Floodplain Risk Management Study

Alexandra Canal Floodplain Risk Management Study and Plan

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Foreword

The NSW Government Flood Prone Land Policy is directed towards providing solutions to existing flood problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the policy, the management of flood prone land is the responsibility of Local Government. The State Government subsidises flood management measures to alleviate existing flooding problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities. The Commonwealth Government also assists with the subsidy of floodplain modification measures.

The Policy identifies the following floodplain management 'process' for the identification and management of flood risks:

1. Formation of a Committee -

   Established by a Local Government Body (Local Council) and includes community group representatives and State agency specialists.

2. Data Collection -

   The collection of data such as historical flood levels, rainfall records, land use, soil types etc.

3. Flood Study -

   Determines the nature and extent of the flood problem.

4. Floodplain Risk Management Study –

   Evaluates floodplain management measures for the floodplain in respect of both existing and proposed development.

5. Floodplain Risk Management Plan –

   Involves formal adoption by Council of a management plan for the floodplain.

6. Implementation of the Plan –

   Implementation of actions to manage flood risks for existing and new development.

This Alexandra Canal Catchment Floodplain Risk Management Study is developed from the previous Flood Study, prepared by Cardno for the City of Sydney Council.

Executive Summary

Cardno were commissioned by the City of Sydney to undertake a Floodplain Risk Management Study and Plan (FRMSP) for the Alexandra Canal Catchment. This FRMSP has been undertaken to define the existing flooding behaviour and associated hazards, and to investigate possible management options to reduce flood damage and risk. The tasks were undertaken alongside community consultation to ensure that community concerns were addressed.

The overall objective of this study is to develop a FRMSP that addresses the existing, future and continuing flood problems, taking into account the potential impacts of climate change, in accordance with the NSW Government's Flood Policy, as detailed in the Floodplain Development Manual (NSW Government, 2005).

The total catchment area is approximately 1,141ha and includes the suburbs of Alexandria, Rosebery, Erskineville, Beaconsfield, Zetland, Waterloo, Redfern, Newtown, Eveleigh, Surry Hills and Moore Park. It is generally bounded by the Eastern Distributor and Moore Park in the east, Gardeners Road in the south, Sydney Park and Newton in the west and Albion Street in the north-east. The majority of the trunk drainage system is owned by Sydney Water Corporation, whilst the feeding drainage systems are primarily owned by Council.

The majority of the catchment is fully developed and consists predominantly of medium to high-density housing, commercial and industrial development with some large open spaces.

A draft flood study has been prepared by Cardno (2013) to define the flood behaviour in the study area, including both mainstream and overland flooding. The Flood Study determined the flood behaviour for the 100 year ARI, 20 year, 10 year, 5 year, 2 year and 1 year Average Recurrence Interval (ARI) events together with the Probable Maximum Flood (PMF). The primary flood characteristics reported for the design events include depths, levels and velocities. The study has also defined the Provisional Flood Hazard for flood-affected areas. An assessment of the impact of blockages of culverts and pits was also undertaken for the flood study.

The community consultation undertaken as part of the FRMS built on the consultation undertaken as part of the Flood Study (Cardno, 2013). The purpose of the Flood Study (Cardno, 2013) consultation was to inform the community about the study and gain an understanding of the community's experience with historical flooding in the catchment. The purpose of the more recent consultation undertaken as part of this FRMS was to inform the community about the study, identify community concerns and attitudes, to gather information from the community on potential options for the floodplain and to develop and maintain community confidence in the study results.

The community consultation consisted of:

- A community brochure and survey;
- A press release; and
- Community information meeting during the public exhibition period.

Provisional flood hazard was defined as part of the Flood Study (Cardno, 2013) based on velocity and depth of flood waters for the PMF, 100 and 5 Year ARI events. The additional hazard factors outlined in the Floodplain Development Manual were considered as part of a true hazard assessment undertaken in this FRMS.

Flooding is likely to cause significant social and economic damages to the community. A flood damage assessment for the existing catchment and floodplain conditions has been undertaken as part of the current study. The assessment is based on damage curves that relate the depth of flooding on a property to the potential damage within the property. Average Annual Damage (AAD) is calculated on a probability approach using the flood damages calculated for each design event.

The average annual damage estimated for the Alexandra Canal floodplain under existing conditions is approximately **$13.0 million** (excluding GST).

The majority of flooding within the Alexandra Canal catchment is characterised by overland flow. The critical duration is between 1 and 3 hours across the catchment, with the peak of the flood reached approximately 30 minutes to 1 hour after the start of the storm. This is considered short duration "flash" flooding. The short time period until flooding occurs does not allow sufficient time to evacuate residents from their properties. A review of the current emergency response arrangements has been undertaken considering the nature of flooding within the catchment.

Floodplain management is primarily employed through development controls and other planning measures. A review of the relevant state and local planning instruments has been undertaken with regards to floodplain management within Alexandra Canal Catchment. The outcomes of this review have been incorporated into the proposed floodplain risk management options.

A key component of development controls relating to floodplain management is the adoption of a flood planning level. The Sydney LEP 2012 currently defines the flood planning level as the 100 year ARI event plus a freeboard of 0.5m. The suitability of this level for planning purposes in the Alexandra Canal Catchment has been review based on flood behaviour and land use types.

Measures available for the management of flood risk can be categorised according to the way in which the risk is managed. Various options for flood risk management have been identified and assessed. These options can be broadly defined into three categories:

- **Flood modification measures** – Flood modification measures are aimed at preventing / avoiding or reducing the likelihood of flood risks. These options reduce the risk by modifying the flood behaviour in the catchment.
- **Property modification measures** – Property modification measures are focused on preventing / avoiding and reducing consequences of flood risks. Rather than necessarily modify the flood behaviour, these options aim to modify properties (both existing and future) so that there is a reduction in flood risk.
- **Emergency response modification measures** – Emergency response modification measures aim to reduce the consequences of flood risks. These measures generally aim to modify the behaviour of people during a flood event.

It is possible to quantitatively assess the economic benefits of some of the options, namely those that were hydraulically modelled, and those with known benefits. For those options, a benefit-cost ratio can be calculated. Where a desktop assessment was utilised for options (as opposed to hydraulic modelling), a detailed economic analysis was not undertaken. In these cases a judgement on the likely economic benefits of the options was made.

A multi-criteria matrix assessment approach has been adopted for the comparative assessment of all options identified using a similar approach to that recommended in the Floodplain Development Manual (2005). This approach uses a subjective scoring system to assess the merits of various options against economic, social and environmental criteria. The principal merits of such a system are that it allows comparisons to be made between alternatives using a common index. In addition, it makes the assessment of alternatives "transparent" (i.e. all important factors are included in the analysis). However, this approach does not provide an absolute "right" answer as to what should be included in the plan and what should be omitted. Rather, it provides a method by which stakeholders can re-examine options and, if necessary, debate the relative scoring assigned. Each option is given a score according to how well the option meets specific considerations.

The outcome of the multi-criteria matrix assessment is a ranked list of potential floodplain risk management options for implementation in the floodplain. The following measures were highly ranked and should be considered for further assessment and / or implementation:

Non-Structural Measures-

- FM15 Liveable Green Network
- FM23 Increased pit cleaning and maintenance
- EM1 Information Transfer to SES
- EM2 Preparation of District DISPLAN
- EM3 Preparation of Local Flood Plan
- PM3 Opportunities related to Large Scale Future Development
- PM2 Development Controls and Policies
- EM5 Public awareness and education
- PM1 LEP Update
- EM6 Flood warning signs at critical locations
- PM9 Flood Proofing Guidelines
- EM4 Flood Warning System and Temporary Refuge

Structural Measures-

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

The implementation strategy for recommended floodplain risk management measures is outlined in the Floodplain Risk Management Plan.

The Draft Flood Study, Draft Floodplain Risk Management Study and Draft Floodplain Risk Management Plan were placed on public exhibition for a period of four weeks from 28 October 2013 to 25 November 2013 to allow input from the community and interested parties to the Study and its outcomes. Exhibition documents were available for review at several community locations and on Council's website.

Details of the exhibition were included in newspapers, mailed/emailed to previous contributors of flood surveys, and emailed to community groups. A community drop-in session was held on Wednesday 20 November 2013 at the Alexandria Town Hall, 73 Garden Street, Alexandria. Officers from Council, Office of Environment and Heritage and Cardno were present and available to answer community questions.

One telephone enquiry was received, three people attended the drop-in session, and one written submission was received. All these were responded to by Council and no further action is required for the Alexandra Canal Floodplain Risk Management Study and Plan.

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Glossary

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded each year; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded each year; it would be fairly rare but it would be relatively large. The 1% AEP event is equivalent to the 1 in 100 year Average Recurrence Interval event.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that periods between exceedances are generally random. That is, an event of a certain magnitude may occur several times within its estimated return period.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events. E.g. some roads may be designed to be overtopped in the 1 in 1 year ARI or 100% AEP flood event.
Development	The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.

Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
Flood hazard	Potential risk to life and limb caused by flooding.
Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood-prone land, rather than being restricted to land subject to designated flood events.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain management measures	The full range of techniques available to floodplain managers.
Floodplain management options	The measures which might be feasible for the management of a particular area.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls.
Flood planning levels	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plains. The concept of FPLs supersedes the “Standard

	flood event" of the first edition of the Manual. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FPLs.
Flood storages	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always, aligned with naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas.
Geographical Information Systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks;

	able-bodied adults would have little difficulty wading to safety.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.
NPER	National Professional Engineers Register. Maintained by Engineers Australia.
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	The flood calculated to be the maximum that is likely to occur.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a more detailed explanation see Annual Exceedance Probability.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.

Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.

Abbreviations

1D	One Dimensional
2D	Two Dimensional
AHD	Australian Height Datum
ARI	Average Recurrence Interval
BoM	Bureau of Meteorology
DCP	Development Control Plan
DECCW	Department of Environment, Climate Change & Water (now OEH)
FPL	Flood Planning Level
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
FRMSP	Floodplain Risk Management Study & Plan
km	kilometres
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
m	metre
m^2	Square metres
m^3	Cubic metres
mAHD	Metres to Australian Height Datum
mm	millimetres
m/s	metres per second
NSW	New South Wales
OSD	On-site Detention
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SES	State Emergency Service
SWC	Sydney Water Corporation

1 Introduction

Cardno were commissioned by the City of Sydney to undertake a Floodplain Risk Management Study and Plan (FRMSP) for the Alexandra Canal Catchment. This FRMSP has been undertaken to define the existing flooding behaviour and associated hazards, and to investigate possible management options to reduce flood damage and risk. The tasks were undertaken alongside community consultation to ensure that community concerns were addressed.

The total catchment area is approximately 1,141ha and includes the suburbs of Alexandria, Rosebery, Erskineville, Beaconsfield, Zetland, Waterloo, Redfern, Newtown, Eveleigh, Surry Hills and Moore Park. It is generally bounded by the Eastern Distributor and Moore Park in the east, Gardeners Road in the south, Sydney Park and Newton in the west and Albion Street in the north-east. The majority of the trunk drainage system is owned by Sydney Water Corporation, while the feeding drainage systems are primarily owned by Council.

The majority of the catchment is fully developed and consists predominantly of medium to high-density housing, commercial and industrial development with some large open spaces.

A draft flood study was prepared in 2012 by Cardno to define the flood behaviour in the study area, including both mainstream and overland flooding. An updated version of the draft report (Cardno, 2013) has subsequently been provided to Council in conjunction with this study, following a review and some minor changes to the flood modelling that was undertaken.

Models were calibrated and verified against four historical storm events that occurred in November 1984, January 1991, April 1998 and February 2001. November 1984 was approximately larger than a 100 year Average Recurrence Interval (ARI) event, while April 1998 was in the order of a 10 year ARI event. The other two events were smaller, with January 1991 roughly a 5 – 10 year ARI event, and February 2001 less than a 1 year ARI event. Using the established models, the flood study determined the flood behaviour for the 100 year ARI, 20 year, 10 year, 5 year, 2 year and 1 year ARI events together with the Probable Maximum Flood (PMF). The primary flood characteristics reported for the design events considered include depths, levels and velocities. The study has also defined the Provisional Flood Hazard for flood-affected areas.

An assessment of the impact of blockages of culverts and pits was also undertaken for the flood study. The results found that the catchment is particularly sensitive to these factors and are therefore considered further in this FRMSP for evaluation of flood planning levels.

A number of flood management options have been examined as part of this Floodplain Risk Management Study to manage flooding within the Alexandra Canal catchment. The identification and examination of these options was done in accordance with the NSW Floodplain Development Manual: The Management of Flood Liable Land ("the Manual") (NSW Government, 2005).

1.1 Study Context

The Floodplain Management process progresses through 6 stages, in an iterative process:

1) Formation of a Floodplain Management Committee;
2) Data collection;
3) Flood Study;
4) Floodplain Risk Management Study;
5) Floodplain Risk Management Plan; and

6) Implementation of the Floodplain Risk Management Plan.

This report represents Stage 4.

1.2 Study Objectives

The overall objective of this study is to develop a FRMSP that addresses the existing, future and continuing flood problems, taking into account the potential impacts of climate change, in accordance with the NSW Government's Flood Policy, as detailed in the Manual (NSW Government, 2005).

This FRMSP was undertaken in two phases:

- Phase 1 – Floodplain Risk Management Study where management issues are assessed, management options are investigated and recommendations are made, and
- Phase 2 – Floodplain Management Plan detailing how flood prone land within the study area is to be managed.

Specific objectives for Phase 1 included:

- Review of the current Flood Study (Cardno, 2013) and (if necessary) re-assess the design flood discharges, velocities, flood levels, hydraulic categories and other relevant flood information for any changes that may have occurred in the Study Area since the flood study was undertaken. Up to date information is required for the full range of potential flood events i.e. up to the PMF or an appropriate extreme flood.
- Review of Council's existing environmental planning policies and instruments including Council's long term planning strategies for the study area, particularly in the light of the potential impact of climate change.
- Identify residential flood planning levels and flood planning area.
- Identify works, measures and restrictions aimed at reducing the social, environmental and economic impacts of flooding and the losses caused by flooding on development and the community, both existing and future, over the full range of potential flood events and taking into account the potential impacts of climate change. Council's aim is to have innovative solutions to the management of the flood hazards within the study area and aims to have effective community consultation and participation throughout the Study.
- To assess the effectiveness of these works and measures for reducing the effects of flooding on the community and development, both existing and future and taking into account the potential impacts of climate change.
- Assess whether the proposed works and measures might produce adverse effects (environmental, social, economic, or flooding) in the floodplain and whether they can be minimised.
- In terms of the Department of Planning Circular PS 07-003 and "Guideline on Development Controls on Low Flood Risk Areas – Floodplain Development Manual", determine if and where exceptional circumstance are appropriate for flood related development controls on residential development on land outside the residential flood planning area.
- Review the local flood plan, identify deficiencies in information and address the issues identified in the DECCW (now OEH) Guideline "SES Requirements from the FRM Process."
- Examination of the present flood warning system, community flood awareness and emergency response measures in the context of the NSW State Emergency Service's developments and disaster planning requirements.

- Examine ways in which the floodplain environment may be enhanced without having a detrimental effect on flooding.
- Identification of modifications required to current policies in the light of investigations
- Council identified the following areas / precincts for redevelopment to accommodate future needs:
  - Midblock Precinct
  - Epsom Park Precinct
  - Green Square Precinct
  - Green Square Town Centre
  - Ashmore Street Estate

The majority of these areas are affected by flooding and to allow redevelopment of these areas flood management solutions are to be investigated. Some individual investigations have already been carried out but these have been reviewed and management solutions assessed for incorporating in the Floodplain Risk Management Plan.

- The City has developed the Liveable Green Network (LGN) Strategy and Master Plan (draft April 2011). Specific flood management measures to be developed based on the LGN strategy and Master Plan.
- Provide flood management strategies to the flood affected areas summarised in **Table 1-1**.

Table 1-1 Flood Affected Areas

Suburb	Flood Affected Streets and Areas
Alexandria	▪ Bourke Road / Doody Street / Ralph Street ▪ Bowden Street ▪ McEvoy Street ▪ Huntley and Coulson Streets ▪ Maddox street ▪ Sydney Park Road ▪ Euston Road ▪ Burrow Road ▪ O'Riordan Street ▪ Botany Road / Wyndham Street/ Buckland Street / Wellington Street
Beaconsfield	▪ Botany Road / Collins Street ▪ Victoria Street and Victoria Lane ▪ Queen Street ▪ Reserve Street
Erskineville	▪ MacDonald Street, ▪ Erskineville Oval and Copeland Street ▪ Ashmore Street ▪ Burren Street ▪ Charles Street ▪ Erskineville Road ▪ Coulson Street and Mitchell Avenue
Eveleigh	▪ Newton Street and Renwick Street ▪ Burren Street ▪ Holdsworth Street ▪ Henderson Street and Mitchell Street
Newtown	▪ Macdonaldtown and Holdsworh Street ▪ Burren Street and Copeland Avenue
Redfern	▪ Boronia Street and Marriott Street ▪ Boronia Street/ Bourke Street/ South Dowling Street ▪ Phillip Street and Baptist Street ▪ Chalmers Street ▪ Phillip Street / Elizabeth Street ▪ Phillip Street / Walkers Street
Rosebery	▪ Morley Avenue / Botany Road / Jones Lane ▪ Cressy Street / Botany Road ▪ Hayes Road / Dunning Avenue / Botany Road ▪ Harcourt Parade / Dunning Avenue / Botany Road ▪ Harcourt parade / Dalmeny Avenue / Tweedmouth Avenue/ Gardeners Road
St Peters	▪ Burrows Road
Surry Hills	▪ Arthur Street / Bourke Street / Nobbs Street / South Dowling Street
Waterloo	▪ Phillip Street and Walker Street ▪ Powell Street and young Street ▪ Phillip Street / Elizabeth Street ▪ Young Street / Danks Street ▪ Elizabeth Street / Wellington Street

Suburb	Flood Affected Streets and Areas
Zetland	▪ Joynton Avenue ▪ Epsom Park ▪ Green square ▪ South Dowling Street

Specific objectives for Phase 2 include:

- Reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk (taking into account the potential impacts of climate change).
- Reduce private and public losses due to flooding.
- Protect and where possible enhance the floodplain environment.
- Be consistent with the objectives of relevant State policies, in particular, the Government's Flood Prone Land and State Rivers and Estuaries Policies and satisfy the objectives and requirements of the Environmental Planning and Assessment Act, 1979.
- Ensure that the Floodplain Risk Management Plan is fully integrated with Council's existing corporate, business and strategic plans, existing and proposed planning proposals, meets Council's obligations under the Local Government Act, 1993 and has the support of the local community.
- Ensure actions arising out of the draft plan are sustainable in social, environmental, ecological and economic terms.
- Ensure that the draft floodplain risk management plan is fully integrated with the local emergency management plan (flood plan) and other relevant catchment management plans.
- Establish a program for implementation which should include priorities, staging, funding, responsibilities, constraints, and monitoring.

2 Catchment Description

The Alexandra Canal catchment covers 1,141ha or 43% of City of Sydney Local Government area, including suburbs of Alexandria, Beaconsfield, Erskineville, Eveleigh, Moore Park, Redfern, Rosebery, Surry Hills, Waterloo and Zetland. Approximately 93% of the total catchment area is within the City of Sydney, with the remaining 7% being shared with the City of Botany Bay, Marrickville and Randwick Councils.

The catchment and study area are shown in Figure 2-1.

Drainage systems consisting of open channels, covered channels, in-ground pipes, culverts and pits convey runoff from the catchment to Alexandra Canal which discharges into the Cooks River. The majority of the trunk drainage system is owned by Sydney Water Corporation, with the feeding drainage systems primarily owned by Council.

The majority of the catchment is fully developed and consists predominantly of medium to high-density housing, commercial and industrial development with some large open spaces that include Moore Park Playing Fields, Moore Park Golf Course, The Australian Golf Course, Sydney Park, Redfern Park, Waterloo Park and Alexandria Park.

Flooding throughout the catchment is a combination of overland flow and mainstream flooding. Mainstream flooding issues tend to occur around Alexandra Canal and the open channels in the study area. Examples of this type of flooding occur at the channel that runs between Alexandra Canal and Bowden Street, the channel near Euston Road and the channel at South Sydney Corporate Park. Elsewhere, flooding is primarily a result of overland flow and the capacity of the stormwater network and overland flowpaths.

A feature of the catchment is the prevalence of ‘trapped’ low points. These areas, due to topographical and development constraints, result in significant ponding and flooding of properties and roads. In a number of these locations, the only way for water to escape is via the pit and pipe system. Examples of these ponding areas include the Coulson Street sag, Joynton Avenue and the ponding upstream of Erskineville Oval.

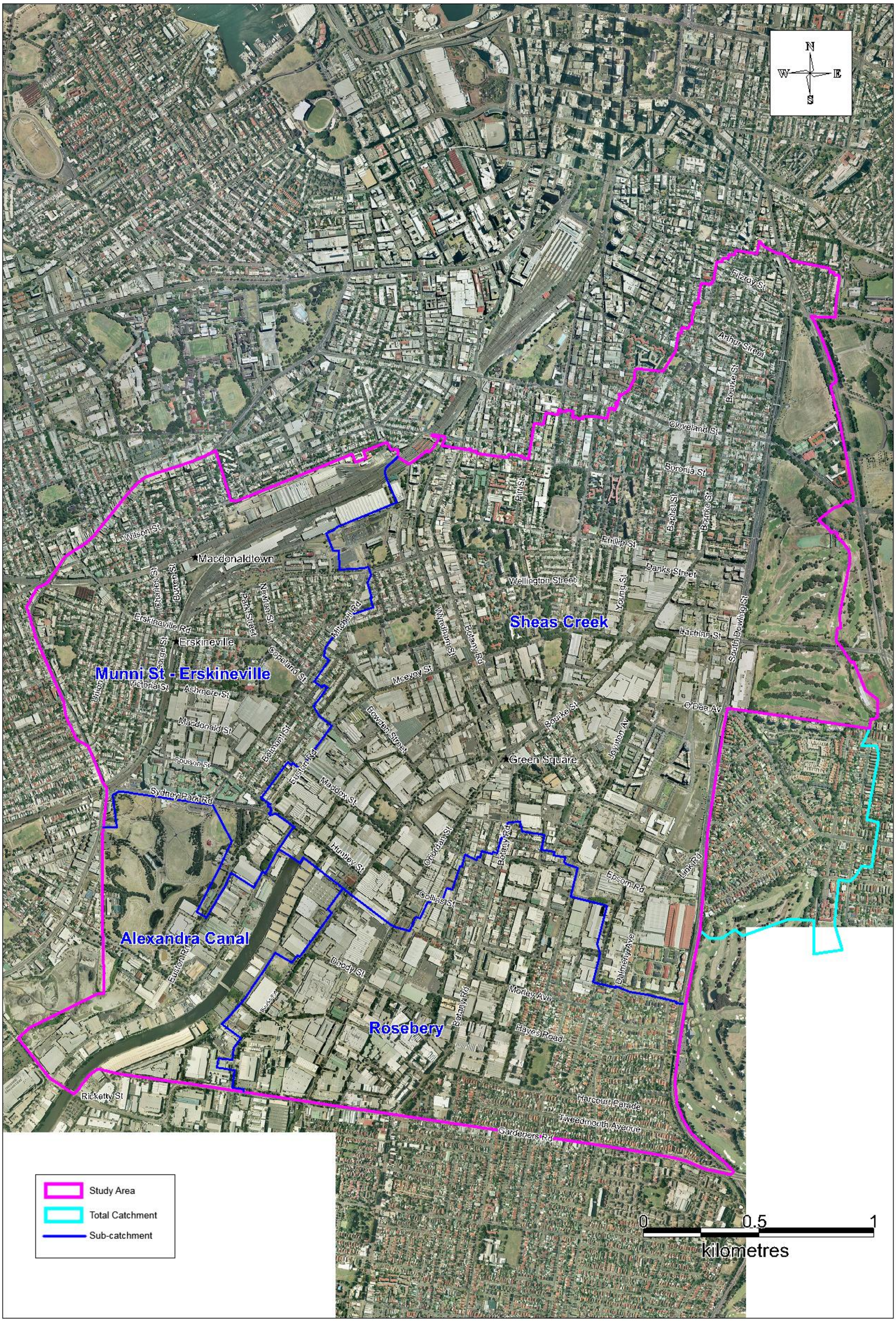

Figure 2-1 Study Area

3 Available Data

3.1 Previous Studies and Reports

3.1.1 Alexandra Canal Catchment Flood Study

The draft Alexandra Canal Catchment Flood Study (Cardno, 2013) is the key input study to the FRMSP. The primary objective of this study was to define the flood behaviour in the study area, including both mainstream and overland flooding. An extensive data compilation and review was undertaken for the study and included a review of a number of previous studies, together with collection of available rainfall records and survey data.

A detailed 1D/2D flood model was established to describe the flooding behaviour throughout the study area. This model incorporates all pits and pipes from data provided by the City of Sydney and has a 4 metre grid resolution. Hydrological modelling was undertaken through the application of the Direct Rainfall methodology.

The models were calibrated and verified against four historical storms; November 1984, January 1991, April 1998 and February 2001. The results of the calibration and verification showed that the model was capable of reproducing the observations from those events, providing confidence in the overall modelling results.

Using the established models, the study has determined the flood behaviour for the 100 year ARI, 20 year, 10 year, 5 year, 2 year and 1 year ARI events as well as the Probable Maximum Flood (PMF). The primary flood characteristics reported for the design events considered include depths, levels and velocities. The study has also defined the Provisional Flood Hazard for flood-affected areas.

Following a review that was undertaken in conjunction with this study, some minor updates were undertaken to the modelling for the flood study, and a revised draft was provided to Council. The key changes that occurred in the modelling are:

- Modification of the terrain in the model between Nobbs Lane and Parkham Lane. This localised area was under construction at the time that the LiDAR was collected, and therefore did not suitably represent the storage in this area.
- Model terrain at Erskineville railway station was revised to refine the representation of overland flowpaths in the vicinity.
- Refinement of hydraulic parameters along Sheas Creek concrete drainage channel.

The above changes were made and incorporated into the updated draft. It is noted that these resulted in only minor localised changes to flood model results to the previous draft.

3.1.2 Green Square – West Kensington Floodplain Risk Management Study & Plan

The relevant documents from the Green Square West Kensington Study are:

- Green Square – West Kensington Floodplain Risk Management Study, Public Exhibition Draft, February 2011, by WMA Water
- Green Square Catchment Floodplain Risk Management Plan, Final Draft, May 2013, by WMA Water

These two documents overlap a part of the study area for the current project, incorporating the eastern part of the Sheas Creek Catchment, inclusive of the Green Square redevelopment area.

The studies identified a number of options for floodplain management and prioritised these options for implementation into a plan. This is similar to the current process undertaken for the study.

Whereas the Green Square West Kensington Studies focused on a portion of the catchment, the current study overviews a much larger study area within the City of Sydney LGA. The measures identified in the Green Square West Kensington studies have been reviewed in conjunction with the identification of options in the current study.

3.1.3 Additional Studies

A number of additional studies have been conducted regarding the Alexandra Canal Catchment. These studies were completed prior to the undertaking of the Flood Study (Cardno 2013) and were reviewed and incorporated into the Flood Study (where relevant). These studies include:

- Green Square Town Centre Flood Mitigation Option Report, 16 July 2008 by Cardno
- Green Square Town Centre Flood Mitigation Option Report Addendum, 12 July 2012 by Cardno
- Green Square Town Centre Floodplain Risk Management Plan, 13 July 2012 by Cardno
- The Liveable Green Network:
  - Volume 1 - Liveable Green Network Strategy and Master Plan Report, draft April 2011
  - Volume 2 – Network Development Assessment, draft April 2011
  - Volume 3 – Background Research and Case Studies, draft April 2011
- Ashmore Precinct Structure Plan Flooding and WSUD Assessment, February 2006 by Cardno
- Ashmore Street Masterplan Flood Assessment, 16 October 2008 by Cardno

3.2 Survey Information

Council provided aerial laser scanning (ALS) ground levels surveyed in 2007 and 2008 for the entire catchment. Generally, the accuracy of the ALS data is +/- 0.15m to one standard deviation on hard surfaces.

Additional field survey was undertaken as part of the Flood Study (Cardno, 2013) by Cardno's surveyors to provide additional detail for the development of the flood model. This included cross-sections of some open-channels, bathymetry of Alexandra Canal, and historical flood level observations.

3.2.1 Floor Level Survey

Detailed survey of building floor levels within the flood inundation extent was conducted in March-April 2013. A total of 1820 floor levels were surveyed:

- 429 by Council in St Peters, Alexandria, Beaconsfield, Rosebery and Zetland; and
- 1391 by Cardno in St Peters, Erskineville, Waterloo, Redfern, and Surry Hills.

This information has been provided separately to Council for privacy reasons and is thus not included in this Report.

3.3 GIS Data

City of Sydney Council provided Geographic Information System (GIS) data for preparing the Alexandra Canal Catchment Flood Study model and reporting. The data included:

- Pit and pipe data
- Cadastre
- 1m and 2m Land Information Centre (LIC) contours
- Aerial photography (2006)
- Road centrelines

Field survey of more than 4500 pits and over 4000 pipes was undertaken by Cardno's surveyors (separate to this study) to provide a detailed database of the locations and dimensions of all Council's pits and pipes within the entire LGA. Invert and surface levels of pits was determined from airborne laser scanning (ALS) levels and details measured directly during survey. This information was collated during the Flood Study (Cardno, 2013).

3.4 Site Inspections

Detailed site inspections of the study area were conducted on numerous occasions during the Flood Study as well for the FRMSP and during the assessment for GSTC and individual developments. The site visits provided the opportunity to review flood issues identified as part of the Flood Study (Cardno, 2013) and identify and review the feasibility of potential flood management strategies.

4 Consultation

4.1 Community Consultation

The community consultation undertaken as part of the FRMS built on the consultation undertaken as part of the Flood Study (Cardno, 2013). The purpose of the Flood Study (Cardno, 2013) consultation was to inform the community about the study and gain an understanding of the community's experience with historical flooding in the catchment.

The purpose of the more recent consultation undertaken as part of this FRMS was to inform the community about the study, identify community concerns and attitudes, to gather information from the community on potential options for the floodplain and to develop and maintain community confidence in the study results.

The community consultation consisted of:

- A community brochure and survey;
- A press release; and
- Public meetings.

4.1.1 Community Brochure and Survey

A community information brochure and questionnaire was prepared and distributed in April 2013 as attached in **Appendix A**. The questionnaire sought information on people's recollection of flooding in the catchment and feedback on potential flood management options. It was mailed to 5,893 properties identified as within the floodplain extent (PMF). An email with the questionnaire was also sent to 165 of the respondents from the questionnaire of the Alexandra Canal Flood Study (Cardno, 2013). An online version of the questionnaire was included on Council's website for public access.

A total of 461 responses were received, primarily as return posted forms, representing a return of approximately 8% of the direct mailed quantity. Of these responses, 402 (88%) were from residents and 53 (11%) were from business. Four respondents did not specify their status.

Property Information

The majority of respondents to the questionnaire are from owner occupied residential properties as summarised in **Table 4-1**. Properties are occupied by a tenant in about 19% of the responses and business accounted for approximately 8%. Some respondents selected multiple descriptions for their property.

Table 4-1 Property Ownership

	All Responses	Residential Responses
Owner Occupied	329 (72%)	318
Occupied by a tenant	88 (19%)	76
Business	37 (8%)	6
Not Specified	4 (1%)	2

A high proportion of respondents live within apartments or freestanding houses, about 46% and 39% respectively, as listed in **Table 4-2**. The catchment has particular property types that dominate particular areas, for example apartment buildings are predominant in the new redevelopment areas and industrial / commercial properties may be concentrated in the lower reaches of the catchment. Potentially apartment blocks would likely provide refuge from floodwaters at the higher levels within the building.

Table 4-2 Property Description

Structure Description	All Responses	
Apartment	213	46.4%
Dual Occupancy	4	0.9%
Dual Occupancy & Commercial	2	0.4%
Freestanding house	179	39.0%
Industrial & Commercial	57	12.4%
Not Specified	4	0.9%

The amount of time that respondents have lived or worked in the catchment is important to evaluate their experience of flood events. Awareness of flooding is dependent on whether a flood event has occurred recently and its magnitude as well as the respondent's location within the floodplain. For this Study, there have been some recent storm events resulting in some flooding and the questionnaire distribution was focussed on properties within the main flood extents.

Of the residents who responded, 60% had resided at their current address less than 10 years, whilst 35% had occupied their current residences greater than 10 years. Fifty-five percent of business respondents had occupied their property less than 10 years, whilst 41% had been there longer than 10 years.

Figure 4-1 shows the proportion of respondents within ranges for their years within the catchment at their current address.

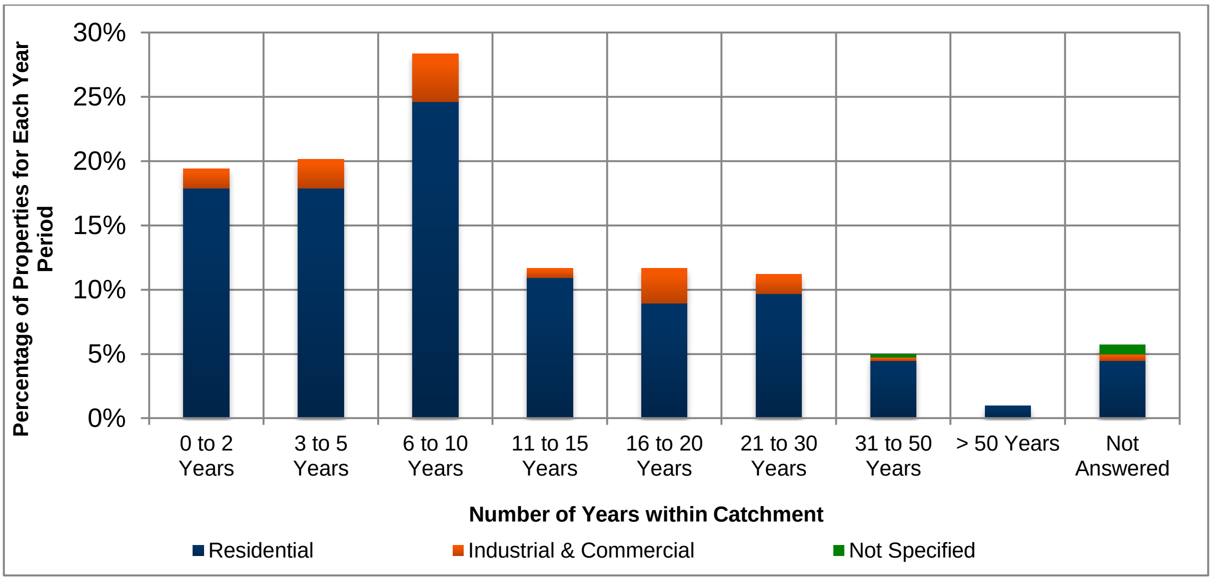

Figure 4-1 Years of Residence

Demographic Information

The age and languages of people within the catchment is important for flood planning within the catchment. Education and potential evacuation plans would take into consideration the age of residents noting potential mobility issues and languages used to provide effective communication. Respondents to the questionnaire may not be a true representation of the whole but does indicate a cross-section of the community. This information should be used in conjunction with the general demographic review undertaken in **Section 7**.

Based on the 461 responses, the number of people working or residing was advised as 1790 comprising 954 residents, 833 related to businesses and three unspecified. The average number of residents per residential property is about two, whereas for businesses the average number of occupants is 16. The predominant age group is between 15 and 64 years as shown in **Figure 4-2** and summarised in **Table 4-3**. This age group represents generally able-bodied persons who may not require assistance in case of evacuation. Of those residents who responded, 93% stated English as their main language at home, whilst 6% of respondents spoke a language other than English such as Chinese (6%), Greek (2%) and French (2%), noting 1% of respondents did not specify.

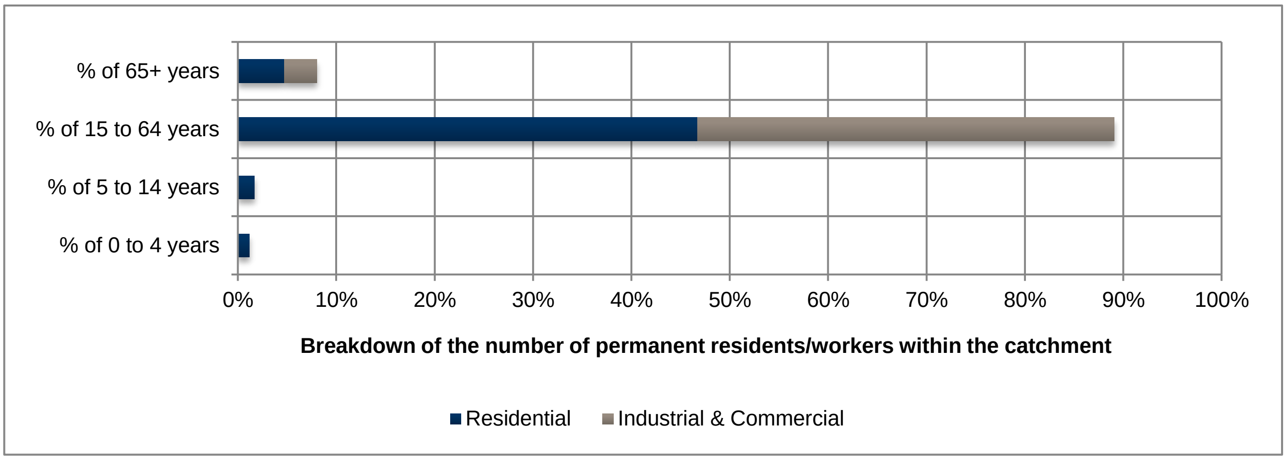

Figure 4-2 Age Groups

Table 4-3 Summary of Age Groups

	Residential	Industrial and Commercial	Total
0 to 4 years	19 (1%)	0	19
25 to 14 years	28 (2%)	0	28
15 to 64 years	783 (46%)	722 (43%)	1505
65+ years	79 (5%)	55 (3%)	136

Flooding Experience and Awareness

About 49% of the 461 respondents indicated they had not experienced flooding as summarised in **Table 4-4**. Of these 224 responses that had not experienced flooding, 213 occupied apartments. Inundation of houses or business was reported for 95 properties, 83 residential and 12 industrial / commercial. Of those who had experienced flooding within their house or business, 53 were residents occupying freestanding houses, 27 occupied apartments, 2 occupied dual occupancies and the remaining 12 were businesses.

Table 4-4 Flood Affectation of Respondents

	Total Responses	Residential Responses	Industrial/Commercial Responses
Yes, floodwaters entered my house/business	95	83	12
Yes, floodwaters entered my yard/surrounds of my business	97	84	13
Yes, the road was flooded and I couldn't get to my car	86	74	12
Yes, other parts of my neighbourhood were flooded	135	124	11
No, I haven't experienced flooding	224	195	29
No Specified	5	2	3

Respondents noted locations where they had witnessed localised flooding, including:

- Buckland Street, Alexandria;
- Maddox Street, Alexandria;
- Brandling Street, Alexandria;
- O'Riordan Street, Alexandria;
- Intersection of Mitchell Road and Huntley Street, Alexandria;
- Pleasant Avenue, Erskineville;
- Smiths Lane, Erskineville;
- George Street, Erskineville;
- Boronia Street Redfern;
- Chalmers Street, Redfern;
- Botany Road, Waterloo;
- Joynton Avenue, Zetland; and
- Marshall Street, Surry Hills.

Historical flooding was noted to have occurred in Alexandria in 1998, Waterloo in 2003, and localised flooding in Redfern (2010 and 2013) and Rosebery (2007).

Photographs of flooding in the catchment provided by residents are shown in **Appendix A**.

Flood Management

Nine approaches to flood management were presented in the questionnaire for respondents to list a preference rating for each approach. A rating of 1 to 5 was presented, with 5 being the most preferred and 1 being least preferred. Of the 461 respondents, 407 were from residential properties and 54 from commercial / industrial properties.

Figure 4-3 shows the flood management approaches in order of preference based on the average of the response ratings. Also shown are the extents of the 25th percentile and 75th percentile scores which show the range within which at least half of the ratings were given.

Table 4-5 summarises the average preference rating of all responses as well as the rating with the highest individual response and the amount that did not specify a preference rating.

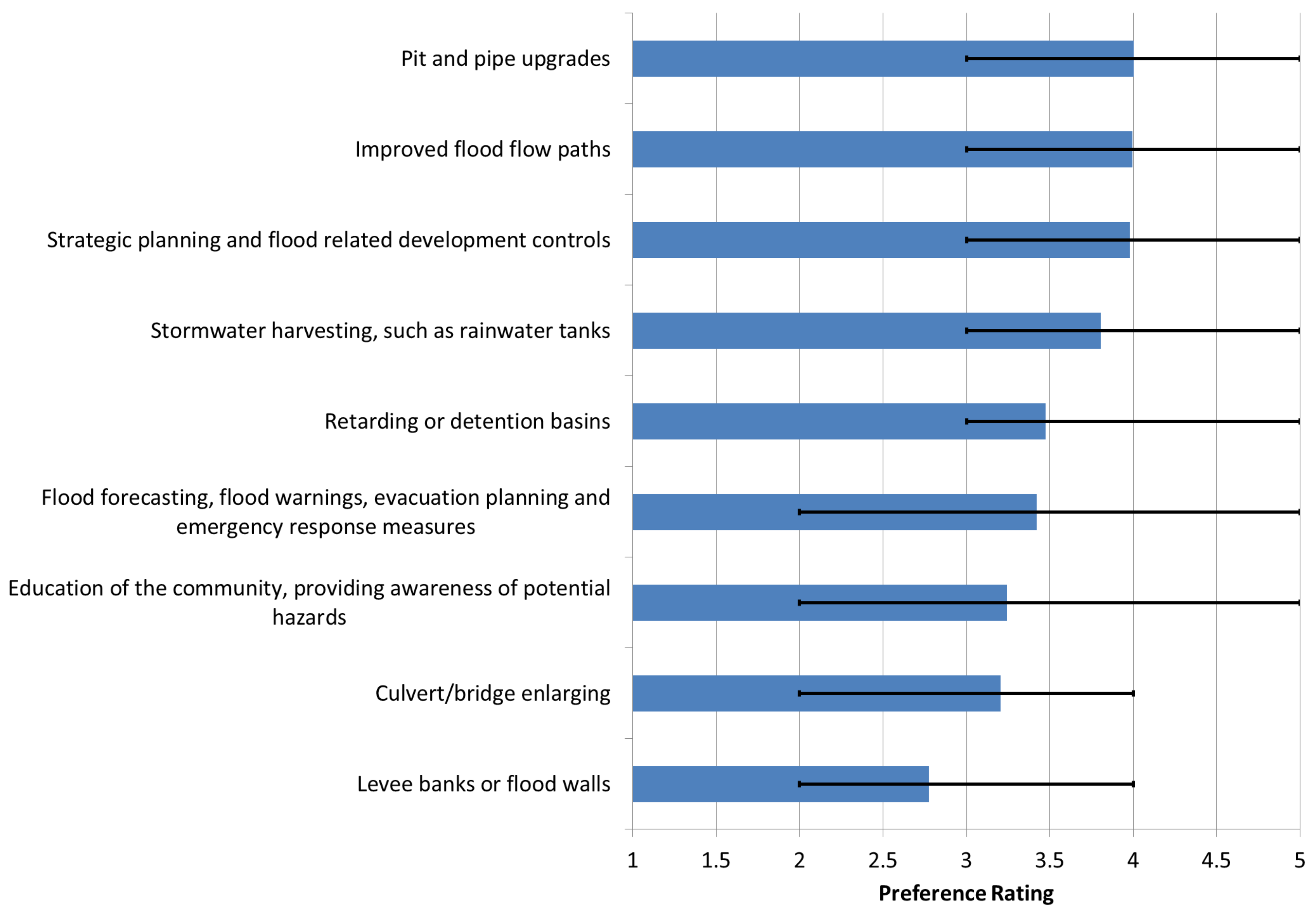

Figure 4-3 Average Rating for Flood Management Approaches

Table 4-5 Flood Management Approach Rating Summary

Flood Management Approach	All Responses	Residential Responses	
	Average Rating	Rating with Highest Response	Not Answered
Pit and pipe upgrades	4.0	5 (31%)	153 (38%)
Improved flood flow paths	4.0	5 (18%)	154 (38%)
Strategic planning and flood related development controls	4.0	5 (26%)	175 (44%)
Stormwater harvesting, such as rainwater tanks	3.8	5 (31%)	131 (33%)
Retarding or detention basins	3.5	5 (18%)	153 (38%)
Flood forecasting, flood warnings, evacuation planning and emergency response measures	3.4	5 (17%)	176 (44%)
Education of the community, providing awareness of potential hazards	3.2	5 (14%)	175 (44%)
Culvert/bridge enlarging	3.2	3 (17%)	179 (45%)
Levee banks or flood walls	2.7	3 (16%)	177 (44%)

The two highest rated approaches; pit / pipe upgrades and improved flowpaths, both aim to reduce the potential inundation of roads and properties by constructing additional capacity to convey flood water to the Canal. Strategic planning and development controls is the highest rated non-structural approach.

Stormwater harvesting approaches may have limited impact on flood inundation within the catchment. The potential advantages are minor due to the relative volume of runoff during a flood event compared to the available storage capacity. Similarly, storages for harvesting may be kept full following an event to provide water for alternative uses but this does not leave free capacity for a follow-up storm event.

Levee banks / flood walls and culvert / bridge enlarging are the least favoured approaches, potentially as other approaches are preferred which would more efficiently convey runoff from the catchment. These approaches may also reduce the visual amenity of the area. Similarly retarding / detention basins were not highly favoured, potentially due to visual impact and loss of open space.

Flood forecasting and education approaches were ranked as sixth and seventh based on the mean rating, however they had a wider range of ratings generally indicating that some respondents were more strongly in favour (or not in favour) of these approaches. The responses do not indicate the reasons for ratings, however it may be summised that these are ranked lower as they are not considered to provide a tangible improvement to flood inundation.

The approaches with the highest percentage for ratings of ‘5’ (being most preferred) were pit / pipe upgrades, strategic planning and stormwater harvesting. Approaches with the highest proportion of no response, potentially indicating they were not favoured, are non-structural measures and culvert / bridge enlarging, and levee banks / flood walls.

Approximately 22% of the total respondents recommended other flood management approaches, most common being maintenance of drains and guttering (litter and debris removal) and improving stormwater drainage capacity (noting that this is the outcome of several of the presented approaches).

Generally, responses to the questionnaire potentially indicate a preference for flood management approaches that will result in tangible reductions to flood inundation in the catchment, such as improved pit and pipe drainage.

4.2 Floodplain Committee and Stakeholder Consultation

The floodplain committee provides an important role in assisting Council in the development and implementation of the Floodplain Management Plan. It comprises of various agency and community representatives. The Cardno project team have reported to the committee and undertaken workshops with the committee and additional stakeholders at key stages of the study.

- Inception Meeting (15th March 2012): An overview of the project purpose, scope and methodology was presented to the Committee. Key issues and ideas regarding the direction of the study were raised by the committee for consideration by Cardno and Council.
- Floodplain Management Committee Meeting (6th June 2012): An overview of the risk management study and plan to date including previous studies conducted by Cardno. A list of management and identifiable options were presented by Cardno for consideration by the committee.
- Floodplain Management Committee Meeting (5th December 2012): This meeting outlined the floodplain risk management process including tasks to be conducted and the results from this study. An extensive and detailed list of processes was provided by Cardno to be considered by the committee.
- Council Internal Workshop (15th April 2013): A workshop was conducted by Cardno with several Council staff providing details of project stakeholders, identification of additional options and the proposed Multi-Criteria Assessment.
- Floodplain Management Committee Workshop (29th April 2013): This workshop was undertaken as a follow-up meeting from the previous Council internal workshop. The workshop further reviewed potential floodplain management options, the results of preliminary options assessments and further developed the Multi-Criteria Assessment.

The outcomes of the workshops on the 14th and 29th April are included in **Appendix B**.

4.3 Public Exhibition

The Draft Flood Study, Draft Floodplain Risk Management Study and Draft Floodplain Risk Management Plan were placed on public exhibition for a period of four weeks from 28 October 2013 to 25 November 2013. This allowed the community and interested parties to review the draft Study and submit comments on the Study and its outcomes.

The exhibition documents were publicly available at the One Stop Shop (Town Hall House), Redfern Neighbourhood Service Centre, Green Square Neighbourhood Service Centre, and Council's Website (www.cityofsydney.nsw.gov.au). Public notices were advertised on commencement of the exhibition in the Sydney Morning Herald, Central Sydney Magazine, Inner West Courier, and Southern Courier.

A community drop-in session was held on Wednesday 20 November 2013 at the Alexandria Town Hall, 73 Garden Street, Alexandria. Officers from Council, Office of Environment and Heritage and Cardno were present and available to answer community questions.

A notification of the public exhibition and an invitation to attend Community Information & Feedback Session was:

- Mailed to 130 stakeholders who had participated in flood surveys;
- Emailed to 560 stakeholders who had participated in flood surveys; and
- Emailed to local community and residents action groups: Cooks River Alliance, Alexandria Residents Action Group, Friends of Victoria Park, Surry Hills Neighbourhood Centre, Friends of Erskineville and Rosebery Residents Action Group.

A hard-copy display for the project was included at Neighbourhood Service Centres. The community drop-in session was promoted via Council's Twitter page with two tweets on the day of the community drop in session.

One resident telephone enquiry was received prior to the community drop-in session regarding proposals to upgrade the trunk drainage at the rear of properties facing Newtown Street, Alexandria. The resident was concerned about the potential for a future upgrade to impact the structural stability of his home. City staff advised that the exhibited studies and plan are a long term strategy, and that an upgrade to the trunk drainage in the location of concern would not occur for at least 10 years and could be up to 50 years away. The resident was concerned about short term works and was satisfied with this response.

There were three attendees at the community drop-in session and three issues were raised:

- A comment was made about historical flooding in Harcourt Parade, Rosebery and seeking information about planned measures in this area. The content of the studies and plans was then reviewed. No further action is necessary.
- A general question was asked regarding development in the Alexandria area and ensuring that there were no adverse impacts arising from future development. A response was provided to the satisfaction of the attendee. No further action.
- A general question was asked regarding opportunities for stormwater reuse as a flood mitigation measure. A response was provided to the satisfaction of the attendee. No further action.

The public exhibition page on Council's website received 170 page views. At closure of the exhibition period one written submission had been received. The submission was made using the resident comment sheet provided for the community drop-in session. The submission indicated general support for the Study and raised no further issues.

5 Existing Flood Behaviour

5.1 Flood Study

A detailed 1D/2D flood model was established as part of the Flood Study (Cardno, 2013) to describe the flooding behaviour throughout the study area. This model incorporated all pits and pipes from data provided by the City of Sydney and had a 4 metre grid resolution. Hydrological modelling was undertaken through the application of the Direct Rainfall methodology.

The models were calibrated and verified against four historical storms; November 1984, January 1991, April 1998 and February 2001. November 1984 was approximately larger than a 100 year ARI event, while April 1998 was in the order of a 10 year ARI event. The other two events were smaller, with January 1991 roughly a 20 – 50 year ARI event, and February 2001 less than a 1 year ARI event. The calibration events were chosen through a combination of both their magnitude, together with the quantity of flood observations from the storm.

The results of the calibration and verification showed that the model was capable of reproducing the observations from those events, providing confidence in the overall modelling results. The models were further verified against the previous studies that have been undertaken within the catchment.

Using the established models, the study has determined the flood behaviour for the 100 year ARI, 20 year, 10 year, 5 year, 2 year and 1 year ARI events together with the Probable Maximum Flood (PMF). The primary flood characteristics reported for the design events considered include depths, levels and velocities. The study has also defined the Provisional Flood Hazard for flood-affected areas.

The 100 Year ARI and PMF extents are shown in **Figures 5-1 and 5-2**. The flooding behaviour across the catchment is described in the following section with regards to each of the sub-catchments as shown in **Figure 5-3**.

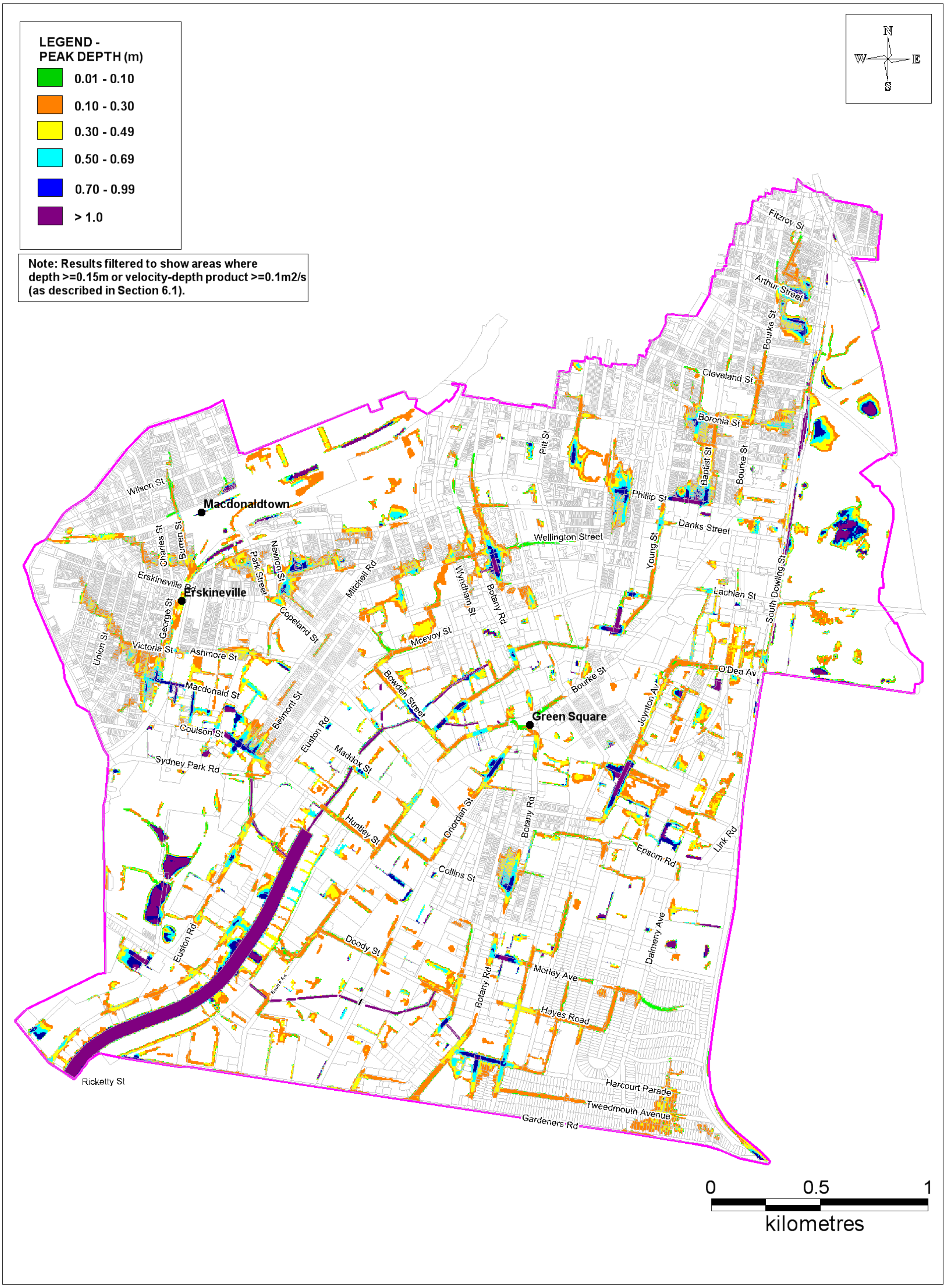

Figure 5-1 100 Year ARI Peak Flood Depths

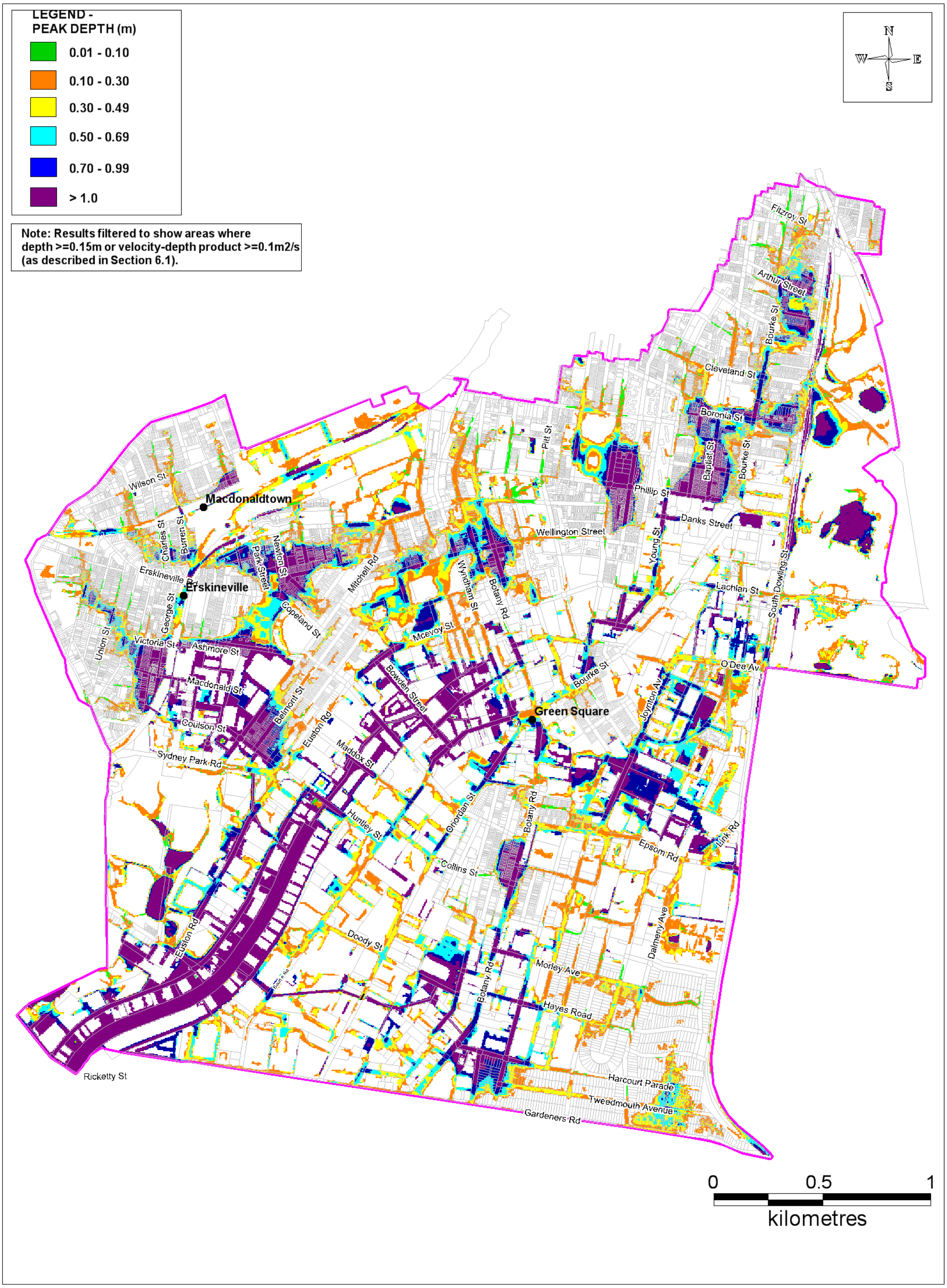

Figure 5-2 PMF Peak Flood Depths

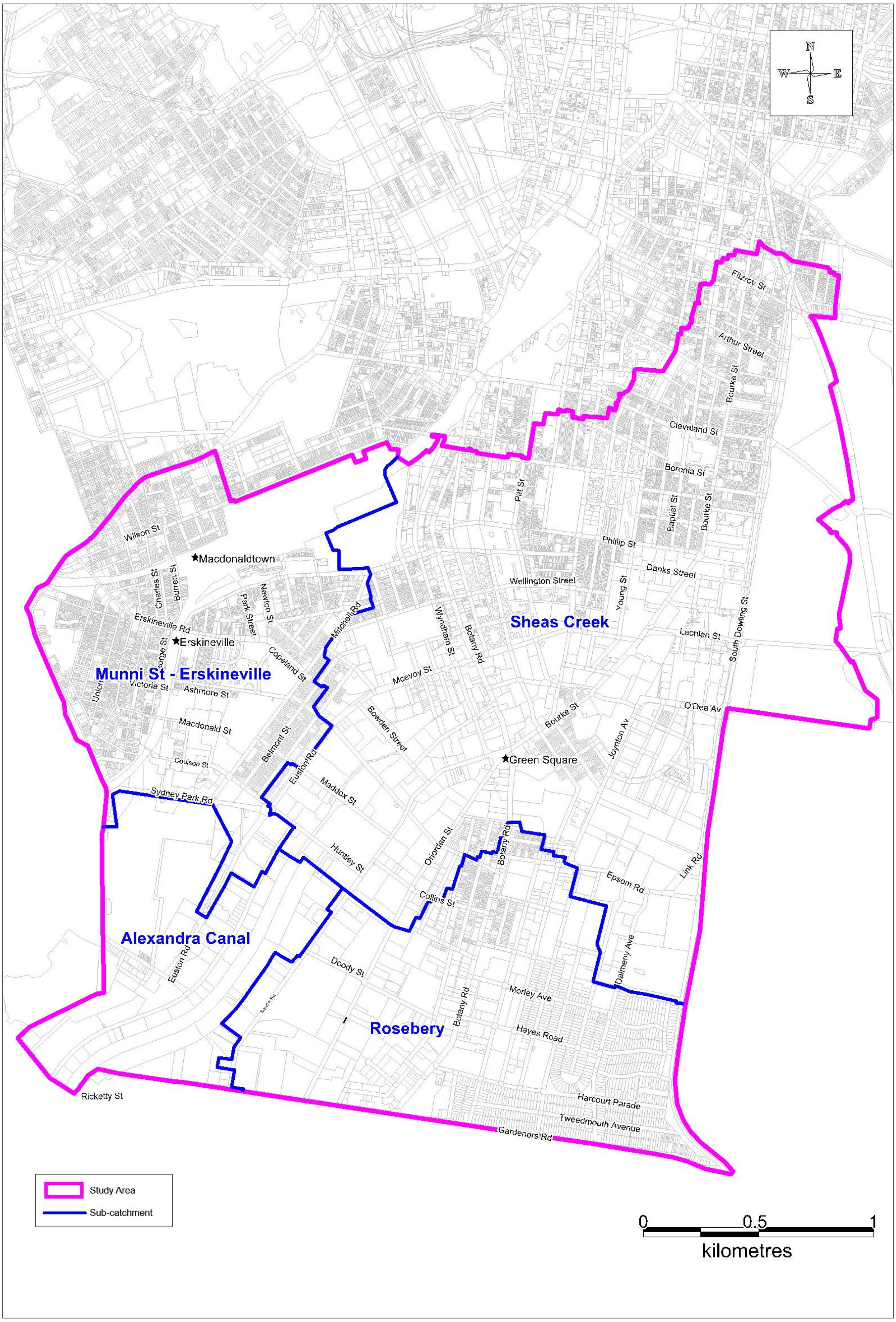

Figure 5-3 Sub-Catchments

5.2 Flooding Behaviour

5.2.1 Munni Street Sub-Catchment

The Munni Street catchment discharges into Alexandra Canal through a concrete channel near Burrows Road. The catchment incorporates a mix of residential and industrial.

The upper parts of the catchment are primarily residential and townhouses. The flowpaths in the upper portions are primarily overland flow, and proceed between the houses and across the roads in these areas. Some ponding occurs north of Macdonaldtown Station and the rail line, due to the obstruction that the rail line creates in this area on Holdsworth Street. Ponding in this area is in the order of 1.7 metres in the 100 year ARI event.

To the west of the Illawarra and Eastern suburbs rail line, an overland flow path forms a ponding and backwater area on Macdonald Street due to the control of the rail underpass on Macdonald Street. Ponding in this area is in the order of 0.8 metres in the 100 year ARI event.

A significant isolated ponding area occurs north of Erskineville Oval and Copeland Street. This area is controlled by the high point and limited capacity of Fox Avenue, as well as from the obstruction of the oval itself. Ponding upstream of this area reaches depths in excess of 1 metre in a 100 year ARI event and affects a number of residential properties.

The industrial area in the centre of the Munni Street catchment is inundated by overland flowpaths which arrive from Macdonald Street (to the west of the rail line) and from the north of Ashmore Street. This overland flow accumulates at a trapped low point at the intersection of Coulson Street and Mitchell Avenue. At this location, the estimated 100 year ARI depths are in the order of 0.9 metres, and increase to around 1.3 metres further west of the intersection on Coulson Street. This ponding area is controlled by the high point which runs between Sydney Park Road and Huntley Street.

5.2.2 Sheas Creek Sub-Catchment

The Sheas Creek catchment drains to a main open channel at Bowden Street conveying runoff to Alexandra Canal south of Huntley Street. Three subsections of the catchment drain toward Bowden Street – Alexandria and Macdonaldtown Branch, Main Branch, and Victoria Branch.

Lowpoints in the roads of the Alexandria and Macdonaldtown Branch result in ponding at Cope Street near Wellington Street, Buckland Street near Gerard Street and at Park Road.

In the Main Branch subsection, a series of lowpoints in roads show ponding of runoff in frequent storm events. These include Phelps Street, Arthur Street, Boronia Street near Marriott Street, along Baptist Street to Phillip Street, Phillip Street near Walker Street, Chalmers Street and Hunter Street. In a larger storm event, runoff flows out of these ponded areas primarily along roads from the north-east of the study area to the open channel at Wyndham Street.

The upstream areas of the Victoria Branch are located outside the study area in West Kensington to the east of South Dowling Street. Runoff is conveyed generally towards Joynton Avenue where box culverts are located to convey water through the area of the proposed Green Square Town Centre towards Mandible Street. Ponding occurs in lowpoints in roadways during frequent ARI events at Joynton Avenue, Botany Road near Bourke Street and O'Riordan Street near Johnson Street. In a larger storm event, a relatively contiguous flowpath along roads is evident from Lachlan Street and South Dowling Street along Joynton Avenue and O'Riordan Street to the open channels.

5.2.3 Rosebery Sub-Catchment

Rosebery sub-catchment is comprised of several sections which drain either to Alexandra Canal or out of the study area south of Gardeners Road. A relatively small portion in the south-eastern corner of the study area, bounded by Dalmeny Avenue and Asquith Avenue, drains toward the south across Gardeners Road. The portion of the catchment bounded by Birmingham Street, Gillespie Avenue and Botany Road also drains across Gardeners Road into the City of Botany Bay LGA.

The majority of the Rosebery sub-catchment comprises the Doody Street drainage area and drains towards the open channel located between properties from Doody Street to Bourke Road. Ponding of runoff is particularly evident at lowpoints in the road at Botany Road near Collins Street, Morley Avenue near Jones Lane, Harcourt Parade near Durdans Avenue, and Ralph Street near Shirley Street.

5.2.4 Alexandra Canal Sub-Catchment

Rainfall on Sydney Park is conveyed to the ponds within the Park and excess runoff may flow towards Euston Road in large ARI events. This sub-catchment generally drains towards Burrows Road which has several lowpoints along its length that are drained by pit and pipe systems. Ponding of runoff occurs in the lowpoints of Euston Road and Burrows Road. In large ARI events, inundation to properties may result from overland flows from upstream areas and or elevated levels in Alexandra Canal itself.

5.3 Historical Flooding

Several significant flooding events have occurred within the Alexandra Canal Catchment. Rainfall analysis would indicate that the most significant flood events occurred in the 1980s and 1990s. However, the majority of the respondents to the community survey undertaken as part of the Flood Study (Cardno, 2013) had only resided in the catchment for less than 10 years. Therefore, little information relating to historical flood events is available as a result of the survey.

Rainfall analysis identified the following key historical events in the catchment as summarised in **Table 5-1**:

- 8 November 1984 (Approximately 100 Year ARI);
- 26 January 1991 (Approximately 20 to 50 Year ARI);
- 10 April 1998 (Approximately 10 to 20 Year ARI); and
- 1 March 28 February 2001 (Approximately 1 Year ARI).

Table 5-1 Approximate ARI of Historical Rainfall Events (Observatory Hill – 66062)

Storm Event	Details	Duration				
		30 mins	60 mins	90 mins	2 hour	3 hour
8th November 1984	Intensity (mm/h)	180	119	104	90	64
	Approx. ARI	*>100y*	*>100y*	*>100y*	*>100y*	*>100y*
26th January 1991	Intensity (mm/h)	120	65	43	32	20
	Approx. ARI	*~50y*	*10-20y*	*5-10y*	*2-5y*	*1-2y*
10th April 1998	Intensity (mm/h)	84	67	48	37	35
	Approx. ARI	*5-10y*	*10-20y*	*~10y*	*5-10y*	*~20y*
28th February 2001	Intensity (mm/h)	44	22	15	11	8
	Approx. ARI	*<1y*	*<1y*	*<1y*	*<1y*	*<1y*

5.4 Flood Hazard

Flood hazard can be defined as the risk to life and limb caused by a flood. The hazard caused by a flood varies both in time and place across the floodplain.

5.4.1 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 provisional flood hazard was defined as part of the Flood Study (Cardno, 2013) using an in-house developed program, which utilises the model results of flood depths and velocity. Provisional flood hazard mapping was prepared for the PMF, 100 Year ARI and 5 Year ARI events as shown in **Figures 5-4 to 5-6**.

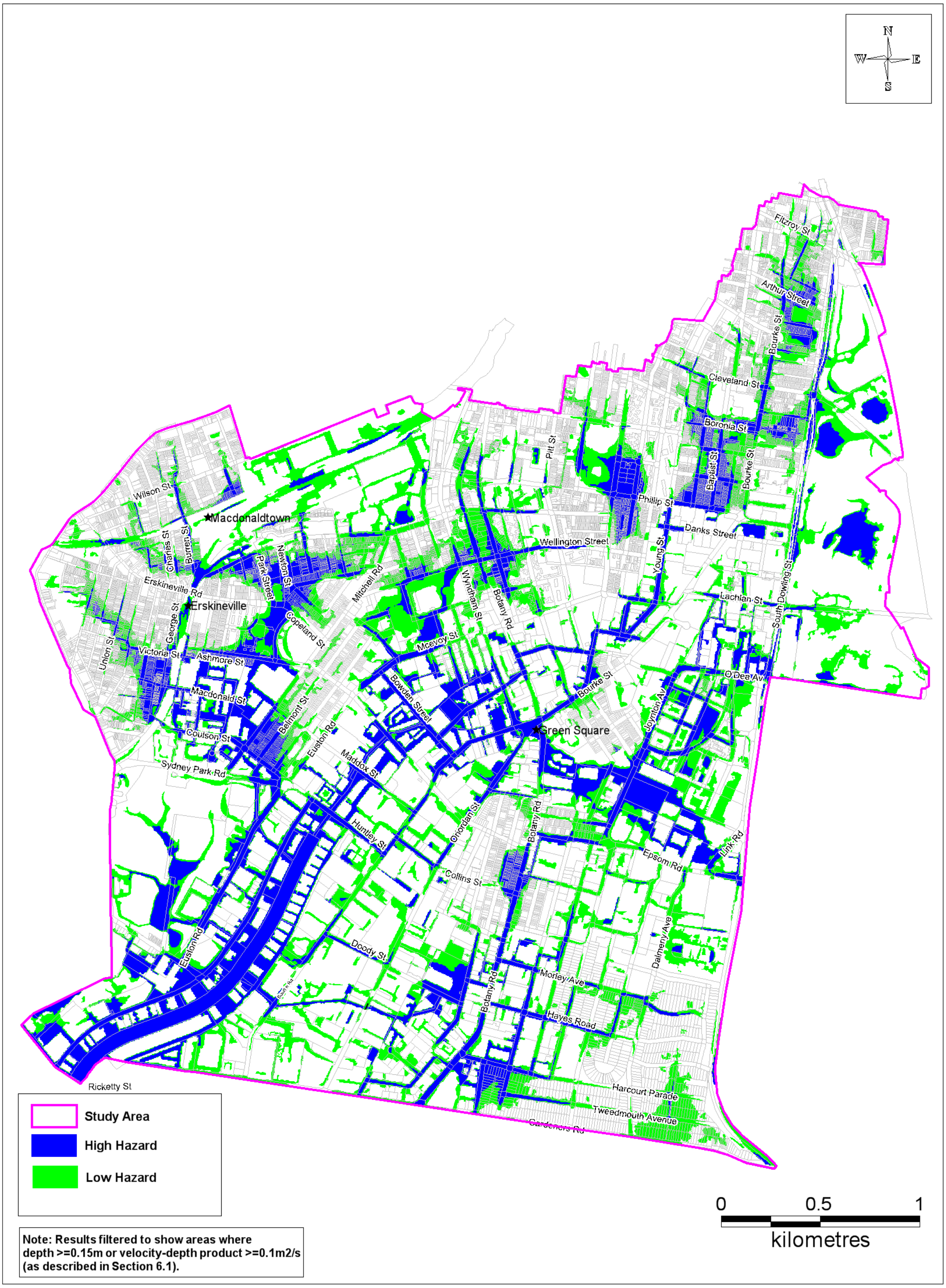

Figure 5-4 PMF Provisional Flood Hazard

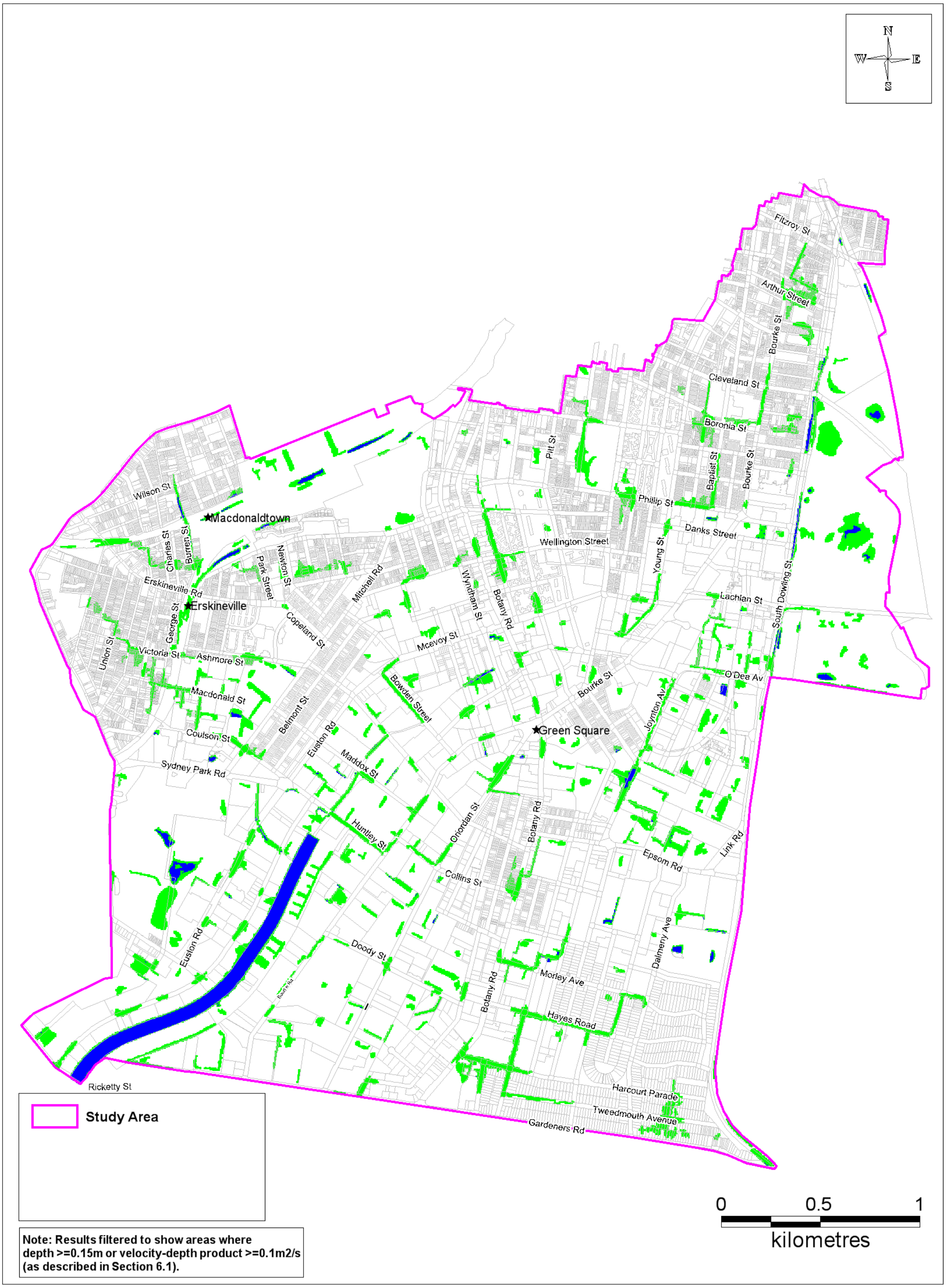

Figure 5-5 100 Year ARI Provisional Flood Hazard

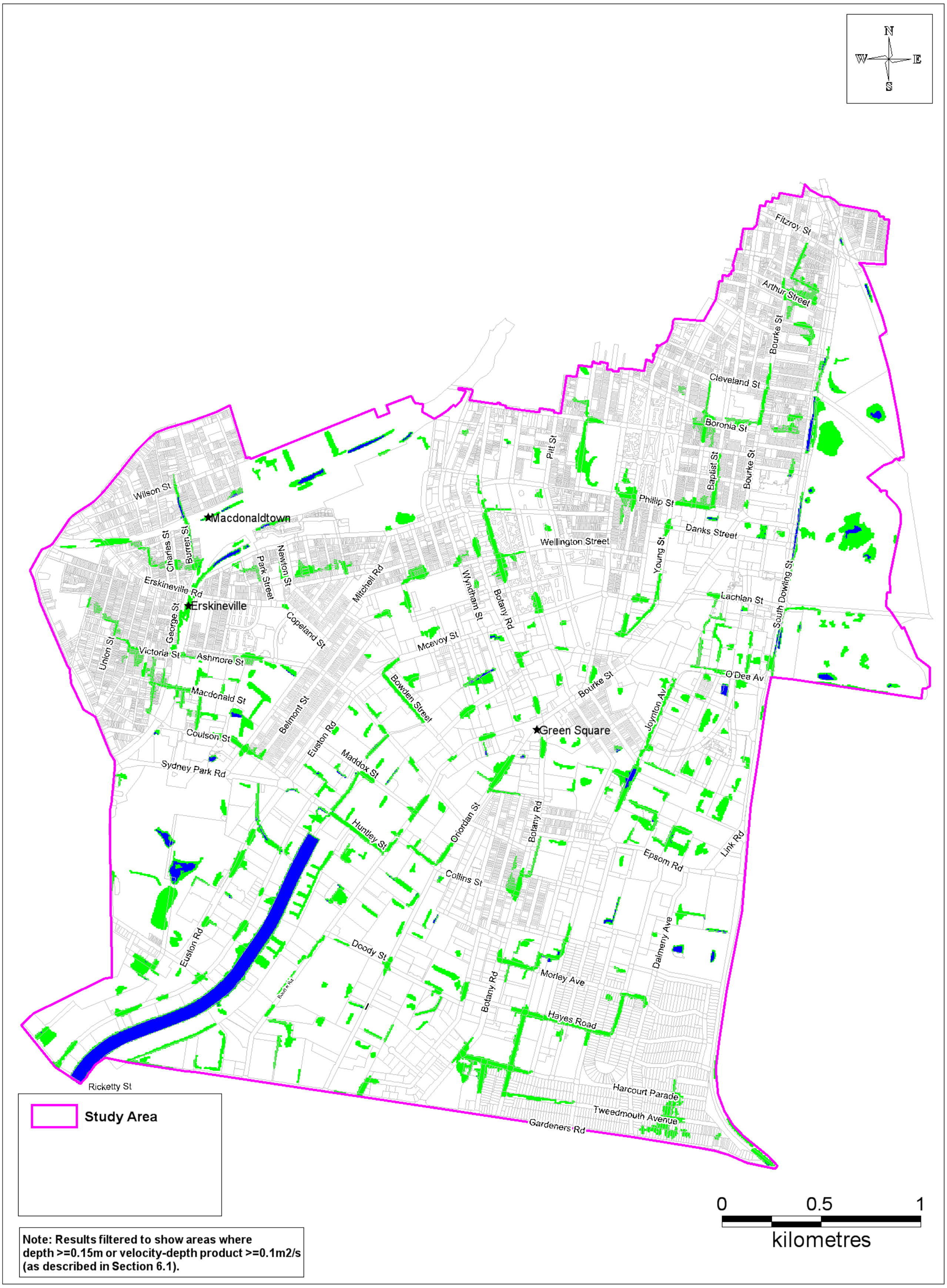

Figure 5-6 5 Year ARI Provisional Flood Hazard

5.4.2 True Flood Hazard

Provisional flood hazard categorisation is based around a function of velocity and depth, and does not consider a range of other factors that influence the "true" flood hazard. In addition to water depth and velocity, other factors contributing to the true flood hazard include:

- Size of the flood,
- Effective warning time,
- Flood readiness,
- Rate of rise of floodwaters,
- Duration of flooding,
- Ease of evacuation,
- Effective flood access, and
- Type of development in the floodplain.

The flood hazard in areas both within the floodplain and those areas outside of the floodplain impacted by flooding have been reviewed against the above listed factors. True Flood Hazard mapping has been undertaken for the 5 Year ARI, 100 Year ARI and the PMF flood event.

Size of Flood

The size of a flood and the damage it causes varies from one event to another. For the purposes of this Floodplain Risk Management Study, provisional flood hazard has been assessed for the 5 Year, 100 Year ARI and PMF events which produce the peak water levels in the floodplain. True hazard has also been assessed for the 5 and 100 Year ARI events as well as the PMF event.

Effective Warning Time

The effective warning time can also be described as the actual time for people to undertake appropriate actions (such as lift or transport belongings and/or evacuate). This time is generally always less than the total warning time available to emergency agencies. This is because of the time needed to alert people to the imminence of flooding and to have them begin effective property protection and/or evacuation procedures.

The critical duration storm for the study area is generally a 60 minute duration event for the 100 year ARI. The peak duration for the PMF event is approximately a 15 minute duration event.

The peak of the flow would therefore generally occur at various locations within the catchment within15 minutes to 2 hours from the start of the rainfall. Therefore, there is little to no warning time throughout the catchment.

However, it is noted that all areas within the catchment are exposed to similar flood response times, and therefore it can be considered that no area within the catchment is any more at risk than another.

The exception to this is overfloor flooding. Due to the critical durations within the catchment, if a property experiences overfloor flooding this will occur within a very short timeframe. This is considered to pose a hazard to these properties, and these should be included in the True Hazard Mapping. As summarised in **Table 6-5**, there are 580 residential properties and 71 commercial properties and 54 industrial properties with overfloor flooding in the 100 year ARI event. Note that these have not been shown on the mapping for privacy reasons, but this data has been provided to Council separately.

Flood Readiness

Flood readiness can greatly influence the time taken by flood-affected residents and visitors to respond in an effective fashion to flood warnings. In communities with a high degree of flood readiness, the response to flood warnings is generally prompt, efficient and effective.

Flood readiness is generally influenced by the time elapsed since the area last experienced severe flooding. The major flood events occurred in the catchment were in November 1984 which was roughly equivalent to a 100 Year ARI event, January 1991 which is approximately 20 to 50 Year ARI event and April 1998 which is approximately 10 to 20 Year ARI event.

Based on the responses from the resident survey (**Section 4**), approximately 5-10% of respondents has been living in the catchment at the time of the 1984 flood event and 1991 flood event.

The responses from the resident survey suggest that around 49% of the residents are not aware of flooding in the catchment. This can be both a function of the understanding of overland flooding, which is commonly associated with stormwater flooding. Furthermore, the short duration of flooding in the catchment may mean that the flooding occurs when the residents are not at home.

It is assumed that flood awareness of larger floods is likely to be relatively low and no particular part of the catchment is likely to be any more prepared for a flood than another, thus flood readiness has not been considered in the preparation of hazard extents.

Rate of Rise of Floodwaters

The rate of rise of floodwaters affects the consequences of a flood. Situations where floodwaters rise rapidly are potentially far more dangerous and cause more damage than situations where flood levels increase slowly. Both the catchment and floodplain characteristics affect the rate of rise.

A rate of rise of 0.5 m/hr has been adopted as indicative of hazardous conditions. However, it is important to note that a rate of rise greater than 0.5 m/hr on its own is not necessarily hazardous. For instance, if the rate of rise is very high but flood depths only reach 200 mm, this is not considered to pose any greater hazard than slowly rising waters. Therefore, peak flood depths were considered in conjunction with the rate of rise in identifying hazardous areas.

A flood depth of 500 mm, combined with a rate of rise greater than 0.5 mm/hr was selected as the trigger depth to identify hazardous conditions. A 500 mm flood depth is well within the range of available information as to when vehicles become unstable even with no flow velocity (Figure L1; NSW Government, 2005).

The mapping provided in **Figure 5-8 to Figure 5-10,** show there are few properties with flow behaviour of these constraints for the 100 and 5 Year ARI events which are not already selected by the provisional high hazard criteria. These areas should be considered with regards to flood planning end emergency response in the catchment.

Duration of Flooding

The duration of flooding or length of time a community, suburb or single dwelling is cut off by floodwaters can have a significant impact on the costs and disruption associated with flooding. Flooding durations are generally less than a couple of hours, and as such this is not considered as a key issue for Alexandra Canal Catchment. **Figure 5-7** shows the critical duration for the catchment in a 100 Year ARI flood event.

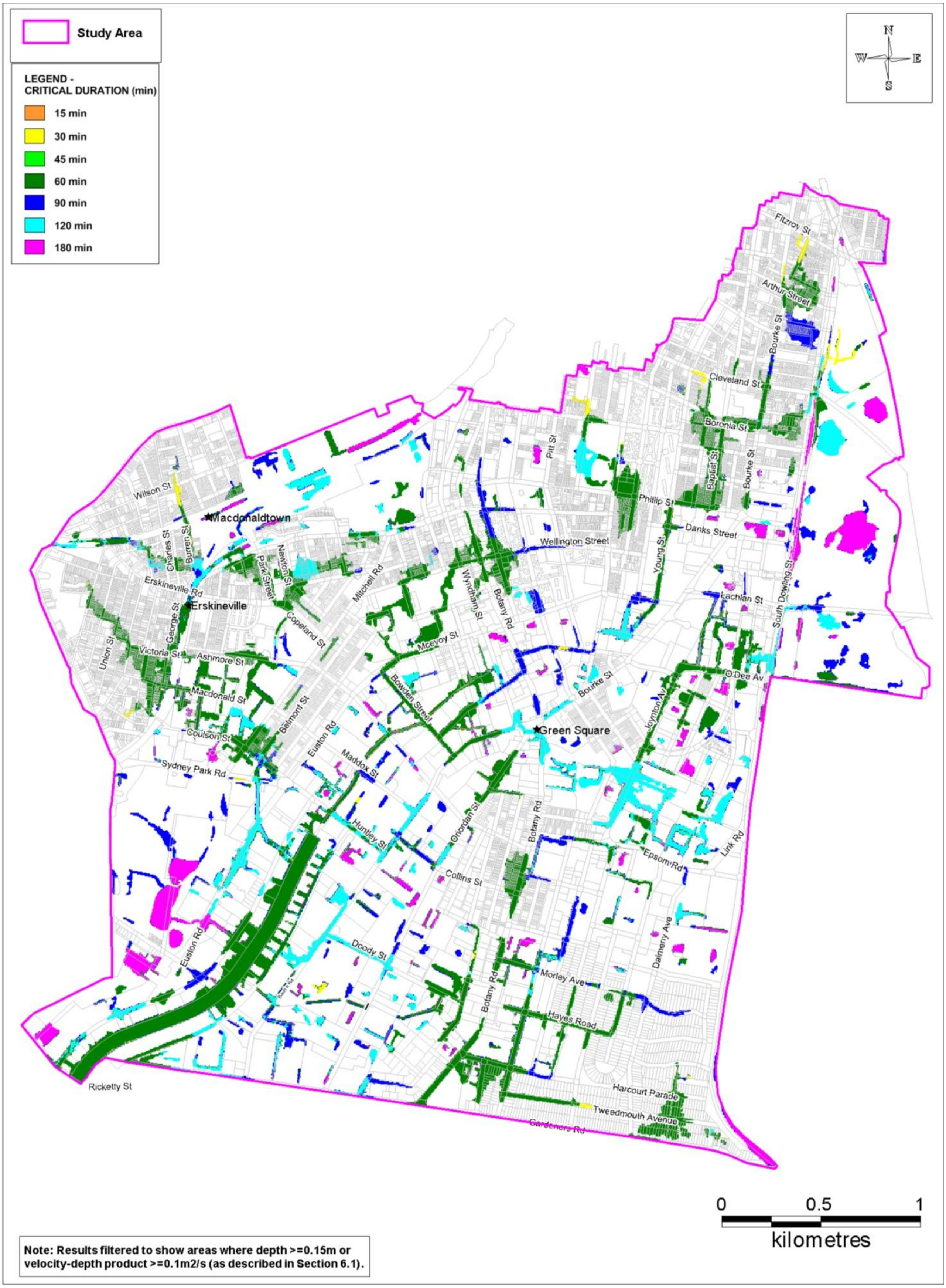

Figure 5-7 100 Year ARI Critical Duration

Ease of Evacuation

The levels of damage and disruption caused by a flood are also influenced by the difficulty of evacuating flood-affected people and property. Evacuation may be difficult because of a number of factors, including:

- The number of people requiring assistance;
- Mobility of people;
- Time of day; and
- Lack of suitable evacuation equipment.

The duration of flooding in the catchment is short, as noted above. Therefore, evacuation issues for the majority of the catchment are not considered to be an issue in a 100 Year ARI. Considering the factor of the number of people requiring assistance and mobility of people, the Waterloo Public School and Alexandria Park Community School are mapped in PMF event because the flood free access are cut off by flood waters.

Effective Flood Access

The availability of effective access routes from flood prone areas can directly influence personal danger and potential damage reduction measures. Effective access means an exit route that remains trafficable for sufficient time to evacuate people and possessions.

Flood access issues vary across the catchment. For the purposes of this assessment properties were identified as being in one of these flood access categories:

- Site is flooded and evacuation required through a high hazard flooded roadway,
- Site is flooded and evacuation is required through a flooded roadway,
- Site is flood free, however all road access is impeded by floodwaters.

The effective flood access mapping shown in **Figure 5-8 to Figure 5-10** identify that there are significant areas within the catchment which do not have effective flood access. In these areas, for the duration of the flooding, evacuation is generally not recommended. In this type of short duration flooding, residents are as likely to put themselves in harms way by evacuating rather than staying indoors.

Type of Development in the Floodplain

The degree of hazard to be managed is also a function of the type of development and resident mobility. This may alter the type of development considered appropriate in new development areas and modify management strategies in existing development areas.

The land-use in the Study Area is a mix of residential, commercial and industrial. No schools, community use buildings, nursing homes or child care centres were identified in a flood inundated area in a 100 Year ARI event.

5.4.2.2 Outcome of True Hazard Assessment

The outcomes of the true hazard assessment has been mapped in **Figure 5-8 to Figure 5-10** for the PMF, 100 year ARI and 5 year ARI flood event.

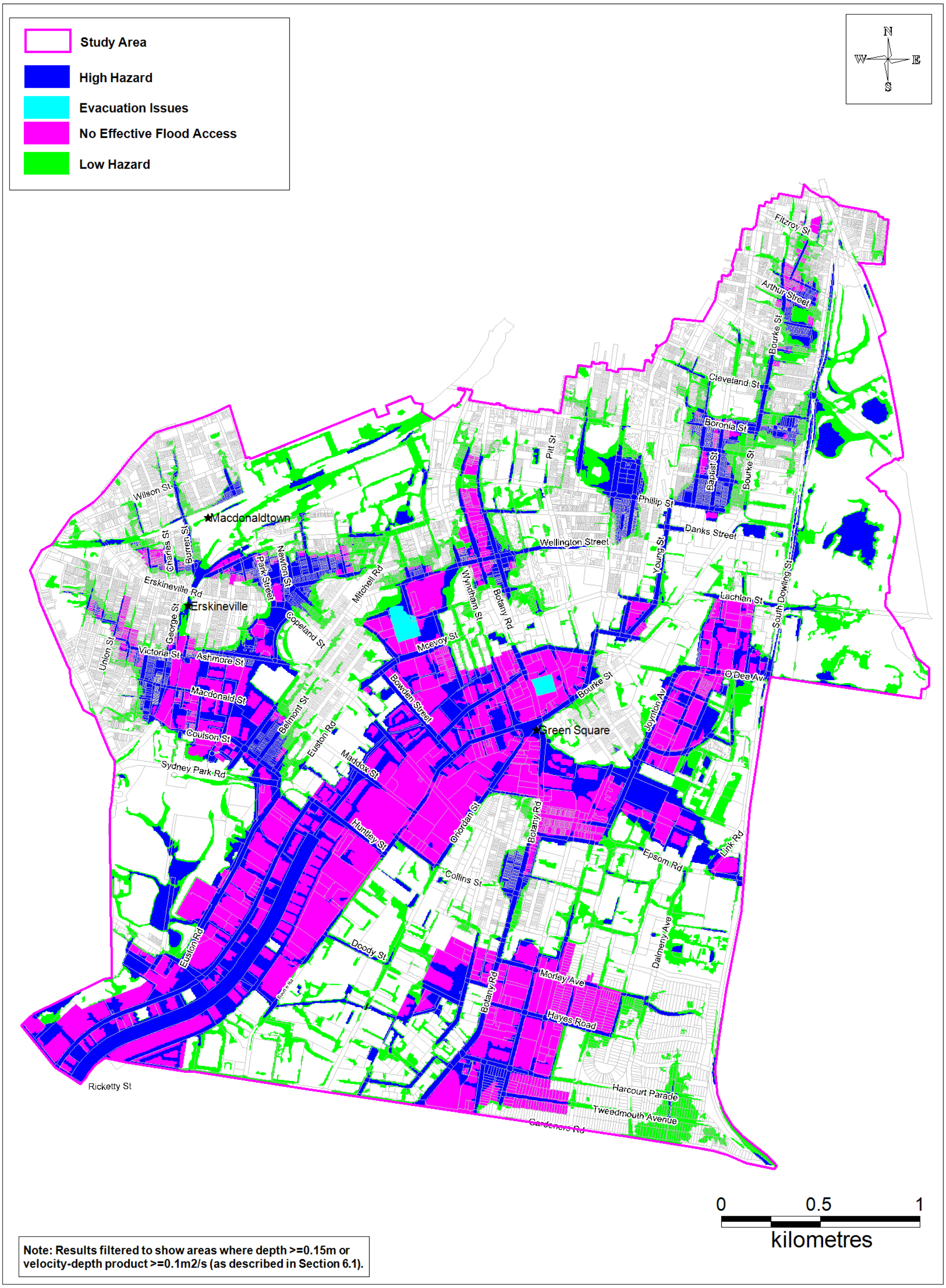

Figure 5-8 PMF True Hazard

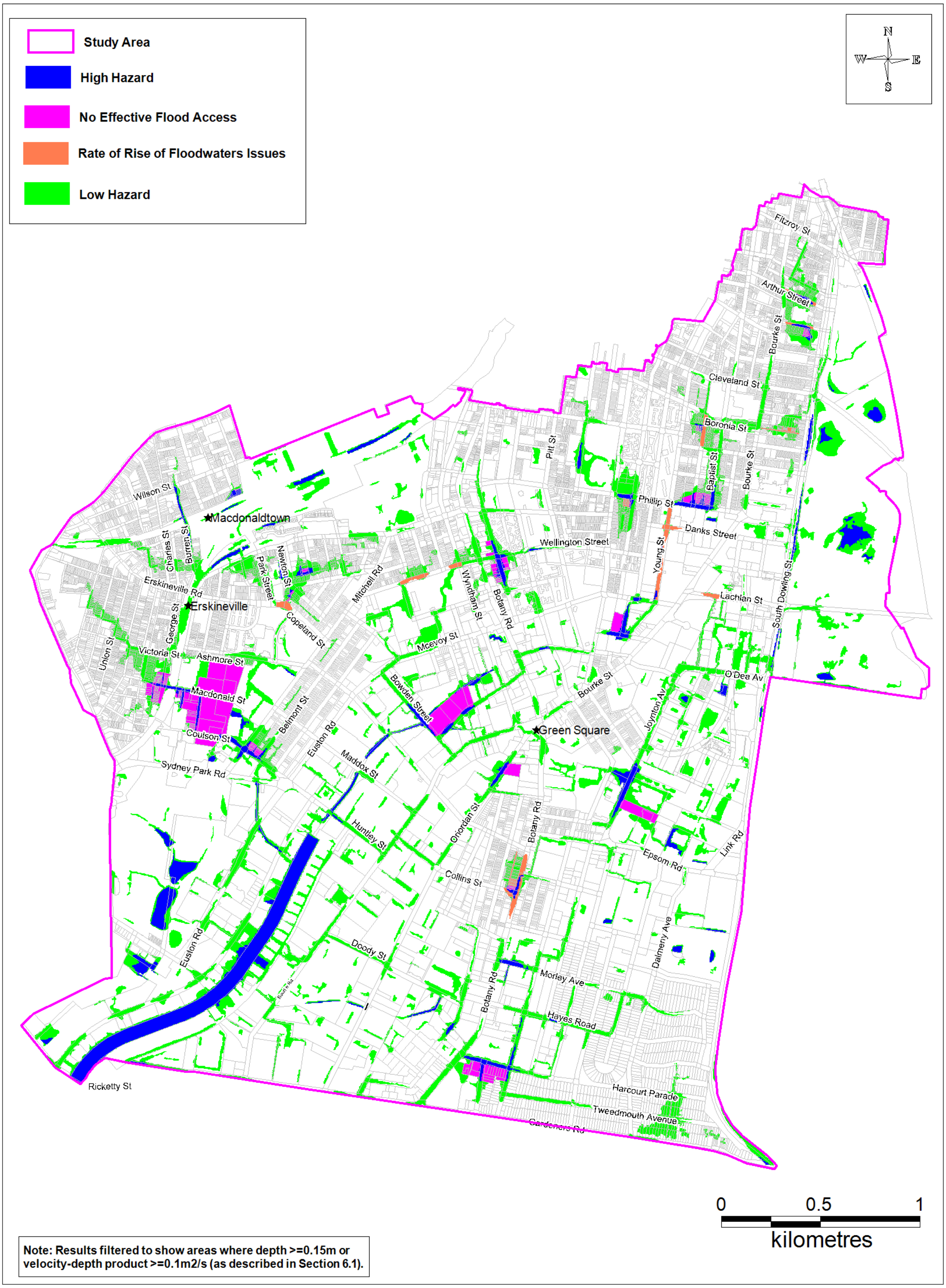

Figure 5-9 100 Year ARI True Hazard

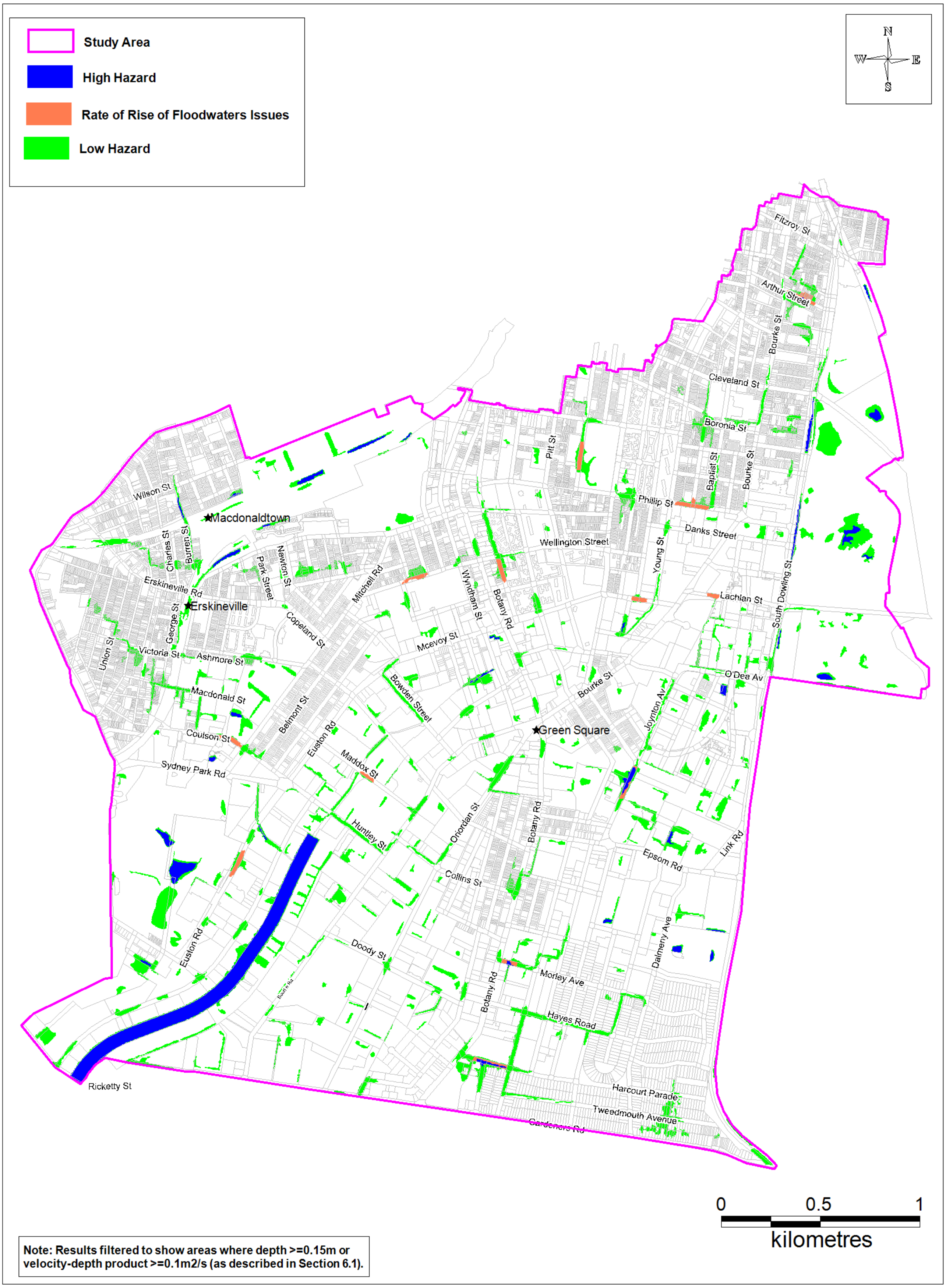

Figure 5-10 5 Year ARI True Hazard

5.5 Hydraulic Categorisation

While Flood Hazard (described in the sections above) relates to the impact of flooding on development and people, Hydraulic Categorisation is used to reflect the impact of development activity on flood behaviour. The Floodplain Development Manual (2005) defines flood prone land to be one of the following three hydraulic categories:

- **Floodway –** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage –** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10 percent.
- **Flood Fringe –** Remaining area of flood prone land after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

Hydraulic categorisation mapping has been undertaken for the 5 and 100 Year ARI together with the PMF using the results from the Draft Flood Study (Cardno, 2013).

The criteria used to define floodways and flood storage is described below (based on Howells et al, 2003). It provides a framework for the FRMSP and guides planning for properties potentially requiring a detailed assessment for future development.

As a minimum, the floodway was assumed to follow the channels from bank to bank. In addition, the following depth and velocity criteria were used to define a floodway:

- Velocity x Depth product must be greater than 0.25 m^2/s and velocity must be greater than 0.25 m/s; OR
- Velocity is greater than 1 m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1 m and/or would cause peak discharges to increase by more than 10 percent. The criteria were applied to the model results as described below.

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10 percent of the conveyance is lost, the criteria for flood storage would be satisfies. To determine the limits of 10 percent conveyance in a cross-section, the depth was determined at which 10 percent of the flow was conveyed. This depth averaged over several cross-sections was found to be 0.2m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2m; AND
- Not classified as floodway.

The hydraulic categories are shown in **Figure 5-11 to Figure 5-13**.

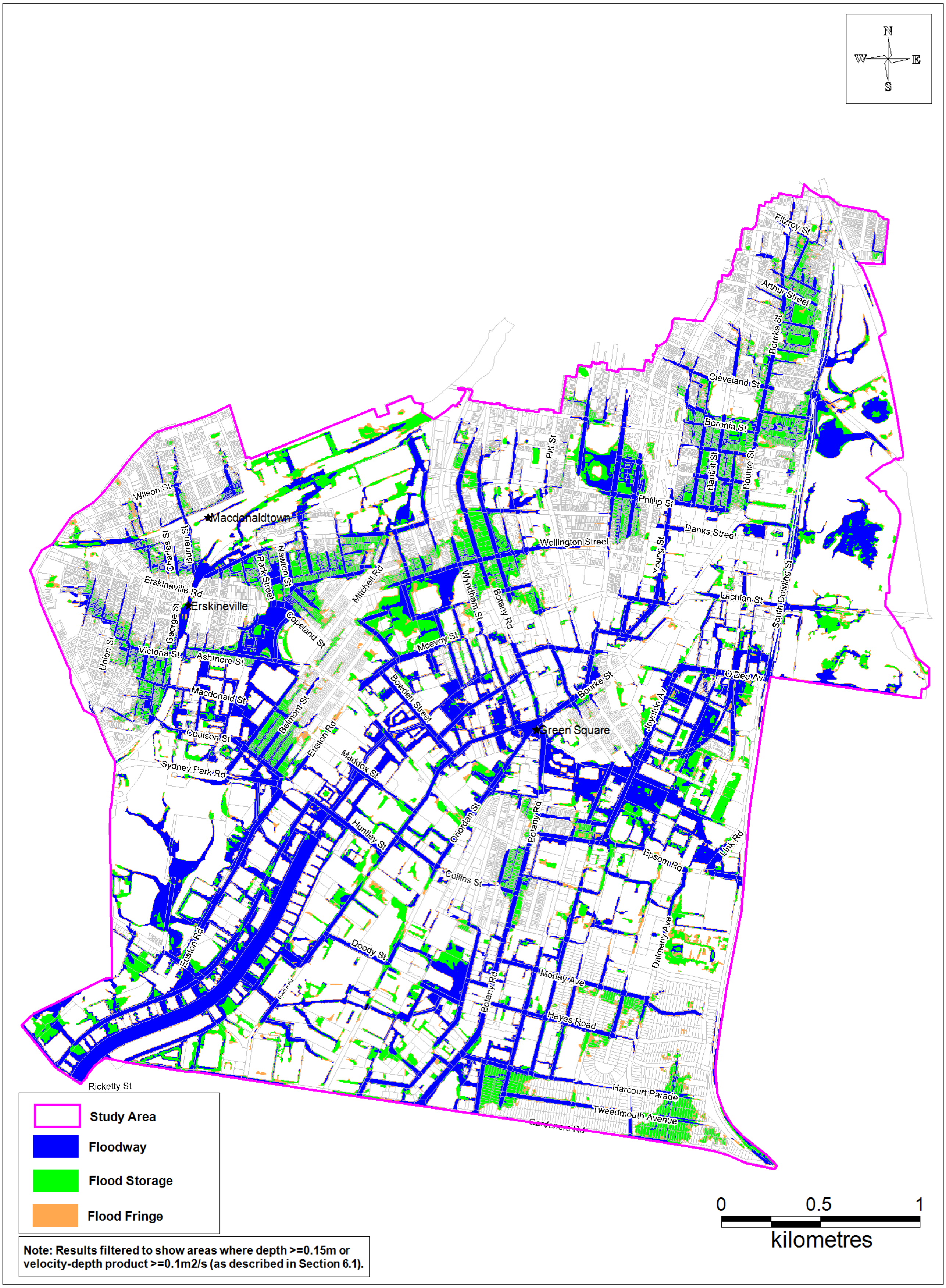

Figure 5-11 Hydraulic Categories – PMF

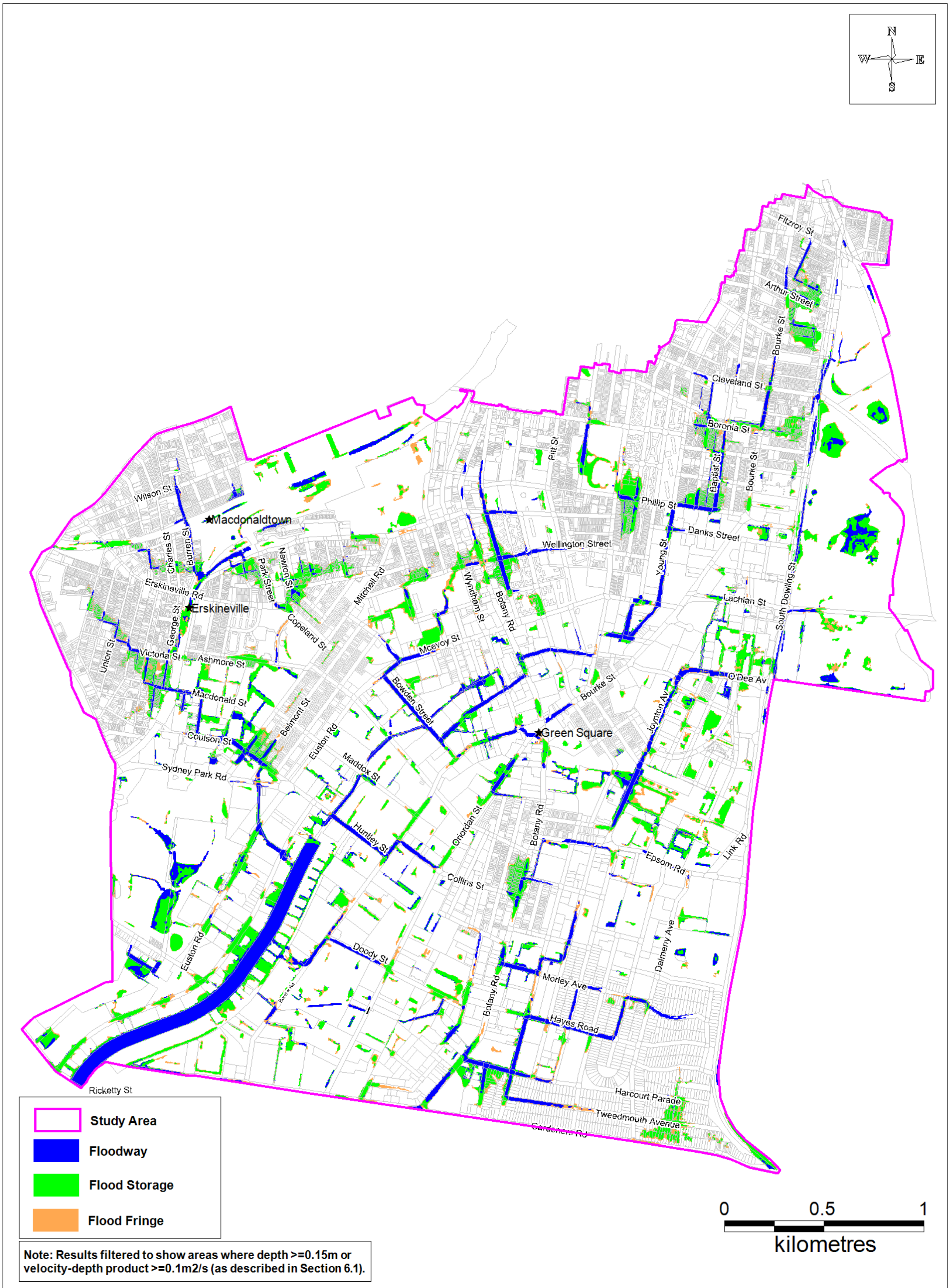

Figure 5-12 Hydraulic Categories – 100 Year ARI

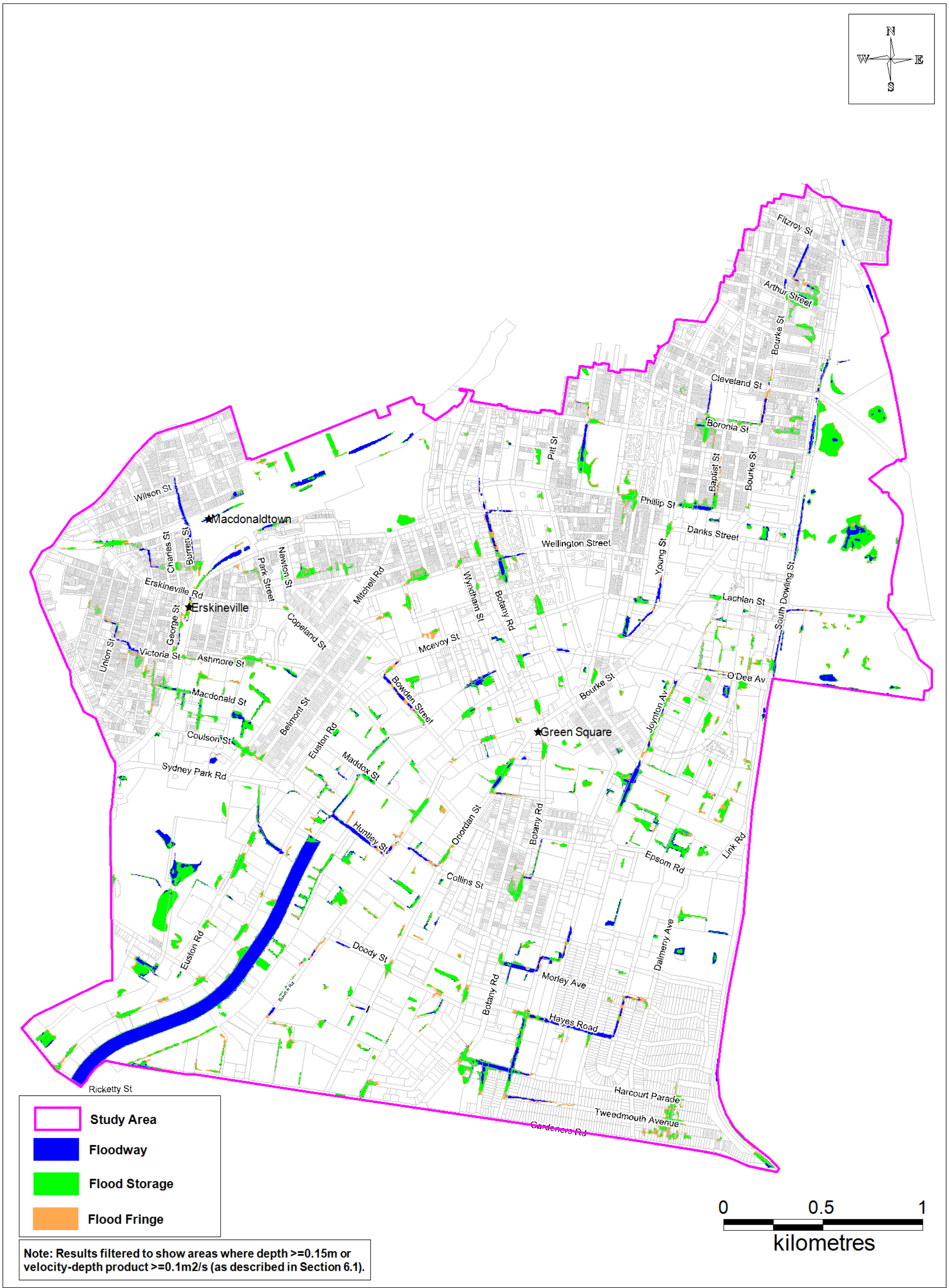

Figure 5-13 Hydraulic Categories – 5 Year ARI