OSD. • The total coverage by impervious area is less than 50% of the site area. The impervious area for the site should include roofs, paving and driveways.

	Upper Parramatta River Trust	Auburn City Council (former)	Kogarah Council (former)
	where the development area includes more than 150 m2 of impervious surfaces nor to dual occupancies; • change of use where no physical changes to the outside of the property are proposed; • areas within large properties (usually commercial or industrial but may be residential) not covered by the development application or construction certificate; • new developments in subdivisions where OSD has already been provided for the entire subdivision; • buildings in Rural/Non-urban areas (Baulkham Hills Shire Council does require OSD for buildings in Rural/Non-urban areas. Contact Council's Subdivision Section to obtain the OSD requirements); • the grassed playing field and vegetated area of public sports and recreational facilities that are not part of a development.	prepared by a suitably qualified engineer is required in this case; or • The property falls within zones 6, 7 and 8.	• Single dwelling sites discharging to an absorption system, which is sized to cater to the 100 year ARI design storm.
Control Standards	• SRD_L = 40 L/s/ha • SRD_U = 150 L/s/ha • SSR = 455 m^3/ha (partitioned into extended detention (lower) and flood detention (upper) storages. Maximum SSR for the extended detention is 300 m^3/ha. • Minimum outlet size = 25mm • Maximum ponding depths above ground = 600 mm (allowable depth of ponding will be varied depending on the nature of the development and the location of the storage).	The SSR and PSD values vary across the catchments within the LGA as follows: PSD = • Zone 1: 80 L/s/ha • Zone 2: 100 L/s/ha • Zone 3: 130 L/s/ha • Zone 4: 150 L/s/ha • Zone 5: 130 L/s/ha SSR = • Zone 1: 530 m3/ha • Zone 2: 455 m3/ha • Zone 3: 370 m3/ha • Zone 4: 325 m3/ha • Zone 5: 370 m3/ha Minimum outlet size: Pipes or orifices with a diameter less than 150mm shall not be acceptable except where protected against blockages using a removable, rustproof screen or wire cage installed around the outlet.	The OSD system shall be designed in accordance with the storage discharge relationships presented in Figure 2.1 below that shows the Site Storage Requirements (SSR) and the Permissible Site Discharge (PSD) relevant to the site's impervious area. The relationships in Figure 2.1 were derived based on catchment investigation undertaken by Kogarah Council.
Rainwater Tank Offsets for OSD	Dedicated Airspace The following reductions in the SSR values may be allowed subject to Council approval: • 50% of the dedicated airspace can be credited against the SSRL; • 100% of the dedicated airspace can be credited against the SSRT; Subject to: • a maximum dedicated airspace credit no greater than the ratio of the area of roof discharging to the rainwater tank to the lot area times the overall site storage volume that is required;	No guidelines provided.	When a rainwater tank is used on the property and is connected to supply toilet flushing and laundry demands, 1/3 of the provided storage volume can be used to offset the required volume for OSD (i.e. SSR).

	Upper Parramatta River Trust	Auburn City Council (former)	Kogarah Council (former)
	• the rainwater tank has a dedicated outlet to ensure that the dedicated airspace is recovered after a storm event and the maintenance schedule specifically requires checking and cleaning of the outlet; • the PSD for the dedicated rainwater tank outlet is no greater than 40 L/s/ha; • all outflows from the rainwater tank (outflows from the dedicated outlet and overflows from the rainwater tank) are discharged to the OSD storage. Dynamic Airspace The reduced SSR values due to dynamic rainwater tank airspace is calculated using: • SSR_L = 300 - (1,950 x Dynamic Airspace (kL) 2.1 x Roof Area (m2) -1.5) • SSR_T = 455 - (1,650 x Dynamic Airspace (kL) 2.3 x Roof Area (m2) -1.5) Subject to: • the development being residential, or its water usage can be considered to approximate that of a residence; • the design is in accordance with Sydney water requirements (visit the Sydney Water website for the current requirements); and • all overflows from the rainwater tanks are directed to the OSD storage.		
Site Area not Draining to OSD	When it is not feasible to direct runoff from the entire site to the OSD system (pending Council's approval) up to 30% of the residual site area may be permitted to bypass the OSD systems. The storage volume is still calculated on the entire site area while the SRD is adjusted downwards.	A portion of the new impervious areas (excluding roof area) shall discharge directly to Council's system if it cannot be drained to the storage facility, provided that the PSD is reduced to compensate for the smaller catchment. No more than 15% of the total site area shall be permitted to bypass the basin. The modified PSD shall be selected from the figure in the OSD calculation sheet. The calculation of storage requirement shall be based on the area which bypasses the basin.	Where possible, the drainage system shall be designed to direct runoff from all the impervious area of the site to the OSD system. If this is not feasible, then up to 20% of the impervious area of the site can bypass the OSD system provided that all the roof runoff is directed to the OSD and the PSD is modified according to the procedure below. The modified SSR (m3/ha) is calculated as = SSR for the whole site / ((1 – X/ total site area) where X is the area of the site bypassing the detention facility. The new PSD is then calculated from Figure 2.1 against the modified SSR. The total provided OSD volume should not be less than that originally calculated for the whole site.
Calculation Methods	An On-Site Detention Calculation spreadsheet has been prepared to ensure that calculations are undertaken in a manner consistent with the procedures described in the guidelines by all OSD designers.	Alternative values for the required storage volume shall be permitted if the applicant can demonstrate to Council's satisfaction, using appropriate computer modelling, that the relevant PSD shall be satisfied. Computation methods based on the approximate triangular method or the rational method shall not be acceptable.	For more complex situations, more detailed modelling can be undertaken using models such as DRAINS to demonstrate meeting the required PSD for the site.

SRD_L – Site Reference Discharge for primary (lower) orifice outlet.

SRD_U – Site Reference Discharge for secondary (upper) orifice outlet.

SSR – Site Storage Requirements

SSR_L – Extended Detention Volume

SSR_T – Overall Detention Volume

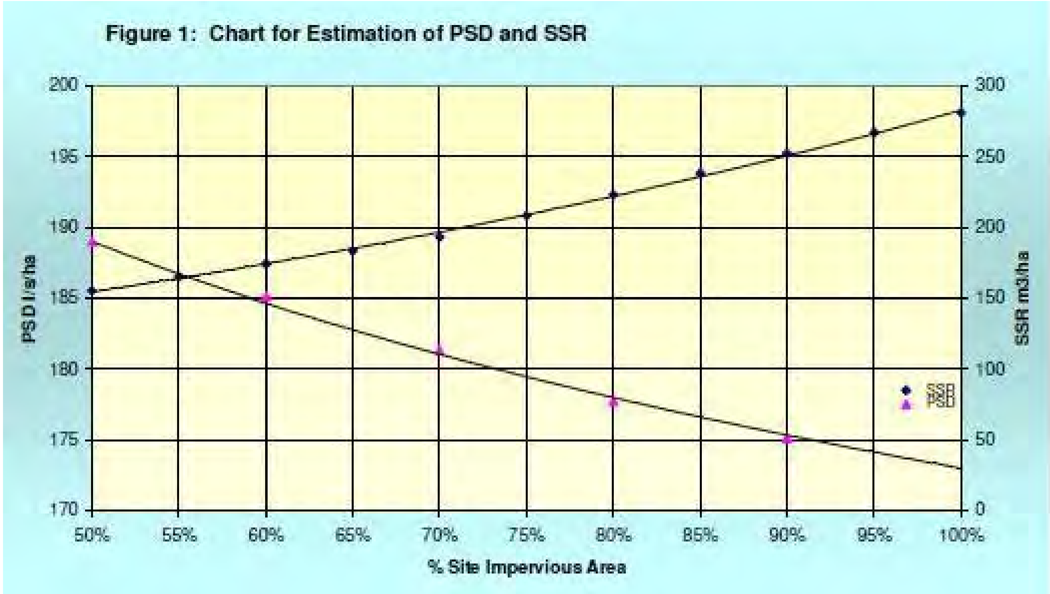


Figure 2-1 Kogarah Council SSR and PSD relationships depending on-site's impervious area

3 Onsite Retention Offsets – Existing Industry Research

Studies have been done within the stormwater industry assessing the appropriateness of incorporating rainwater tanks and OSD. Several key studies and their findings have been discussed briefly below.

Impact of Rainwater Tank and On-site Detention Options on Stormwater Management in the Upper Parramatta River Catchment (Coombes, P., Frost, A. and Kuczera, G., 2001)

In 2000 the Upper Parramatta River Catchment Trust (UPRCT) engaged Associate Professor George Kuczera, Peter Coombes and Dr Geoff O'Loughlin to determine how much of the volume of a rainwater tank, whose water is used for non-potable purposes, can be included in the site's OSD storage, without compromising the OSD system's flood mitigation performance.

The investigation involved generating a 1000-year rainfall record at six-minute intervals for the upper Parramatta River catchment. The record has been applied to a computer model of water usage on individual properties to simulate the performance over 1000 years of different combinations of OSD-only, rainwater tank only and combined systems.

The principal objective of this study is to determine by how much do rainwater tanks reduce the amount of OSD storage required to satisfy UPRCT's policy.

The study identified an average percentage of rainwater tank volume that could be counted as storage for OSD for various allotment scenarios as shown in Table 3.1.

Table 3.1 Average percentage of rainwater tank volume that can be counted as OSD site storage Volume of rainwater tank counting as OSD storage (%)

Scenario	No airspace in tank	50% airspace in tank
Allotment	42	65
Duplex	50	72
Townhouses	40	53
Walk up apartments	32	51

The study also found that on the lot scale the OSD systems reduced the peak discharge as required, but the on-site retention only reduced the volume of discharge, the peak flows remained the same. It was argued that peak discharges at the lot scale had little or no bearing on the floods at a catchment scale, as flooding is a volume driven process. However, a management measure that may reduce peak discharges at the lot scale but also reduces flood volumes can make an important contribution to reduce flooding.

Study on the Combined Effects of OSD and Rainwater Tanks on the Upper Parramatta River Catchment at Varying Sub-Catchment Scales (Cardno Willing, 2002, Additional Assessments: 2004, Supplementary Assessments: 2005)

The results provided by Coombes et al (2001) were considered to provide only an interim answer because the study only looked at individual sites and did not investigate the cumulative impact on peak discharges from groups of dwellings with rainwater tanks. As part of further detailed analysis of the cumulative impacts on peak discharges was undertaken by Cardno Willing in 2003 and 2004, the interaction of rainwater tanks and OSD tanks was investigated. Analyses were undertaken of both rainwater tanks with dedicated airspace and dynamic airspace.

Based on the analysis of the results reported in Cardno Willing, 2004 the SSR values in the UPRCT OSD Handbook – Fourth Edition (2005), were reduced based on the dedicated airspace of rainwater tanks.

Based on the analyses of the results of various rainwater tank simulations undertaken in 2004 and reported by Cardno Willing, 2005, the procedures outlined in Table 2.1 and used in the UPRCT OSD Handbook (2005) were allowed to calculate reductions in the SSR values as a result of likely dynamic airspace.

Rainwater Tanks for On-site Detention in Urban Developments in Western Sydney: An Overview (van der Sterren, M., Rahman, A., Barker, G., Ryan, G. and Shrestha, S., 2007)

This paper presents a brief overview of the on-site detention and retention practices adopted in greater Western Sydney. It has been found that policies differ significantly for different councils.

Since 1991, the UPRCT has conducted stormwater modelling works using XP-RAFTS model for 100 year average recurrence interval (ARI) flow which resulted in a permissible site discharge (PSD) and site storage requirement (SSR) (UPRCT, 2005). These requirements are used to design the OSD system, which generally results in very large detention tanks.

Some Councils have followed the lead by UPRCT and conducted modelling to determine PSD. Penrith City Council, for example, has conducted a simulation, which resulted in different PSDs for different areas of the Council. On the other hand, Councils such as the Blue Mountains City Council and Hawkesbury City Council have not conducted such modelling, and use the pre-development run-off as the constraint to design the OSD system (Hawkesbury City Council, 2000; Blue Mountain City Council, 2005). Furthermore, Hawkesbury City Council and Blue Mountain City Council do not have a significant local catchment flooding problem and have therefore not implemented the UPRCT requirements.

Mains Water Savings and Stormwater Management Benefits from Large Architecturally-Designed

Under-Floor Rainwater Storages **(Lucas, L. and Coombes, P., 2009)**

This paper provides monitoring of water use between January 2008 and December 2008 at a residential home in Hornsby Heights (NSW) that employs large architecturally-designed under-floor rainwater storages (4 x 16 kL cells). Water demand was continuously monitored using smart water meters to reveal intra-daily water use patterns. Based on this data, the PURRS model was used to continuously simulate the performance of the rainwater harvesting system using long-term climate records (at 6-minute timesteps) at the Hornsby House. The attributes of the rainwater harvesting strategy at this house was then applied to Adelaide, Brisbane, Canberra, Darwin, Hobart, Melbourne, Sydney and Perth; and simulated using PURRS with appropriate water demands (3-person household) and long-term rainfall records. Results indicate significant mains water savings and stormwater management benefits, such as reduced requirements for OSD, can be obtained using large architecturally-designed under-floor rainwater storages in all Australian capital cities.

The long-term rainfall record for Sydney (BOM data, Observatory Hill) and attributes of the Hornsby house, such as water demand, diurnal water use pattern and lot, roof and impervious areas, were used in the PURRS to determine reductions in runoff volumes and peak discharge.

Five different scenarios were investigated:

- BAU: “business-as-usual” (no demand management or rainwater storage);
- DM Only: demand management only (water saving appliances such as dual-flush toilets, and rated shower heads, dishwasher and washing machine);
- DM+5kL: Demand Management and 5kL rainwater storage;

- DM+16kL: Demand Management and 16kL rainwater storage; and
- DM+64kL: Demand Management and 64kL rainwater storage.

Table 3.2 shows the % reduction in runoff volumes compared to BAU. Note that "DM only" does not reduce stormwater runoff volumes. The use of larger rainwater storages only slightly reduced stormwater runoff volumes when compared to the DM+5kL scenario.

Table 3.2: Reduction in Runoff Volumes from the Allotment (Lucas et al, 2009)

	DM Only	DM + 5kL	DM + 16kL	DM + 64 kL
% reduction compared to BAU	0	18	24	26

The results showed that when allotment-scale rainwater storages are present there is a considerable reduction in peak discharge over a range of ARI values. However, the significance of these reductions depends on the criteria used to design stormwater treatment structures (i.e. sediment control, street drainage or flood management). It was found that only the 64kL rainwater storage provided significant benefits with regards flood management and reduce the requirement for OSD.

The Use of Rainwater Tanks as a Supplement or Replacement for On-site Stormwater Detention (OSD) in the Knox area of Victoria **(Coombes, 2009)**

This study investigated the use of rainwater tanks to supplement or replace on-site detention for stormwater management in the Knox City Council area in Victoria. The performance of a range of infill development scenarios is compared to the objectives outlined in Knox City Council's stormwater drainage guidelines that require on-site detention to limit peak stormwater discharges from 5 year ARI storm events as indicated by a weighted runoff coefficient of 0.4. The use of discrete rational method assessments reliant on weighted runoff coefficients is compared to the results of continuous simulation using local rainfall. This study has assumed that an effective impervious area of 0% coincides with a weighted runoff coefficient of 0.4.

Many local government authorities (including Knox City Council) currently recommend the use of discrete triangular hydrograph methods for evaluation of on-site detention systems. However, methods that employ design storms based on annual series evaluation of peak discharges cannot replicate the actual performance of volume sensitive systems. Actual rainfall events contain greater range of rainfall volumes than design storms; include many peaks in each storm event and a number of significant peak discharges in any year.

The PURRS model utilises real continuous rainfall records (6 minute time steps) and partial series analysis of peak discharges (a process which includes a maximum peak discharge from each storm event rather than a single maximum peak discharge for each year in the analysis) to understand the impact of on-site detention and rainwater tanks.

Analysis of duplex, triplex, townhouse, unit and warehouse developments reveals that rainwater tanks can provide a similar service to on-site detention systems whilst also providing significant water conservation. The on-site detention service provided by rainwater tanks is primarily dependent on rainwater use from the tank and roof areas connected to the tanks. Tank size was found to be a secondary variable.

An additional important aspect of designing rainwater harvesting systems for the management of peak stormwater discharges highlighted by this study is that there are optimum combinations of rainwater demands and connected roof areas. Reducing the area of roof connected to each rainwater tank for a given rainwater demand can improve the performance of the system. Up to a threshold, reductions in connected roof areas can allow water levels in rainwater tanks to be drawn down more frequently allowing greater reductions in peak discharges. Connection of large roof areas to rainwater tanks can produce a situation

where runoff into tanks from roof catchments overwhelms water demands from the tanks resulting in limited reductions in peak stormwater discharges.

The retention number proposed in this study in combination with the proportion of the development that is roof area connected to rainwater tanks was shown to be an indicator of the performance of rainwater tanks for stormwater detention. This study has also utilised the concept of "effective impervious area" to bridge the technical void between continuous simulation and discrete Rational Method assessments. It is noted that this study is limited to several development scenarios at a single rainfall location. This analysis has also focused on a single demographic profile and a sole objective of reducing 5 year ARI peak stormwater discharges to a given rate as defined by a weighted runoff coefficient.

A summary of the study results in shown in **Table 3.3.**

Table 3.3: Roof Area and Rainwater Tank Size for Compliance with Knox City Council's OSD Policy (Coombes, 2009)

	% of Site Area = Roof Area	Tank Size to Achieve Compliance with Council's OSD Policy
Duplex	11 %	No Compliance
	21 %	> 3 kL
	42 %	10 kL
Triplex	8.8 %	No Compliance
	17.5 %	> 2 kL
	35 %	> 4 kL
Townhouse	8.5 %	No Compliance
	16.9 %	> 3 kL
	33.9 %	10 kL
Units	10 %	No Compliance
	20 %	> 30 kL
	40 %	> 30 kL
Warehouse	13 %	No Compliance
	26 %	> 50 kL
	51 %	No Compliance

Rainwater Tank Options for Stormwater Management in the Upper Parramatta River Catchment (Coombes, P., Frost, A., Kuczera, G., O'Loughlin, G. and Lees, S., 2004)

This study investigated the extent to which rainwater tanks reduce the amount of on-site stormwater detention (OSD) storage required to satisfy the Upper Parramatta River Catchment Trust's (UPRCT's) OSD policy. In view of the limitations of the design storm approach, a continuous simulation approach was adopted. The DRIP stochastic rainfall model was linked with an allotment water balance model to evaluate different allotment scenarios using a 1000-year synthetic pluviograph record. The DRIP model was calibrated to a 53-year pluviograph located at Ryde. Comparison with statistics not used in calibration showed that DRIP performed satisfactorily. In particular, good agreement with observed intensity-frequency duration (IFD) curves was obtained, whereas AR&R IFD curves consistently underestimated the observed IFDs. Scenarios involving combinations of OSD, using 10kL rainwater tanks with 0 and 5 kL of detention storage were examined. For allotments with single dwellings between 50 to 70% of the tank volume can be counted towards the allotment's OSD volume. For a townhouse development, this percentage varied between 36% and 53%. Rainwater tanks used in the single dwelling and townhouse scenarios are expected to reduce mains water consumption by 39% - 30% and 32% - 27% respectively. The variation depends on the number of occupants and the amount of tank airspace reserved for detention storage and the fraction of allotment drained by the rainwater tank(s).

UPRCT On-site Detention Handbook (Fourth Addition)

In addition to the assessments outlined above which were undertaken on behalf of the UPRCT, The Handbook (Fourth Edition) also outlined the results of various rainwater tank simulations to identify the airspace at the start of a storm within a rainwater tank.

The following procedure was identified to calculate the rainwater tank dynamic airspace at the start of a storm:

$$\textit{Dynamic airspace (kL)} = 8.7 \times \textit{Nett Tank Volume (kL)}^{1.05} \times \textit{Roof Area (m}^{2}\textit{)}^{-0.5} \times \textit{Demand (kL/d)}^{0.35}$$

Where the Nett Tank Volume = Total Tank Volume – Dedicated Airspace – Top Up Volume.

4 Catchment Analysis

4.1 RAFTS Development

An XP-RAFTS hydrological model was established for the Whites Creek Catchment. The Whites Creek catchment is approximately 187 ha. The catchment rises to the south of Parramatta Road (external to the study area) to an elevation of approximately 46m AHD and includes portions of Leichhardt and Annandale. The southern portion of the Creek is a box culvert and Whites Creek Lane follows the majority of the length of this culvert. The culvert discharges into an open channel between Booth Street and Piper Street, and eventually discharges into Rozelle Bay to the east of The Crescent at an elevation of approximately 0m AHD. The land use within the catchment is highly urbanised and is predominantly residential.

Whites Creek Catchment has been selected as a representative catchment for the entire study area of the Leichhardt Flood Risk Management Study. Catchment analysis of various on-site detention (OSD) scenarios within this catchment will be used to inform the recommendations regarding OSD policy in the study area.

4.1.1 Model Set Up

Sub-Catchment Delineation

The catchment was divided into 160 sub-catchments based on the topographic and structural features. Contour data (0.5m contours), pipe network data and the cadastre was utilized to perform the subcatchment delineation. The average area of each sub-catchment is 1.2 hectares. The sub-catchment layout of the Whites creek catchment is presented in **Figure 4-1** and the RAFTS nodes are shown in **Figure 4-2**.

Land Use

Each sub-catchment was categorised according to the land uses contained within and appropriate impervious percentages were applied to each land use category. **Table 4-1** shows the impervious/pervious percentages used for each category.

Table 4-1: Impervious/Pervious Percentages

Land Use Category	Impervious (%)	Pervious (%)
Residential	60	40
Commercial	80	20
Open Space	5	95

Residential land use roughly occupied 137 hectares which represents 73% of the Whites Creek Catchment.

Figure 4-1 - Whites Creek Sub-Catchments

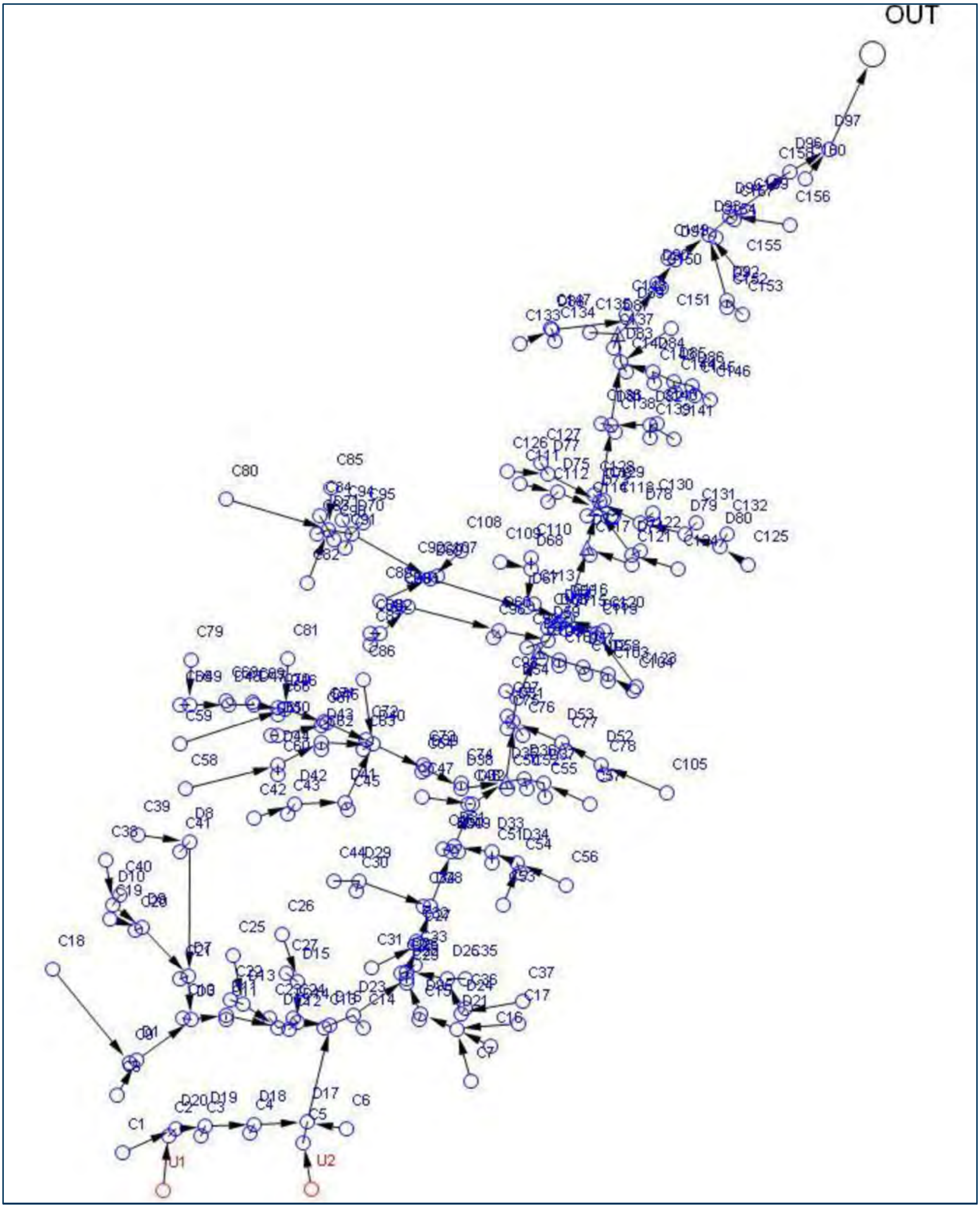


Figure 4-2 - RAFTS Model (160 node catchment model)

Rainfall Losses

The initial and continuing rainfall loss rates for impervious/pervious areas are presented in **Table 4-2**, which are based on Leichhardt LGA Flood Study (Cardno, 2014).

Table 4-2: Rainfall Loss Rate

Rainfall Loss Rate	Impervious Area	Pervious Area
Initial loss (mm)	1.5	10
Continuing loss (mm/hr)	0	2.5

Catchment Roughness

The values of catchment roughness were also based on Leichhardt LGA Flood Study (Cardno, 2014). The adopted values were 0.015 for impervious area, and 0.10 for pervious area.

Design Rainfall

The design rainfall was based on Leichhardt LGA Flood Study (Cardno, 2014). The rainfall intensities for the 5 year, 20 year and 100 year ARI events are provided in **Table 4-3**. The 1-2 hour duration event was critical for the majority of the Whites Creek Catchment.

Table 4-3: Key Rainfall Intensities

Rainfall Event	Intensity (mm/hr)		
	5yr ARI	20yr ARI	100yr ARI
45 minute	62	83	110
1 hour	53	71	95
90 minute	41	55	73
2 hour	34	45	60

4.1.2 Model Verification

The verification of the RAFTS model was undertaken by comparing the results of the 100 year ARI event extracted from the hydraulic model (SOBEK) with that of the hydrological model (XP- RAFTS). The SOBEK model was run using “rainfall on the grid” to simulate flows. It is not always expected that the results of the hydraulic and hydrologic models will exactly match (in fact, even two separate traditional hydrological models with similar parameters can produce significantly different results). However, where there are differences some interpretation of the results can be made, and the models can be checked as to why this is the case.

The comparison was undertaken along the major flow paths. It must be noted that the significant hydraulic controls, such as culverts and localised depression storages, would not be accounted in the hydrological model. The primary aim of this comparison was to ensure that the timing and peak flows from the direct rainfall hydraulic model (SOBEK) were reasonable, with a focus on the runoff areas rather than the mainstream flooding areas.

The locations where the models are compared are shown in **Figure 4-3**. Peak flow and volume estimated by the XP-RAFTS and SOBEK models at the comparison points for the 100 year ARI 60 minute event from the two sub-catchments are listed in **Table 4-5**.

Table 4-5: Sub-catchment Results for SOBEK and XP-RAFTS Models

Category	Catchment Area (ha)	Peak Flow (m^3/s)			Volume (m^3)		
		XP-RAFTS	SOBEK	% Change	XP-RAFTS	SOBEK	% Change
Node D14	24.17	10.15	8.15	19.85%	21771	19585	10.00%
Node D26	51.29	27.05	25.45	5.80%	64021	58743	8.25%
Node D40	22.32	8.60	8.65	-0.90%	19658	16225	17.45%
Node D54	104.42	42.50	40.80	3.98%	112046	98998	11.65%
Node D69	19.94	7.80	6.95	11.1%	17383	13175	24.20%

These results indicate a very reasonable agreement between the Direct Rainfall (SOBEK) and the XPRAFTS models. The overall volume of runoff is higher in the XP-RAFTS model than in the SOBEK model due to storage effects. The SOBEK model has an elevation grid that details localised depression storages, such as at roads, properties, and buildings, that are not represented in the XP-RAFTS model.

Peak flows are also reduced in the SOBEK model compared to the XP-RAFTS model due to the storage effects and due to the elevation and roughness grids in SOBEK that result in more detailed assessment of the conveyance and concentration of flows. Time-series hydrographs extracted at these locations are shown in **Chart 1** to **Chart 5** which show a similar rise and fall timing between the two models. The RAFTS hydrographs generally show an earlier start to flow than the SOBEK model due the lack of detailed storage and conveyance calculations.

Figure 4-3 - Comparison Nodes

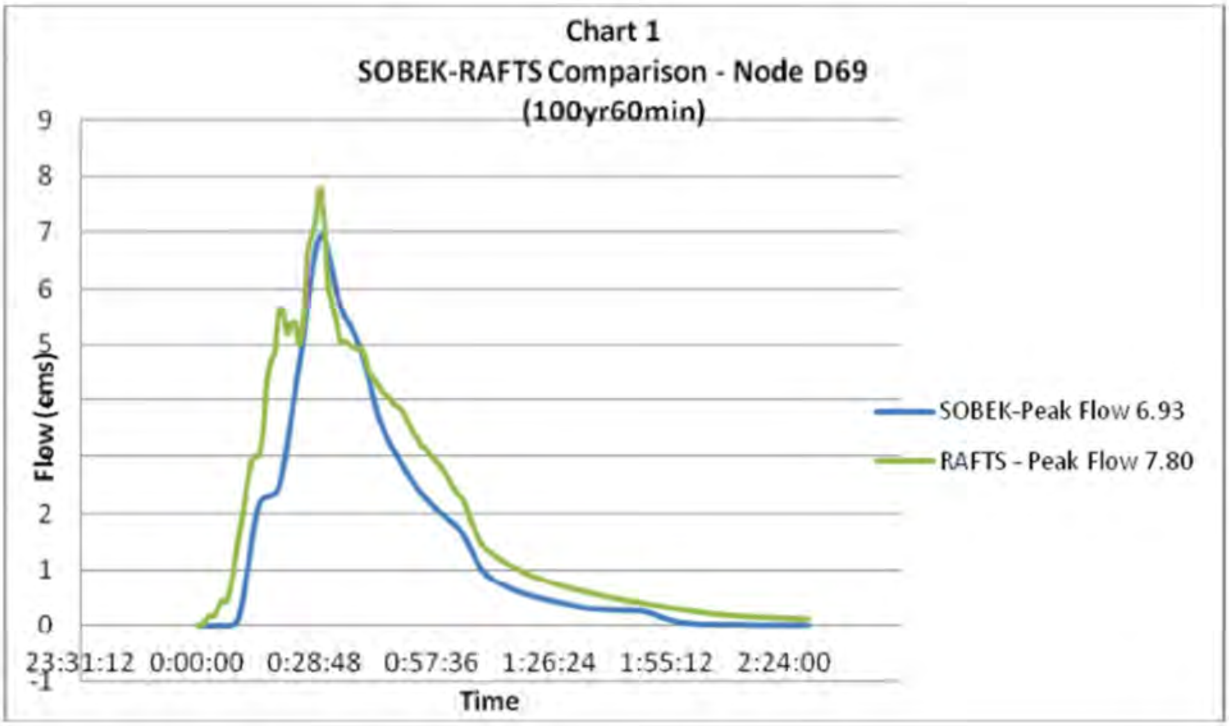


Chart 1
SOBEK-RAFTS Comparison - Node D69
(100yr60min)
9
8
7
6
5
4
3
2
1
0
-1
Flow (cms)
23:31:12 0:00:00 0:28:48 0:57:36 1:26:24 1:55:12 2:24:00
Time
SOBEK-Peak Flow 6.93
RAFTS - Peak Flow 7.80

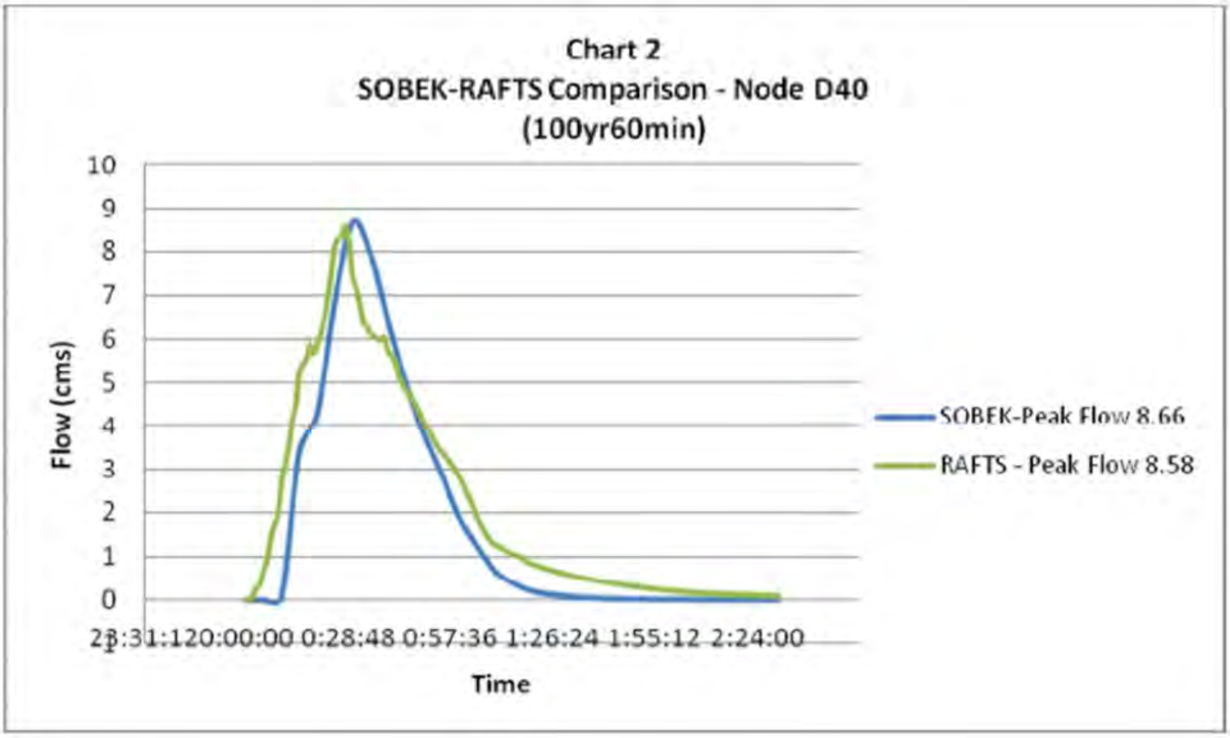


Chart 2
SOBEK-RAFTS Comparison - Node D40
(100yr60min)
10
9
8
7
6
5
4
3
2
1
0
-1
Flow (cms)
23:31:12 0:00:00 0:28:48 0:57:36 1:26:24 1:55:12 2:24:00
Time
SOBEK-Peak Flow 8.66
RAFTS - Peak Flow 8.58

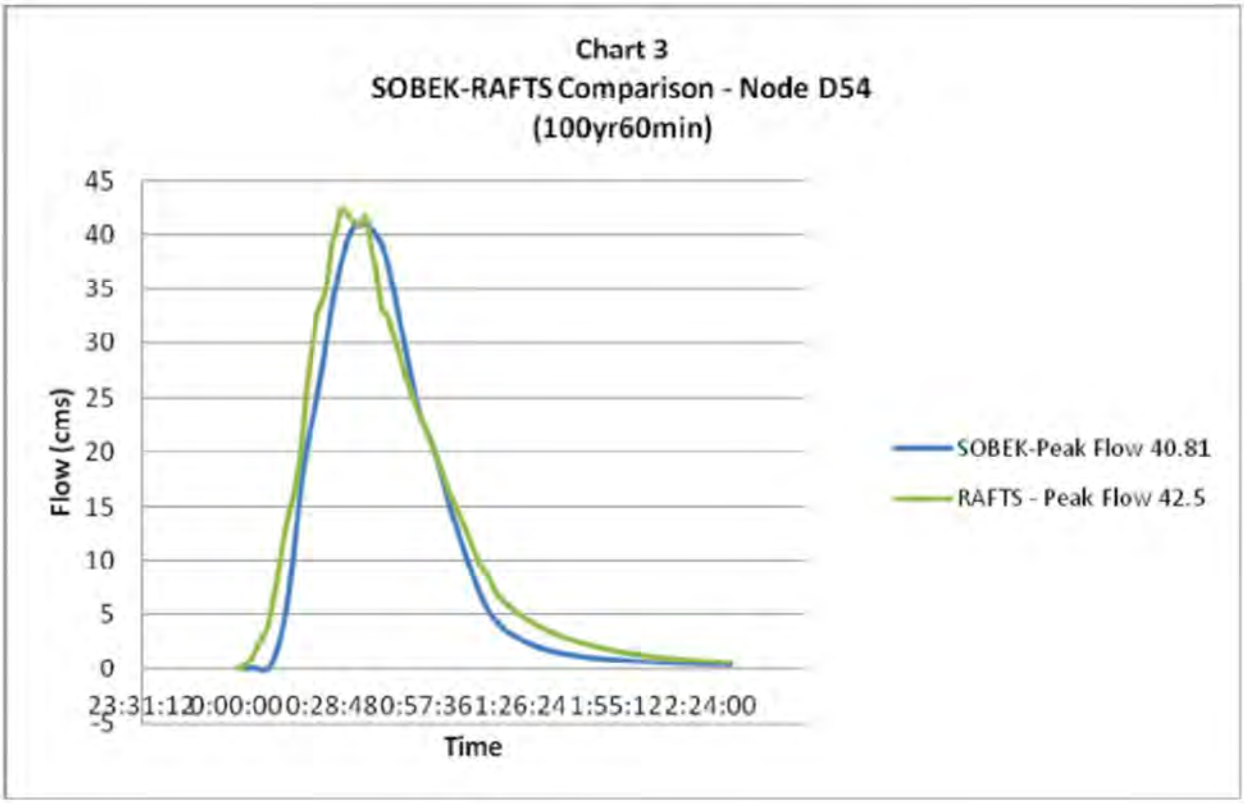


Chart 3
SOBEK-RAFTS Comparison - Node D54
(100yr60min)
45
40
35
30
25
20
15
10
5
0
-5
Flow (cms)
23:31:12
0:00:00
0:28:48
0:57:36
1:26:24
1:55:12
2:24:00
Time
SOBEK-Peak Flow 40.81
RAFTS - Peak Flow 42.5

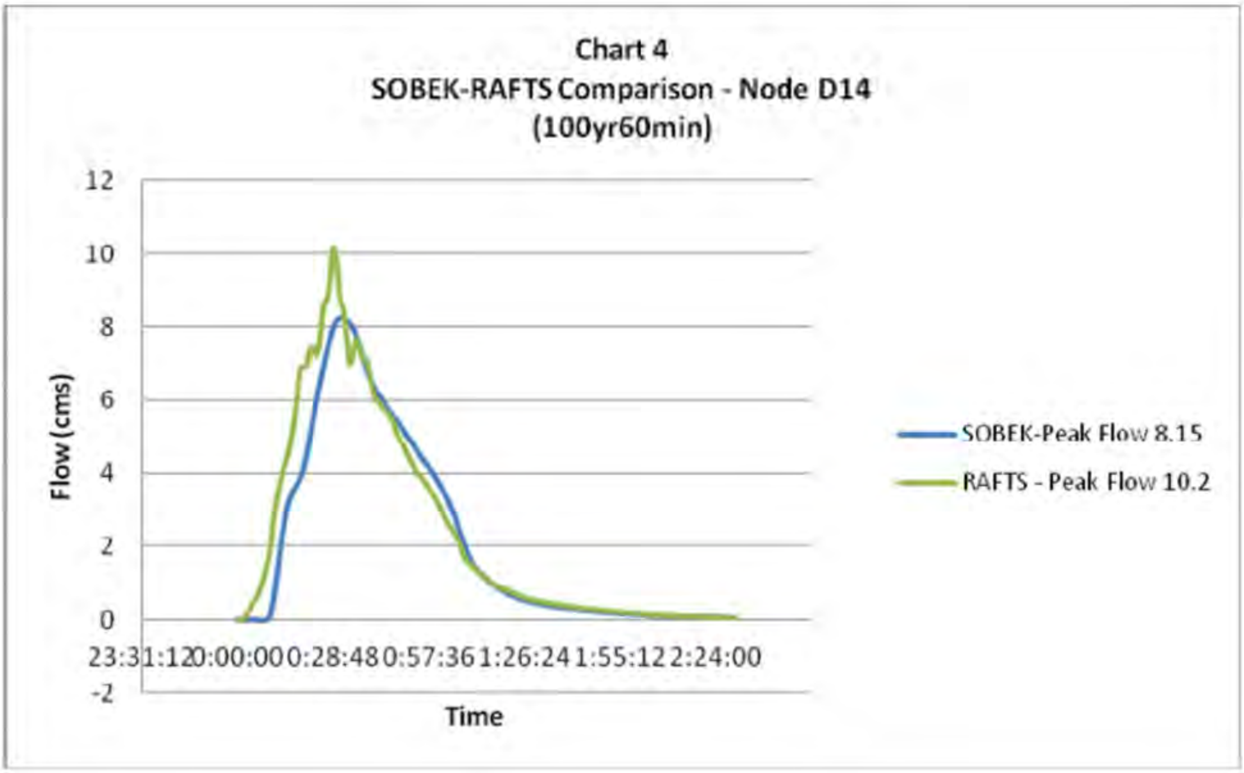
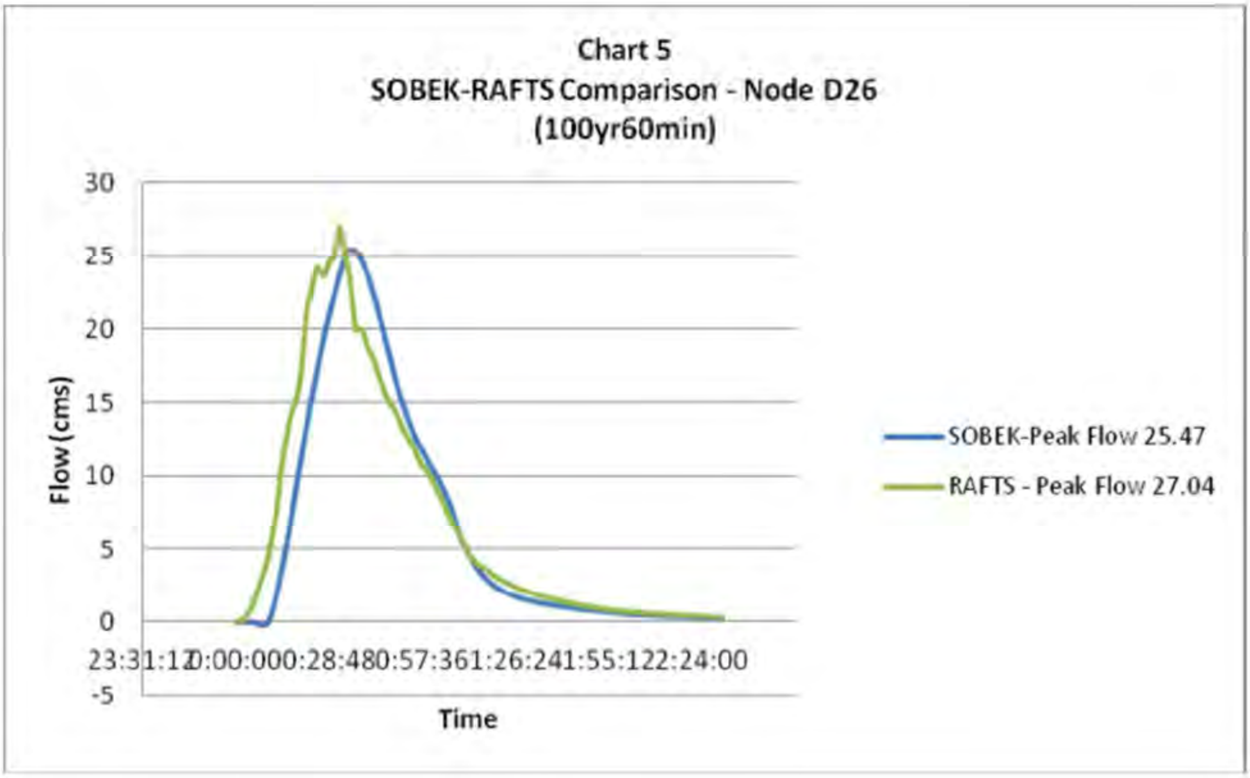


Chart 4
SOBEK-RAFTS Comparison - Node D14
(100yr60min)
12
10
8
6
4
2
0
-2
Flow (cms)
23:31:12
0:00:00
0:28:48
0:57:36
1:26:24
1:55:12
2:24:00
Time
SOBEK-Peak Flow 8.15
RAFTS - Peak Flow 10.2



4.1.3 Incorporating OSD into the Model

On-site detention was initially incorporated into the model for a test sub-catchment only. This allowed the model results to be verified on a small scale to ensure the OSD module was performing appropriately and also allowed a comparison of local effects of OSD compared to regional impacts.

The test sub-catchment is shown in **Figure 4-4**. The test sub-catchment was selected to ensure an appropriate combination of commercial / industrial, residential and road areas. The test sub-catchment has a total area of 13.6 ha which consists of 48% combined commercial and industrial, 35% residential, and 17% road.

As discussed in **Section 2.1.3**, a portion of properties may not feasibly be able to drain to OSD either partially or completely due to site topography. It was determined that those properties with greater than 1.5m fall from the street level would face difficulties draining to OSD. The test catchment was identified to contain approximately 5 percent of the property area within these “downhill” properties. For the purposes of the hydrological assessment, it was assumed that these properties would not contain OSD.

4.1.3.1 High Early Discharge

High early discharge (HED) systems work by routing stormwater runoff into a smaller secondary pit, located inside the OSD system at the location of the control outlet, allowing overflow to spill stormwater runoff to the main OSD storage. The stormwater runoff reaches its peak discharge rate faster as the water in the secondary pit fills up quicker due to the smaller area of the secondary pit. By allowing a greater rate of runoff at the commencement of the storm event the OSD volume to be provided to restrict post development flows back to pre-development levels may be reduced.

All hydrologic modelling was undertaken for scenarios with High Early Discharge (HED) turned on and off. The use of OSD without HED reduces the peak local drainage discharges when compared to OSD with HED.

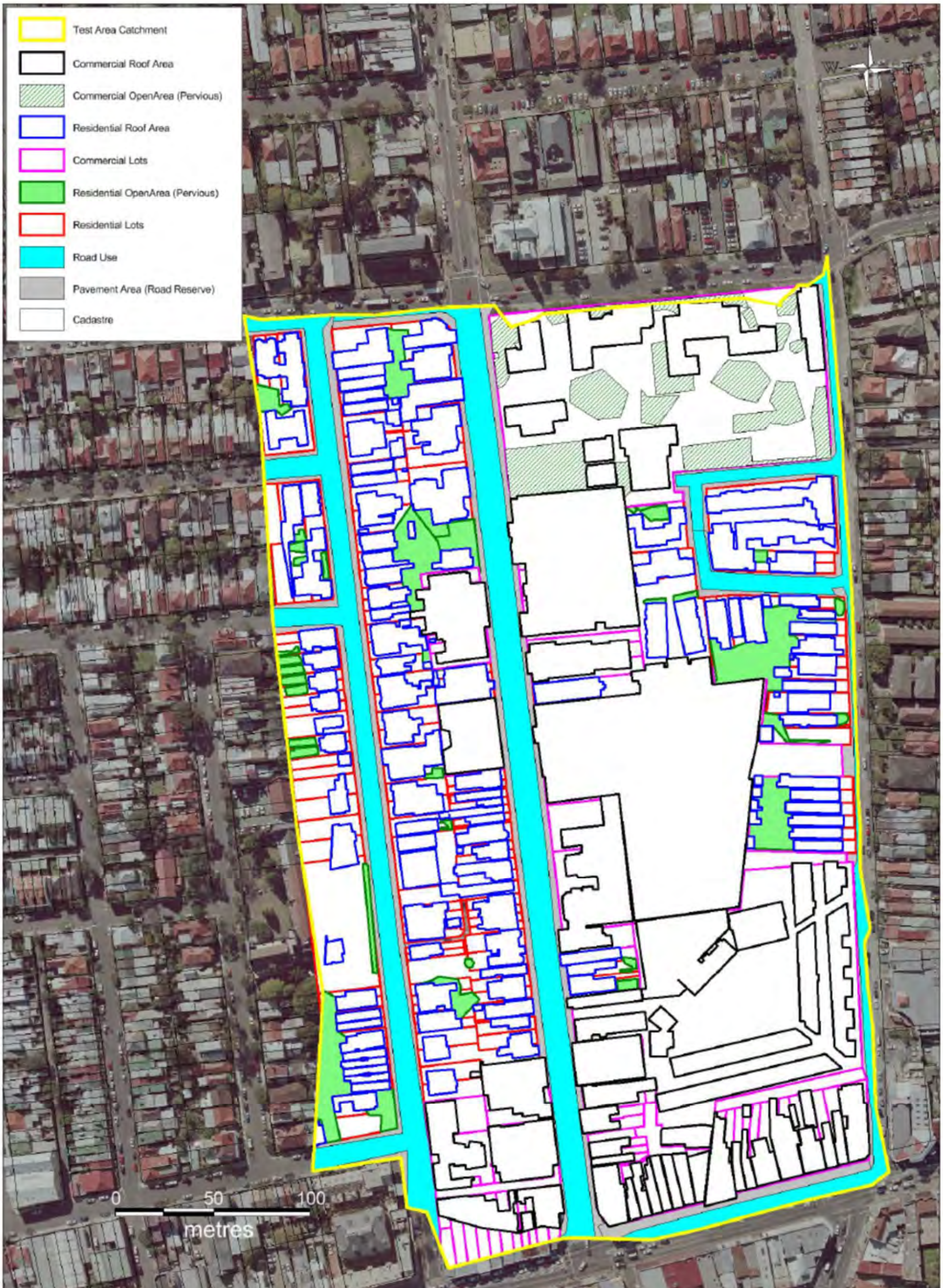


Figure 4-4 Land Use for Test Sub-Catchment

4.2 On-site Detention Scenario Analysis

The hydrological model was utilised to review Council's existing approach to OSD and to assess serval alternative approaches.

The modelling of Council's existing OSD approach involved:

- **Review of Council's current policy with regards to catchment wide flood impacts:** Council's current policy requires the discharge from the site in a 100 Year ARI event (post development) to be equal to the 5 Year ARI pre-development flows from the site. The RAFTS model was utilised to assess the SSR required to achieve this objective for the catchment as a whole.
- **Review of the existing calculation methods in Council's policy:** Council's existing OSD Policy is fairly flexible with regards to the calculation methods employed. This generally results in calculations only accounting for the immediate catchment and therefore assessing a critical duration of likely less than 30 minutes. On average, the existing calculation methods result in an SSR of approximately 2,000 L per lot. The benefits of this storage volume were assessed for the catchment as a whole.

Additional scenarios were then modelled as follows:

- **No OSD in Downstream Portion of Catchment:** Hydrological modelling was undertaken to assess the impacts of not applying OSD to the downstream portions of the Whites Creek Catchment.
- **No OSD on Low Density Residential Development:** While OSD can often more readily be included in commercial, industrial and high density developments, low density (i.e. single lot) residential development can be restricted by lot size and other site constraints such as the ability to excavate for OSD. As such, the impacts of not applying OSD to low density residential development was assessed.
- **Rainwater Tank Offsets for Low Density Residential Development:** The use of rainwater tanks instead of OSD was modelled for all low density residential development across the catchment.

4.3 Results

4.3.1 Review Council's Existing OSD Policy

Council's existing OSD Policy requires post development 100 Year ARI flows to be reduced to 5 Year ARI flows using OSD. The SSR and PSD values required to meet this objective were calculated using the test sub-catchment. The results were then extrapolated across the Whites Creek Catchment to see if the local catchment calculations resulted in the same reductions in flows across the wider catchment.

The test sub-catchment was modelled in RAFTS with no OSD for the 5 year, 20 year, 50 year and 100 year ARI events and each for the 45 minute, 1 hour, 90 minute and 2 hour duration storms. The resulting hydrographs were used to calculate the volume difference between the 100 year and 5 year ARI for the four durations. The results are shown in **Table 4-6**.

Table 4-6 – SSR required for 100 year ARI flows to be reduced to 5 year ARI flows

	45 min	1 hour	90 min	2 hour
SSR (m^3/ha)	256.1	300.4	248.0	229.4

The PSD was calculated using the 5 year ARI peak flow for the four durations since the objective of the OSD was to achieve a 5 year ARI flow from a 100 year ARI flow. The peak flows were then divided by the area of the representative sub-catchment. The results are presented in **Table 4-7**.

Table 4-7 – PSD required for 100 year ARI to fall to a 5 year ARI

	45 min	1 hour	90 min	2 hour
5yr Peak Flow (m^3/s)	3.7	4.1	4.3	4.0
PSD (L/s/ha)	353.4	384.2	409.1	374.0

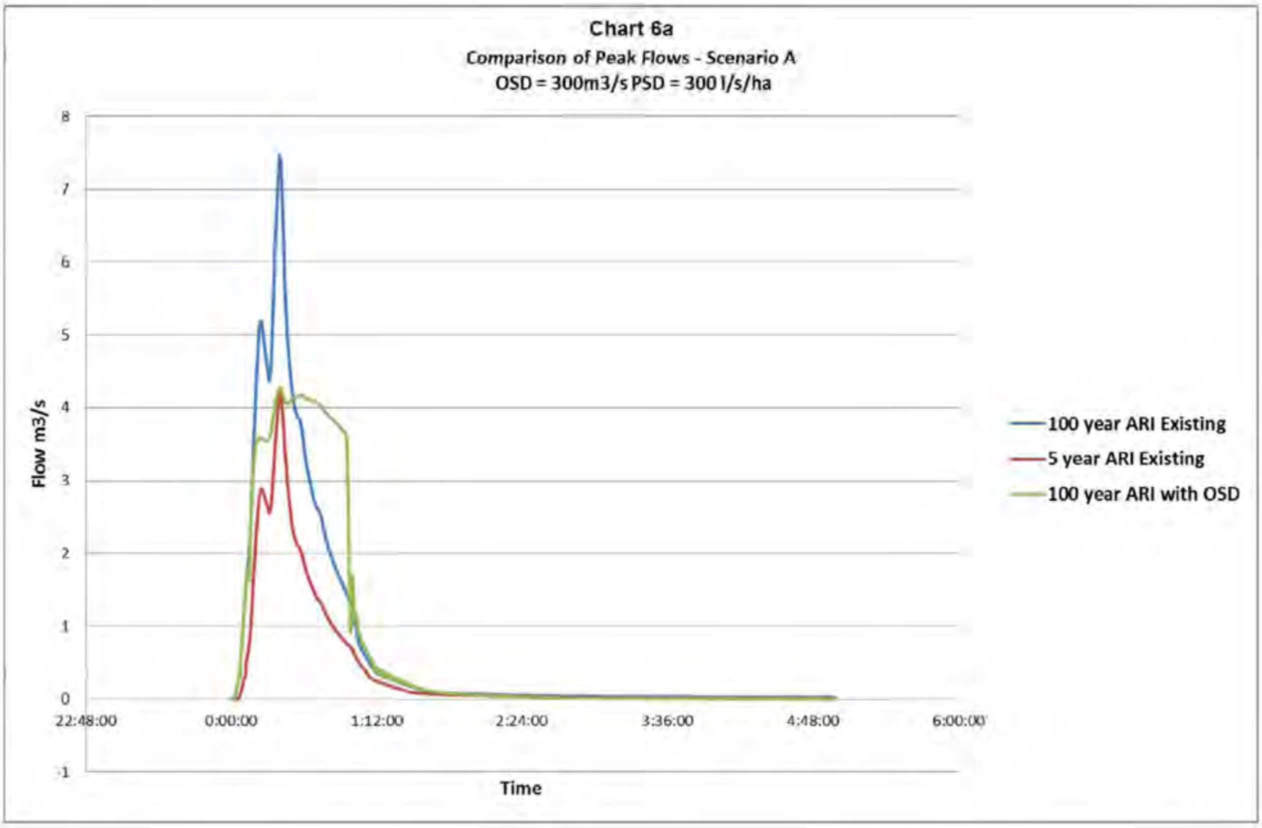
The critical duration for the test sub-catchment is 1 hour. Therefore, the following 1 hour SSR and PSD values were used as initial estimates for the OSD modelling in RAFTS:

- SSR = 300 m^3/ha
- PSD = 384 l/s/ha

The above values were then refined and verified for the local test sub-catchment using RAFTS. The updated SSR and PSD requirements are:

- SSR = 300 m^3/ha
- PSD = 300 l/s/ha

The updated estimates reduced the 100 year ARI flow for the 1 hour duration to the 5 year ARI flow in the representative catchment modelled in RAFTS. The hydrograph for Scenario A is depicted in **Chart 6a**.



The OSD parameters were then applied to the Whites creek catchment. Charts 6b to 10 depict the comparison of the flows with and without OSD for the nodes in **Table 4-5**.

It was found that while the OSD parameters calculated for the test sub-catchment were effective for the local catchment, the larger the contributing catchment became, the less effective the same OSD parameters were. At the catchment outlet (i.e. the most downstream point), there is almost no resulting difference in the peak flows as a result of OSD.

Some testing was also undertaken for large SSR requirements. However, very little difference in the results was observed.

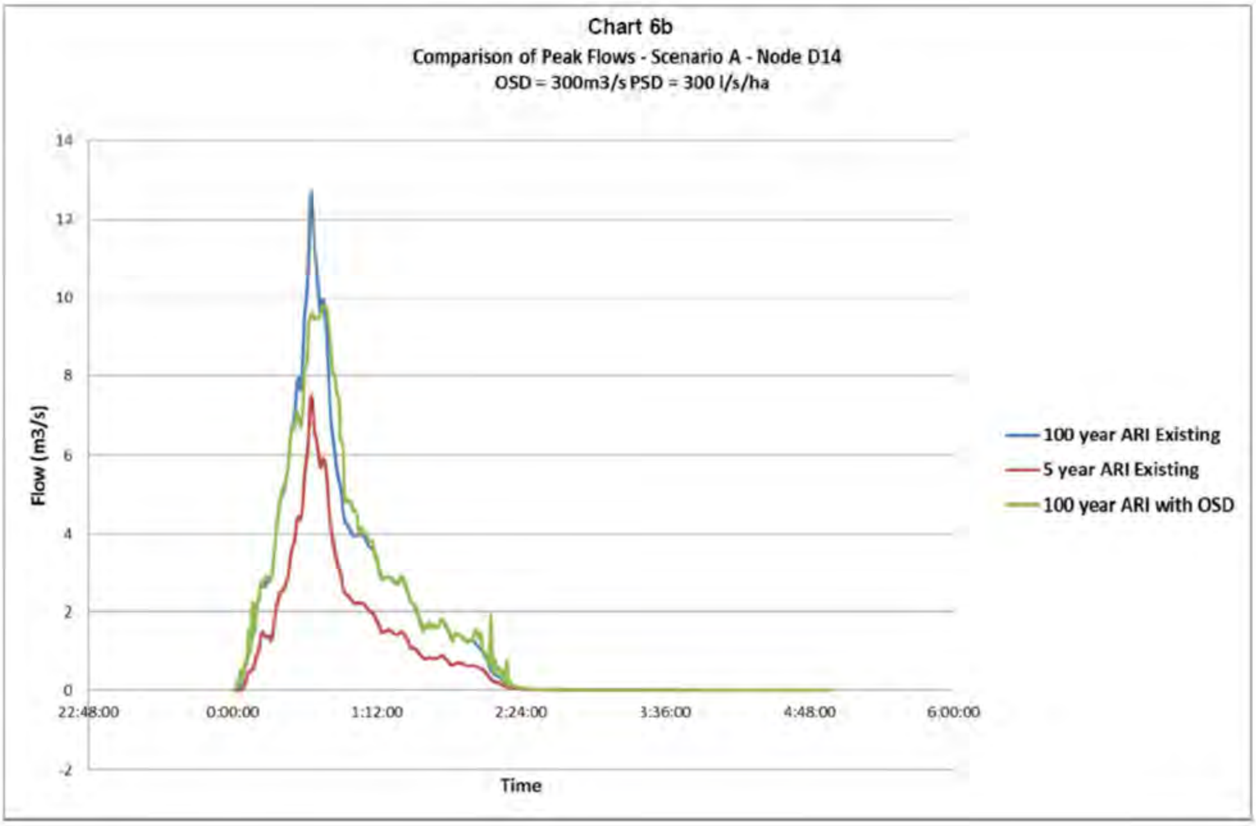


Chart 6b
Comparison of Peak Flows - Scenario A - Node D14
OSD = 300m3/s PSD = 300 l/s/ha
Flow (m3/s)
Time
14
12
10
8
6
4
2
0
-2
22:48:00
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
100 year ARI Existing
5 year ARI Existing
100 year ARI with OSD

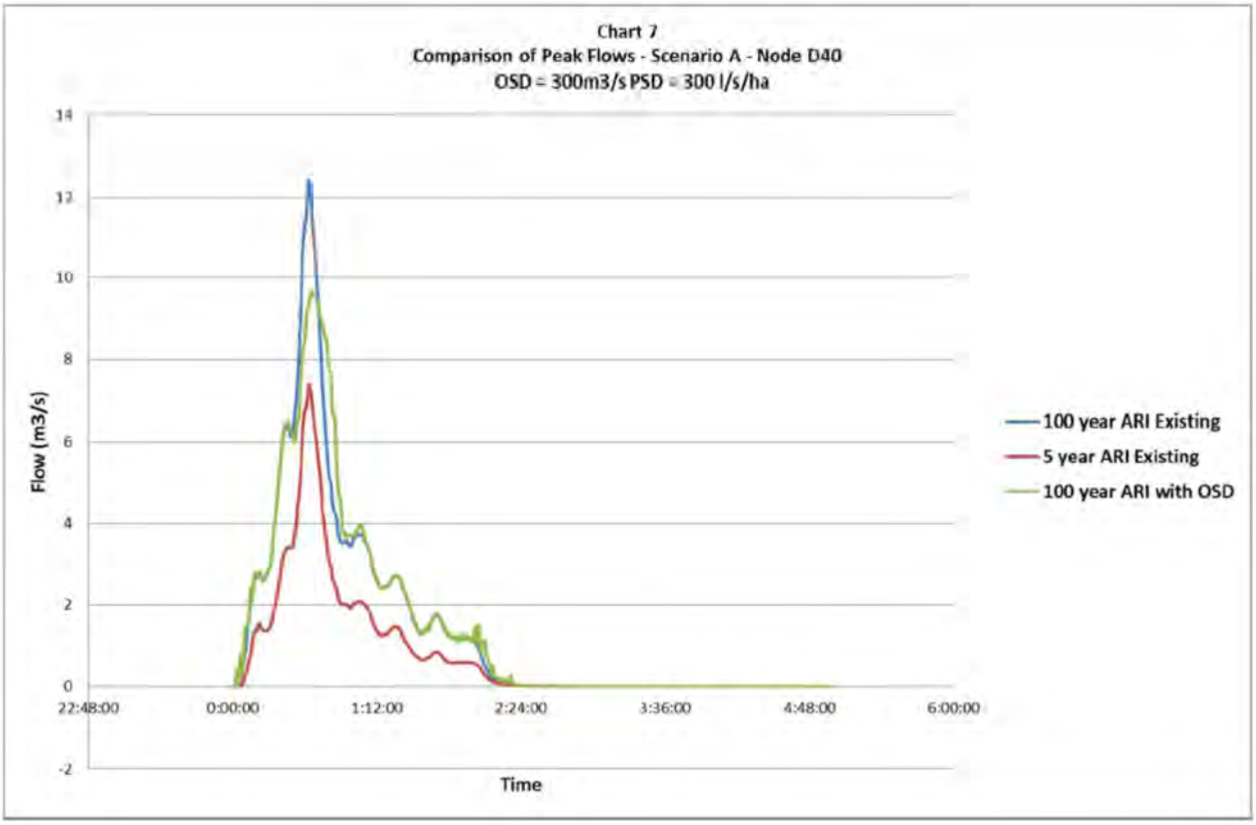


Chart 7
Comparison of Peak Flows - Scenario A - Node D40
OSD = 300m3/s PSD = 300 l/s/ha
Flow (m3/s)
Time
14
12
10
8
6
4
2
0
-2
22:48:00
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
100 year ARI Existing
5 year ARI Existing
100 year ARI with OSD

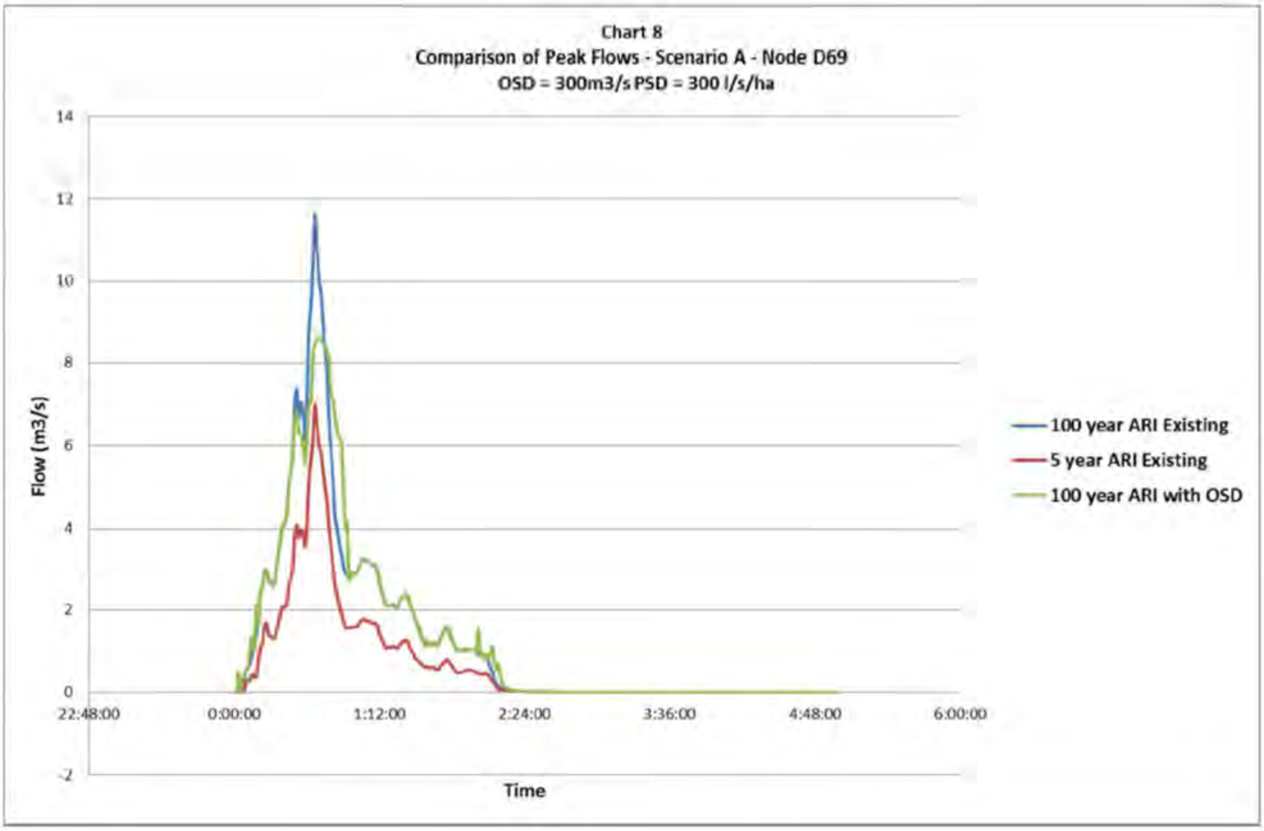


Chart 8
Comparison of Peak Flows - Scenario A - Node D69
OSD = 300m3/s PSD = 300 l/s/ha
14
12
10
8
6
4
2
0
-2
Flow (m3/s)
22:48:00
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
Time
100 year ARI Existing
5 year ARI Existing
100 year ARI with OSD

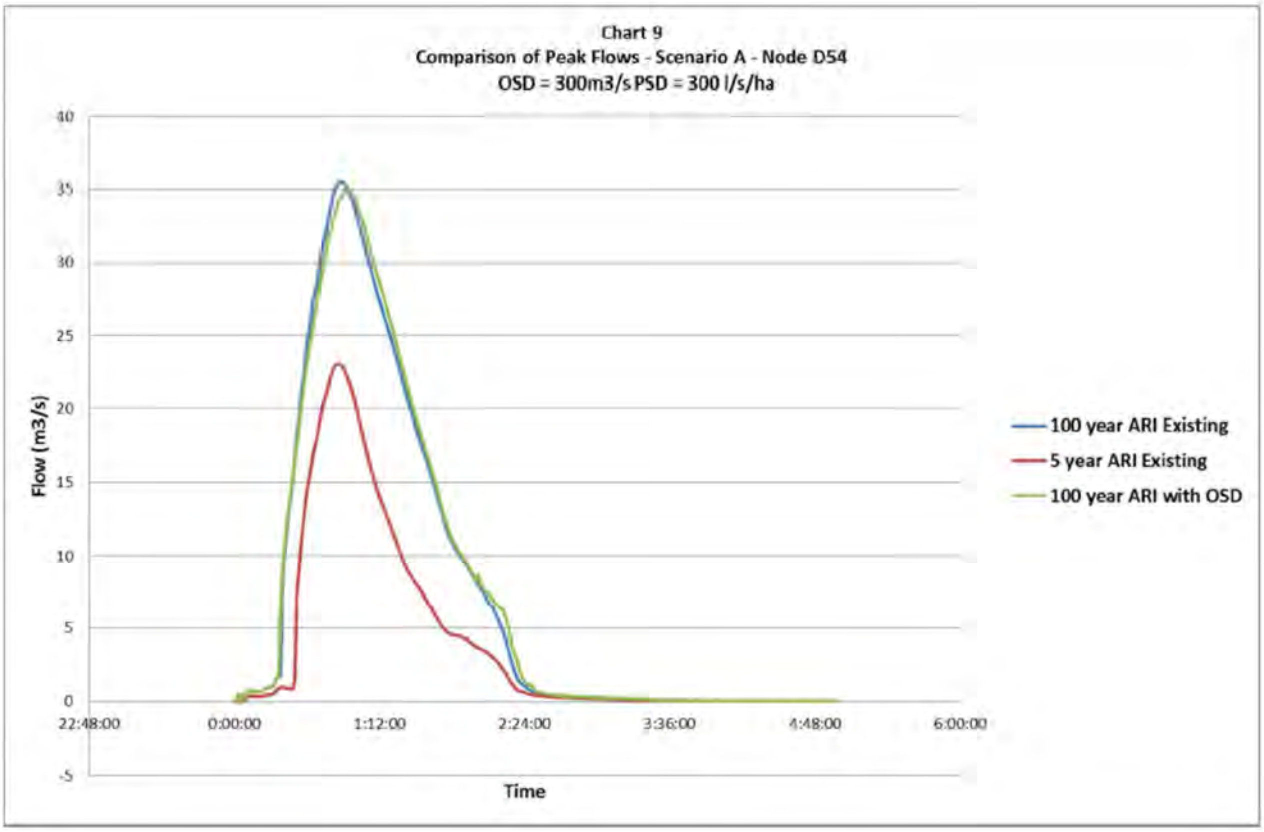
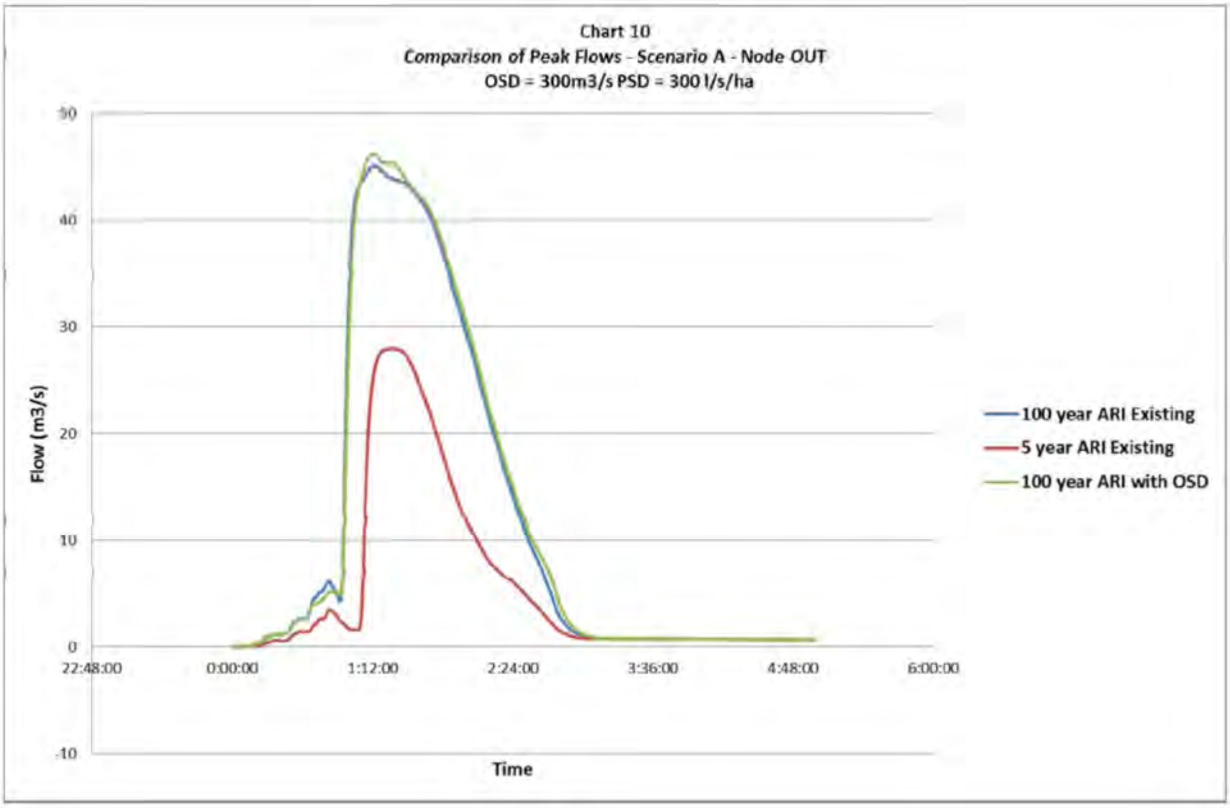


Chart 9
Comparison of Peak Flows - Scenario A - Node D54
OSD = 300m3/s PSD = 300 l/s/ha
40
35
30
25
20
15
10
5
0
-5
Flow (m3/s)
22:48:00
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
Time
100 year ARI Existing
5 year ARI Existing
100 year ARI with OSD



4.3.2 Review of the existing calculation methods in Council's policy

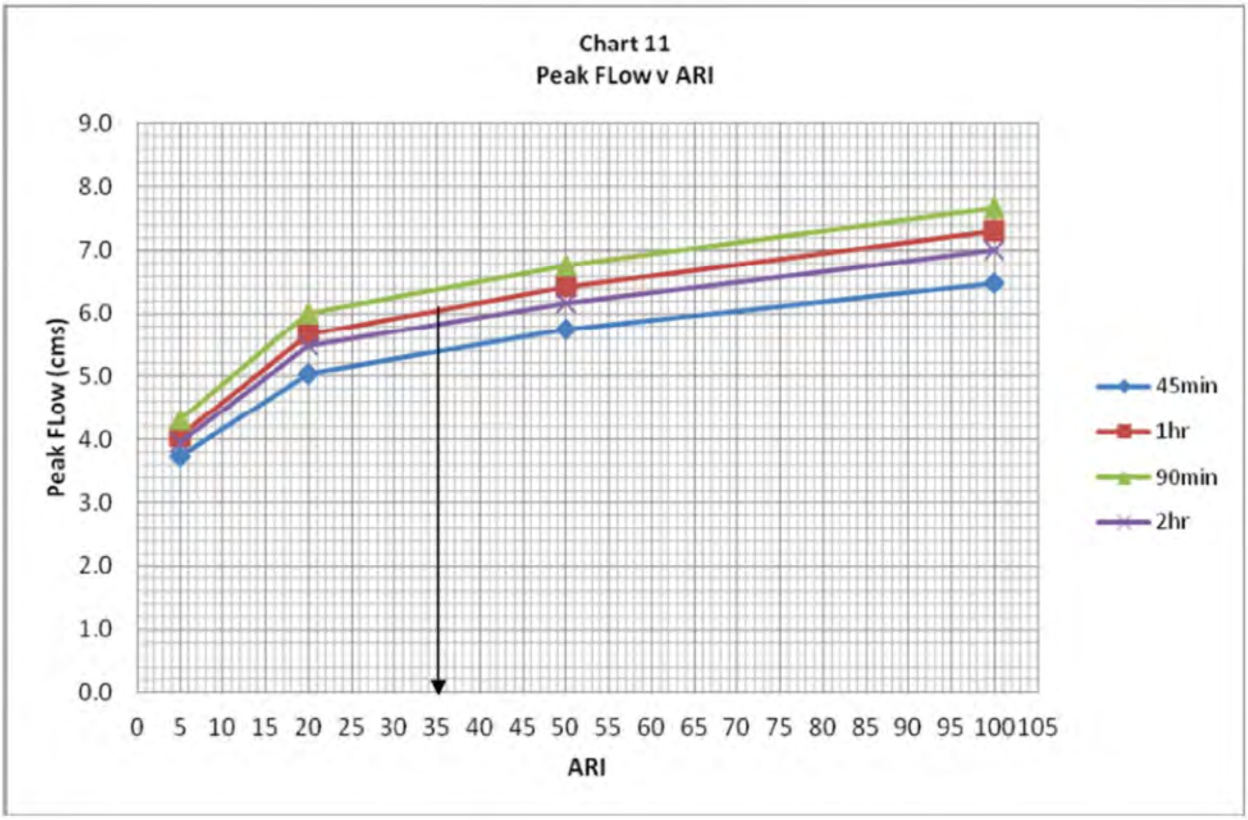
Council has advised that the existing calculation methods generally result in an approximately SSR of 2,000 L/lot. This equates to approximately 68 m^3/ha. This is significantly less than the SSR calculated above. This is likely to be due to the fact that in the absence of any specifications, calculations have generally been done for the immediate catchment only resulting in the application of a short critical duration (likely to be less than 30 minutes). The critical duration for the catchment is generally greater than 1 hour. This would result in a significantly smaller volume of rainfall being assessed for OSD application.

The existing policy was tested for the test sub-catchment within a spreadsheet and RAFTS. The policy was then also applied across the Whites Creek Catchment.

The test sub-catchment has a peak flow of 7.5 m^3/s for the 100 year ARI, 1 hour duration under existing conditions. The peak flow with a SSR of 68 m^3/s was 6.01 m^3/s for the same hydrograph. The reduction in peak flow shows that the OSD has some effect on the 100 year ARI. In order to determine the effectiveness of the OSD (SSR = 68 m^3/s a Peak Flow v ARI chart (Chart 11) was utilised. Chart 11 was plotted by extracting the peak flow data of the representative catchment (Table 4-8).

Table 4-8 Peak Flows

ARI	45min Peak Flow (m^3/s)	1hr Peak Flow (m^3/s)	90min Peak Flow (m^3/s)	2hr Peak Flow (m^3/s)
5	3.7	4.1	4.3	4.0
20	5.0	5.7	6.0	5.5
50	5.7	6.4	6.8	6.2
100	6.5	7.3	7.7	7.0



The equivalent ARI for the peak flow of 6.01 m^3/s was 35 Year ARI for the one hour duration. This identifies that the SSR of 68 m^3/s was not able to reduce the 100 year ARI flow to a 5 year ARI flow for the test subcatchment. Instead, the SSR only achieved a 35 year ARI flow.

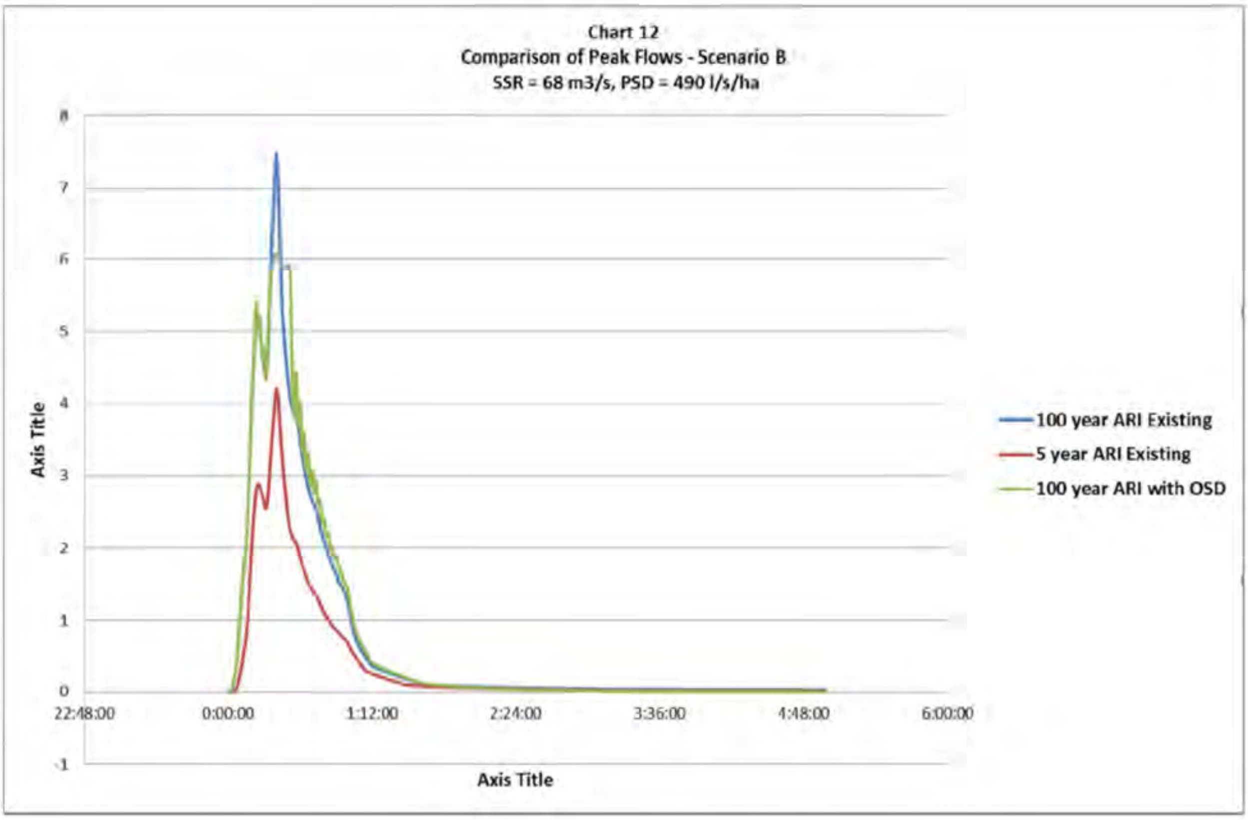
Based on a peak flow of 6.01 m^3/s and the area of the test sub-catchment and the SSR estimated by Council, the following initial SSR and PSD values were identified:

- SSR = 68 m^3/ha
- PSD = 569 l/s/ha

The above values were then refined and verified for the local test sub-catchment using the RAFTS model to achieve the 35 Year ARI flows. The updated SSR and PSD requirements are:

- SSR = 68 m^3/ha
- PSD = 490 l/s/ha

Chart 12 shows the comparison of peak flows (extracted from RAFTS) for the representative catchment area for the 100 Year Ari flows without OSD, the 100 Year ARI flows when an SSR of 68 m^3/ha is applied (i.e. approximately 2,000L per lot) and the 5 Year ARI flows without OSD (Council's Policy Objective).



The OSD parameters were then applied to the Whites Creek Catchment. It was found that OSD was effective for the local catchment but ineffective in the global catchment. **Charts 14 to 18 depict** the existing to OSD comparison for the nodes in **Table 4-5** excluding node 26. The charts depict that the existing OSD policy is inadequate for the local and global catchments.

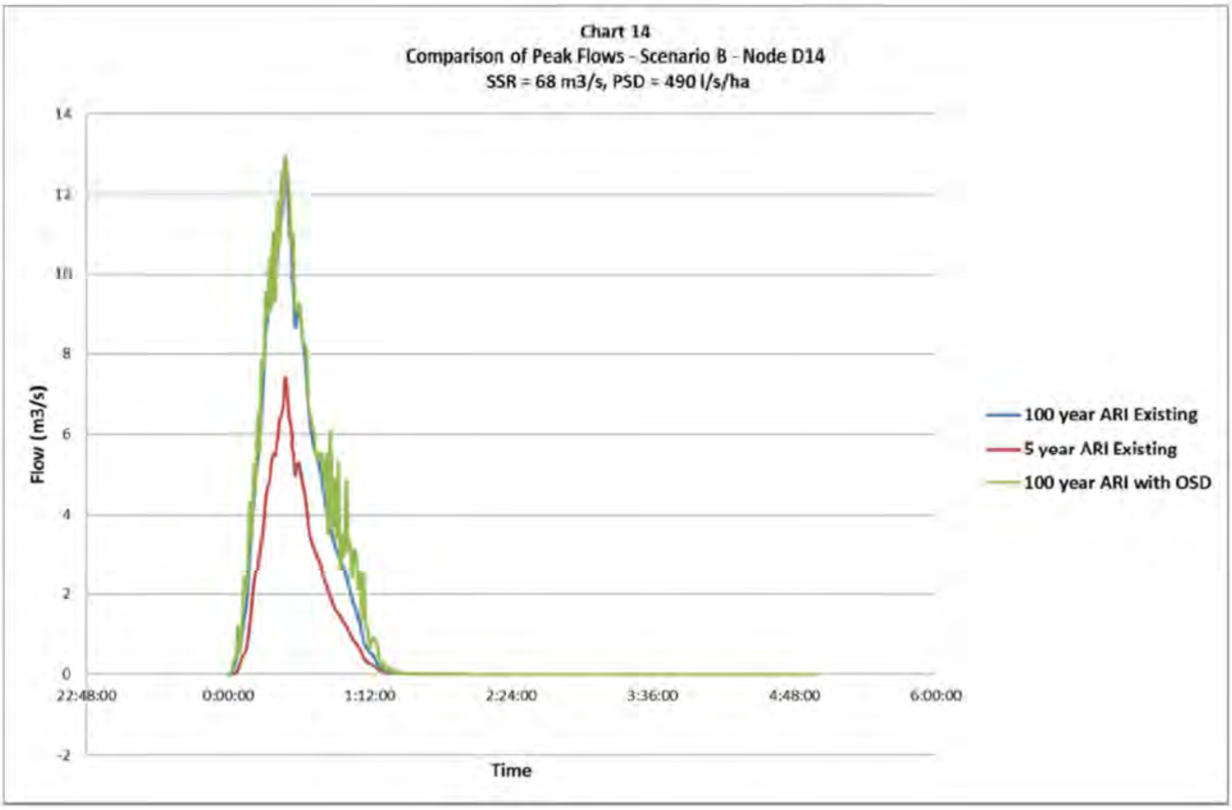


Chart 14
Comparison of Peak Flows - Scenario B - Node D14
SSR = 68 m3/s, PSD = 490 l/s/ha
Flow (m3/s)
Time
100 year ARI Existing
5 year ARI Existing
100 year ARI with OSD

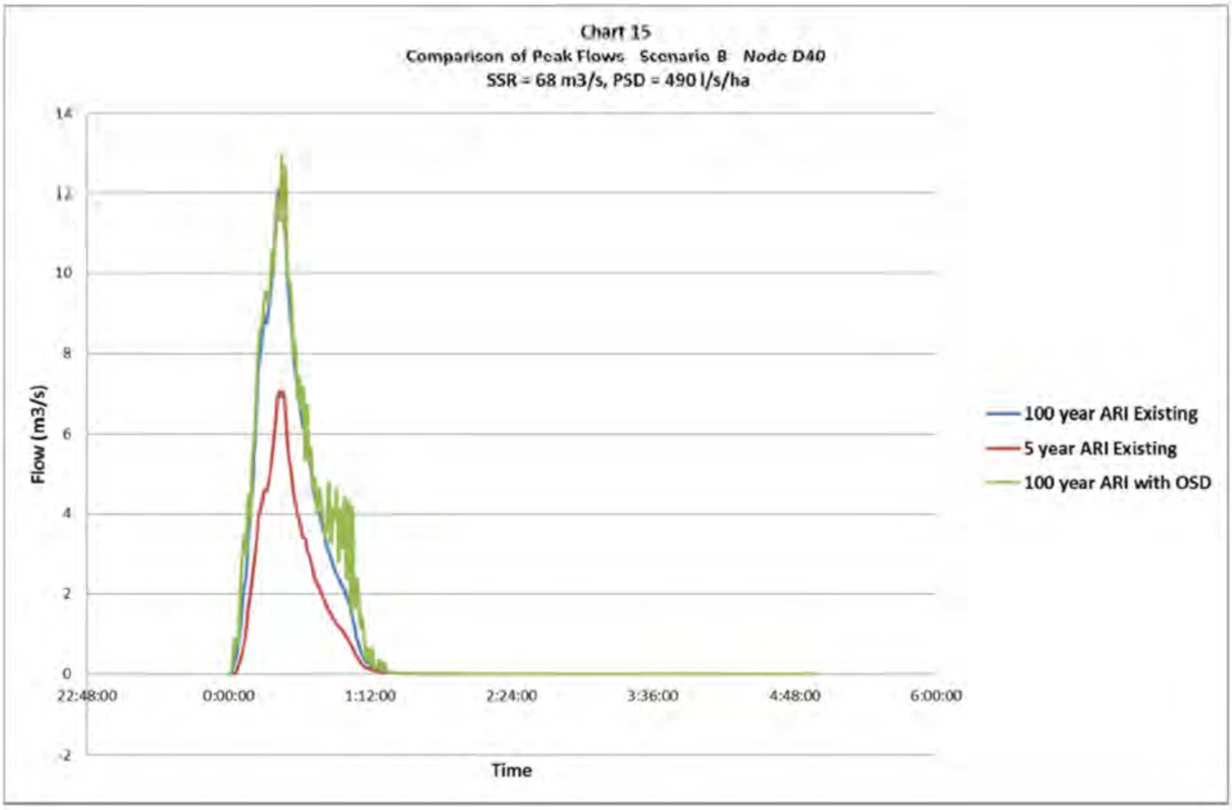


Chart 15
Comparison of Peak Flows Scenario B Node D40
SSR = 68 m3/s, PSD = 490 l/s/ha
Flow (m3/s)
Time
100 year ARI Existing
5 year ARI Existing
100 year ARI with OSD

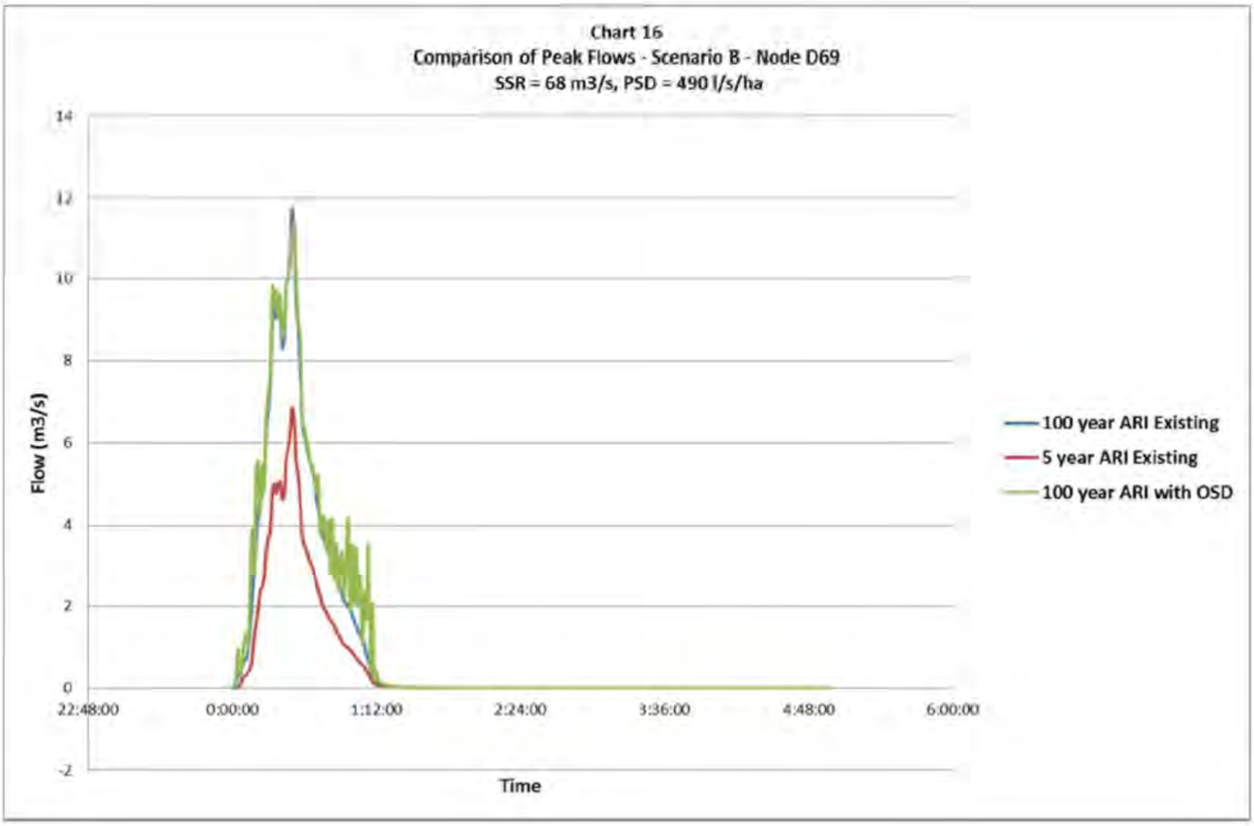


Chart 16
Comparison of Peak Flows - Scenario B - Node D69
SSR = 68 m3/s, PSD = 490 l/s/ha
Flow (m3/s)
Time
100 year ARI Existing
5 year ARI Existing
100 year ARI with OSD

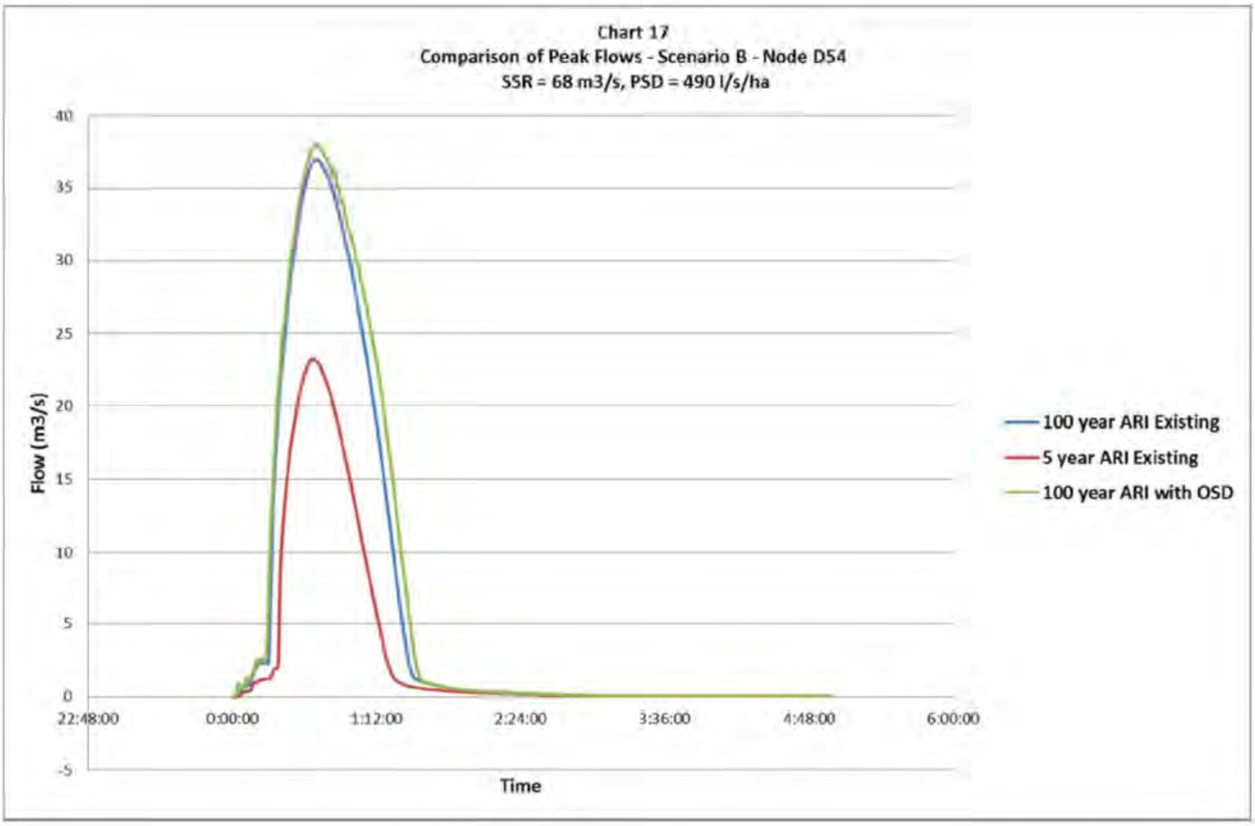


Chart 17
Comparison of Peak Flows - Scenario B - Node D54
SSR = 68 m3/s, PSD = 490 l/s/ha
Flow (m3/s)
Time
100 year ARI Existing
5 year ARI Existing
100 year ARI with OSD

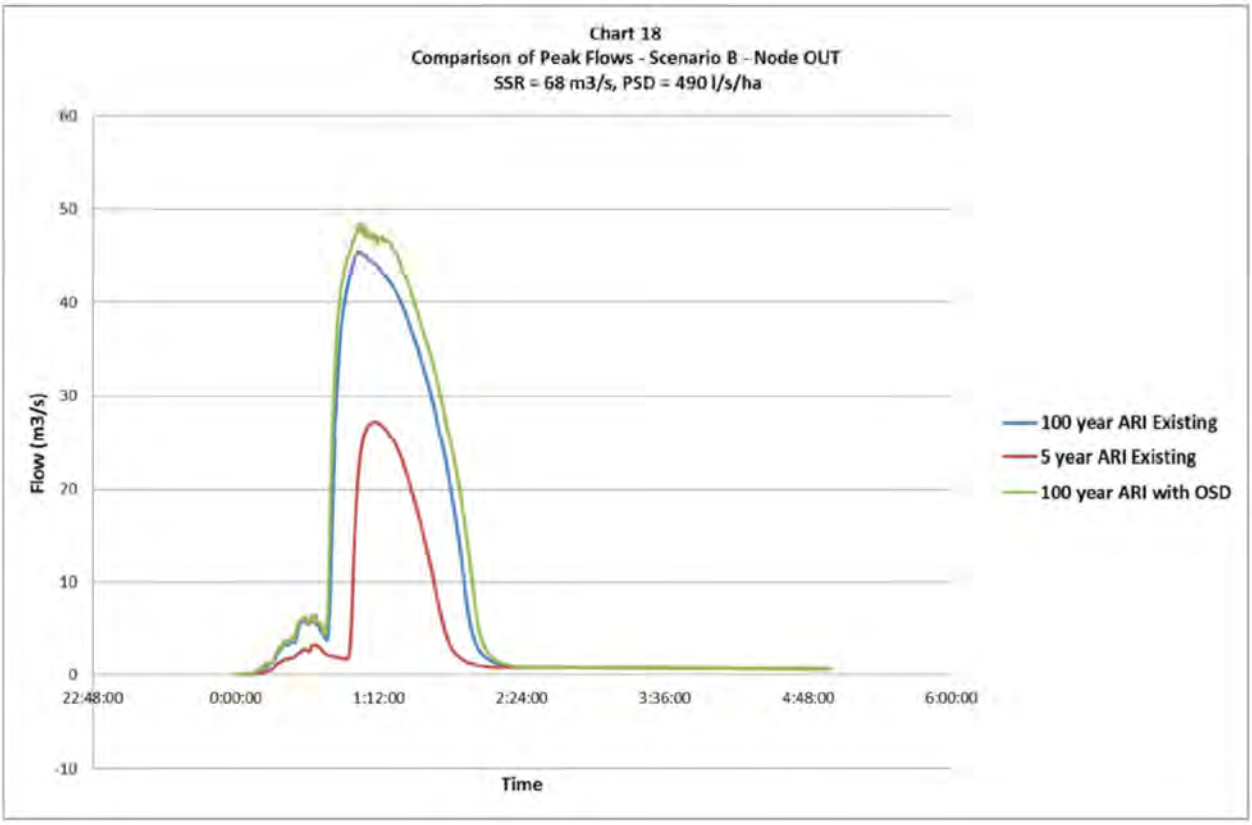


Table 4-9 gives a summary of the peak flows for the different scenarios for the representative catchment.

Table 4-9 – Summary of the Peak flow for the Different scenarios for the representative Catchment (RAFTS)

	Existing – 100year Peak Flow	Existing – 5year Peak	Scenario A Peak Flow	Scenario B Peak Flow
Flow (m3/s)	7.4 7	4.21	6.09	4.20

4.3.3 Downstream OSD Exclusion Zones

The modelling identified that applying OSD had benefits at a small scale but there were limited benefits at the downstream end of the catchment. Exclusion zones for OSD can be applied where the implementation of OSD has negligible benefits or in some cases, actually worsens flooding. For example, it may be beneficial to allow the flows in the downstream portions of the catchment to be discharged prior to the flows from the upstream areas "coming through". By detaining the local flows in the downstream areas, the flood peaks may actually end up coinciding with other catchment flows, thereby resulting in increased flood levels or durations of flooding.

Hydrological modelling was undertaken to assess the impacts of not applying OSD to the downstream portions of the Whites Creek Catchment. OSD was not applied downstream of Node C73 (see **Figure 4-1)**.

The following OSD parameters were modelled in the upstream areas:

- SSR = 300 m3/ha
- PSD = 300 l/s/ha

The results for both the OSD applied across the whole catchment and OSD removed from the exclusion zones are shown in **Figures 4-5 and 4-6**.

The results indicate that there is very little difference in flood behaviour within the 100 Year ARI flood extent when comparing the application of OSD in the exclusion zones and without OSD in these zones. The small difference that is shown should be interpreted within the context of the limitations of the hydrological modelling. As such, the difference is not considered to be of likely significance.

Although the flood behaviour is not impacted within the 100 Year ARI flood extent, there are local benefits to applying OSD within the exclusion zone. This may include management of property flows to the street, reduced ponding depths on roads and public areas and general reduced likelihood of drainage issues.

4.3.4 No OSD on Low Density Residential Development

While OSD can often more readily be included in commercial, industrial and high density developments, low density (i.e. single lot) residential development can be restricted by lot size and other site constraints such as the ability to excavate for OSD. As such, the impacts of not applying OSD to low density residential development was assessed.

The following OSD parameters were applied:

- Low density (i.e. single lot) residential development: no OSD or OSR
- All other development type: SSR = 300 m^3/ha and PSD = 300 L/s/ha

The results are shown in **Figure 4-7**, this should be compared against **Figure 4-5** to interpret the impact of this scenario on drainage and flood flows. The model results showed that due to the fact that the majority of land use in the catchment is low density residential development, the lack of OSD on these properties resulted in almost no reduction in flood flows across the catchment.

4.3.5 Hydrological Testing of Rainwater Tank Offsets

The research currently available regarding the use of rainwater tanks for OSD suggests that there are considerable opportunities for providing OSD offsets in traditional rainwater tanks.

Council has in the past allowed a rainwater tank offset of 2.5 OSR : 1 OSD. The effectiveness of this approach was tested by reducing the OSD for all lots by 1m^3 and applying a rainwater tank volume of 2,500 L (2.5m^3). The results are shown in **Figure 4-8**. This should be compared against **Figure 4-5** to interpret the impact of this offset scenario has on drainage flows and flood flows. It was found that this significantly reduced the effectiveness of OSD, with the 100 Year ARI Flows in the upstream reaches being reduced to approximately 50 Year ARI flows.

An alternative approach was then assessed as follows:

- OSD was applied to all development except low density (i.e. single lot) residential development at the following rate:
    - SSR = 300m^3/ha and PSD = 300 L/s.
- OSR was applied to all low density (i.e. single lot) residential development, using 5,000 L/lot.

In both of the scenarios above, it has been assumed that the same rainwater tank policy has been applied upstream of the study boundary (i.e. upstream of Parramatta Road).

The results are shown in **Figure 4-9**. This should be compared against **Figure 4-5** to interpret the impact of this offset scenario has on drainage flows and flood flows. The results identified that while the flood management outcomes are not as beneficial as applying OSD to all development types, there is still a flood benefit from this approach (reductions of the 100 Year ARI flows to approximately 20 Year ARI flows in the upstream reaches of the floodplain).

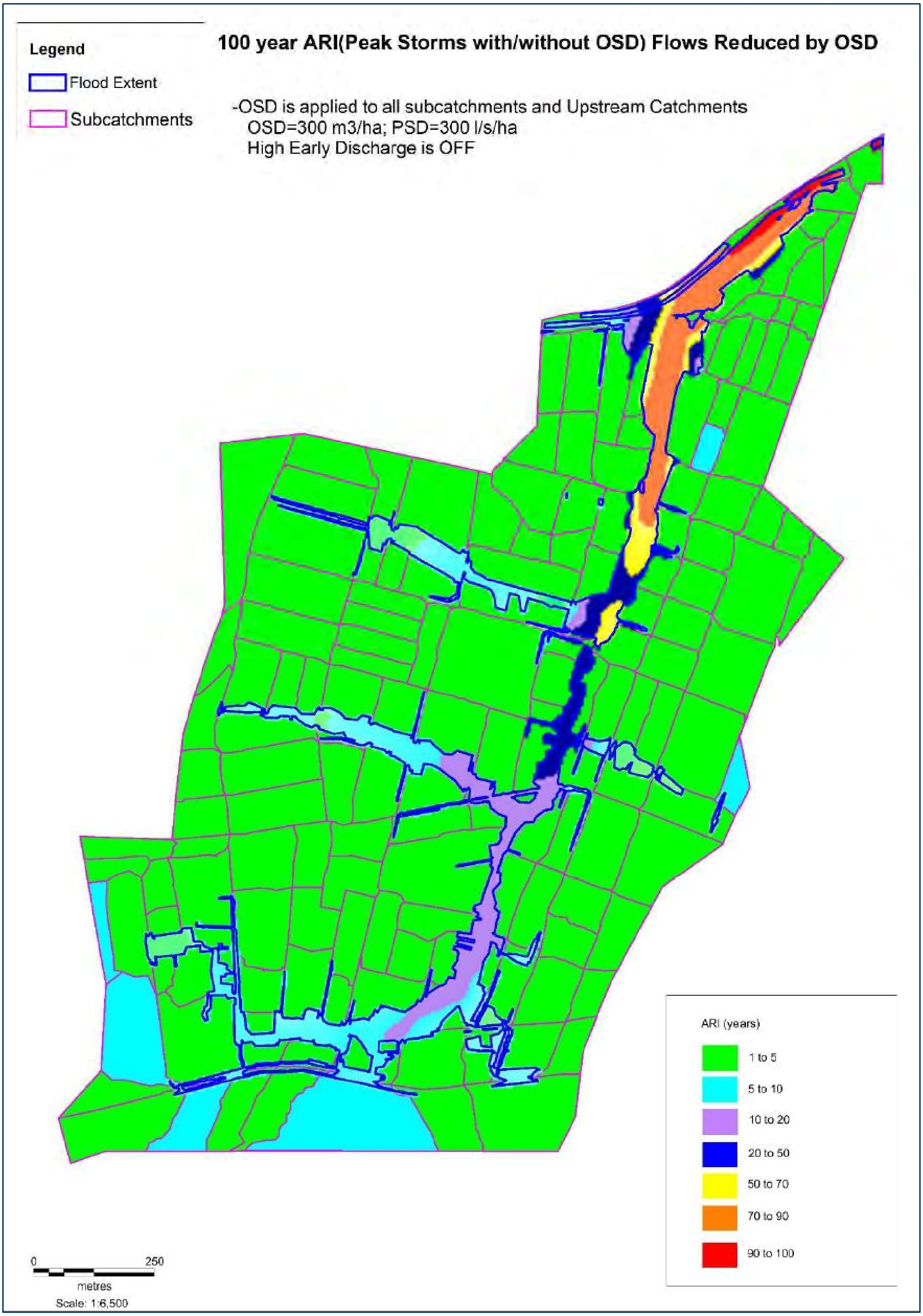


Figure 4-5 OSD Applied to Entire Catchment

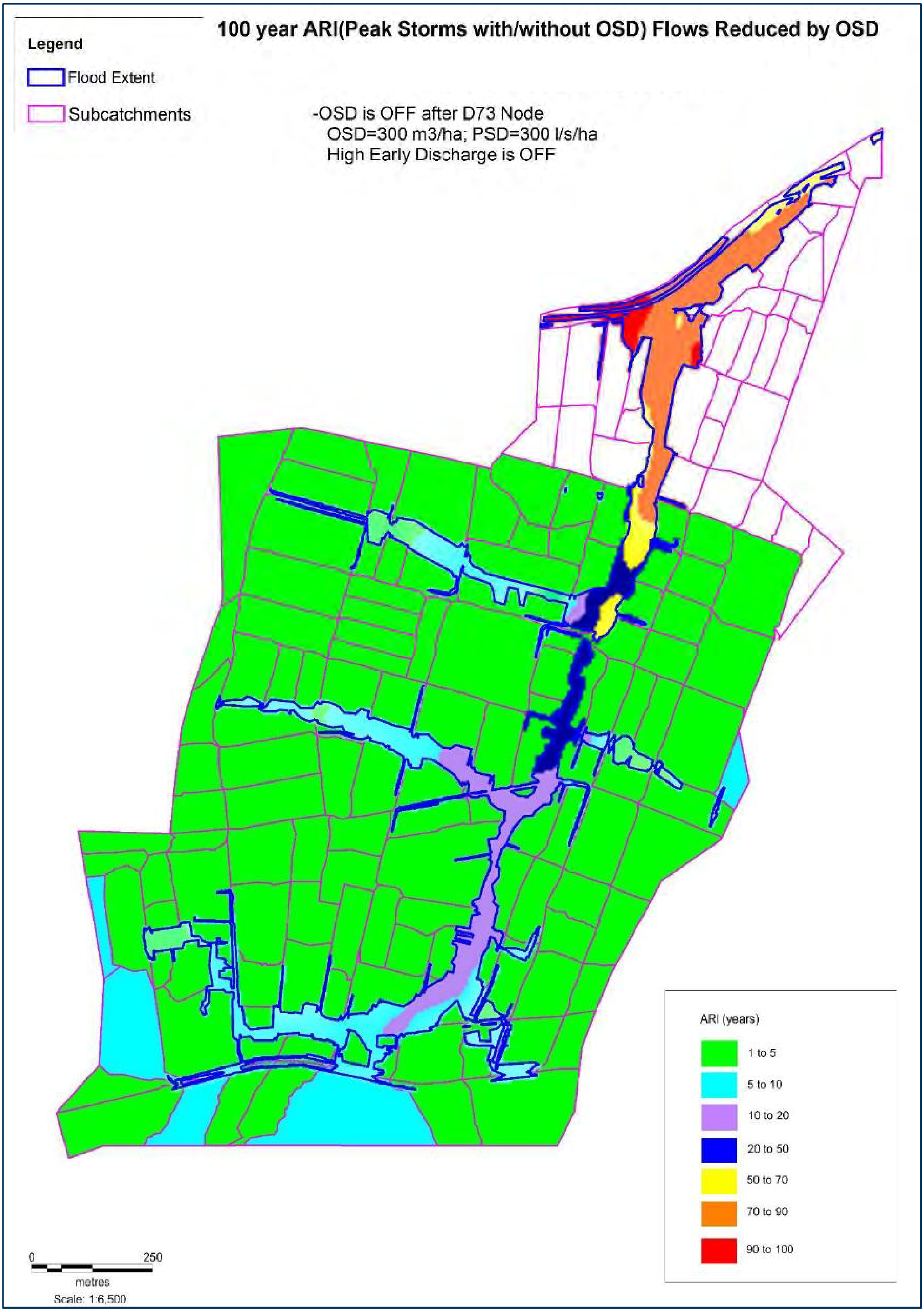


Figure 4-6 OSD not Applied in Exclusion Zones

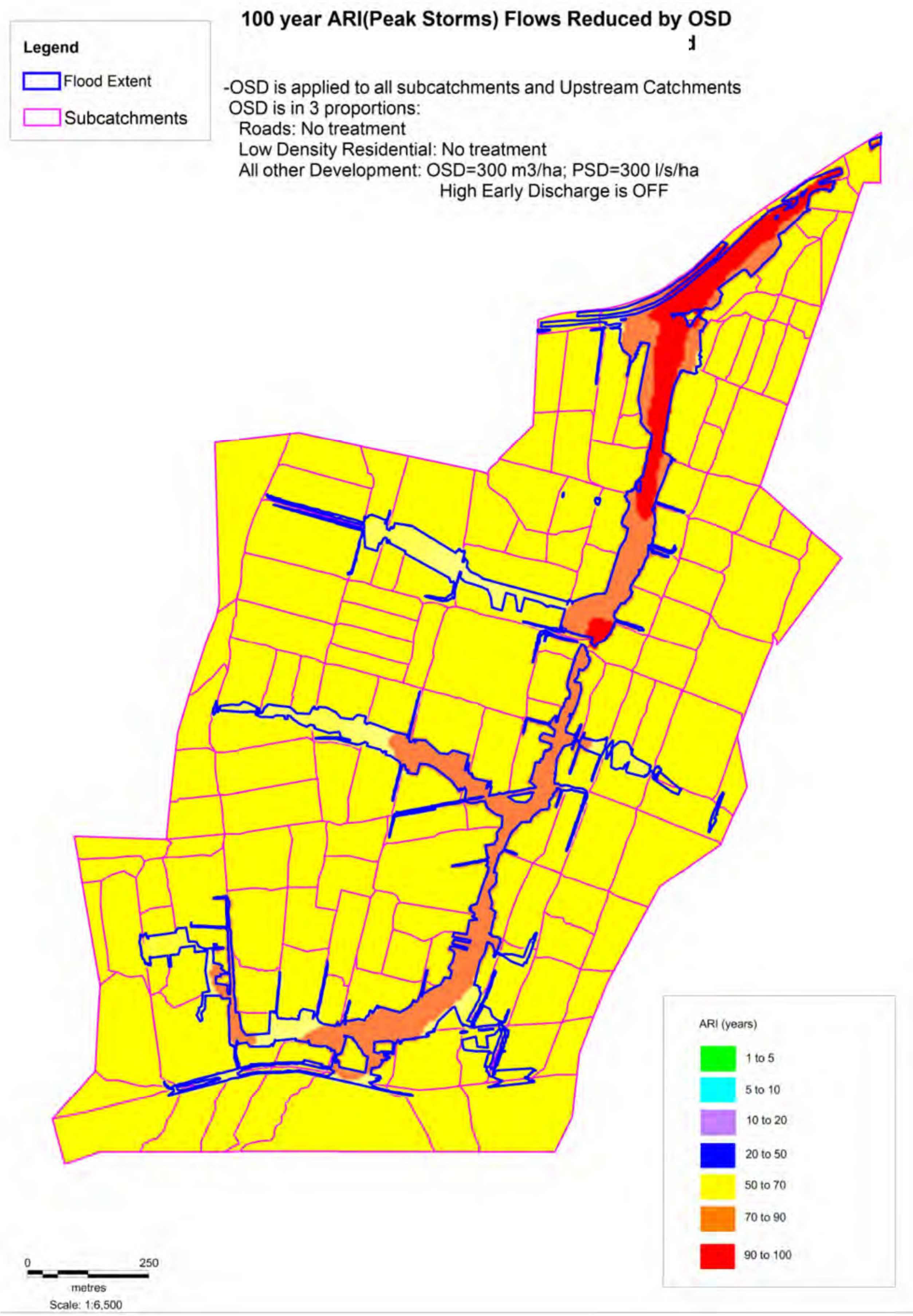


Figure 4-7 No OSD on Low Density Residential Development

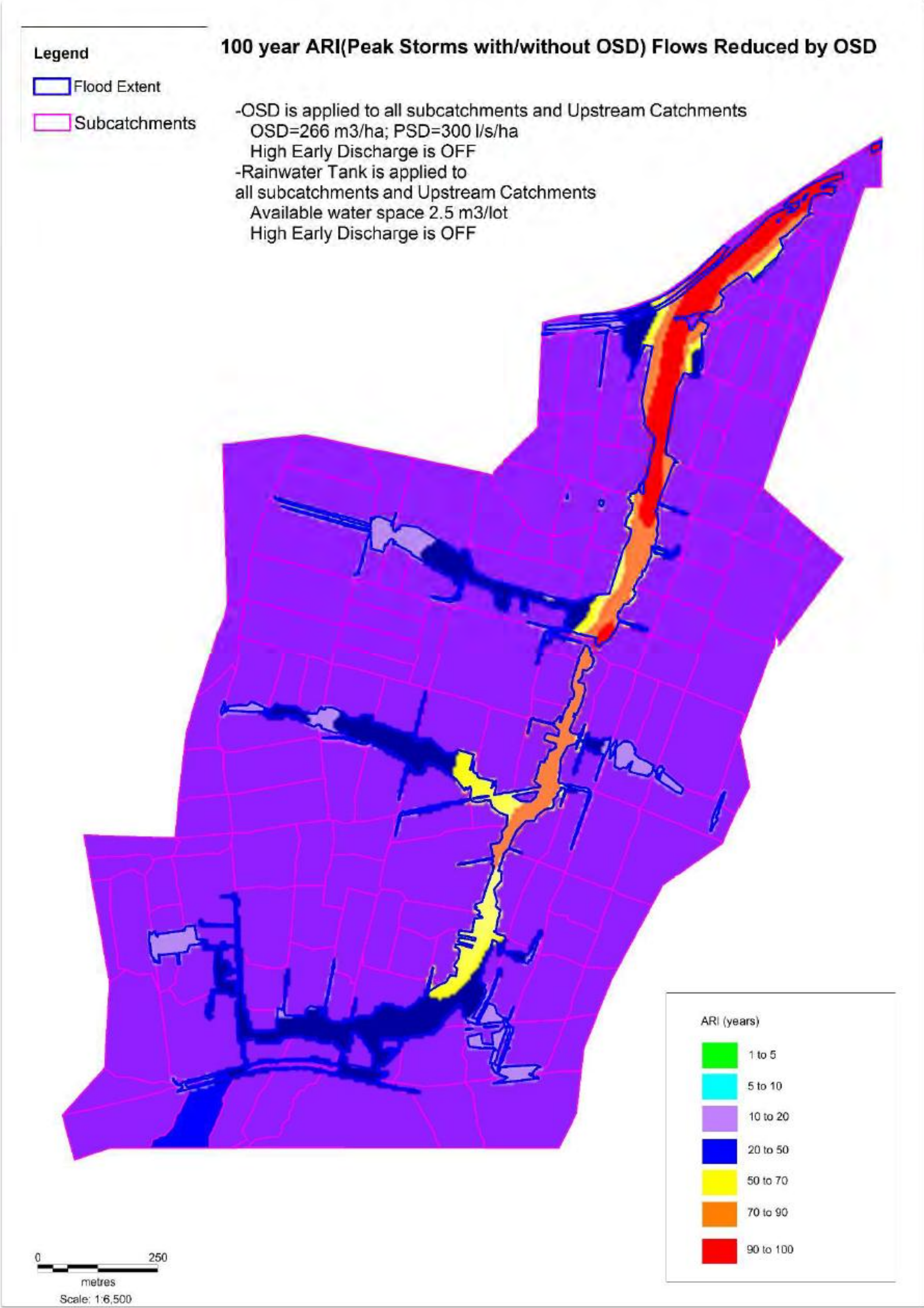


Figure 4-8 Testing 2,500L Rainwater Tank Offset for OSD

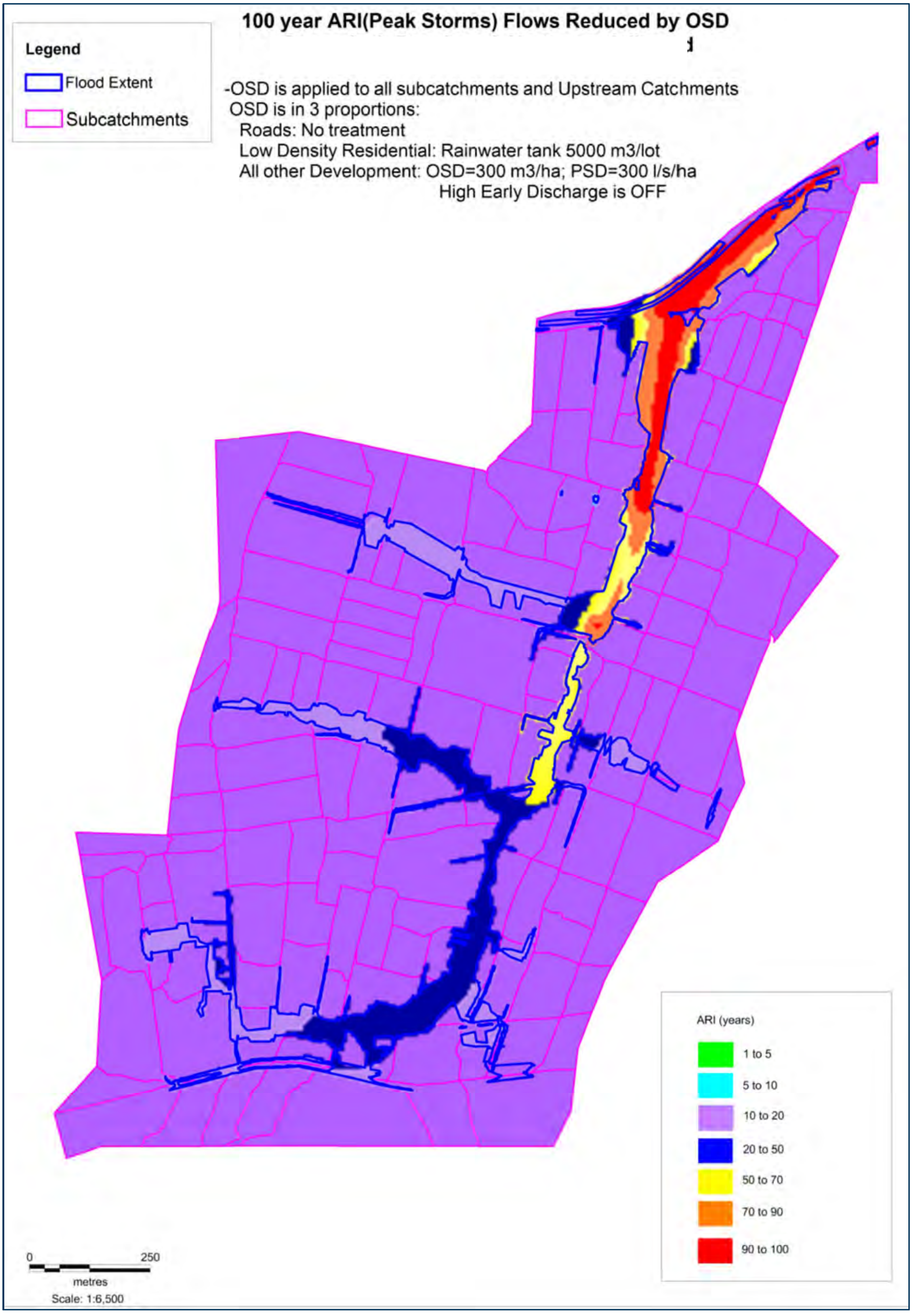


Figure 4-9 Testing 5,000L Rainwater Tank for Low Desnrity Residential

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Leichhardt Floodplain Risk Management Study and Plan

APPENDIX D

MITIGATION OPTION ASSESSMENTS SUB-CATCHMENT REPORTS

Cardno

Shaping the Future

Area 1 - Hawthorne Canal Options Assessment

Leichhardt Flood Risk Management Study and Plan

NA49913094

Prepared for
Inner West Council

Cardno
Shaping the Future

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Figures

1 Hawthorne Canal Catchment Description

The catchment for Hawthorne Canal is in the order of 670 hectares in size, and is the single largest catchment in the study area. A large portion of the catchment, greater than 400 hectares, is located outside of the study area.

The majority of the flooding issues within the Hawthorne Canal catchment occur upstream of the rail line that runs generally parallel to the canal. In this area, there are no formalised creeks or channels, and when the capacity of the existing pipe system is exceeded overland flow proceeds down streets and through properties.

There are a number of tributaries of the Canal in this area, the largest of which originates from upstream of Parramatta Road (outside of the study area).

The rail line itself forms a major hydraulic control in the study area, and significant ponding occurs upstream of this location. The ponding is largely influenced by the capacity of the culverts under the rail line connecting to Hawthorne Canal. The high hazard classification in this area is depth governed.

Flooding from the main Canal itself is limited to the west of the rail line, and does not affect a significant number of properties within the Study Area. However, flood levels within the Canal can affect the conveyance of flows from the culverts originating on the eastern side of the rail line.

The options proposed for assessment in the report are located within the study area portion of the Hawthorne Canal Catchment.

The location of the Hawthorne Canal Catchment within the Study Area is shown in Figure 1-1.

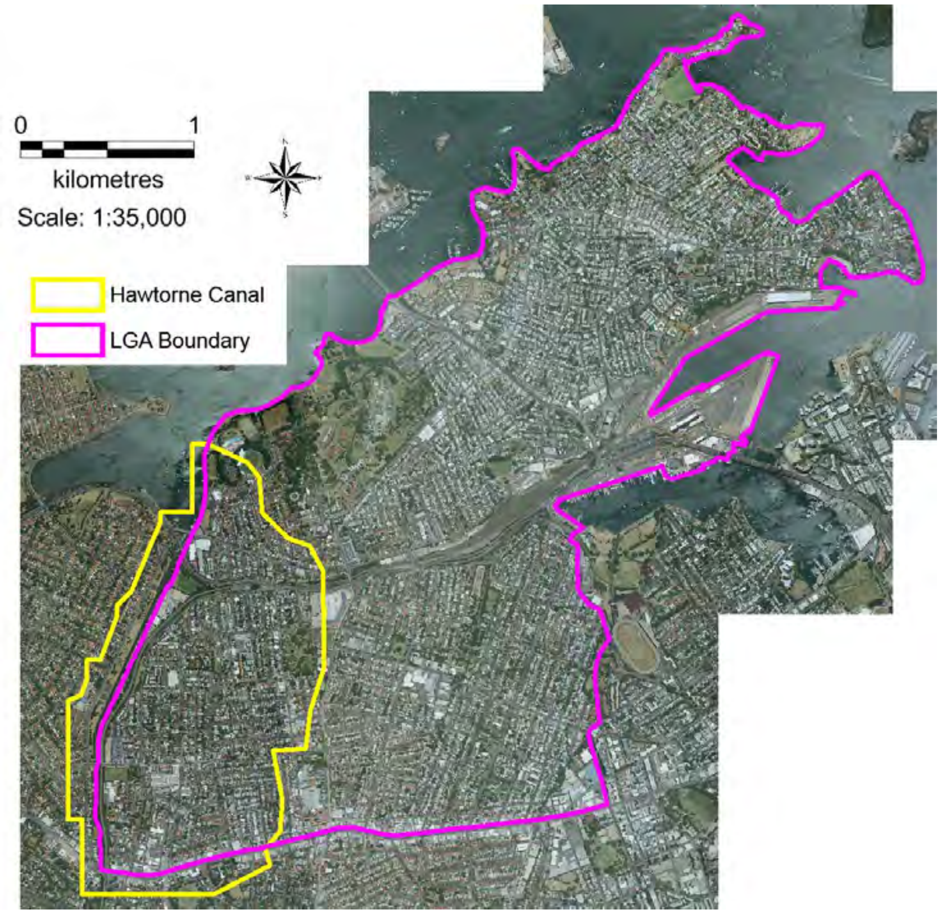


Figure 1-1 Hawthorne Canal Catchment Location

2 Flood Mitigation Options Identification

2.1 Flood Modification Measures for Hawthorne Canal

The existing flood behaviour within the Hawthorne Canal is detailed in the Leichhardt Flood Study (Cardno 2014). Based on the flood model results, historical information and engineering judgement, possible flood modification measures (i.e. structural measures) for the study area were identified.

The various management options were identified taking into consideration the:

- flood behaviour and flow in the 20 year ARI event;
- grade of pipe (upstream and downstream); and
- preliminary availability and location of easements.

It should also be noted that Sydney Water and RMS may also play a major role in regards to fund allocation for the options recommended. Sydney Water's approach to flood-related improvement works on its assets is that Sydney Water will work with Councils to deliver the works (typically on a 50:50 cost-sharing basis) and provided Sydney Water has funding available within its Flood Risk Program. It is assumed that RMS will provide all the funding for the transverse pipe sections across State roads. Currently no allocation of RMS funding has been assigned for infrastructure travelling longitudinally along State Roads. It is likely that some contribution would be required from RMS for these upgrades in State Road easements. The total cost for HC-FM5 was allocated to RMS.

Flood modification measures for the Hawthorne Canal Catchment have been identified based on opportunities to connect with future upgrades and improvements.

2.2 Hawthorne Canal Flood Mitigation Options

Within the Hawthorne Canal catchment five (5) sets of options were modelled. These are shown in **Table 2-1** and **Figure 2-1**. The 100yr, 20yr and 5yr ARI peak water level difference plots for each mitigation option are attached at the end of this appendix report.

Table 2-1 Hawthorne Canal Mitigation Options

Option Description	Option Name	ID
Beeson Street Flow Path - Additional pipes /culverts from Parramatta Road to Hawthorne Canal via Beeson Street.	Beeson Street Flow Path HC-FM1	HC-FM1
Marion Street Flow Path – Additional pipes or duplication of existing network from Reuss Street to Hawthorne Canal via Elswick Street, Flood Street and Marion Street.	Marion Street Branch HC-FM2	HC-FM2
Regent Street Flow Path – Additional pipes/culverts from Elswick Street to Hawthorne Canal (via Regent Street and Darley Road). Also extra pipes at Darley Road to reduce flood depths on the Road.	Regent Street Branch HC-FM3	HC-FM3
Hubert Street Flow Path - Additional pipes/ culverts from William Street to Hawthorne Canal via Hubert Street and Darley Road.	Hubert Street Branch HC-FM4	HC-FM4
Darley Road - Proposed culverts through the rail embankment to drain flood waters from Darley Road to Hawthorne Canal.	Darley Road Branch HC-FM5	HC-FM5

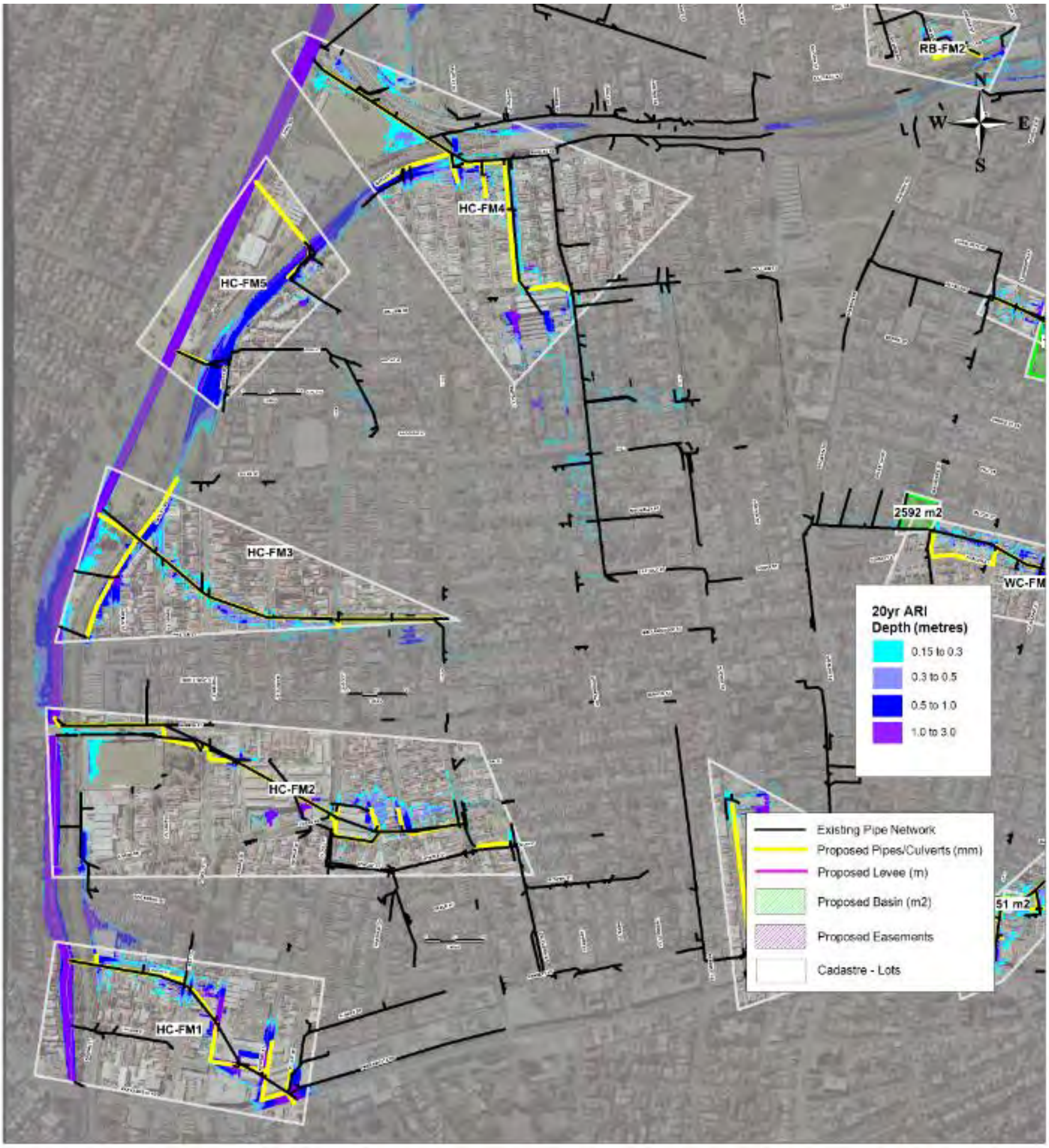


Figure 2-1 Hawthorne Canal Mitigation Options Locations

2.2.1 Beeson Street Flow Path HC-FM1

HC-FM1 consists of additional pipes and culverts from Parramatta Road to Hawthorne Canal via Beeson Street. This option aims to mitigate flood inundation due to the 20 year ARI flood event. The option is expected to mitigate the inundation experienced along the sections of Flood Street, George Street, Upward Street and Tebbutt Street that are located between Parramatta Road and Kegworth Street. Flooding on Beeson Street is also expected to reduce.

Under existing conditions, the worst flooding due to the 20 year ARI event takes place on Flood Street, George Street, Upward Street and Parramatta Road with depths up to 1.9m.

The main branch of the option comprises of a box culvert (2.4m x 2.1m) that is 625m in length. There are also 1800mm diameter pipes connecting to the culverts at Parramatta Road, Flood Street and George Street as well as a pipe at the western end of Beeson Street.

There is a new development currently underway at 22 George Street, Leichhardt. This development has incorporated re-routing and upgrading if the existing trunk drainage pipeline passing through the property, consistent with the recommendations of this mitigation option. The development is also required to make provision for a future overland flow path between McAleer and Upward Streets to cater for larger storm events, consistent with the objectives of this mitigation option.

Construction of the culvert from Flood Street to George Street along Parramatta Road will be difficult, as there are challenges with the grade and there are likely to be significant services in this area. If any re-development is scheduled to occur in the industrial block between Flood Street and George Street, the proposed culvert could be incorporated into the development which would simplify the design. It should be noted that this option would also rely on drainage upgrade on the Southern side of Parramatta Road, within Petersham.

Potential constraints for this measure also include construction of a pipeline under the rail corridor and pipe crossings of major roads, especially Parramatta Road, with associated costs due to construction, services and traffic management requirements. Any pipeline upgrade between Upward Street and Tebbutt Street will most likely be reliant upon future development of these properties and being able to incorporate the upgraded pipeline and overland flow path into the development.

In regards to cost allocation between the primary asset owners, both RMS and Sydney Water could potentially share a majority of the cost alongside Council. The transverse drainage across Tebbutt Street and Parramatta Road would ideally be allocated to RMS while the remaining major trunk drainage upgrades will potentially be the responsibility of Sydney Water.

2.2.2 Marion Street Branch HC-FM2

HC-FM2 on Marion Street contains new pipes and modifications to the existing network. The option begins from Reuss Street and ends at Hawthorne Canal via Elswick Street, Flood Street and Marion Street. The aim of the option is to mitigate flood inundation due to the 20 year ARI event which produces flooding at the car park adjacent to Lord Street.

The main branch of the option comprises of a 1500mm diameter pipe that is 900m in length. Pipes, 900mm in diameter, connect to the main branch on Edith Lane, Ivory Lane and Flood Street and a 600mm diameter pipe is used on Reuss Street.

The final alignment of the upgrades would be subject to ongoing liaison with Sydney Water to look at potential opportunities to upgrade Sydney Water pipelines located nearby in lieu of additional pipelines through 1A Lords Road.

There will be costs associated due to construction, services and traffic management requirements. There is potential for RMS (Foster Road transverse crossing) and Sydney Water (Main trunk drainage) to share some of the cost.

2.2.3 Regent Street Branch HC-FM3

This option consists of two major branches. One branch is along Darley Road between Walter Street and Allen Street. The Darley Road branch consists of a Culvert (1.5mx0.9m) that is 350m in length. This culvert targets the ponding which occurs behind the rail line on Darley Road.

The other branch starts from Elswick Street and ends at Hawthorne Canal and consists of 900mm and 1200mm diameter pipes with a combined length of 650m plus a box culvert (1.8m x 1.5m) with a length of 80m. This branch travels through Regent Street and crosses Edith Street, Flood Street, Burfitt Street, Foster Street and Daniel Street and finally Darley Road and then beneath the railway track and into Hawthorne Canal. Heavy flooding as a result of the 20 year ARI storm event is expected at the intersection of Darley Road and Loftus Street with depths in this location of around 1.1m.

A major constraint for this measure consists of the tunnelling under the railway line plus other construction costs that maybe required for pipe crossings beneath the railways line. To reduce these costs and construction constraints the viability of construction of a new pipeline from Darley Road via the existing pedestrian subway between Darley Road and Hawthorne Canal instead of tunnelling beneath the railway line could also be investigated.

In addition to the tunnelling constraint the pipeline has to be upgraded through substantial lengths of private property, which may require the buyback of 4 properties. It is likely to be more feasible to continue the pipeline through the four properties, because an alternative alignment to reduce the property buy-backs will require pits at a depth of 3m below the current road level.

In regards to the primary asset owners in the area (RMS, Sydney Water and Council), RMS could possibly be apportioned part of the upgrade cost. The cost applicable to RMS would involve the transverse drainage in Foster Street.

It is noted that an alternative is to split this option into two components, being those works upstream and downstream of Darley Road . Construction of the Darley Road culvert and crossing under the rail line would assist in alleviating the flooding in this area, without construction of the longer pipe up to Elswick Street which has a number of constraints.

2.2.4 Hubert Street Branch HC-FM4

HC-FM4 consists of pipes and culverts from William Street to Hawthorne Canal via Hubert Street and Darley Road. There are two types of culverts. One is a 2.4mx2.1m culvert 300m in length that begins from the Charles Street/Darley Road Intersection and drains onto Hawthorne Canal after crossing Canal Road. The other culvert (2.1mx1.8m) is 90m in length and travels along Darley Road between Hubert Street and Charles Street. The proposed pipes consist of a 1800mm diameter line and a separate 1200mm diameter line. The 1800mm diameter pipe is 320m in length and starts on Francis Street, travels along William Street and then onto Hubert Street, finally ending at Darley Road. The 1200mm diameter pipes are located on an Un-Named Lane between Hubert Street and Charles Street, Charles Street and Darley Road.

The worst of the flooding is predominantly on Darley Road with depths approaching the 1m level during the 20 year ARI storm event. Potential constraints include costs due to construction, services and traffic management requirements on Darley Road.

An alternative is split this option into two components, being initially the construction of the works at Darley Road , with a long term aim to construct the other upstream sections. This would assist in addressing the flooding issues on Darley Road.

RMS funding could be investigated for works that involve transverse drainage in Darley Road.

2.2.5 Darley Road Branch HC-FM5

The Darley Road branch consists two sections of proposed culverts that cross through the rail embankment to drain flood waters from Darley Road to Hawthorne Canal. One section consists of a culvert (1.8m x 1.2m) with a length of 60m and is on Darley Road between Athol Street and Lyall Street. The other section consists of a 1200mm diameter pipe starting from the William Street/ Darley Road intersection then connecting to a 1.8m x 1.2m culvert on Darley road that crosses beneath the rail embankment.

Major flooding due to the 20 year ARI storm event is on Darley Road with depths to around 1.25m. A major constraint for this measure consist of the tunnelling plus other construction costs that maybe required for pipe crossing at the railways line.

RMS funding could be investigated to contribute for most of the costs related with this option. This includes the sections that are upgraded on Darley Road.

3 Mitigation Option Modelling Outcomes

The Hawthorne Canal flood mitigation options were assed for the 5, 10, 20, 50 and 100 Year ARI design flood events, along with the PMF event.

The outcomes of the modelling are shown in the 5, 20, and 100 Year ARI water level difference plots attached at the end of this catchment report.

A summary of the impacts on flood behaviour for each option is provided below.

3.1 Beeson Street Flow Path HC-FM1

The proposed increase in drainage capacity of mitigation option HC-FM1 is shown to reduce overland flows along the Beeson Street flow path. The mitigation strategy shows water level decreases of 0.2m – 0.5m along sections of Parramatta Road, Flood Street, George Street, Upward Street and McAleer Street, and Beeson Street leading into Hawthorne Canal.

Significant reductions are apparent at properties located on Upward Street, Tebbutt Street, Beeson Street and Kegworth Street. Modelling of this mitigation strategy indicates that 63 properties would have a decrease in water level of more than 0.15m in the 20 Year ARI event.

3.2 Marion Street Branch HC-FM2

The increase in drainage capacity at the Marion Street Branch proposed in HC-FM2 is shown to decrease flood levels by 0.2m – 0.5m in the vicinity of Ivory Street, Edith Street and Edith Lane in the 20 Year ARI event. Significant water level decreases of more than 0.5m are also apparent at the car park adjacent to Lord Street in this event. A 0.2m – 0.5m water level decrease is also visible in properties between Edith Street and Flood Street in the 20 Year ARI event. Results indicate that 21 properties would experience a decrease in water level of more than 0.15m in the 20 Year ARI event due to this mitigation strategy.

3.3 Regent Street Branch HC-FM3

Mitigation option FM3 shows significant water level decreases of more than 0.5m in some areas of Darley Road between Walter Street and Allen Street in the 20 Year ARI event. Decreases are also observable upstream, along Regent Street at Elswick Street, Edith Street and Flood Street, as well as Burfitt Street, Forster Street and Daniel Street towards Hawthorne Canal. The increased conveyance under the railway to Hawthorne Canal reduces flood levels on a number of residential properties, with 22 properties showing a water level decrease of more than 0.15m in the 20 Year ARI event.

3.4 Hubert Street Branch HC-FM4

Mitigation option HC-FM4 shows significant decrease in water levels either side of the railway at Darley Road and Charles Street. The most significant reductions are seen at the intersections of Darley Road and Falls Street, Elswick Street and Charles Street. These reductions are between 0.2m and 0.5m in the 20 Year ARI event. Water level decreases of 0.01m to 0.2m are also observable at Blackmore Park and along Canal Road in the 20 Year ARI event. Results indicate that 26 properties would experience a decrease in water level of more than 0.15m in the 20 Year ARI event due to this mitigation strategy.

3.5 Darley Road Branch HC-FM5

Mitigation option HC-FM5 shows a decrease in ponding along Darley Road between Walter Street and Falls Street due to an increase in conveyance beneath the railway embankment to Hawthorne Canal. The majority of this water level decrease in the 20 Year ARI is between 0.2m and 0.5m. Results indicate that 9 properties would experience a decrease in water level of more than 0.15m in the 20 Year ARI event due to this mitigation strategy.

4 Economic Assessment of Flood Damages in the Hawthorne Canal Catchment

4.1 Hawthorne Canal Mitigation Options Damages Assessment

An assessment of damages for the existing condition in the Hawthorne Canal Catchment is presented in the Floodplain Risk Management Study. The approach adopted for calculating the existing damages has been repeated for the modelling results from the mitigation options proposed for the Hawthorne Canal catchment.

The economic flood damage results for each of the options and the existing scenarios are presented in **Table 4-1** to **Table 4-6**. The reductions in properties affected by overground and overfloor flooding, total damages and AAD are provided.

The total reduction in damaged properties and the associated reduction in damage costs for each mitigation strategy is summarised in **Table 4-6**. This table represents a summary of differences between existing and Mitigation scenarios presented in **Table 4-1** to **Table 4-5**.

The flood damages assessment is a useful tool for comparing the merits of various options, it is not a precise flood risk analysis tool and the limitation associated with the assessment should be considered when interpreting the results.

The following information should be considered when interpreting the damages data:

- Negative property or dollar values represent increases from the existing scenario.
- Where an option results in a reduction in flood depths there may not be any reduction in the flood damages where:
  - The reduction in flood depths or extent occur in open space or roadways; or
  - The reduction in flood depths occurs on properties that were not impacted by over floor flooding (i.e. the flooding on the property grounds is shallower but still exists).
- The flood damages are calculated at a discrete location on each property. This location is where the floor level and ground level survey was obtained from. As such, if the flooding occurs at another location on the property other than the survey point, this property will not register any damages with regards to this damages assessment.
- Commercial and industrial damages are only incurred when over floor flooding exists.
- The reduction in the number of properties impacted as a result of an option may vary between different flood events due to the performance of the proposed work under the different flow behaviour of each flood event.

Table 4-1 HC_FM1 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	91	82	109	109	$ 7,774,777	$ 6,821,243
Commercial	3	3	4	4	$ 1,302,890	$ 1,290,785
Industrial	38	32	38	36	$ 7,811,077	$ 6,991,709
PMF Total	**132**	**117**	**151**	**149**	**$ 16,888,744**	**$ 15,103,737**
100yr ARI						
Residential	18	6	40	37	$ 1,009,407	$ 290,063
Commercial	2	0	2	2	$ 110,694	$ -
Industrial	24	13	26	22	$ 3,648,873	$ 1,224,851
100yr ARI Total	**44**	**19**	**68**	**61**	**$ 4,768,973**	**$ 1,514,914**
50yr ARI						
Residential	18	7	39	35	$ 960,444	$ 315,935
Commercial	2	0	2	2	$ 104,434	$ -
Industrial	24	9	25	21	$ 3,310,125	$ 1,284,383
50yr ARI Total	**44**	**16**	**66**	**58**	**$ 4,375,003**	**$ 1,600,318**
20yr ARI						
Residential	13	4	32	28	$ 704,390	$ 246,953
Commercial	1	0	2	2	$ 84,980	$ -
Industrial	20	8	22	20	$ 2,604,302	$ 1,039,801
20yr ARI Total	**34**	**12**	**56**	**50**	**$ 3,393,671**	**$ 1,286,754**
10yr ARI						
Residential	11	4	23	19	$ 569,359	$ 231,269
Commercial	1	0	2	2	$ 79,321	$ -
Industrial	20	6	20	18	$ 2,224,903	$ 865,964
10yr ARI Total	**32**	**10**	**45**	**39**	**$ 2,873,583**	**$ 1,097,233**
5yr ARI						
Residential	4	2	11	8	$ 237,109	$ 95,268
Commercial	1	0	2	2	$ 70,209	$ -
Industrial	18	4	19	16	$ 1,667,896	$ 480,795
5yr ARI Total	**23**	**6**	**32**	**26**	**$ 1,975,215**	**$ 576,063**
Total Annual Average Damage					**$ 965,931**	**$ 376,372**

Table 4-2 HC_FM2 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	131	116	223	222	$ 8,039,935	$ 7,185,828
Commercial	6	6	6	6	$ 695,940	$ 680,626
Industrial	2	2	2	2	$ 2,628,273	$ 2,442,588
PMF Total	**139**	**124**	**231**	**230**	**$ 11,364,148**	**$ 10,309,043**
100yr ARI						
Residential	26	16	55	53	$ 1,956,331	$ 1,123,743
Commercial	5	4	5	4	$ 361,630	$ 146,889
Industrial	0	0	1	1	$ -	$ -
100yr ARI Total	**31**	**20**	**61**	**58**	**$ 2,317,961**	**$ 1,270,632**
50yr ARI						
Residential	19	16	49	48	$ 1,601,238	$ 1,119,109
Commercial	5	4	5	4	$ 282,991	$ 142,482
Industrial	0	0	1	1	$ -	$ -
50yr ARI Total	**24**	**20**	**55**	**53**	**$ 1,884,229**	**$ 1,261,591**
20yr ARI						
Residential	18	15	43	42	$ 1,498,207	$ 985,487
Commercial	4	3	4	4	$ 109,477	$ 106,782
Industrial	0	0	0	0	$ -	$ -
20yr ARI Total	**22**	**18**	**47**	**46**	**$ 1,607,684**	**$ 1,092,270**
10yr ARI						
Residential	17	11	39	39	$ 1,344,886	$ 859,912
Commercial	3	2	4	4	$ 104,526	$ 100,790
Industrial	0	0	0	0	$ -	$ -
10yr ARI Total	**20**	**13**	**43**	**43**	**$ 1,449,412**	**$ 960,702**
5yr ARI						
Residential	13	10	32	31	$ 1,023,686	$ 798,536
Commercial	2	2	4	4	$ 99,131	$ 99,082
Industrial	0	0	0	0	$ -	$ -
5yr ARI Total	**15**	**12**	**36**	**35**	**$ 1,122,817**	**$ 897,618**
Total Annual Average Damage					**$ 515,255**	**$ 384,745**

Table 4-3 HC_FM3 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	113	111	180	178	$ 6,977,319	$ 6,663,452
Commercial	0	0	0	0	$ -	$ -
Industrial	1	1	1	1	$ 203,585	$ 204,891
PMF Total	**114**	**112**	**181**	**179**	**$ 7,180,904**	**$ 6,868,343**
100yr ARI						
Residential	42	24	78	75	$ 2,204,349	$ 1,297,488
Commercial	0	0	0	0	$ -	$ -
Industrial	1	1	1	1	$ 92,138	$ 484
100yr ARI Total	**43**	**25**	**79**	**76**	**$ 2,296,487**	**$ 1,297,972**
50yr ARI						
Residential	36	18	75	70	$ 1,884,444	$ 1,003,401
Commercial	0	0	0	0	$ -	$ -
Industrial	1	0	1	1	$ 83,715	$ -
50yr ARI Total	**37**	**18**	**76**	**71**	**$ 1,968,159**	**$ 1,003,401**
20yr ARI						
Residential	28	13	64	56	$ 1,395,539	$ 729,808
Commercial	0	0	0	0	$ -	$ -
Industrial	1	0	1	1	$ 80,480	$ -
20yr ARI Total	**29**	**13**	**65**	**57**	**$ 1,476,018**	**$ 729,808**
10yr ARI						
Residential	18	11	52	46	$ 1,062,192	$ 639,099
Commercial	0	0	0	0	$ -	$ -
Industrial	1	0	1	1	$ 74,296	$ -
10yr ARI Total	**19**	**11**	**53**	**47**	**$ 1,136,488**	**$ 639,099**
5yr ARI						
Residential	14	10	42	39	$ 854,526	$ 600,027
Commercial	0	0	0	0	$ -	$ -
Industrial	1	0	1	1	$ 66,071	$ -
5yr ARI Total	**15**	**10**	**43**	**40**	**$ 920,598**	**$ 600,027**
Total Annual Average Damage					**$ 426,625**	**$ 264,516**

Table 4-4 HC_FM4 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	216	221	372	373	$ 15,099,829	$ 15,406,768
Commercial	23	23	24	24	$ 749,167	$ 760,372
Industrial	0	0	0	0	$ -	$ -
PMF Total	**239**	**244**	**396**	**397**	**$ 15,848,996**	**$ 16,167,140**
100yr ARI						
Residential	82	71	178	177	$ 5,885,739	$ 5,516,880
Commercial	7	7	11	11	$ 127,183	$ 127,194
Industrial	0	0	0	0	$ -	$ -
100yr ARI Total	**89**	**78**	**189**	**188**	**$ 6,012,923**	**$ 5,644,074**
50yr ARI						
Residential	74	63	169	169	$ 5,395,138	$ 4,962,925
Commercial	7	7	10	10	$ 126,664	$ 126,654
Industrial	0	0	0	0	$ -	$ -
50yr ARI Total	**81**	**70**	**179**	**179**	**$ 5,521,802**	**$ 5,089,578**
20yr ARI						
Residential	62	55	155	152	$ 4,744,297	$ 4,342,642
Commercial	7	5	10	10	$ 126,245	$ 85,826
Industrial	0	0	0	0	$ -	$ -
20yr ARI Total	**69**	**60**	**165**	**162**	**$ 4,870,542**	**$ 4,428,468**
10yr ARI						
Residential	57	49	146	141	$ 4,218,891	$ 3,893,819
Commercial	7	5	10	10	$ 125,738	$ 85,315
Industrial	0	0	0	0	$ -	$ -
10yr ARI Total	**64**	**54**	**156**	**151**	**$ 4,344,629**	**$ 3,979,134**
5yr ARI						
Residential	46	42	112	108	$ 3,445,695	$ 3,258,243
Commercial	7	5	9	9	$ 124,934	$ 84,519
Industrial	0	0	0	0	$ -	$ -
5yr ARI Total	**53**	**47**	**121**	**117**	**$ 3,570,629**	**$ 3,342,762**
Total Annual Average Damage					**$ 1,484,594**	**$ 1,383,183**

Table 4-5 HC_FM5 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	64	63	83	83	$ 4,001,594	$ 4,002,015
Commercial	0	0	0	0	$ -	$ -
Industrial	3	3	3	3	$ 267,663	$ 265,222
PMF Total	**67**	**66**	**86**	**86**	**$ 4,269,257**	**$ 4,267,238**
100yr ARI						
Residential	24	15	47	47	$ 1,164,144	$ 732,444
Commercial	0	0	0	0	$ -	$ -
Industrial	1	1	1	1	$ 92,138	$ 84,869
100yr ARI Total	**25**	**16**	**48**	**48**	**$ 1,256,281**	**$ 817,312**
50yr ARI						
Residential	17	12	47	47	$ 893,077	$ 612,722
Commercial	0	0	0	0	$ -	$ -
Industrial	1	1	1	1	$ 83,715	$ 82,774
50yr ARI Total	**18**	**13**	**48**	**48**	**$ 976,792**	**$ 695,496**
20yr ARI						
Residential	12	10	40	39	$ 578,480	$ 426,423
Commercial	0	0	0	0	$ -	$ -
Industrial	1	1	1	1	$ 80,480	$ 80,527
20yr ARI Total	**13**	**11**	**41**	**40**	**$ 658,959**	**$ 506,949**
10yr ARI						
Residential	8	6	34	33	$ 413,894	$ 295,650
Commercial	0	0	0	0	$ -	$ -
Industrial	1	1	1	1	$ 74,296	$ 74,316
10yr ARI Total	**9**	**7**	**35**	**34**	**$ 488,189**	**$ 369,966**
5yr ARI						
Residential	2	2	21	20	$ 175,441	$ 129,619
Commercial	0	0	0	0	$ -	$ -
Industrial	1	1	1	1	$ 66,071	$ 66,091
5yr ARI Total	**3**	**3**	**22**	**21**	**$ 241,513**	**$ 195,711**
Total Annual Average Damage					**$ 164,717**	**$ 130,584**

Table 4-6 Reduction in Damages Associated with Each Option

	Overfloor flooding properties reduction	Overground flooding properties reduction	Total Damage Reduction ($)	AAD Reduction ($)
	HC-FM1			
PMF event	15	2	$ 1,785,006	$25,193
100yr ARI event	25	7	$ 3,254,059	$30,144
50yr ARI event	28	8	$ 2,774,685	$73,224
20yr ARI event	22	6	$ 2,106,918	$97,082
10yr ARI event	22	6	$ 1,776,349	$158,775
5yr ARI event	17	6	$ 1,399,152	$209,873
Total				**$594,290**
	HC-FM2			
PMF event	15	1	$ 1,055,105	$10,511
100yr ARI event	11	3	$ 1,047,329	$8,350
50yr ARI event	4	2	$ 622,639	$17,071
20yr ARI event	4	1	$ 515,414	$25,103
10yr ARI event	7	0	$ 488,710	$35,695
5yr ARI event	3	1	$ 225,199	$33,780
Total				**$130,510**
	HC-FM3			
PMF event	2	2	$ 312,561	$6,555
100yr ARI event	18	3	$ 998,515	$9,816
50yr ARI event	19	5	$ 964,759	$25,665
20yr ARI event	16	8	$ 746,211	$31,090
10yr ARI event	8	6	$ 497,388	$40,898
5yr ARI event	5	3	$ 320,570	$48,086
Total				**$162,109**
	HC-FM4			
PMF event	Assumed to be equal to the existing case damages1			
100yr ARI event	11	1	$ 368,849	$4,005
50yr ARI event	11	0	$ 432,224	$13,114
20yr ARI event	9	3	$ 442,074	$20,189
10yr ARI event	10	5	$ 365,494	$29,668
5yr ARI event	6	4	$ 227,867	$34,180
Total				**$101,157**
	HC-FM5			
PMF event	1	0	$ 2,020	$2,205
100yr ARI event	9	0	$ 438,969	$3,601
50yr ARI event	5	0	$ 281,297	$6,500
20yr ARI event	2	1	$ 152,010	$6,756
10yr ARI event	2	1	$ 118,223	$8,201
5yr ARI event	0	1	$ 45,802	$6,870
Total				**$34,133**

[1] A modelling instability produced unreliable results for the PMF design event for FM4. The results available, would suggest the flow behaviour would not be impacted significantly in the PMF as a result of this option.

4.2 Benefit to Cost Ratio of Options

The economic evaluation of each modelled measure was assessed by considering the reduction in the amount of flood damages incurred for the design events and by then comparing this value with the cost of implementing the measure.

Table 4-7 summarises the results of the economic assessment of each of the flood management options. The indicator adopted to rank these measures on economic merit is the benefit-cost ratio (B/C), which is based on the net present worth (NPW) of the benefits (reduction in AAD) and the costs (capital and ongoing), adopting a 7% discount rate and an implementation period of 50 years.

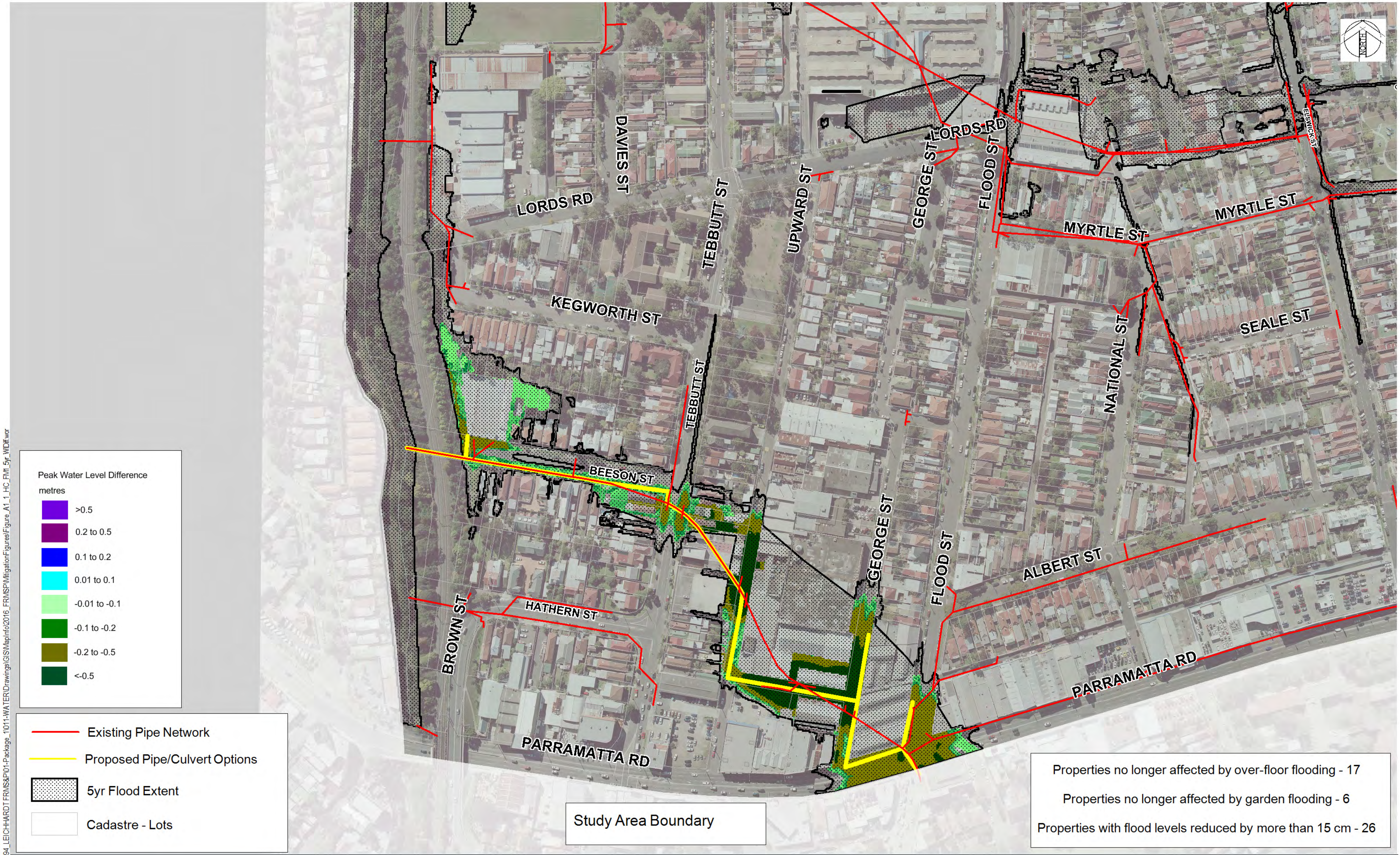
The benefit-cost ratio provides an insight into how the damage savings from a measure, relate to its cost of construction and maintenance:

- Where the benefit-cost is greater than 1 the economic benefits are greater than the cost of implementing the measure;
- Where the benefit-cost is less than 1 but greater than 0, there is still an economic benefit from implementing the measure but the cost of implementing the measure is greater than the economic benefit;
- Where the benefit-cost is equal to zero, there is no economic benefit from implementing the measure; and
- Where the benefit-cost is less than zero, there is a negative economic impact of implementing the measure.

Table 4-7 Summary of Economic Assessment of Flood Management Options

Option ID	Option Description	NPW of Reduction in AAD	NPW of Cost of Implementation	B/C Ratio	Economic Ranking
HC_FM1	Additional pipes /culverts from Parramatta Road to Hawthorne Canal via Beeson Street.	$8,202,000	$11,588,000	0.71	1
HC_FM2	Additional pipes or duplication of existing network from Reuss Street to Hawthorne Canal via Elswick Street, Flood Street and Marion Street.	$1,801,000	$10,634,000	0.17	3
HC_FM3	Additional pipes/culverts from Elswick Street to Hawthorne Canal (via Regent Street and Darley Road). Also extra pipes at Darley Road to reduce flood depths on the Road.	$2,237,000	$17,194,000	0.13	5
HC_FM4	Additional pipes/ culverts from William Street to Hawthorne Canal via Hubert Street and Darley Road.	$1,400,000	$8,398,000	0.17	4
HC_FM5	Proposed culverts through the rail embankment to drain flood waters from Darley Road to Hawthorne Canal.	$471,000	$2,729,000	0.17	2

Hawthorne Canal Mitigation Option Figures



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INNER WEST COUNCIL
LEICHHARDT FRMS&P

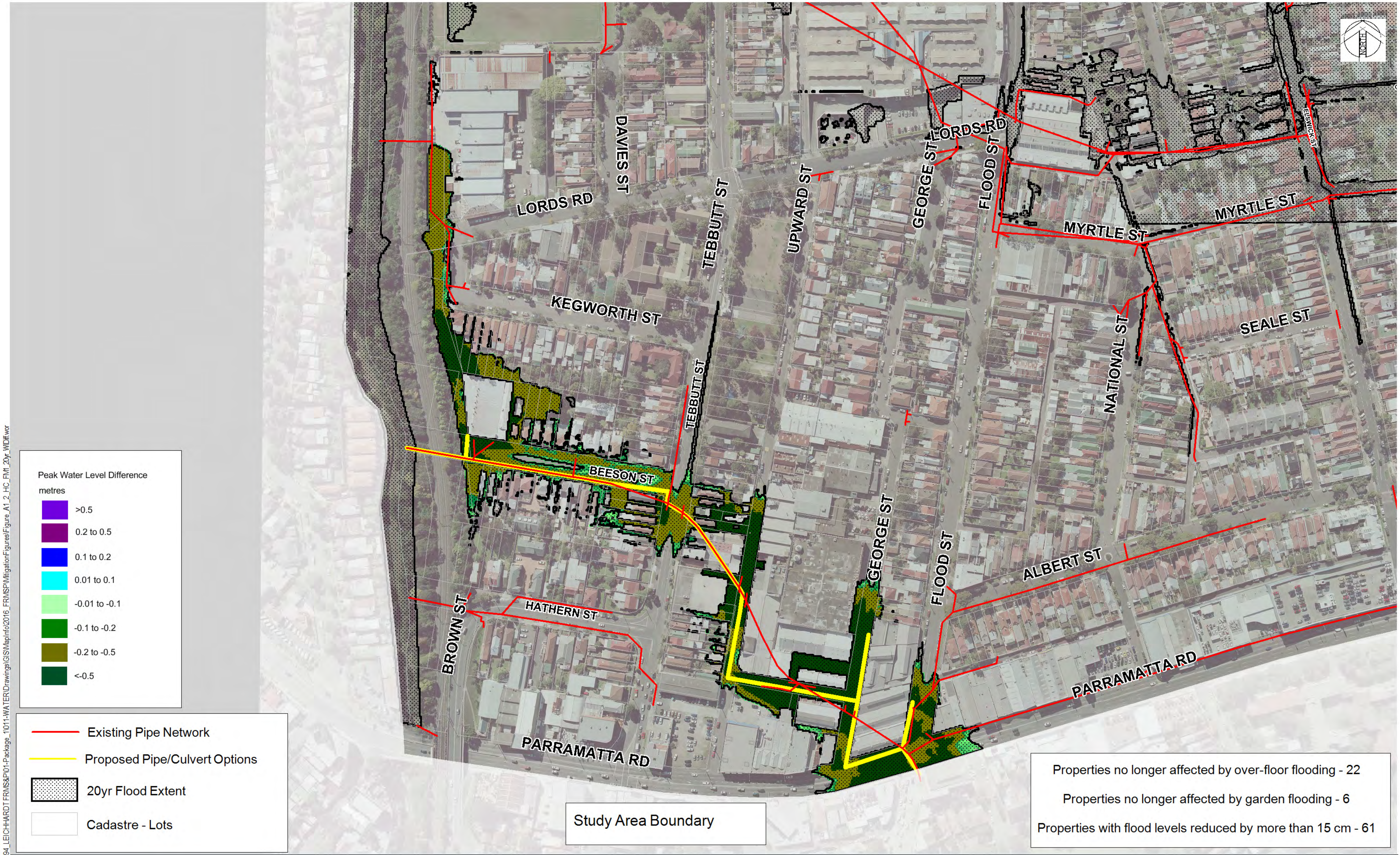
HC_FM1 5YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_1

Date
03/2017

HC_FM1_5yr_WlDiff
Drawing Number

Size
A3

03
Revision



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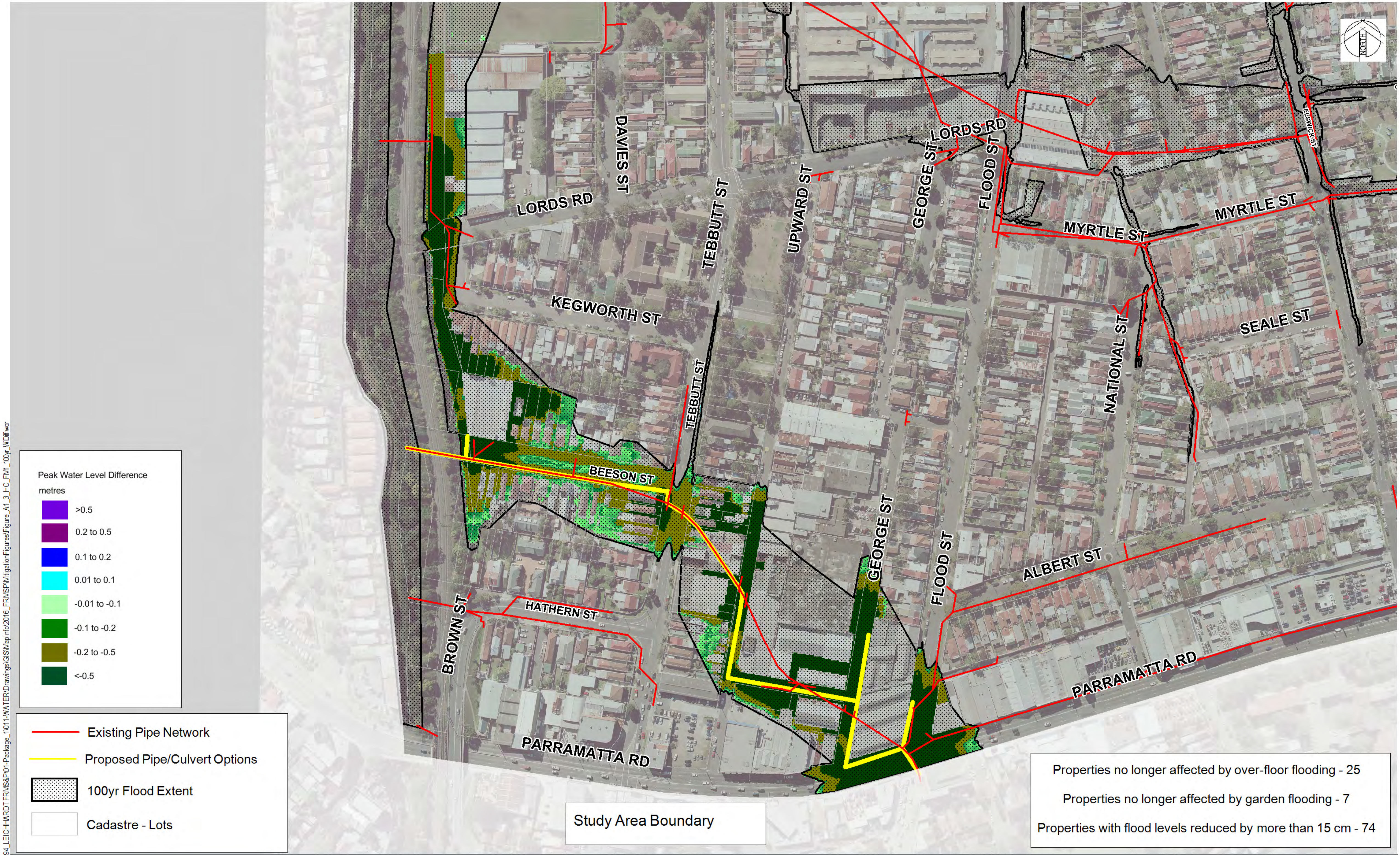
HC_FM1 20YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_2

Date
03/2017

Size
A3

HC_FM1_20yr_WlDiff
Drawing Number

03
Revision



Properties no longer affected by over-floor flooding - 25

Properties no longer affected by garden flooding - 7

Properties with flood levels reduced by more than 15 cm - 74

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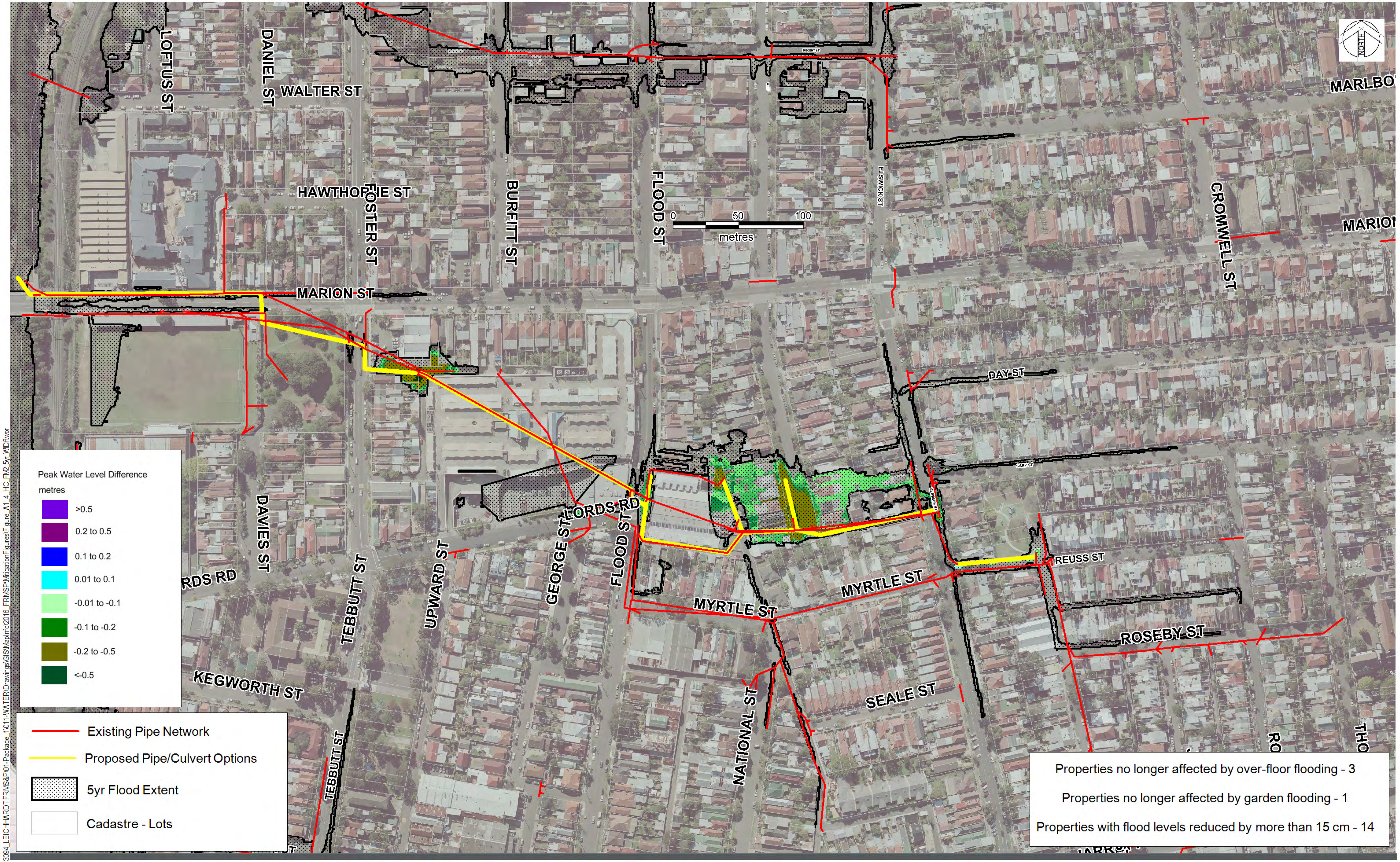
HC_FM1 100YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_3

Date
03/2017

HC_FM1_100yr_WlDiff
Drawing Number

Size
A3

03
Revision



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INNER WEST COUNCIL
LEICHHARDT FRMS&P
HC_FM2 5YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_4

Date
03/2017

HC_FM2_5yr_WlDiff
Drawing Number

Size
A3

03
Revision

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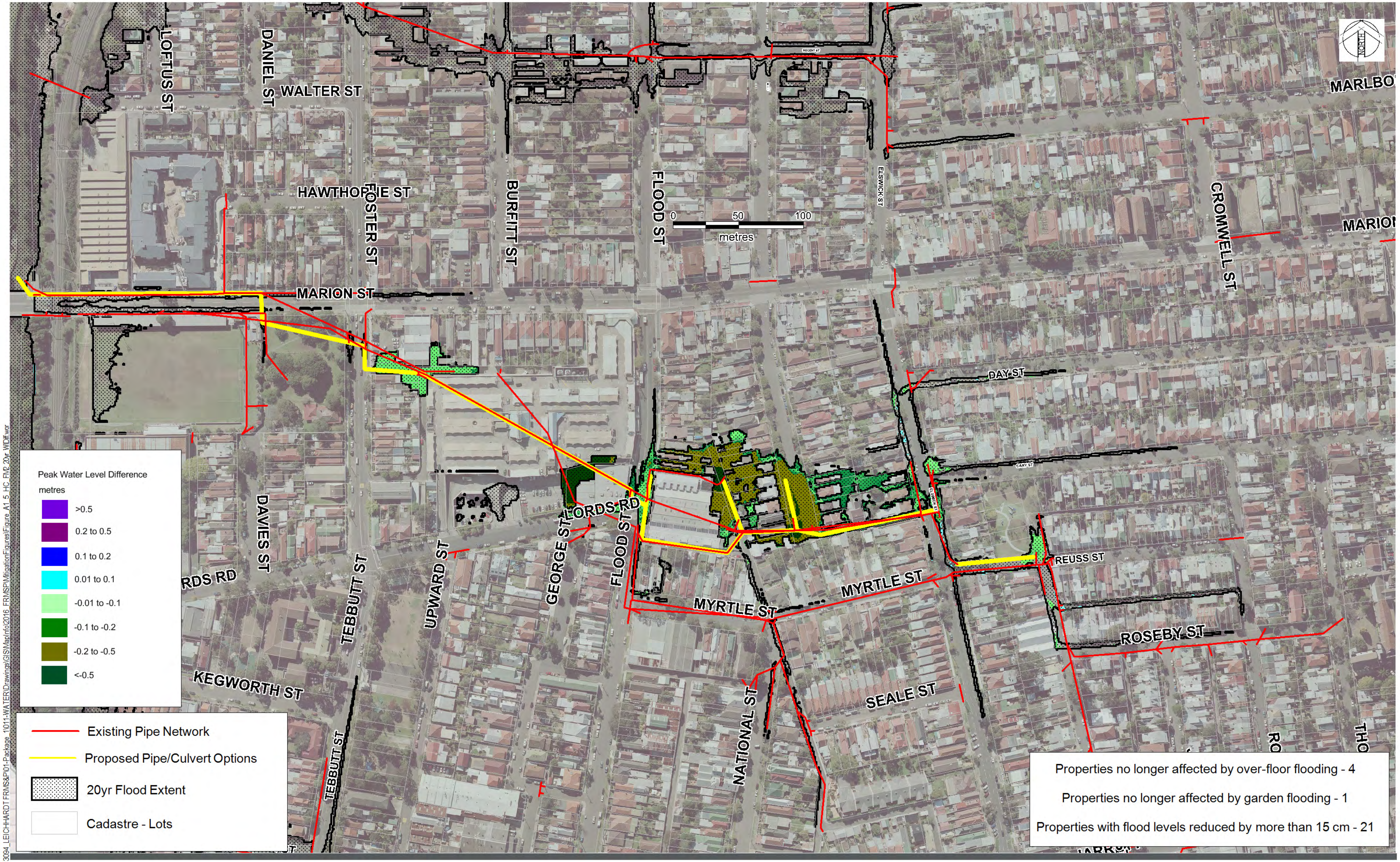

INNER WEST COUNCIL
LEICHHARDT FRMS&P
HC_FM2 20YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_5

Date
03/2017

Size
A3

HC_FM2_20yr_WlDiff
Drawing Number

03
Revision

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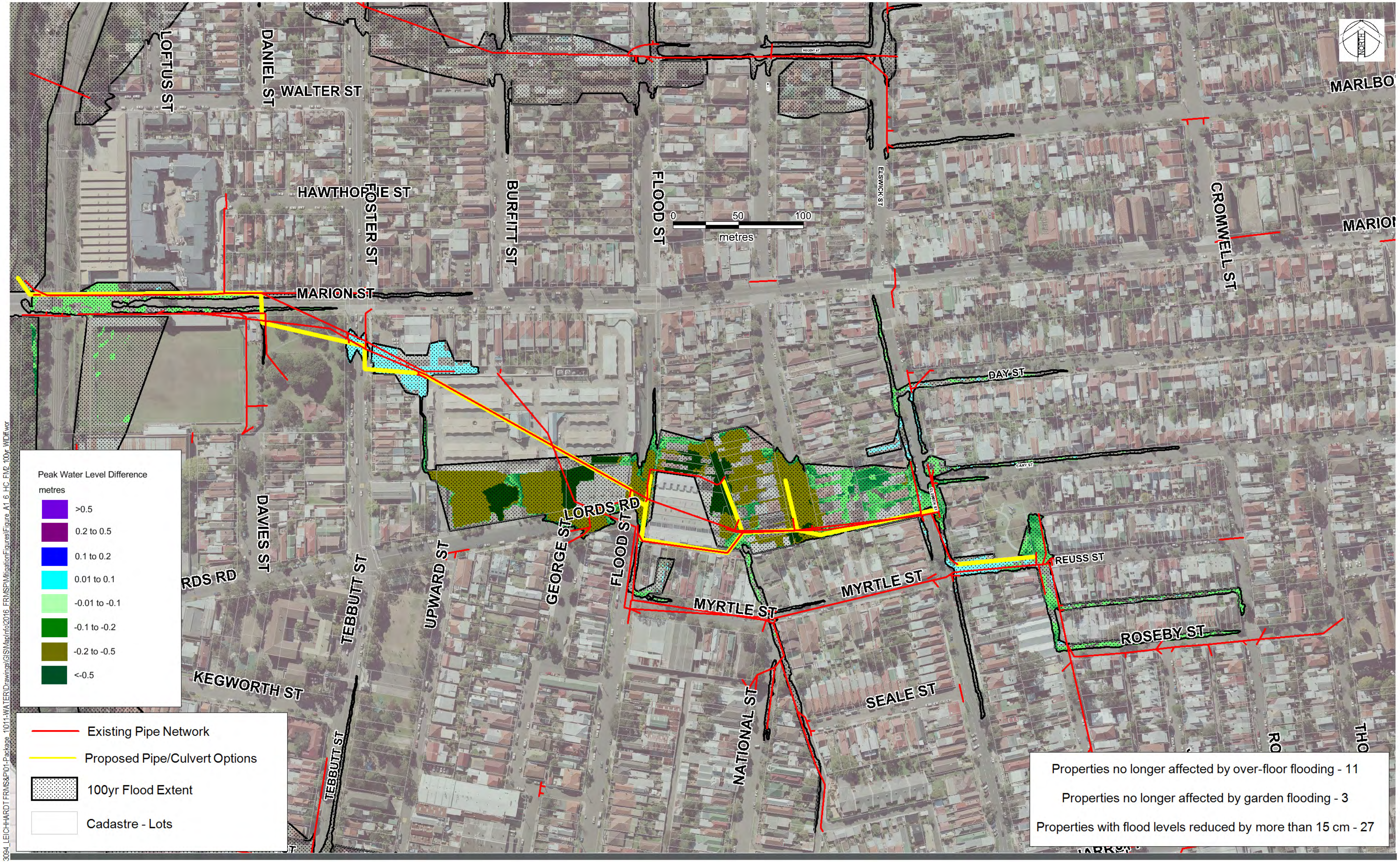

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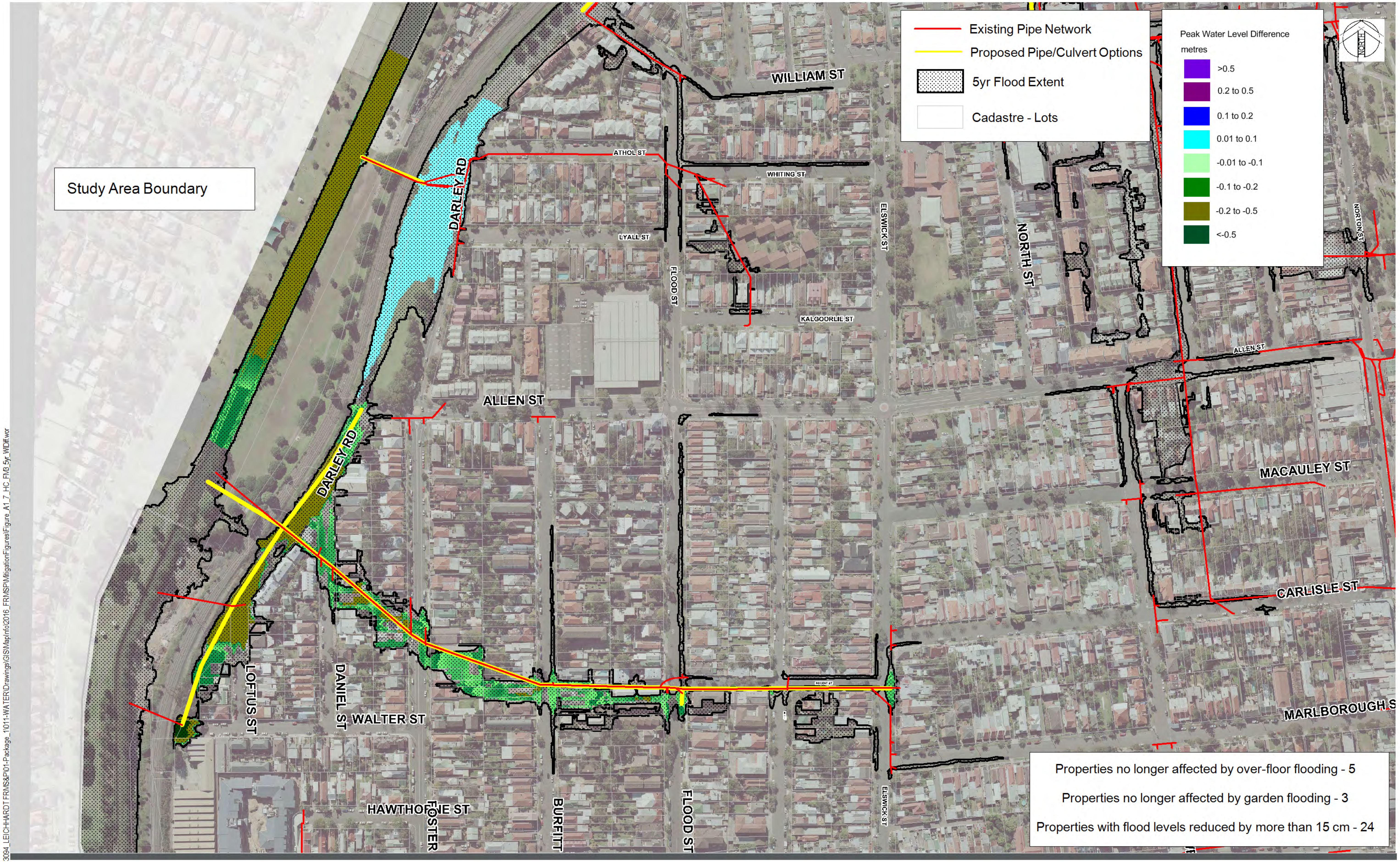
LEICHHARDT FRMS&P
HC_FM2 100YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_6

Date
03/2017

Size
A3

HC_FM2_100yr_WlDiff
Drawing Number

03
Revision



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INNER WEST COUNCIL
LEICHHARDT FRMS&P
HC_FM3 5YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_7

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HC_FM3_5yr_WlDiff
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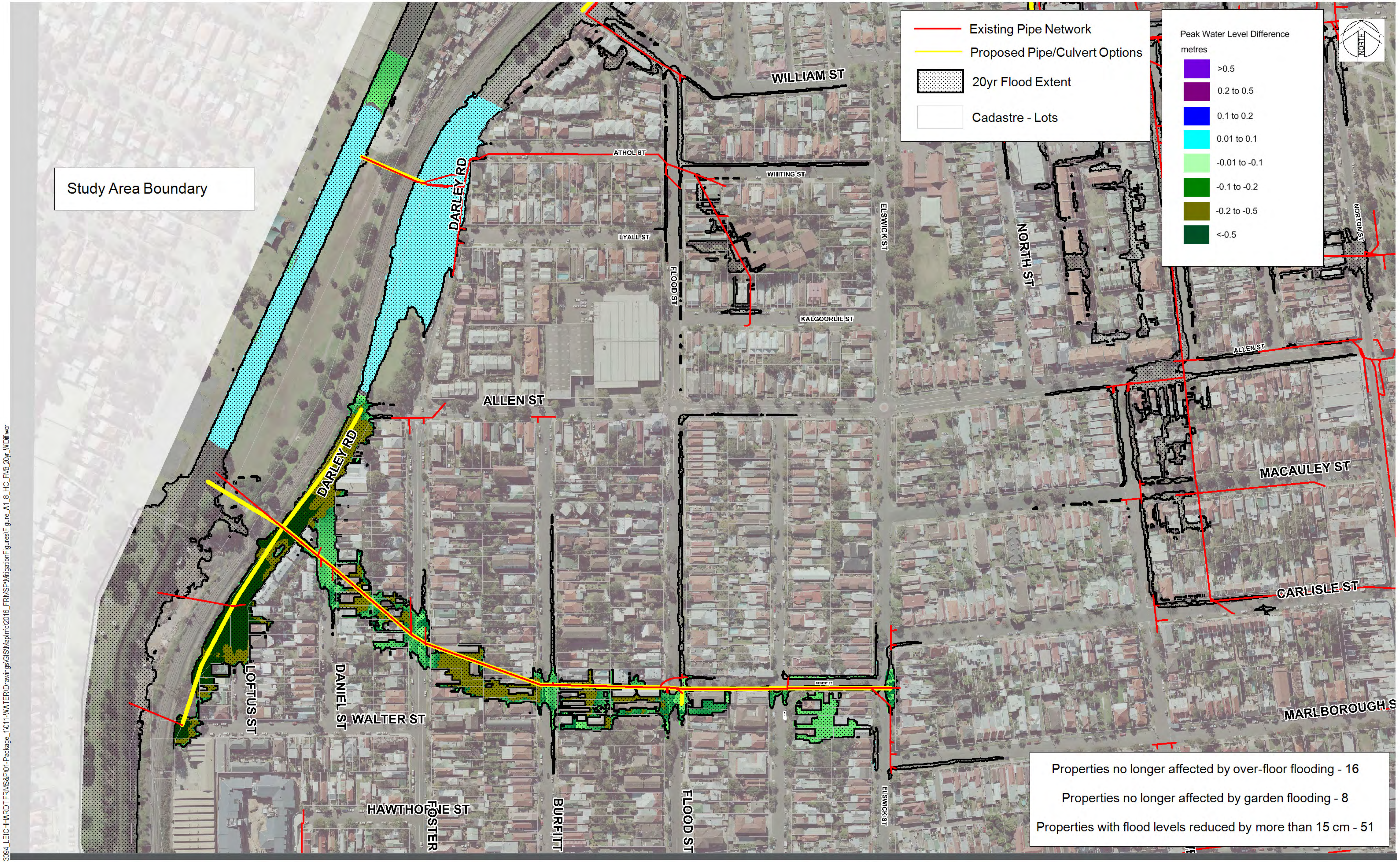

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INNER WEST COUNCIL
LEICHHARDT FRMS&P
HC_FM3 20YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_8

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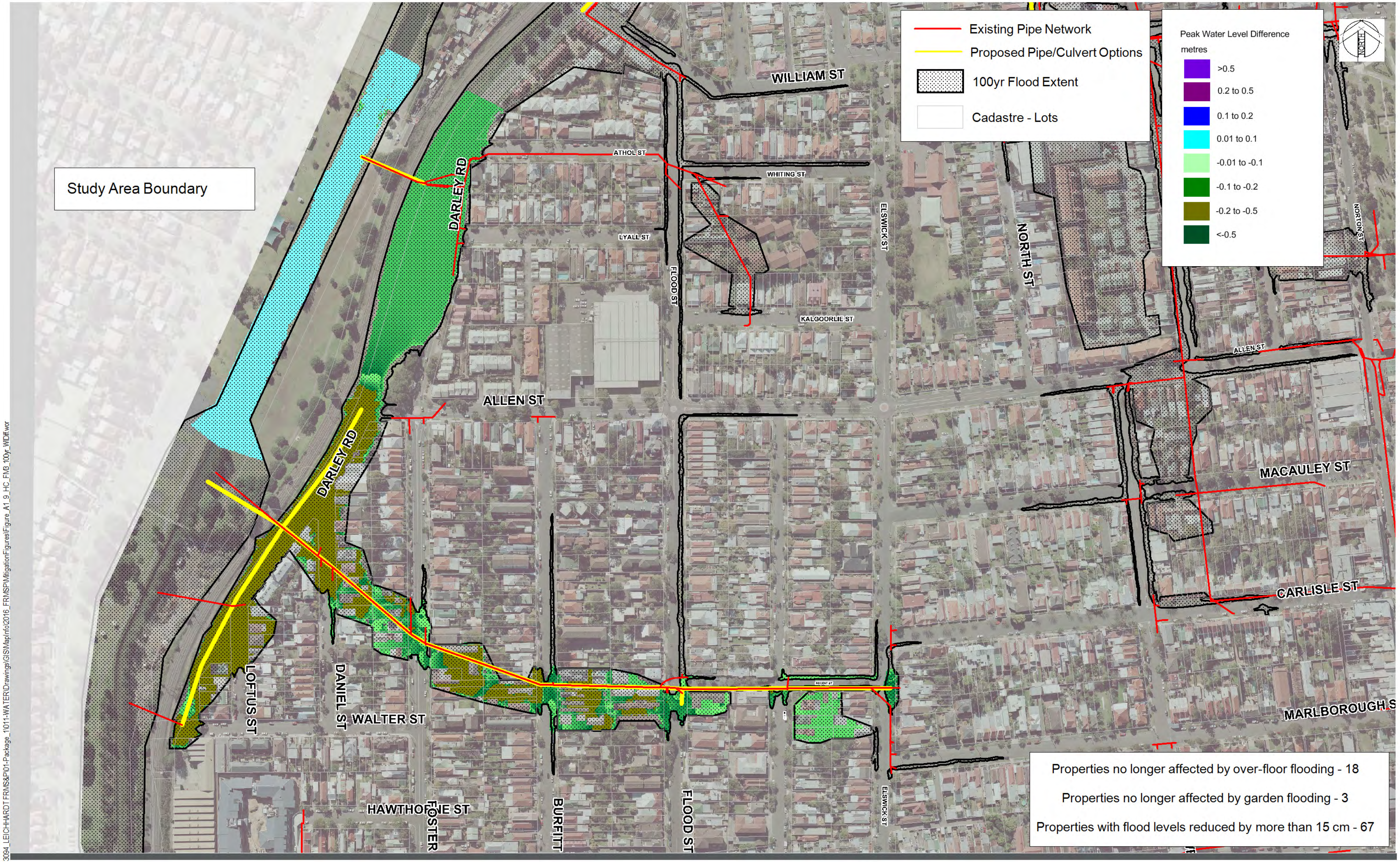

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INNER WEST COUNCIL
LEICHHARDT FRMS&P
HC_FM3 100YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_9

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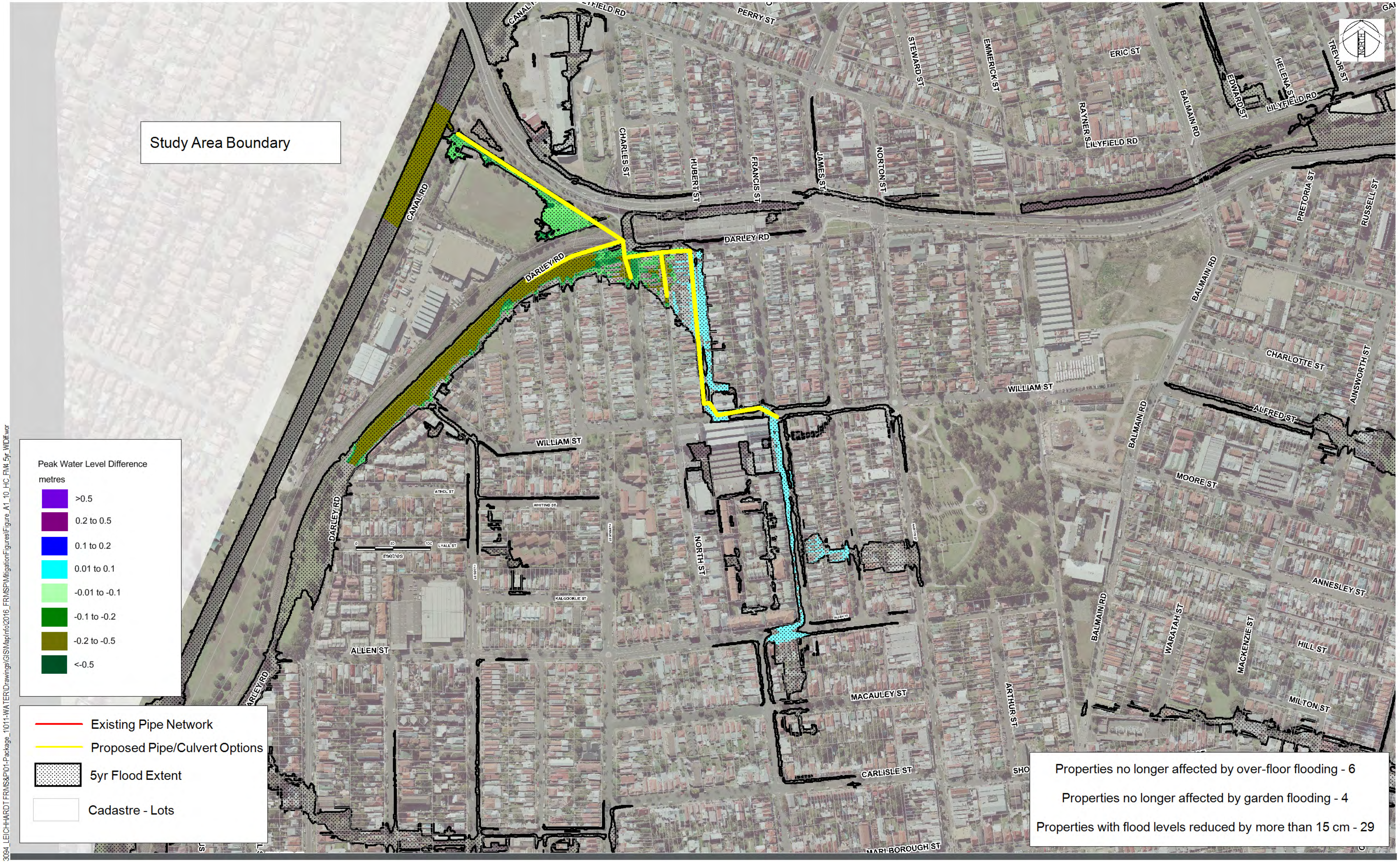
Drawing Number	Revision



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INNER WEST COUNCIL
LEICHHARDT FRMS&P
HC_FM4 5YR ARI WL DIFF
MITIGATION LESS EXISTING
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HC_FM4_5yr_WlDiff
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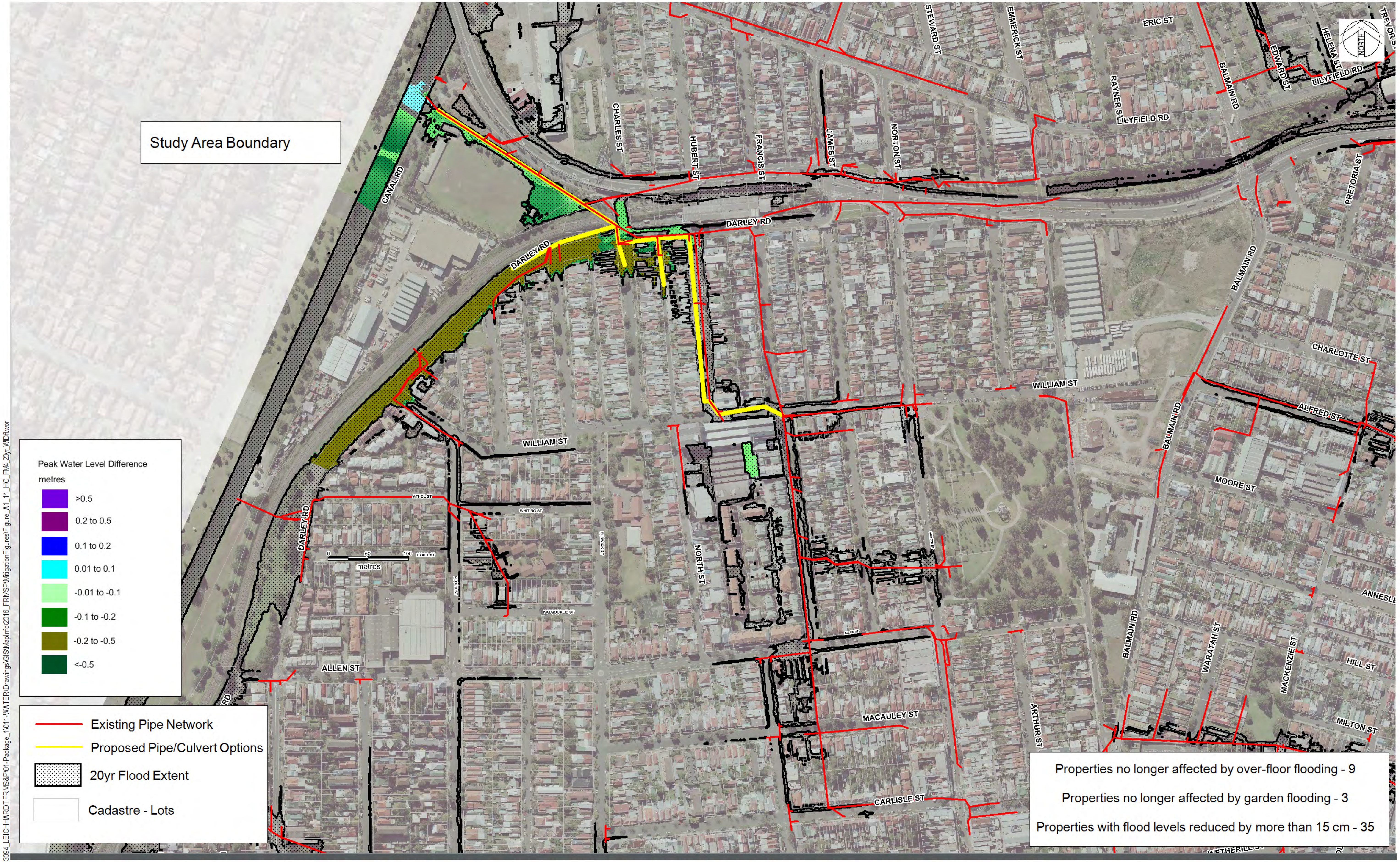

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HC_FM4 20YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_11

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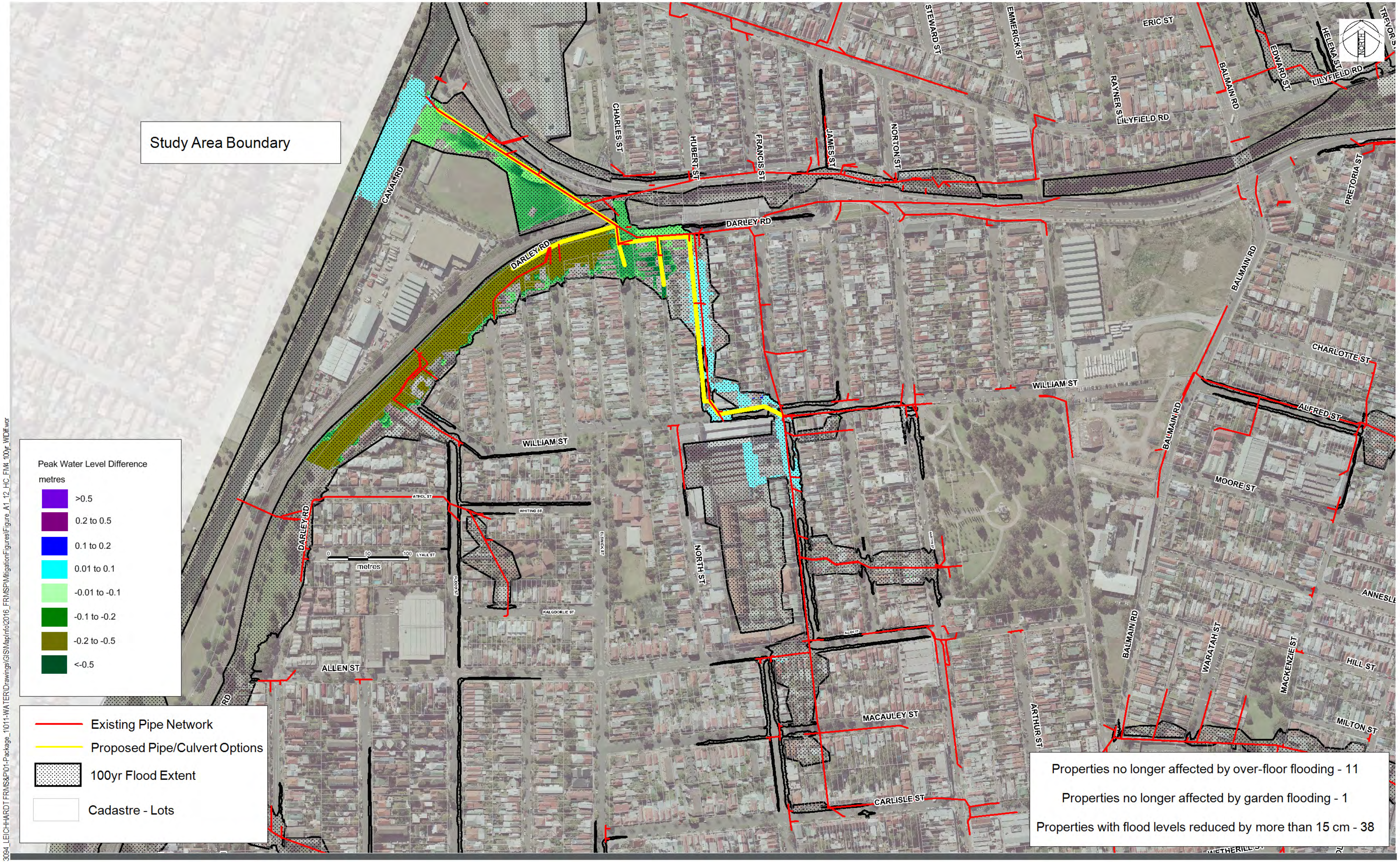

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LEICHHARDT FRMS&P
HC_FM4 100YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_12

Date 03/2017

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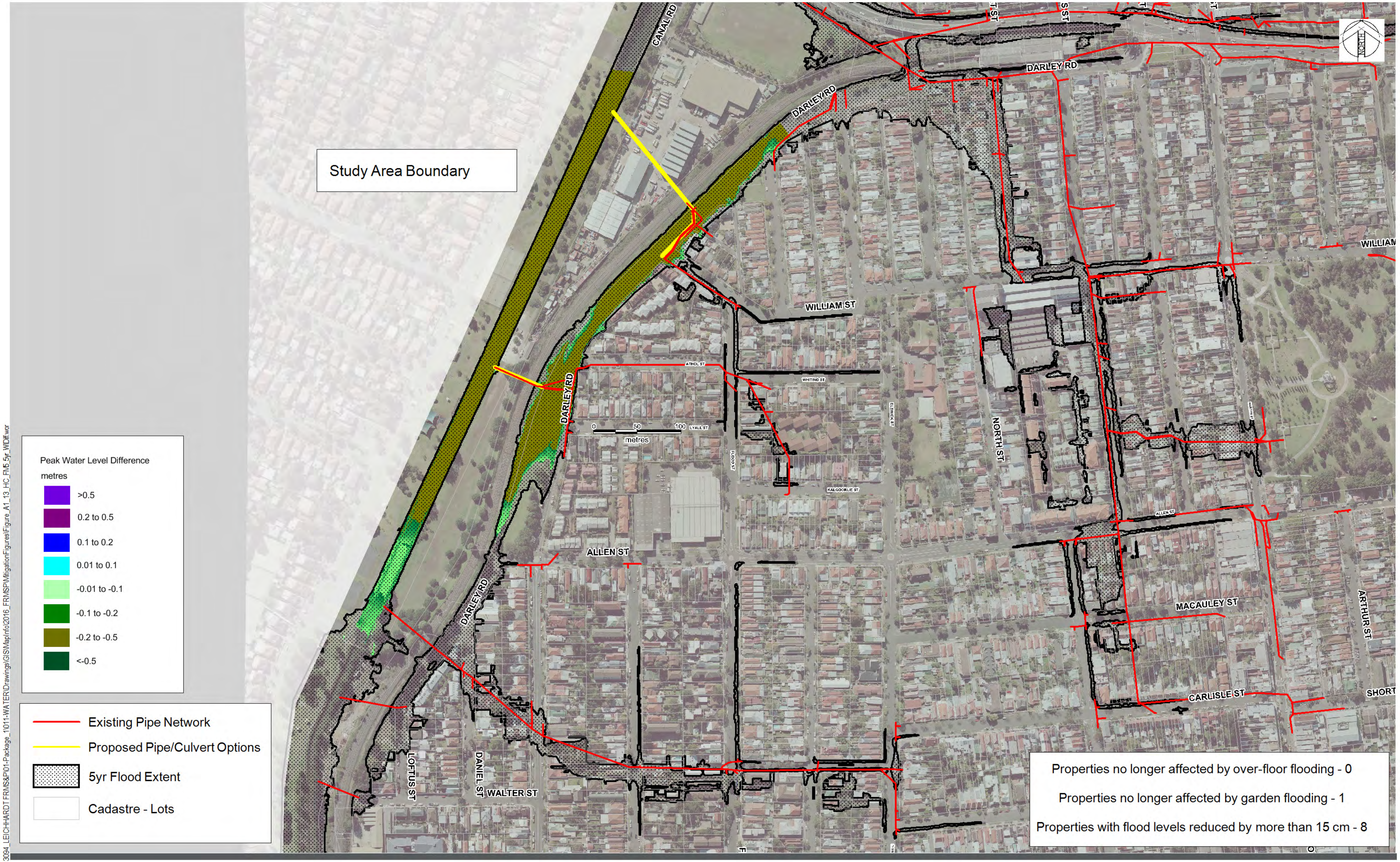

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LEICHHARDT FRMS&P
HC_FM5 5YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_13

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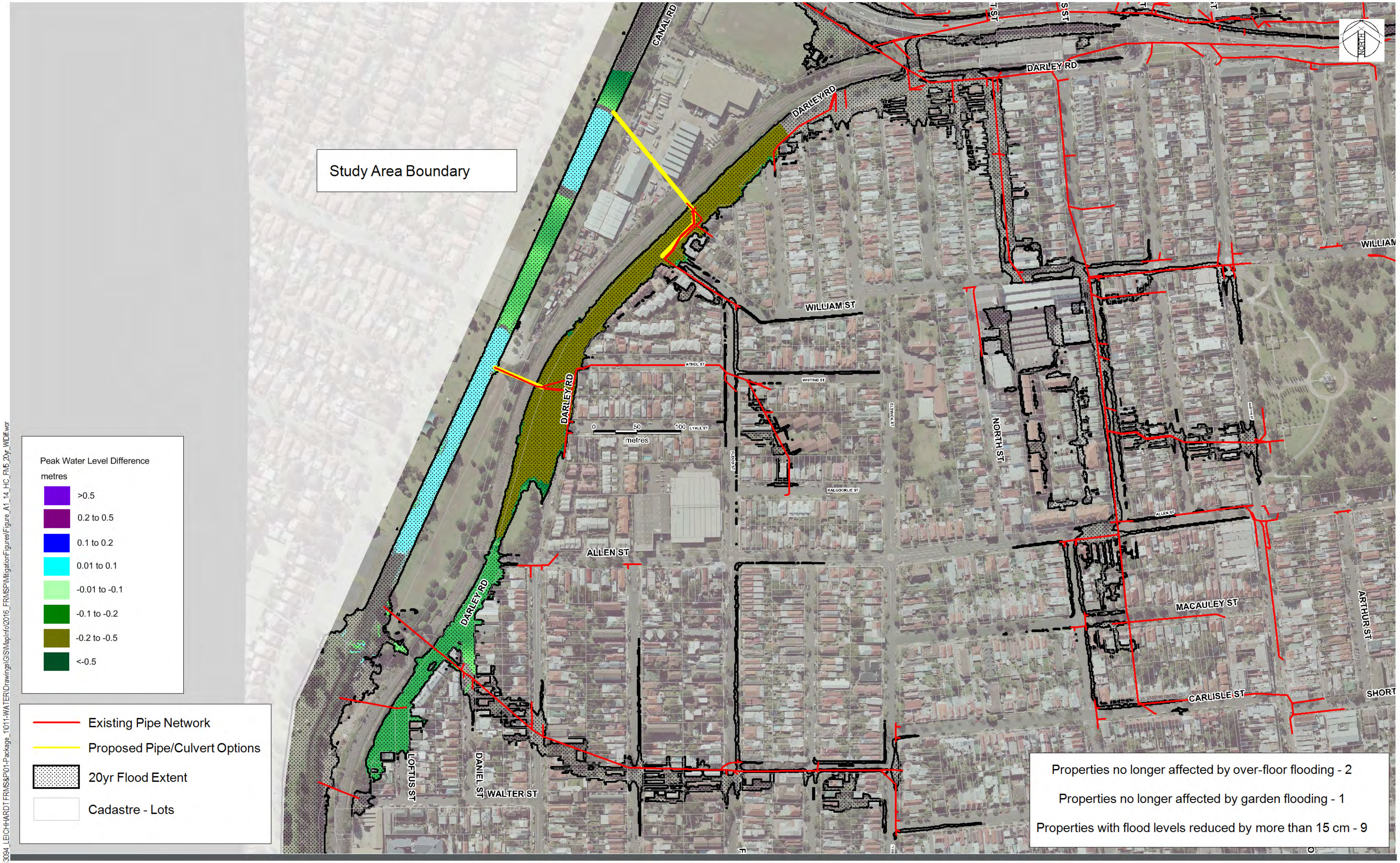
Revision: 03



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INNER WEST COUNCIL
LEICHHARDT FRMS&P
HC_FM5 20YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_14

Date
03/2017

HC_FM5_20yr_WlDiff
Drawing Number

Size
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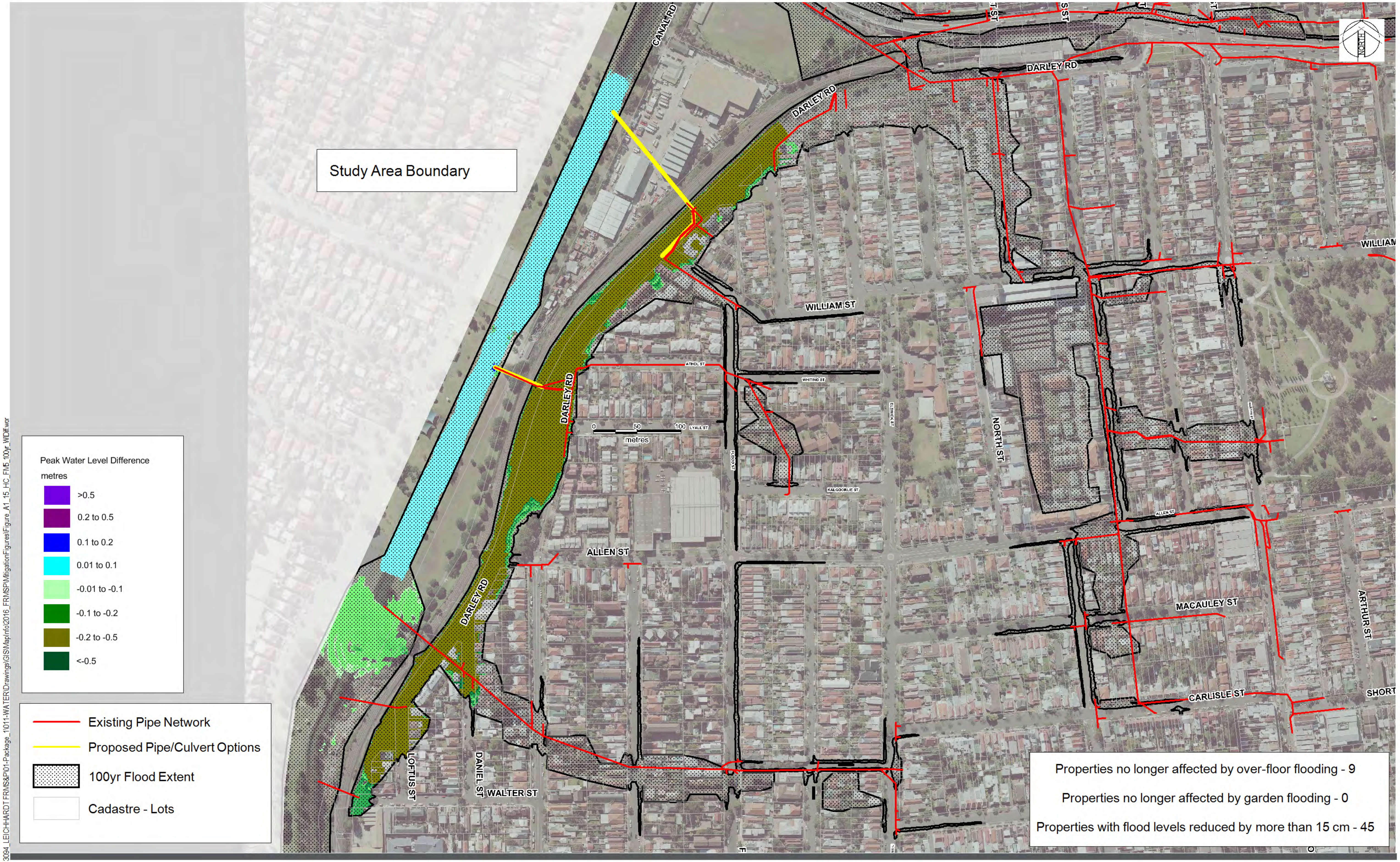
Revision



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INNER WEST COUNCIL
LEICHHARDT FRMS&P
HC_FM5 100YR ARI WL DIFF
MITIGATION LESS EXISTING
FIG_A1_15

Date	03/2017
Size	A3
Drawing Number	HC_FM5_100yr_WlDiff
Revision	03

Area 2 - Johnstons Creek Options Assessment

Leichhardt Flood Risk Management Study and Plan

NA49913094

Prepared for
Inner West Council

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Figures

1 Johnstons Creek Catchment Description

Johnstons Creek originates from the south of the study area. The catchment within study area is in the order of approx.100 hectares in size. A large portion of Johnstons Creek is also located within the City of Sydney LGA, including all areas north of The Crescent. A short section of the creek within the study area, from Parramatta Road to approximately Water Street, is a covered channel. The remainder is an open concrete lined channel.

The majority of the length of the main creek is followed by parkland, which limits flood impacts on adjacent properties. However, a number of tributaries to the main creek result in overland flooding of properties in these areas.

The options proposed for assessment in the report are only located within the study area portion of the Johnstons Creek Catchment.

The location of the Johnstons Creek Catchment within the study area is shown in **Figure 1-1.**

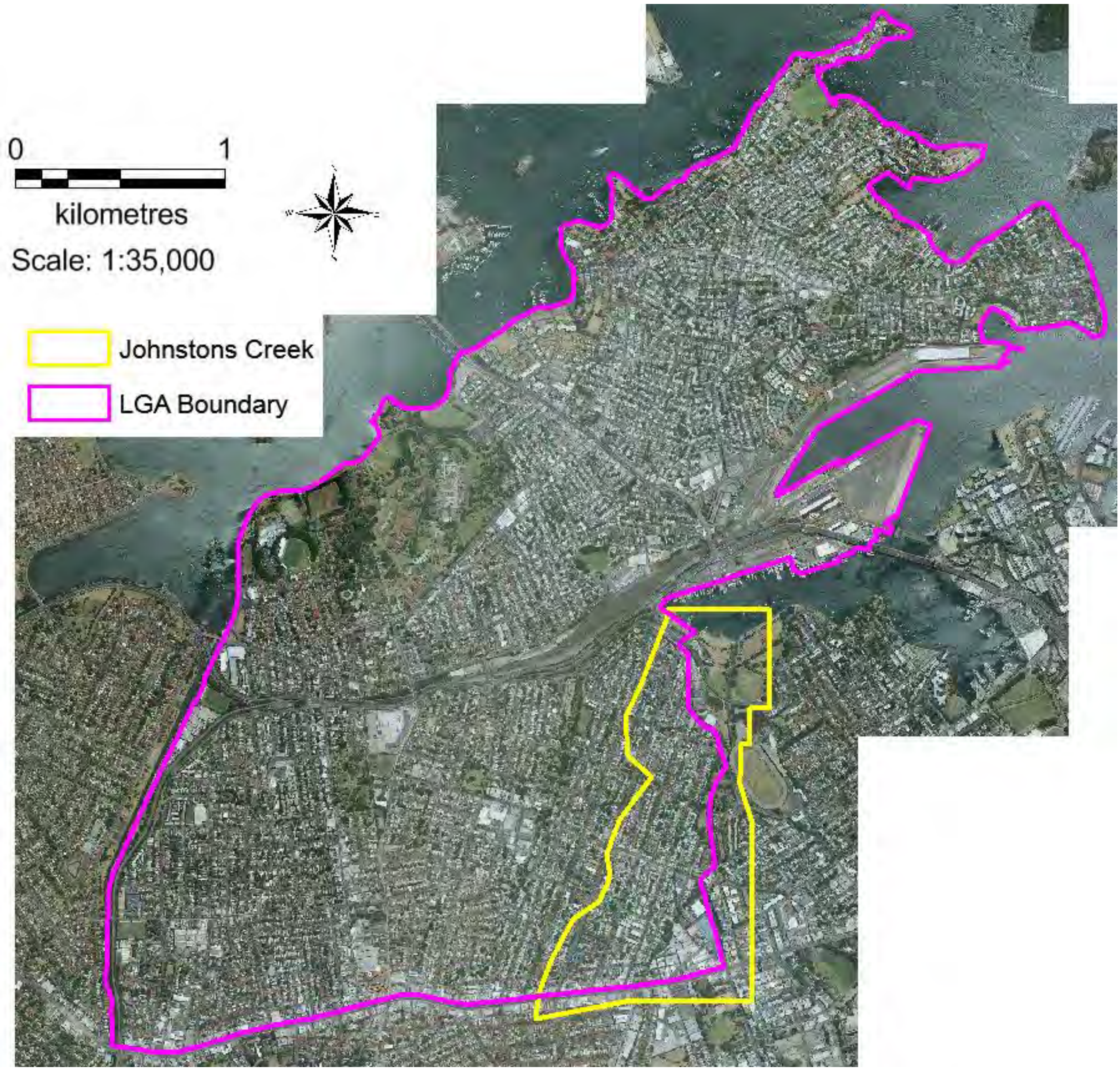

Figure 1-1 Johnstons Creek Catchment Location

2 Flood Mitigation Options Identification

2.1 Flood Modification Measures for Johnstons Creek

The existing flood behaviour within Johnstons Creek is detailed in the Leichhardt Flood Study (Cardno 2014). Based on the flood model results, historical information and engineering judgement, possible flood modification measures (i.e. structural measures) for the study area were identified.

The various management options were identified taking into consideration the:

- flood behaviour and flow in the 20 year ARI event;
- grade of pipe (upstream and downstream); and
- preliminary availability and location of easements.

It should also be noted that Sydney Water and RMS may also play a major role in regards to fund allocation for the options recommended. Sydney Water's approach to flood-related improvement works on its assets is that Sydney Water will work with Councils to deliver the works (typically on a 50:50 cost-sharing basis) and provided Sydney Water has funding available within its Flood Risk Program. It is assumed that RMS will provide all the funding for the transverse pipe sections across State roads. Currently no allocation of RMS funding has been assigned for infrastructure travelling longitudinally along State Roads. It is likely that some contribution would be required from RMS for these upgrades in State Road easements.

Options have been proposed within the Inner West Council portion of the Johnstons Creek catchment. It is noted that City of Sydney Council has also undertaken a Floodplain Risk Management Study for portions of the Johnstons Creek catchment. Options identified by City of Sydney Council have not been duplicated in the Leichhardt FRMS.

Flood modification measures for the Johnstons Creek Catchment have been identified based on opportunities to connect with future upgrades and improvements.

2.2 Johnstons Creek Flood Mitigation Options

Within the Johnstons Creek catchment six (6) sets of options were modelled. These are shown in **Table 2-1** and **Figure 2-1**. The 100yr, 20yr and 5yr ARI peak water level difference plots for each mitigation option are attached at the end of this appendix report.

Table 2-1 Johnstons Creek Mitigation Options

Option Description	Option Name	ID
Johnston Street Flow Path – Proposing additional pipes/ culverts and duplication of existing pipe network from Johnston St to Johnstons Creek open channel. Additional pipes on Parramatta Rd, Trafalgar St, Albion St and Nelson St.	Johnston Street Branch JC-FM1	JC-FM1
Pyrmont Bridge Road Flow Path – Additional pipes or duplication of existing network from Parramatta Rd to Johnstons Creek via Pyrmont Bridge Rd.	Pyrmont Bridge Road Branch JC-FM2	JC-FM2
View Street Flow Path – Duplication of existing pipe network or additional pipes from View St to Johnston Creek (via Trafalgar St, Nelson St and Taylor St).	View Street Branch JC-FM3	JC-FM3
Rose Street Flow Path - Additional pipes from Rose St/Johnston St to Federal Park via View St and Trafalgar St. Proposed Easement downstream of The Crescent to drain flood waters from the low point of the Rd.	Rose Street Branch JC-FM4	JC-FM4
Additional pipes within Johnstons Creek Catchment – At Bayview Crescent, Piper St and at Wigram Rd.	Wigram Road Branch JC-FM5	JC-FM5

Levee option	Piper Street Branch JC-FM5	JC-FM6

Figure 2-1 Johnstons Creek Mitigation Options Locations

2.2.1 Johnston Street Branch JC-FM1

JC-FM1 proposes additional pipes, a culvert and duplication of the existing pipe network from Johnston Street to Johnstons Creek open channel. The option starts from Johnston Street with a 750mm diameter pipe that connects to a 600mm diameter pipe on Trafalgar Street. Next, a 1050mm diameter pipe takes over and travels through Albion Street eventually connecting to a 1.8m x 1.6m culvert (200m) that follows the alignment of Johnstons Creek. Additional pipes are located at Nelson Street (600mm diameter), McCarthy Lane (1200mm diameter), Parramatta Road (1200mm diameter) and Cahill Street (1200mm diameter).

Major flooding due the 20 year ARI storm event is present within the block between Trafalgar Street and Nelson Street, with flood depths in this location up to 1.3m. Flooding is also present under existing conditions at the northern end of the proposed culverts with depths in this location up to 2.2m.

Potential constraints for this measure include the pipe crossings of major roads, with associated costs due to construction, services and traffic management requirements.

RMS may potentially provide funding for the transverse section across Johnston Street while Sydney Water may provide funding for upgrading Johnston Creek Channel.

2.2.2 Pyrmont Bridge Road Branch JC-FM2

This option proposes additional pipes and/or duplication of the existing network from Parramatta Road to Johnstons Creek via Mallet Street and Pyrmont Bridge Rd. The option consists of a 1650mm diameter pipe with a length of 440m. The majority of the flooding under existing conditions is present on Parramatta Road close to Mallet Street with a flood depth of 0.2m in the 20 Year ARI event.

Potential constraints for this measure include interaction with private property and pipe crossings of major roads, especially Parramatta Road, with associated costs due to construction, services and traffic management requirements. Further, this option would rely on drainage upgrades on the southern side of Parramatta Road, which is external to the study area.

Funding from Sydney Water and RMS could potentially be allocated for the majority of the works.

2.2.3 View Street Branch JC-FM3

JC-FM3 consists of proposed pipes from View Street to Johnston Creek via Trafalgar Street, Trafalgar Lane, Nelson Street, Nelson Lane and Taylor Street. The major proposed drainage branch is composed of a 900mm diameter pipe with a length of 500m. Additionally, a 600mm diameter pipe is proposed to connect to the major branch on Nelson Lane. Trafalgar Street is exposed to the worst of the flooding under existing conditions, with the 20 year ARI storm event resulting in flood depths of up to 1.9m.

Potential constraints for this measure include pipe crossings of roads with associated costs due to construction, services and traffic management requirements.

Funding from Sydney Water may be available for upgrades to the main trunk drainage.

2.2.4 Rose Street Branch JC-FM4

The Rose Street Branch option consists of proposed pipes and a culvert from the Rose St/Johnston St intersection to Federal Park via View Street and Trafalgar Street. It also includes a proposed easement (not included in capital cost estimate) downstream of The Crescent to drain flood waters from the low point of the road. The option consists of a proposed 900mm diameter pipe section with 900mm diameter branches. The 900mm diameter pipe eventually connects to a box culvert (1.2m x 1.2m) that is located along The Crescent that drains onto Federal Park. The option also proposed three 1050mm diameter pipes to connect into the culvert.

There is a new development currently underway at 233A Johnston Street. Annandale. This development has incorporated upgrade of the drainage system and re-routing of the existing overland flow path through the site to Rose Street.

The City of Sydney may be involved in this option as this option crosses into their LGA. Additionally, the easement is required to access the existing open channel. The majority of the flooding under existing conditions takes place on The Crescent with the 20 year ARI storm event resulting in flood depths up to 0.7m.

Funding from Sydney Water (for the main trunk drainage at the Crescent) and RMS funding may be available for a majority of the cost. The RMS funding would be allocated towards the transverse pipe upgrades on Johnston Street and The Crescent.

2.2.5 Additional pipes within Johnstons Creek Catchment JC-FM5

This option proposes additional pipes in four separate locations in order to minimise the flooding due to the 20 year ARI storm event. The first sets of pipes (900mm diameter) are proposed to be located along Johnston Street and then cross at Bayview Crescent and The Crescent. The rest of the pipes (900mm diameter) are proposed to be located on The Crescent (close to The Crescent/Nelson Street intersection), on Piper Street (Between Nelson Street and Nelson Lane) and on Wigram Road (Start point on Booth Lane).

The majority of the flooding under existing conditions takes place along Johnstons Creek due to the 20 year ARI storm event. Where options have been proposed, flood depths reach up to 2m.

A majority of the capital cost of the option will potentially be the responsibility of RMS, especially for the works carried out on Johnston Street and the Crescent. Sydney Water will also be responsible for the works on Piper Street.

The City of Sydney may be involved in discussions for this option as it is partially located within the City of Sydney LGA.

2.2.6 Levee Option JC-FM6

A levee or embankment is proposed on Nelson Lane, starting from the northern end of Taylor Street in order to minimise flooding adjacent to Johnstons Creek. The Levee is proposed to be 270m in length and 1m high.

Significant constraints may include the level of excavation and or fill that will be required to place the levee and ensuring that there are no adverse flooding impacts on the eastern side of Johnston’s Creek.

3 Mitigation Option Modelling Outcomes

The Johnstons Creek flood mitigation options were assessed for the 5, 10, 20, 50 and 100 Year ARI design flood events, along with the PMF event.

The outcomes of the modelling are shown in the 5, 20, and 100 Year ARI water level difference plots attached at the end of this catchment report.

A summary of the impacts on flood behaviour for each option is provided below.

3.1 Johnston Street Branch JC-FM1

The proposed increase in drainage capacity of mitigation option JC-FM1 is shown to reduce overland flows along the Johnston Street flow path. The water level difference results show a decrease of 0.10m – 0.50m along the flow path in the 100 Year ARI event. The proposed mitigation strategy shows water level decreases along sections of Parramatta Road, Johnston Street, Trafalgar Street, Nelson Street, Albion Street and Mccarthy Lane, and along the closed section of Johnston's Creek.

Increases in water levels are also seen along the open channel downstream of Water Street in an order of 0.01m to 0.10m. These increases are largely confined to the creek reserves, however, some impacts are seen on industrial properties.

3.2 Pyrmont Bridge Road Branch JC-FM2

Mitigation option JC-FM2 shows significant flood level decreases of more than 1.00m on Bignell Lane and 0.60m on Pyrmont Bridge Road in a 100 Year ARI event. A 0.01m – 0.10m water level decrease results along parts of Parramatta Road and along the Pyrmont Bridge Road flowpath.

Increases in water levels are also seen along the open channel in an order of 0.01m to 0.06m in all events. These increases downstream are largely confined to the creek reserves. However, there are some increases in flooding within residential properties.

3.3 View Street Branch JC-FM3

The proposed increase in drainage capacity of mitigation option JC-FM3 shows decrease in water levels along the View Street Branch flowpath. The mitigation strategy shows water level decreases in an order of 0.10m to 0.45m for all the modelled design events on View Street, Trafalgar Street, Trafalgar Lane, Nelson Street and Nelson Lane.

Minor increases in flood levels are observed in the downstream reaches within the open space areas.

3.4 Rose Street Branch JC-FM4

Mitigation option JC-FM4 shows significant decrease in water levels on The Crescent up to 0.30m in a 20 Year ARI event. The proposed increase in drainage capacity results in decreases in water levels along the Rose Street Branch flowpath in the order of 0.01m to 0.30m in a 20 Year ARI event. The most significant reductions are seen on Johnstons Street, View Street, parts of Rose Street and The Crescent.

3.5 Additional pipes within Johnstons Creek Catchment JC-FM5

The proposed increase in drainage capacity in Johnston Street shows decreases in water levels in an order of 0.01m to 0.10m along Johnston Street and The Crescent.

Proposed mitigation works on Piper Street reduces flood levels between Nelson Street and Nelson Lane up to 0.45m in a 20 Year ARI.

The proposed mitigation option on Wigram Road (near Booth Lane) reduces water levels up to 0.10m in all the modelled design events.

3.6 Levee Option JC-FM6

The proposed Levee or Embankment mitigation option on Nelson Lane will have an adverse impact. Significant increases of flood levels up to 0.50m are seen in all the modelled design events on Nelson Lane upstream of the Levee. This option is not recommended as a preferred option due to the adverse impacts.

4 Economic Assessment of Flood Damages in the Johnstons Creek Catchment

4.1 Johnstons Creek Mitigation Options Damages Assessment

An assessment of damages for the existing condition in the Johnstons Creek Catchment is presented in the Floodplain Risk Management Study. The approach adopted for calculating the existing damages has been repeated for the modelling results from the mitigation options proposed for the Johnstons Creek catchment.

The economic flood damage results for each of the options and the existing scenarios are presented in **Table 4-1 to Table 4-6**. The reductions in properties affected by overground and overfloor flooding, total damages and AAD are provided. Negative values represent increases from the existing scenario.

The total reduction in damaged properties and the associated reduction in damage costs for each mitigation strategy is summarised in **Table 4-7**. This table represents a summary of differences between existing and Mitigation scenarios presented in **Table 4-1** to **Table 4-6.**

The flood damages assessment is a useful tool for comparing the merits of various options, it is not a precise flood risk analysis tool and the limitation associated with the assessment should be considered when interpreting the results.

The following information should be considered when interpreting the damages data:

- Negative property or dollar values represent increases from the existing scenario.
- Where an option results in a reduction in flood depths there may not be any reduction in the flood damages where:
  - The reduction in flood depths or extent occur in open space or roadways; or
  - The reduction in flood depths occurs on properties that were not impacted by over floor flooding (i.e. the flooding on the property grounds is shallower but still exists).
- The flood damages are calculated at a discrete location on each property. This location is where the floor level and ground level survey was obtained from. As such, if the flooding occurs at another location on the property other than the survey point, this property will not register any damages with regards to this damages assessment.
- Commercial and industrial damages are only incurred when over floor flooding exists.
- The reduction in the number of properties impacted as a result of an option may vary between different flood events due to the performance of the proposed work under the different flow behaviour of each flood event.

Table 4-1 JC_FM1 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	112	108	170	168	$ 6,905,349	$ 6,455,078
Commercial	40	37	49	47	$ 1,943,047	$ 1,725,697
Industrial	27	27	30	30	$ 4,692,758	$ 4,606,772
PMF Total	**179**	**172**	**249**	**245**	**$ 13,541,155**	**$ 12,787,547**
100yr ARI						
Residential	37	34	62	59	$ 1,644,421	$ 1,519,454
Commercial	17	11	31	29	$ 753,831	$ 488,308
Industrial	12	13	13	13	$ 949,341	$ 1,099,228
100yr ARI Total	**66**	**58**	**106**	**101**	**$ 3,347,593**	**$ 3,106,989**
50yr ARI						
Residential	36	31	58	55	$ 1,559,031	$ 1,394,390
Commercial	15	9	29	28	$ 700,125	$ 381,108
Industrial	12	12	13	13	$ 884,929	$ 930,406
50yr ARI Total	**63**	**52**	**100**	**96**	**$ 3,144,085**	**$ 2,705,904**
20yr ARI						
Residential	34	26	52	49	$ 1,447,881	$ 1,116,214
Commercial	14	8	22	21	$ 562,005	$ 296,458
Industrial	12	12	13	13	$ 891,189	$ 830,262
20yr ARI Total	**60**	**46**	**87**	**83**	**$ 2,901,074**	**$ 2,242,934**
10yr ARI						
Residential	30	21	51	49	$ 1,307,856	$ 930,701
Commercial	13	8	22	21	$ 499,235	$ 279,004
Industrial	12	12	13	13	$ 842,284	$ 763,863
10yr ARI Total	**55**	**41**	**86**	**83**	**$ 2,649,375**	**$ 1,973,568**
5yr ARI						
Residential	21	19	44	41	$ 974,485	$ 878,861
Commercial	13	8	20	19	$ 456,919	$ 269,869
Industrial	12	12	12	13	$ 747,004	$ 769,549
5yr ARI Total	**46**	**39**	**76**	**73**	**$ 2,178,409**	**$ 1,918,280**
Total Annual Average Damage					**$ 914,483**	**$ 770,509**

Table 4-2 JC_FM2 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	89	91	108	108	$ 5,401,038	$ 5,470,598
Commercial	16	16	19	19	$ 1,146,777	$ 1,144,707
Industrial	51	44	61	60	$ 7,890,238	$ 6,277,209
PMF Total	**156**	**151**	**188**	**187**	**$ 14,438,053**	**$ 12,892,515**
100yr ARI						
Residential	29	30	43	43	$ 1,239,326	$ 1,278,776
Commercial	8	8	11	11	$ 335,511	$ 336,078
Industrial	23	18	29	29	$ 2,363,025	$ 1,296,158
100yr ARI Total	**60**	**56**	**83**	**83**	**$ 3,937,862**	**$ 2,911,012**
50yr ARI						
Residential	28	29	40	40	$ 1,166,060	$ 1,209,098
Commercial	7	7	11	11	$ 307,551	$ 308,174
Industrial	22	17	26	25	$ 1,997,649	$ 1,188,249
50yr ARI Total	**57**	**53**	**77**	**76**	**$ 3,471,260**	**$ 2,705,521**
20yr ARI						
Residential	26	27	37	37	$ 1,063,721	$ 1,110,604
Commercial	6	6	9	9	$ 237,490	$ 237,517
Industrial	20	17	22	22	$ 1,790,969	$ 1,124,498
20yr ARI Total	**52**	**50**	**68**	**68**	**$ 3,092,181**	**$ 2,472,618**
10yr ARI						
Residential	23	22	36	36	$ 961,578	$ 941,382
Commercial	6	6	9	9	$ 225,808	$ 223,965
Industrial	19	17	20	20	$ 1,431,804	$ 1,027,135
10yr ARI Total	**48**	**45**	**65**	**65**	**$ 2,619,190**	**$ 2,192,482**
5yr ARI						
Residential	15	15	32	33	$ 660,168	$ 682,756
Commercial	6	6	7	7	$ 222,620	$ 233,743
Industrial	18	17	18	18	$ 1,155,131	$ 865,923
5yr ARI Total	**39**	**38**	**57**	**58**	**$ 2,037,919**	**$ 1,782,422**
Total Annual Average Damage					**$ 908,695**	**$ 767,500**

Table 4-3 JC_FM3 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	79	68	106	105	$ 4,963,436	$ 4,536,044
Commercial	8	7	16	16	$ 149,216	$ 128,920
Industrial	0	0	0	0	$ -	$ -
PMF Total	**87**	**75**	**122**	**121**	**$ 5,112,653**	**$ 4,664,964**
100yr ARI						
Residential	11	10	22	22	$ 667,145	$ 585,978
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
100yr ARI Total	**11**	**10**	**22**	**22**	**$ 667,145**	**$ 585,978**
50yr ARI						
Residential	11	10	23	23	$ 647,491	$ 572,370
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
50yr ARI Total	**11**	**10**	**23**	**23**	**$ 647,491**	**$ 572,370**
20yr ARI						
Residential	11	10	20	20	$ 613,983	$ 551,606
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
20yr ARI Total	**11**	**10**	**20**	**20**	**$ 613,983**	**$ 551,606**
10yr ARI						
Residential	10	9	18	18	$ 498,757	$ 449,900
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
10yr ARI Total	**10**	**9**	**18**	**18**	**$ 498,757**	**$ 449,900**
5yr ARI						
Residential	7	6	13	13	$ 352,684	$ 291,045
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
5yr ARI Total	**7**	**6**	**13**	**13**	**$ 352,684**	**$ 291,045**
Total Annual Average Damage					**$ 177,684**	**$ 154,645**

Table 4-4 JC_FM4 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	69	65	108	108	$ 3,979,076	$ 3,803,742
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
PMF Total	**69**	**65**	**108**	**108**	**$ 3,979,076**	**$ 3,803,742**
100yr ARI						
Residential	21	18	40	38	$ 1,339,891	$ 1,104,829
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
100yr ARI Total	**21**	**18**	**40**	**38**	**$ 1,339,891**	**$ 1,104,829**
50yr ARI						
Residential	19	17	35	35	$ 1,239,310	$ 1,039,956
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
50yr ARI Total	**19**	**17**	**35**	**35**	**$ 1,239,310**	**$ 1,039,956**
20yr ARI						
Residential	18	16	33	32	$ 1,157,013	$ 992,966
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
20yr ARI Total	**18**	**16**	**33**	**32**	**$ 1,157,013**	**$ 992,966**
10yr ARI						
Residential	18	15	28	27	$ 1,090,293	$ 925,472
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
10yr ARI Total	**18**	**15**	**28**	**27**	**$ 1,090,293**	**$ 925,472**
5yr ARI						
Residential	15	11	20	19	$ 936,480	$ 798,922
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
5yr ARI Total	**15**	**11**	**20**	**19**	**$ 936,480**	**$ 798,922**
Total Annual Average Damage					**$ 373,426**	**$ 319,777**

Table 4-5 JC_FM5 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	8	8	8	8	$ 1,501,106	$ 1,520,227
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
PMF Total	**8**	**8**	**8**	**8**	**$ 1,501,106**	**$ 1,520,227**
100yr ARI						
Residential	0	0	3	3	$ 8,999	$ 3,000
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
100yr ARI Total	**0**	**0**	**3**	**3**	**$ 8,999**	**$ 3,000**
50yr ARI						
Residential	0	0	3	3	$ -	$ 3,000
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
50yr ARI Total	**0**	**0**	**3**	**3**	**$ -**	**$ 3,000**
20yr ARI						
Residential	0	0	0	0	$ -	$ -
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
20yr ARI Total	**0**	**0**	**0**	**0**	**$ -**	**$ -**
10yr ARI						
Residential	0	0	0	0	$ -	$ -
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
10yr ARI Total	**0**	**0**	**0**	**0**	**$ -**	**$ -**
5yr ARI						
Residential	0	0	0	0	$ -	$ -
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
5yr ARI Total	**0**	**0**	**0**	**0**	**$ -**	**$ -**
Total Annual Average Damage					**$ 7,595**	**$ 7,690**

Table 4-6 JC_FM6 Flood Damage Assessment Summary

Event / Property type	Properties with Overfloor Flooding		Properties with Overground Flooding		Estimated Total Damage ($ June 2016)	
	Existing Case	*Mitigation Case*	*Existing Case*	*Mitigation Case*	*Existing Case*	*Mitigation Case*
PMF Event						
Residential	70	70	71	71	$ 3,947,417	$ 4,023,200
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
PMF Total	**70**	**70**	**71**	**71**	**$ 3,947,417**	**$ 4,023,200**
100yr ARI						
Residential	4	19	24	24	$ 180,231	$ 691,205
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
100yr ARI Total	**4**	**19**	**24**	**24**	**$ 180,231**	**$ 691,205**
50yr ARI						
Residential	4	16	21	21	$ 153,024	$ 637,614
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
50yr ARI Total	**4**	**16**	**21**	**21**	**$ 153,024**	**$ 637,614**
20yr ARI						
Residential	1	16	20	20	$ 82,224	$ 605,635
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
20yr ARI Total	**1**	**16**	**20**	**20**	**$ 82,224**	**$ 605,635**
10yr ARI						
Residential	1	13	16	16	$ 57,211	$ 468,568
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
10yr ARI Total	**1**	**13**	**16**	**16**	**$ 57,211**	**$ 468,568**
5yr ARI						
Residential	0	8	10	10	$ 22,828	$ 322,596
Commercial	0	0	0	0	$ -	$ -
Industrial	0	0	0	0	$ -	$ -
5yr ARI Total	**0**	**8**	**10**	**10**	**$ 22,828**	**$ 322,596**
Total Annual Average Damage					**$ 36,743**	**$ 163,665**

Table 4-7 Reduction in Damages Associated with Each Option

	Overfloor flooding properties reduction	Overground flooding properties reduction	Total Damage Reduction ($)	AAD Reduction ($)
	JC-FM1			
PMF event	7	4	$ 753,607	$4,971
100yr ARI event	8	5	$ 240,603	$3,394
50yr ARI event	11	4	$ 438,181	$16,445
20yr ARI event	14	4	$ 658,141	$33,349
10yr ARI event	14	3	$ 675,807	$46,797
5yr ARI event	7	3	$ 260,129	$39,019
Total				**$143,974**
	JC-FM2			
PMF event	5	1	$1,545,538	$12,861
100yr ARI event	4	0	$1,026,850	$8,963
50yr ARI event	4	1	$ 765,739	$20,780
20yr ARI event	2	0	$ 619,563	$26,157
10yr ARI event	3	0	$ 426,708	$34,110
5yr ARI event	1	-1	$ 255,498	$38,325
Total				**$141,195**
	JC-FM3			
PMF event	12	1	$ 447,689	$2,644
100yr ARI event	1	0	$ 81,166	$781
50yr ARI event	1	0	$ 75,121	$2,062
20yr ARI event	1	0	$ 62,377	$2,781
10yr ARI event	1	0	$ 48,857	$5,525
5yr ARI event	1	0	$ 61,639	$9,246
Total				**$23,039**
	JC-FM4			
PMF event	4	0	$ 175,333	$2,052
100yr ARI event	3	2	$ 235,062	$2,172
50yr ARI event	2	0	$ 199,353	$5,451
20yr ARI event	2	1	$ 164,047	$8,222
10yr ARI event	3	1	$ 164,821	$15,119
5yr ARI event	4	1	$ 137,558	$20,634
Total				**$53,649**
	JC-FM5			
PMF event	0	0	-$ 19,121	-$66
100yr ARI event	0	0	$ 5,999	$15
50yr ARI event	0	0	-$ 3,000	-$45
20yr ARI event	0	0	$ -	$0
10yr ARI event	0	0	$ -	$0
5yr ARI event	0	0	$ -	$0
Total				**-$96**
	JC-FM6			
PMF event	0	0	-$ 75,782	-$2,933
100yr ARI event	-15	0	-$ 510,974	-$4,978
50yr ARI event	-12	0	-$ 484,590	-$15,120
20yr ARI event	-15	0	-$ 523,411	-$23,369
10yr ARI event	-12	0	-$ 411,356	-$35,556
5yr ARI event	-8	0	-$ 299,768	-$44,965
Total				**-$126,922**

4.2 Benefit to Cost Ratio of Options

The economic evaluation of each modelled measure was assessed by considering the reduction in the amount of flood damages incurred for the design events and by then comparing this value with the cost of implementing the measure.

Table 4-8 summarises the results of the economic assessment of each of the flood management options. The indicator adopted to rank these measures on economic merit is the benefit-cost ratio (B/C), which is based on the net present worth (NPW) of the benefits (reduction in AAD) and the costs (capital and ongoing), adopting a 7% discount rate and an implementation period of 50 years.

The benefit-cost ratio provides an insight into how the damage savings from a measure, relate to its cost of construction and maintenance:

- Where the benefit-cost is greater than 1 the economic benefits are greater than the cost of implementing the measure;
- Where the benefit-cost is less than 1 but greater than 0, there is still an economic benefit from implementing the measure but the cost of implementing the measure is greater than the economic benefit;
- Where the benefit-cost is equal to zero, there is no economic benefit from implementing the measure; and
- Where the benefit-cost is less than zero, there is a negative economic impact of implementing the measure.

Table 4-8 Summary of Economic Assessment of Flood Management Options

Option ID	Option Description	NPW of Reduction in AAD	NPW of Cost of Implementation	B/C Ratio	Economic Ranking
JC-FM1	Johnston Street Flow Path – Proposing additional pipes/ culverts and duplication of existing pipe network from Johnston St to Johnstons Creek open channel. Additional pipes on Parramatta Rd, Trafalgar St, Albion St and Nelson St.	$1,987,000	$8,109,000	0.25	2
JC-FM2	Pyrmont Bridge Road Flow Path – Additional pipes or duplication of existing network from Parramatta Rd to Johnstons Creek via Pyrmont Bridge Rd.	$1,949,000	$6,182,000	0.32	1
JC-FM3	View Street Flow Path – Duplication of existing pipe network or additional pipes from View St to Johnston Creek (via Trafalgar St, Nelson St and Taylor St).	$318,000	$3,039,000	0.10	4
JC-FM4	Rose Street Flow Path - Additional pipes from Rose St/Johnston St to Federal Park via View St and Trafalgar St. Proposed Easement downstream of The Crescent to drain flood waters from the low point of the Rd.	$740,000	$3,491,000	0.21	3
JC-FM5	Additional pipes within Johnstons Creek Catchment – At Bayview Crescent, Piper St and at Wigram Rd.	-$1,000	$2,447,000	0.00	5
JC-FM6	Levee option	-$1,752,000	$633,000	-2.77	6

Johnstons Creek Mitigation Option Figures