catchment if the 1% AEP event is to be mitigated by drainage works.

9.3.4. Trunk Drainage Upgrade – New Drainage to Darling Harbour (FM – CA04)

Option Description

Option FM – CA04 describes a new trunk drainage line from King Street to Darling Harbour, with the goal of reducing property and road affectation in the 1% AEP. As with the previous two options, the new pipe was tested as an alternative to FM – CA01 to determine the relative effectiveness of alternatives to that option. The proposed upgrade consists of three 1.5 m x 1.5 m pipes from King Street to a new outlet into Darling Harbour near the west end of King Street, as well as two new 1.5 m x 1.5 m pipes under Pitt Street Mall. The length of the new pipes to Darling Harbour is approximately 630 m and there is a fall of around 15 m, which gives a grade of approximately 2.3%. In comparison, the trunk upgrade along Pitt Street is around 1.6%.

Modelled Impacts

The proposed new drainage line results in significant improvement for King Street and the downstream area. The impact of the proposed works on the 1% AEP flood level is shown on Figure 29, while Figure 30 shows the change in hazard in the same event. The reduction in flood level is as follows:

- 0.3 – 0.4 m lower on Pitt Street Mall
- 0.6 – 1.1 m lower on King Street
- 0.1 – 0.2 m lower on Pitt Street north of King Street
- 0.1 – 0.2 m lower on George Street from King Street to Hunter Street

The reduction in flood level is widespread and is comparable to that achieved by FM - CA01, with around the same benefit from Pitt Street Mall up to Martin Place, and less benefit (from FM - CA04) for the hotspots north of Martin Place. The reduction in hazard is also widespread, with all high hazard removed from Pitt Street up to Circular Quay, as well as on the low points adjacent to Pitt Street. There is no adverse impact at Darling Harbour or on King Street.

Evaluation

New drainage from King Street to Darling Harbour would provide significant reduction in flood risk while also being feasible as part of a larger program of works. The drainage would remove a significant portion of runoff from the southern hotspots (Pitt Street Mall and King Street) which then benefits the remaining hotspots along Pitt Street. The benefit relates to property flooding (significantly reduced around King Street), hazardous road and pedestrian area flooding, and improving the FPL requirements for the area. As an alternative to the three previously described measures, it has the advantage of benefitting one area without causing downstream adverse impacts. For this reason, the option could be carried out prior to (or instead of) a larger upgrade such as FM - CA01, which may not be feasible for cost and practicality issues.

9.3.5. Overland Flowpath – Surface Adjustment to Pitt Street Mall (FM –

CA05)

Option Description

Option FM - CA01 describes modification to Pitt Street Mall with the goal of mitigating inundation of property and the pedestrian area in the 1% AEP event. Pitt Street Mall has many commercial properties that are flooded overfloor in a 1% AEP event. Reduction of the peak flood level in this area is a desired alternative to property modification options such as flood proofing or raised floor levels. The option involves lowering all of Pitt Street Mall by 0.3 m in order to increase the conveyance of the overland flowpath which flows north through the mall. The lowered section has an area of approximately 4000 m^2. The option also includes a new stormwater pit near the north of the mall to drain the lowered area into the existing stormwater network. In order to maintain the existing floor levels and entrances in the mall, the lowered area would have a permeable covering (e.g. a grate) to the height of the current ground surface. The lowered area may also be concentrated to the sides or the middle of the mall, in which case the depth may need to be greater (e.g. 0.5 m).

Modelled Impacts

Lowering Pitt Street Mall is able to achieve a significant reduction in the peak flood level and benefit the affected properties. The impact of the proposed works on the 1% AEP flood level is shown on Figure 31. The reduction in flood level is around 0.3 m for most of the lowered section, with 0.1-0.2 m reduction at the King Street end. There is no adverse impact downstream, while the upstream area near the intersection with Market Street has minimal reduction (<0.01 m). In the existing conditions, flood depths along the mall are 0.2-0.3 m on the east side and 0.3-0.4 m on the west side. Therefore, the reduction achieved by the works accounts for the majority of the overfloor flood depth at the location. However, while the depth above floor will be reduced for the properties, the depth on Pitt Street Mall is largely unchanged, as the ground has been lowered.

Evaluation

The measure achieves a significantly reduced flood level for the properties along Pitt Street Mall, however, it may be difficult to implement. The lowered flood level corresponds to significant reduction in the property affectation in the area, with the 0.3-0.4 m depth of flow along most of Pitt Street Mall in the existing case reduced to less than 0.1 m. There is also a large reduction in the area's flood risk, given the high pedestrian usage in the area and the change in hazard to pedestrians when the majority of the flow is moved below a grated surface. The main constraints with regards to the measure are incorporating the works into the existing streetscape, given that there is likely a high density of services under Pitt Street Mall.

9.3.6. Overland Flowpath – Surface Adjustment to Martin Place (FM – CA06)

Option Description

Option FM – CA06 describes modifications to Martin Place aimed at improving overland flow behaviour. The modifications consist of lowering the existing ground surface by 0.3 m on the north and south side of the section of Martin Place between Pitt Street and George Street. The lowered areas would act as swales to divert runoff to the trunk drain on Pitt Street. Currently, the area's grading means that sheet flow across the area flows towards Pitt Street. The lowered area also

includes small pipes (0.1 m diameter) to discharge runoff in a regular rainfall event. The works were assessed for their impact on the 5% AEP event, when hazardous flow occurs in the area.

Modelled Impacts

The measure redistributes overland flow and does not result in adverse impacts downstream. The impact of the two lowered areas on the 5% AEP flood level is shown on Figure 31, which also shows the location of the works. The reduction in peak flood level is around 0.05 m in the area, with the existing depth of 0.1 m on the northern side of Martin Place reduced to less than 0.05 m. The two swales have around 0.3 m of depth.

Evaluation

The measure improves overland flow behaviour in Martin Place, however, the benefit is limited to the reduced hazard for pedestrians. The redistributed flow means the overland flowpath, which in the 5% AEP event is around 0.1 m deep with velocities of 0.5 m/s (on the north side), is almost wholly contained in a swale, which would be covered with a grate or similar cover. The existing flood behaviour is categorised as low hydraulic hazard and would not pose a threat to most pedestrians. However, Martin Place's function as a pedestrian thoroughfare in the CBD means that improving the area's flood risk is warranted. The proposed works are straightforward to construct (relative to the other structural measures) and could be incorporated into other surface works occurring in the area.

9.3.7. Trunk Drainage Upgrade – George Street near Wynyard (FM – CA07)

Option Description

Option FM – CA07 describes a drainage upgrade on George Street with the goal of reducing property and road affectation in the 1% AEP on George Street. George Street has an overland flowpath running parallel to the flowpath on Pitt Street, but with less flow as it is higher and less catchment area. The majority of the overland flow turns right at Hunter Street and connects to the Pitt Street flow. The proposed upgrade consists of a new pipe (0.9 m diameter) on George Street from Wynyard Street to Hunter Street, where it connects to the existing trunk drainage. The new drainage will include additional pits along the section of George Street.

Modelled Impacts

The proposed works result in minor improvement for the upgraded section and the downstream area on Hunter Street and Pitt Street. The impact of the proposed works on the 1% AEP flood level is shown on Figure 33, which also shows the location of the upgrade. The reduction in peak flood level is around 0.01 m on George Street, 0.09 m on Hunter Street and 0.03 to 0.06 m on Pitt Street. The minor reductions mean that significant depth and flow remains in each of the areas. The new pipe conveys up to 0.8 m^3/s; however, its flow is reduced at the downstream end where it connects to the trunk drainage, which is already full from the upstream area.

Evaluation

The measure does not provide significant improvement for the George Street hotspot and highlights the difficulty of upgrading sections of the stormwater network. The reduction in the 1% AEP peak flood level is minor and would not justify large-scale drainage works as has been

assessed. The performance of the new drainage is limited by the downstream drainage, which does not have any capacity to take additional flow from George Street. This also indicates that larger upgrades to that assessed will also be limited by the downstream capacity.

9.3.8. Drainage Upgrade – Phillip Street (FM – CA08)

Option Description

Option FM – CA08 describes a drainage upgrade on Phillip Street with the goal of reducing property and road affectation in the 10% AEP event. The section of Phillip Street between Martin Place and Hunter Street has a slight topographic depression that causes runoff to accumulate in the area. The ponding is minor relative to other flood affected areas in the catchment, and it has been included as a minor hotspot for this reason. The design event has been chosen based on the City's goal for the stormwater network to mitigate road flooding up to the 10% AEP event (there is limited property affectation at the hotspot). The upgrade consists of additional pit and pipe capacity to increase flow to the existing stormwater pipe, which does not require upgrade.

Modelled Impacts

The proposed works result in significant improvement for the affected section of Phillip Street and are relatively feasible. The impact of the proposed works on the 10% AEP flood level is shown on Figure 35, which also shows the location of the new drainage, while Figure 34 shows the existing flood behaviour in the 10% AEP event. The reduction in flood level is up to 0.5 m and the 10% AEP depth is all but removed under the measure. The figure also shows that pipe flow out of the area increases from 0.4 to 0.6 m^3/s. This indicates that the existing drainage has capacity to take additional flow, but that this requires the additional pit/pipe drainage. The measure of only increasing the pit sizes was also tested and was found to not produce the same benefit, demonstrating the feeder pipe capacity requires upgrade.

Evaluation

The measure results in significant improvement for the Phillip Street area (minor hotspot) and is straightforward to implement, relative to other investigated works. The pit and pipe upgrade increases flow in the street's drainage and drains the above-ground ponding in a 10% AEP event. In the existing case, the ponding of just over 0.5 m depth is associated with risk of submerged vehicles and blocked building entrances. As with other areas in the catchment, there is a high density of people in the area, especially on weekdays during business hours. The required works are small-scale and could be incorporated into other drainage or sub-surface works in the area.

9.3.9. Data Collection – Catchment Specific Flood Damages Assessment (FM – CA09)

Description

Option FM-CA09 consists of a catchment specific flood damages assessment of properties in the Sydney CBD and review of cost benefit analysis of recommended flood modifications measures. The catchment specific flood damages assessment would investigate the various property types in the City Area catchment, describe how properties' different construction materials, entrance types and nature and location of stock relate to the cost of flooding on a property type basis and

review the both estimation of flood damages across the catchment and cost benefit analysis of flood modification measures.

The option has been included as a site-specific flood modification measure as it would largely inform the construction of site-specific measure in the catchment. It has also not been scored in the multi-criteria assessment matrix in Section 9.5 as most of the criteria are not relevant to the measure (e.g. impact on flooding, social/environmental cost).

Discussion

Several floodplain risk management measures involving large scale drainage upgrades have been evaluated for the City Area Catchment that have costs in the order of $10-30 million. The cost/benefit ratios of these options have been estimated at less than 0.5 i.e. reduction in flood damages due to the works is less than half the total cost of the works.

This cost benefit analysis is used to justify and prioritise works and is based on the estimation for flood damages described in Section 5 which relates a depth of flooding to an economic cost on a property basis. This method has several limitations when used for estimating flood damages for the City Area catchment including:

- Many of the properties are commercial (rather than residential) for which no standard damage curve exists;
- Construction material and building standards within the catchment are variable, with buildings ranging from the 1800s to the present day;
- Type of commercial premises are variable, with a wide range of retail, cafes, bars and restaurants, and specialty services; and
- Many properties within the area have multi floor basements.

These limitations provide some uncertainty as to the accuracy of the estimated flood damages and the cost benefit analysis of proposed flood mitigation works. A catchment specific flood damages assessment would provide an in-depth evaluation the vulnerability of various property types to flooding and provide standard damage curves for typical properties within the City Area. These damage curves will result in a higher degree of accuracy in the assessment of flood damages and provide more reliable estimates of the reduction in damages for various mitigation options.

Evaluation

The catchment specific flood damages assessment will provide more accurate information on flood damages within the City Area catchment and provide a more reliable assessment of the benefits of flood mitigation measures, potentially providing a greater economic justification for the large-scale pit and pipe works in the catchment.

9.3.10. Economic Assessment of Site Specific Measures

The cost effectiveness of the site specific management measures in reducing flood liability within the catchment was determined using the benefit/cost (B/C) approach. A costing was estimated

for each measure and this was compared, where appropriate, to the measure's reduction in AAD. Where no significant benefit to AAD was found, the measure's cost effectiveness was assessed qualitatively.

Costing

Detailed cost estimates have been prepared for each measure and these are summarised in Table 20, with detailed costing in Appendix C. It is important to note that these are estimates and should be revised prior to the detailed design phase of the measures to obtain a more accurate costing. For the trunk drainage upgrade measures, the large capacity of the upgrade's pipes meant that the width of the upgrade was comparable to the width of the available area (i.e. roadway and footpaths). Such a large upgrade would incur additional costs due to the re-location of existing services, and this has been accounted for by a higher contingency multiplier in the costing estimates. For surface adjustment measures, previous works in the area have indicated that construction of this nature is far more expensive in the CBD than in other areas, largely due to the very high density of development and the resulting complications. This means that costing estimation does not yield realistic estimates. Estimates have therefore been based on the most recent refurbishment of Pitt Street Mall, which cost approximately $11 million.

Table 20: Costings of Management Measures

Option	Capital	Maintenance per year
FM-CA01 Trunk Drainage Upgrade – Alfred Street to Market Street	$ 30,080,100	$ 12,540
FM-CA02 Trunk Drainage Upgrade – Pitt Street and King Street	$ 8,096,900	$ 4,920
FM-CA03 Trunk Drainage Upgrade – Alfred Street to Bridge Street	$ 18,650,600	$ 7,200
FM-CA04 Trunk drainage Upgrade – New Drainage to Darling Harbour	$ 21,704,800	$ 8,200
FM-CA05 Overland Flowpath – Surface Adjustment to Pitt Street Mall	$ 13,000,000	$ 10,000
FM-CA06 Overland Flowpath – Surface Adjustment to Martin Place	$ 5,000,000	$ 10,000
FM-CA07 Trunk Drainage Upgrade – George Street near Wynyard*	ND*	ND
FM-CA08 Drainage Upgrade – Phillip Street	$ 575,800	$ 540

*Not Determined. Option not costed as produced no significant benefit to flood behaviour

Table 20 shows that the drainage capacity upgrade Measure FM – CA01 is the most costly, as it involves the longest section of trunk drainage being upgraded, followed by the more localised upgrades, all of which require significantly large works. It should be noted that all cost estimates are largely approximate due to the uncertainty around possible additional costs arising from construction complications in a densely urbanised area. The costs should be used as an indication of order of magnitude and of the relative cost between the measures.

Damage Assessment of Measures

The total damage costs were evaluated for three of the measures and compared against the existing base case, as shown in Table 21. The assessment for the three measures was carried out in accordance with OEH guidelines utilising data obtained from the flood level survey and height-damage curves that relate the depth of water above the floor with tangible damages. The damages were evaluated for a range of design events from the 0.5 EY up to the PMF. The

mitigation measures' AAD and the 'Existing' AAD that they were compared with each used a less conservative blockage scenario (kerb inlet pits 20% blocked, sag pits 50% blocked) than in the other design results (kerb inlet pits 50% blocked, sag pits 100% blocked), which corresponds to the City's design blockage for pits with lintels > 1.0 m.

The reason for the other five options not being assessed in this way are:

- FM-CA02 does not produce significant reduction in overfloor inundation;
- FM-CA03 has significant constructability issues as it involves diverting around 20 m3/s of overland flow into the subsurface drainage, within very limited space;
- FM-CA06 is aimed at mitigating flow hazardous to pedestrians and so has minimal effect on overfloor inundation;
- FM-CA07 produces negligible benefit to flood behaviour; and
- FM-CA08 significant improves road affectation on Phillip Street but does not affect property inundation, except for one property.

Table 21: Average Annual Damage Reduction of Management Measures

Measure	AAD	Reduction in AAD due to Measure
FM-CA01 Trunk Drainage Upgrade – Alfred Street to Market Street	$ 815,822	$ 862,377
FM-CA04 Trunk drainage Upgrade – New Drainage to Darling Harbour	$ 1,269,976	$ 408,223
FM-CA05 Overland Flowpath – Surface Adjustment to Pitt Street Mall	$ 1,563,524	$ 114,675

The results show that the large scale Pitt Street drainage upgrade has the greatest reduction in AAD, with a reduction of $862,377 that approximately halves the catchment's AAD. The other two measures also have significant benefit and are proportional to their scope of works. It should be noted that all of the measures may underestimate the reduction in flood damages, as the effects of flooding at each commercial property can only be roughly approximated, and that some premises cannot be accurately assessed using the standard damages assessment due to the complexity of flow through them, for example a below ground area below a building which is connected to other buildings.

Benefit Cost Ratio of Measures

Following estimation of the measure's cost and AAD, the benefit/cost ratio (B/C) of three of the measures was calculated. The B/C is the ratio of the net present worth of the reduction in flood damages (benefit) compared to the cost of the works and is used to compare the economic worth of a set of works to others in the area. Table 22 lists the reduction in AAD due to the measures, and compares this to the works' capital and maintenance costs to produce a B/C. The measures' B/C was between 0.3 and 4.7, with values above 1 indicating that the economic benefit of the measure is greater than its cost.

Table 22: Benefit/Cost Ratio for Management Measures

Measures	Benefit			Cost Estimate			
	AAD	Reduction in AAD	NPW of AAD Reduction*	Capital	Maintenance (Annual)	NPW of Costs*	B/C Ratio
FM-CA01	$815,822	$862,377	$ 12,734,500	$ 30,080,100	$ 12,540	$ 30,265,300	0.4
FM-CA04	$1,269,976	$408,223	$ 6,028,100	$ 21,704,800	$ 8,200	$ 21,826,000	0.3
FM-CA05	$1,563,524	$114,675	$ 1,693,400	$ 13,000,00	$ 10,000	$ 13,147,670	0.1

* NPW: Net present worth calculated over 50 years at 7%,

The three measures presented in Table 22 have a B/C of less than 1, indicating they are not justifiable on economic grounds alone. However, as described in this section, the high-density urban area means that both the cost of works and the estimate of property damage have large uncertainties. As described, the cost has factored the space constraints into the estimate, but there may be further construction issues that increase the cost. With regards to damages, they may be much higher than has been estimated (and therefore the reduction in damages also larger), but are difficult to estimate in further detail without damage curves specific to the various types of commercial development.

The analysis does not consider social factors, environmental factors and risk to life which cannot be quantified in monetary terms but would have been a net contributor to the benefits that could be gained from these management measures.

9.4. Catchment Wide Management Measures

9.4.1. Property Modification - Flood Planning Levels (PM – CA01)

The flood planning level (FPL) is used to define land subject to flood related development controls and is generally adopted as the minimum level to which floor levels in the flood affected areas must be built. The FPL includes a freeboard above the design flood level. It is common practice to set minimum floor levels for residential buildings, garages, driveways and even commercial floors as this reduces the frequency and extent of flood damages. Freeboards provide reasonable certainty that the reduced level of risk exposure selected (by deciding upon a particular event to provide flood protection for) is actually provided.

The main aim of the FPLs is to reduce the damages experienced by the property owner during a flood. Elevating a house floor level above the FPL will ensure that flood damages are significantly reduced. Council have specified FPL requirements in their *Interim Floodplain Management Policy* prior to the completion of the Floodplain Risk Management Plans for the entire LGA and we endorse this move. It is important that the same requirements are applied throughout the LGA to new development or redevelopments regardless of whether the Floodplain Risk Management Plan have been completed for the catchment or not. The only exception would be if the Floodplain Risk Management Plan proposes a change to these FPLs.

9.4.2. Property Modification - Development Control Planning (PM – CA02)

The Interim Floodplain Management Policy provides general requirements for new developments on flood liable land within the catchment, Flood Planning Level requirements for different development types and guidelines on flood compatible materials. This document serves as an interim policy for managing floodplain within the Council LGA which will be withdrawn once Council complete Floodplain Risk Management Plans for the entire LGA and then integrate outcomes from these plans into planning controls.

9.4.3. Property Modification - Flood Proofing (PM – CA03)

An alternative to house raising for buildings that are not compatible or not economically viable, is flood proofing or sealing off the entry points to the building. This measure has the advantage that it is generally less expensive than house raising and causes less social disruption. Flood proofing requires sealing of doors and possibly windows (new frame, seal and door); sealing and re-routing of ventilation gaps in brick work; sealing of all underfloor entrances and checking of brickwork to ensure there are no gaps or weaknesses in mortar. It is generally only suitable for brick buildings with concrete floors and it can prevent ingress from outside depths of up to one metre. Greater depths may cause structural problems (buoyancy) unless water is allowed to enter. Generally an existing house can be sealed for approximately $10,000. New development and extensions allow the inclusions of flood appropriate materials and designs meaning the actual cost of flood proofing can be significantly less when compared to buildings requiring retro-fitting of flood proofing measures.

Flood proofing should also consider suitable electrical installation to as to avoid the risk of electrocution. A minimum aim should be to have all properties in flood hazard areas to, at least, be fitted with a circuit breaker although ideally for all new development all unsealed electrical circuits should be at the Flood Planning Level (FPL).

Additionally, flood proofing can involve the raising of easily damaged/high cost items such as commercial stock, equipment and machinery. New buildings should have floor levels above the flood planning level.

Permanent flood proofing options are more suitable for commercial and industrial buildings where there are only limited entry points and aesthetic considerations are less of an issue. Also there are issues of compliance with other regulations such as fire safety and maintenance issues as well as access issues. However flood compatible building or renovating techniques should be employed for extensions or renovations where appropriate.

Minimising the chance of electrocution by turning off the electricity supply during a flood should be standard practice for both residents and commercial owners during floods. The risk of electrocution can also be reduced by installing electrical circuits above, at least, the flood planning level.

Responsibility for flood-proofing in the City Area catchment should fall to property owners, and

should be initiated by the City. The majority of buildings in the catchment have a single owner that then leases different floors or suites to tenants. The majority of ground floor premises are commercial, with some properties having multiple ground floor tenants. Commercial premises are varied in nature, with the degree of flood risk often dependant on a store's contents and its location relative to the ground. This means that different flood-affected premises require different types of flood-proofing. The building owners can determine the most appropriate options for their property, depending on the degree of flood affectation and the nature of the commercial premises, and carry out suitable flood proofing. It is recommended that City of Sydney carry out a consultation program with flood affected properties (i.e. those in flooding hotspots) in order to provide information to building owners about possible flood proofing options.

9.4.4. Response Modification - Flood Warning and Evacuation (RM – CA01)

Flood warning can significantly reduce damages and risk to life and studies have shown that flood warning systems generally have high benefit/cost ratio if sufficient warning time is provided.

Flood warning and the implementation of evacuation procedures by the SES are widely used throughout NSW to reduce flood damages and protect lives. The Bureau of Meteorology (BoM) is responsible for flood warnings on major river systems which the SES disseminates to the local community. Adequate warning gives residents time to move goods and cars above the reach of floodwaters and to evacuate from the immediate area to designated evacuation points or flood free ground. The effectiveness of a flood warning scheme, known as the effective flood warning time, depends on:

- The maximum potential warning time before the onset of flooding;
- The actual warning time provided before the onset of flooding. This depends on the adequacy of the information gathering network and the skill and knowledge of the operators; and
- The flood awareness of the community responding to a warning.

For overland flow flooding providing a flood warning is more difficult than for area impacted by mainstream floods. For river systems, predictions of potential peak flood height and timing are possible with a high degree of reliability afforded by upstream gauges. However, predicting urban overland flow peak flood levels is not necessarily practicable. Overland flooding usually occurs soon after, or at the same time, as intense rainfall. Spatial differences in the rainfall patterns may go undetected by the sparse rainfall gauge network. Furthermore the extent of flood levels can vary over the study area. Therefore, weather warnings are often more useful with regard to providing warning to residents and businesses. Weather warnings issued by BOM can advise if flooding is expected.

Given the speed with which floods can occur a more realistic system may be the additional service of communication of flood risk via SMS alerts or online social media, i.e. Twitter, Facebook etc. the responsibility for which would be SES with assistance from City of Sydney, RMS and other authorities. The measure may also involve establishing a system where existing electronic signage on major roads is used to warn of a flood event occurring, and not to drive into

floodwaters. The SES would be responsible for this with assistance from City of Sydney, RMS and other authorities.

The changing use of the CBD over the course of a day means that the response will be largely dependent on the time of day the flooding occurs. For example, flooding during rush hour (approximately 7:30 am to 9:30 am and 4:30 pm to 6:30 pm on weekdays) will disrupt a large number of commuters and drivers, with most city streets having constant traffic between 7:00 am and 7:00 pm on weekdays. This means that people are likely to react to flooding as a crowd, whereby observed danger to a single person (e.g. crossing fast moving or deep water) will then influence the onlookers, and generally improve pedestrians' decision making. A flood event then will also mean emergency services will have very impaired road access. A flood event outside these hours will affect far fewer people, with most buildings empty at night, but there is higher risk of an individual taking a dangerous action (e.g. walking or driving into floodwaters).

9.4.5. Response Modification - Flood Emergency Management (RM – CA02)

It may be necessary for some occupants to evacuate buildings in a major flood. This would usually be undertaken under the direction of the lead agency under the EMPLAN, the SES. Some people may choose to leave on their own accord based on flood information from the radio or other warnings, and may be assisted by local residents. The main problems with all flood evacuations are;

- They must be carried out quickly and efficiently;
- There can be confusion about 'ordering' evacuations, with rumours and well-meaning advice taking precedence over official directions which can only come from the lead agency, the SES;
- They are hazardous for both rescuers and the evacuees;
- Residents are generally reluctant to leave their homes, causing delays and placing more stress on the rescuers;
- People (residents and visitors) do not appreciate the dangers of crossing floodwaters; and
- In dense urban areas (such as the City Area catchment), a designated evacuation area will become quickly congested, and it will generally be safer to stay indoors on an above-ground level.

For this reason, the preparation of a flood emergency response plan helps to minimise the risk associated with evacuations by providing information regarding evacuation routes, refuge areas and what to do/not to do during floods. It is the role of the Regional Emergency Management Committee and Local Emergency Management Committee to develop these plans for vulnerable communities.

A REMPLAN should be prepared for the Sydney West Emergency Management Region (of which City Area catchment is part) to outline emergency response arrangement specific to the district.

Further, it is recommended that a LEMPLAN with consequent management guide - flood by the Local Emergency Management Committee to outline the following details:

- Evacuation centres in close proximity to the floodplain which are flood free sites with flood free access;
- Recommend the use of Variable Message Signs for use during a flood event for flood affected roads;
- Inclusion of a description of local flooding conditions;
- Identification of potentially flood affected vulnerable facilities; and
- Identification of key access road subject to flooding.

Although flood warning is limited, a local disaster plan should be continually updated to include the latest information on design flood levels and details on roads, properties, and other facilities which would be flood affected. The plan should give particular focus to the severely affected areas and identify areas where people can simply move up within a building to escape flood risk. In this catchment, moving up to an above ground level of a building will greatly reduce the flood risk to an individual. Areas with some of the highest flood risk will be underground garages/car parks in areas with significant flood affectation, where runoff can potentially inundate and fill the below-ground space. Discussion of evacuation should also acknowledge the difficulty with moving out of the catchment during a flood event (due to the high density of people and the limited road/footpath capacity) and that people will often be safest remaining in above ground levels of buildings, for example, in shops, department stores, shopping malls, office buildings or hotels.

9.4.6. Response Modification - Community Awareness Programme (RM – CA03)

The success of any flood warning system and the evacuation process in reducing flood losses and damages depends on:

- *Flood Awareness*: How aware is the community of the flood threat? Has it been adequately informed and educated?
- *Flood Preparedness*: How prepared is the community to react to the threat of flooding? Do they (or the SES) have damage minimisation strategies (such as sand bags, raising possessions) which can be implemented?
- *Flood Evacuation*: How prepared are the authorities and the residents to evacuate households to minimise damages and the potential risk to life during a flood? How will the evacuation be done, where will the evacuees be moved to?

Public information and the level of public awareness are keys in reducing flood damages and losses. A more aware community will suffer less losses and damage than an unprepared community.

The importance of flood awareness was noted by City of Sydney after flooding on the 24th August 2015. The event, which caused flooding in most of the hotspots, confirmed expected flood behaviour in a number of areas, including Pitt Street Mall and King Street. It was noted that data from this event, particularly photos and videos that showed the flood behaviour in well-known

locations, clearly communicated the possible flooding behaviour in the area. It was also noted that such data was not necessarily shared with City of Sydney from people who took photos or videos, and that a coordinated campaign, such as a dedicated website or even social media methods for collecting people's experiences, is required to collect a more complete picture of the event. It is recommended that this be incorporated into any community awareness programme for the catchment.

9.5. Assessment Matrix

9.5.1. Background

Multi-variate decision matrices are recommended in the Floodplain Development Manual (Reference 1) and therefore it is also a recommendation of this report that multi-variate decision matrices be developed for specific management areas, allowing detailed benefit/cost estimates, community involvement in determining social and other intangible values, and local assessment of environmental impacts.

The criteria assigned a value in the management matrix are:

- Risk to life;
- Impact on flood behaviour (reduction in flood level, hazard or hydraulic categorisation) over the range of flood events;
- Number of properties benefited by measure;
- Technical feasibility (design considerations, construction constraints, long-term performance);
- Community acceptance and social impacts;
- Economic merits (capital and recurring costs versus reduction in flood damages);
- Financial feasibility to fund the measure;
- Long term performance;
- Environmental and ecological benefits;
- Impacts on the State Emergency Services;
- Political and/or administrative issues; and
- Long-term performance given the potential impacts of climate change.

The scoring system for the above criteria is provided in Table 23 and largely relates to the impacts in a 1% AEP event. The matrix below is designed to set out a general scheme to illustrate how a local matrix might be developed. These criteria and their relative weighting may be adjusted in the light of community consultations and local conditions. Tangible costs and damages are also used as the basis of B/C analysis for some measures.

Table 23: Matrix Scoring System

SCORE:	-3	-2	-1	0	1	2	3
Impact on Flood Behaviour	>100mm increase	50 to 100mm increase	<50mm increase	no change	<50mm decrease	50 to 100mm decrease	>100mm decrease
Number of Properties Benefited	>5 adversely affected	2-5 adversely affected	<2 adversely affected	none	<2	2 to 5	>5
Technical Feasibility	major issues	moderate issues	minor issues	neutral	moderately straight-forward	Straight-forward	no issues
Community Acceptance	majority against	most against	some against	neutral	minor	most	majority
Economic Merits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Financial Feasibility	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Environmental & Ecological Benefits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Impacts on SES	major disbenefit	moderate disbenefit	minor disbenefit	neutral	minor benefit	moderate benefit	major benefit
Political / administrative Issues	major negative	moderate negative	minor negative	neutral	few	very few	none
Long Term Performance	major disbenefit	moderate disbenefit	minor disbenefit	neutral	positive	good	excellent
Risk to Life	major increase	moderate increase	minor increase	neutral	minor benefit	moderate benefit	major benefit

9.5.2. Results

The assessment matrix is given in Table 24, with each of the assessed management measures scored against the range of criteria. It is important to note that the approach undertaken does not provide an absolute “right” answer as to what should be included in the Management Plan but is rather for the purpose of providing an easy framework for comparing the various options on an issue by issue basis which stakeholders can then use to make a decision. For the same reason, the total score given to each measure, and the subsequent rank, is only an indicator to be used for general comparison.

Table 24: Multi-Criteria Assessment of Management Options

Ref	Option	Section in Report	Design Event (AEP)	Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Community Acceptance[1]	Economic Merits	Financial Feasibility	Environmental/Ecological Benefits	Impact on SES	Political/Admin Issues	Long Term Performance	Risk to Life	Total Score	Rank (Total)
Flood Modification Measures																
FM-CA01	Trunk Drainage Upgrade – Alfred Street to Market Street	9.4.1	1%	3	3	-3	-1	2	-3	-1	3	-3	1	3	4	8
FM-CA02	Trunk Drainage Upgrade – Pitt Street and King Street	9.4.2	1%	1	2	-2	-1	1	-2	0	2	-2	1	1	1	11
FM-CA03	Trunk Drainage Upgrade – Alfred Street to Bridge Street	9.4.3	1%	2	2	-3	-1	1	-2	0	1	-2	1	1	0	13
FM-CA04	Trunk Drainage Upgrade – New Drainage to Darling Harbour	9.4.4	1%	2	2	-2	-1	1	-2	0	2	-2	1	2	3	9
FM-CA05	Overland Flowpath – Lower Pitt Street Mall	9.4.5	1%	2	2	-1	-1	1	-1	-1	2	-2	2	2	5	7
FM-CA06	Overland Flowpath – Lower Martin Place	9.4.6	10%	1	1	-1	-1	0	0	0	1	-2	2	0	1	11
FM-CA07	Trunk Drainage Upgrade – George Street near Wynyard	9.4.7	1%	1	1	-2	-1	1	-2	0	0	-3	1	0	-4	14
FM-CA08	Drainage Upgrade – Phillip Street	9.4.8	10%	2	1	-1	-1	1	-1	0	1	-1	1	1	3	9
Property Modification Measures																
PM-CA01	Property Modification - Flood Planning Levels	9.5.1	N/A	0	0	0	1	2	2	0	1	0	3	1	10	2
PM-CA02	Property Modification - Development Control Planning	9.5.2	N/A	0	0	0	1	2	2	0	1	1	3	1	11	1
PM-CA03	Property Modification - Flood Proofing	9.5.3	N/A	0	0	-1	1	2	1	0	1	-1	2	1	6	6
Response Modification Measures																
RM-CA01	Response Modification - Flood Warning and Evacuation	9.5.4	N/A	0	0	-1	1	1	2	0	2	2	0	2	9	3
RM-CA02	Response Modification - Flood Emergency Management	9.5.5	N/A	0	0	-1	1	2	2	0	2	1	0	1	8	5
RM-CA03	Response Modification - Community Awareness Programme	9.5.6	N/A	0	0	2	1	2	2	0	2	1	-2	1	9	3

[1] *Community Acceptance scores were based on a limited number of submissions received following the public exhibition period.*

As shown in the matrix, most the structural measures score lowly on economic merit, as they do not have favourable B/C ratios, and on financial feasibility, as all require a large capital outlay. In addition, they have technical feasibility issues, either relating to the potential issues in the design of the required drainage or ground lowering. Low scores in these three categories result in a much lower score than most of the response modification and property modification measures.

The five highest ranking measures scored between 8 and 10, which indicates that they are all generally equivalent under this assessment. They all require relatively little financial outlay, and will lower the economic cost of flooding in the catchment. Flood Proofing also scores well, but ranks lower due to its potential political/administrative issues and lower technical feasibility

Based on the matrix, the measures for future implementation are ranked in the order as tabulated in Table 25.

Table 25: Ranking of Management Measures

Rank	Ref	Options	Score
1	PM-CA02	Property Modification - Development Control Planning	11
2	PM-CA01	Property Modification - Flood Planning Levels	10
3=	RM-CA01	Response Modification - Flood Warning and Evacuation	9
3=	RM-CA03	Response Modification - Community Awareness Programme	9
5	RM-CA02	Response Modification - Flood Emergency Management	8
6	PM-CA03	Property Modification - Flood Proofing	6
7	FM-CA05	Overland Flowpath – Lower Pitt Street Mall	5
8	FM-CA01	Trunk Drainage Upgrade – Alfred Street to Market Street	4
9=	FM-CA04	Trunk Drainage Upgrade – New Drainage to Darling Harbour	3
9=	FM-CA08	Drainage Upgrade – Phillip Street	3
11=	FM-CA06	Overland Flowpath – Lower Martin Place	1
11=	FM-CA02	Trunk Drainage Upgrade – Pitt Street and King Street	1
13	FM-CA03	Trunk Drainage Upgrade – Alfred Street to Bridge Street	0
14	FM-CA07	Trunk Drainage Upgrade – George Street near Wynyard	-4

Note: '=' denotes equal position. E.g. '3=' refers to equal third rank.

Of the 14 management options presented here, 11 have been recommended for implementation as part of the City Area Catchment Floodplain Risk Management Plan. The three discarded options are FM-CA02, FM-CA03 and FM-CA07. These measures either have very minor benefit (FM-CA07), are less effective than alternatives (FM-CA02) or are not considered technically feasible (FM-CA03).

10. ACKNOWLEDGEMENTS

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11. REFERENCES

1. NSW Government
Floodplain Development Manual
April 2005

2. BMT-WBM
City Area Flood Study
Final Report, 2014

3. Sydney Water
'Tank Stream' webpage accessed September 2015 at https://www.sydneywater.com.au/SW/teachers-students/facts-about-water/secondary-students/history-of-water-in-sydney/tank-stream/index.htm

4. Sydney Water
City Area (SWC 29) Capacity Assessment
December 1991

5. City of Sydney
Interim Floodplain Management Policy
May 2014

6. NSW Department of Environment and Climate Change
Flood Emergency Response Classification of Communities
October 2010

7. Howells *et. al.*
Defining the Floodway – Can One Size Fit All?
2004

8. NSW Department of Environment and Climate Change
Floodplain Risk Management Guideline – Residential Flood Damages
October 2007

Figures


FIGURE 1
STUDY AREA
CITY AREA CATCHMENT
Dawes Point
Millers Point
Barangaroo
The Rocks
Alfred St
Circular Quay
Essex St
Pitt St
Bridge St
George St
Western Distributor Freeway
Wynyard
Erskine St
Angel Place
York St
Martin Pl
Martin Place
St James
Castlereagh St
Market St
Hyde Park
QVB
Elizabeth St
Park St
N
Study Area
0
200
400
600
800
m
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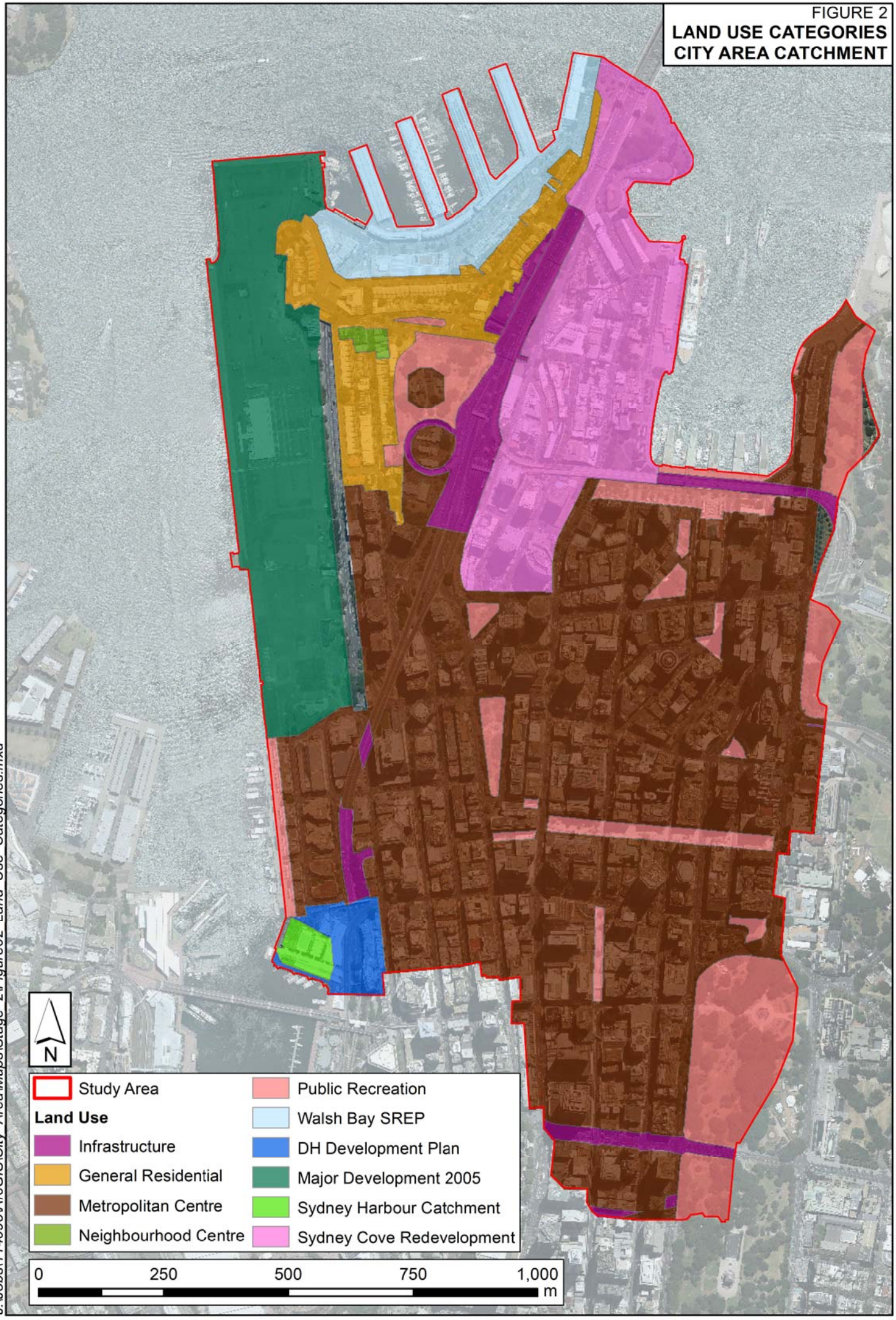
FIGURE 2
LAND USE CATEGORIES
CITY AREA CATCHMENT
N
Study Area
Land Use
Infrastructure
General Residential
Metropolitan Centre
Neighbourhood Centre
Public Recreation
Walsh Bay SREP
DH Development Plan
Major Development 2005
Sydney Harbour Catchment
Sydney Cove Redevelopment
0
250
500
750
1,000
m
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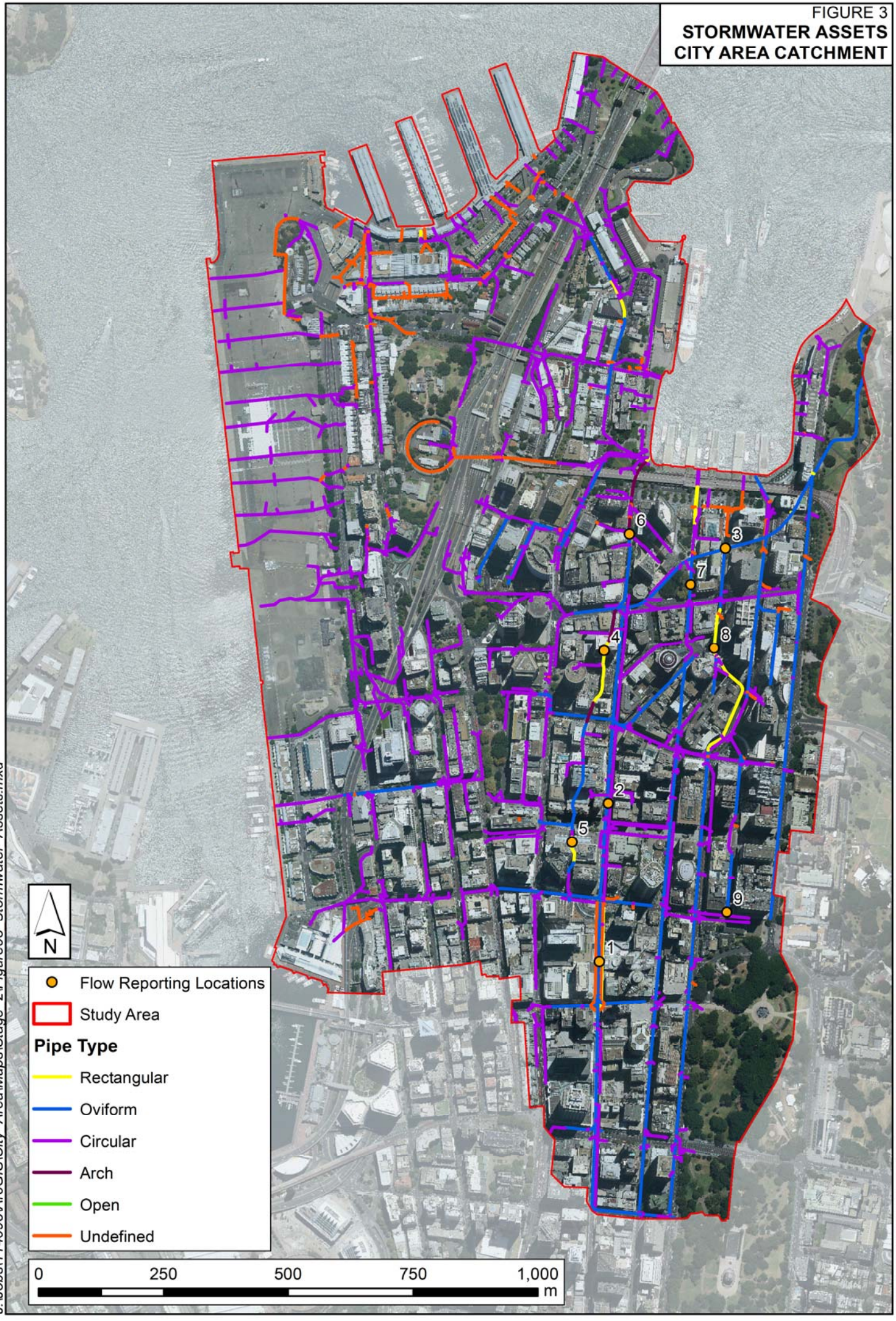
FIGURE 3
STORMWATER ASSETS
CITY AREA CATCHMENT
N
Flow Reporting Locations
Study Area
Pipe Type
Rectangular
Oviform
Circular
Arch
Open
Undefined
0
250
500
750
1,000
m
1
2
3
4
5
6
7
8
9
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FIGURE 4
HOTSPOT LOCATIONS
CITY AREA CATCHMENT

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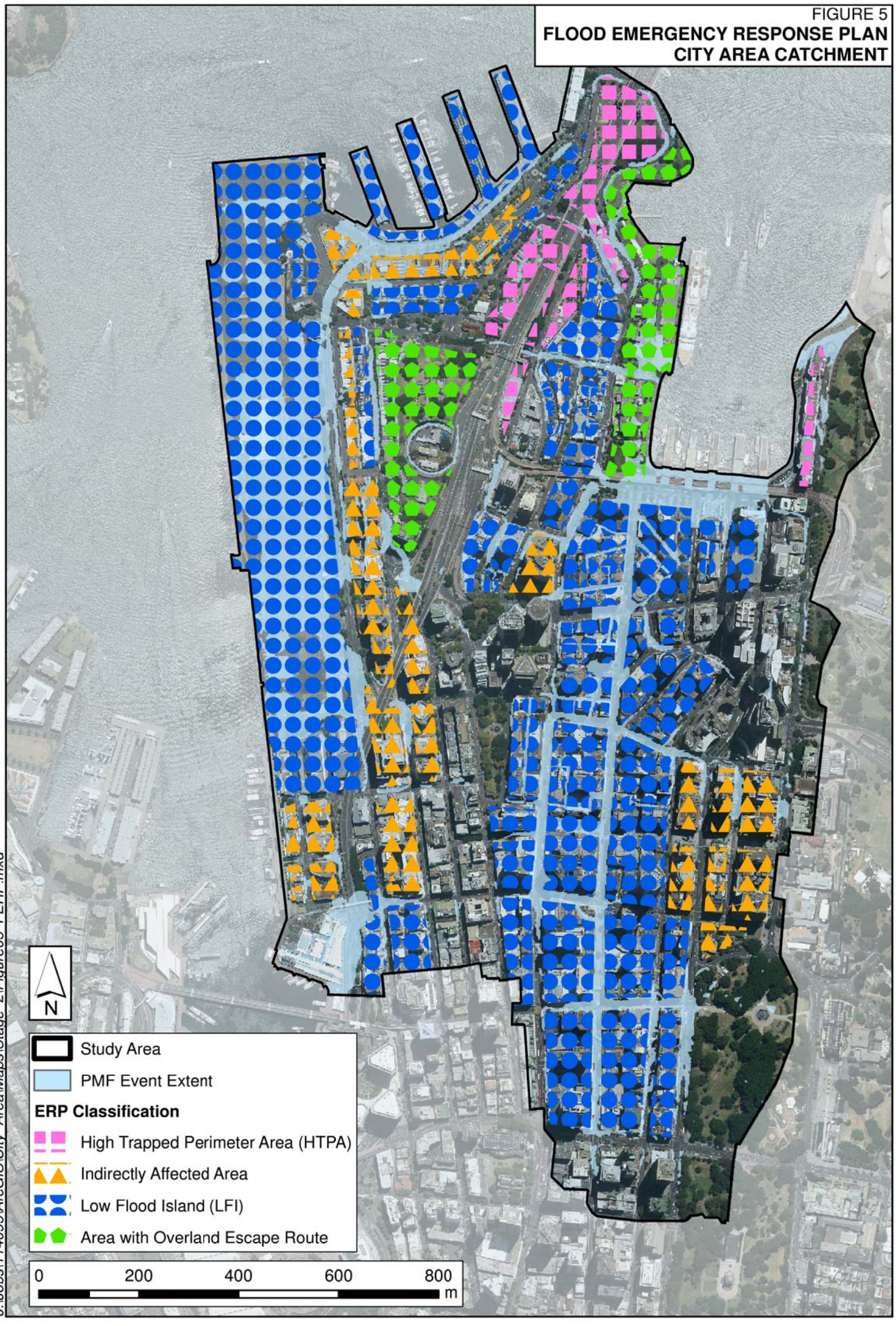
FIGURE 5

FLOOD EMERGENCY RESPONSE PLAN
CITY AREA CATCHMENT



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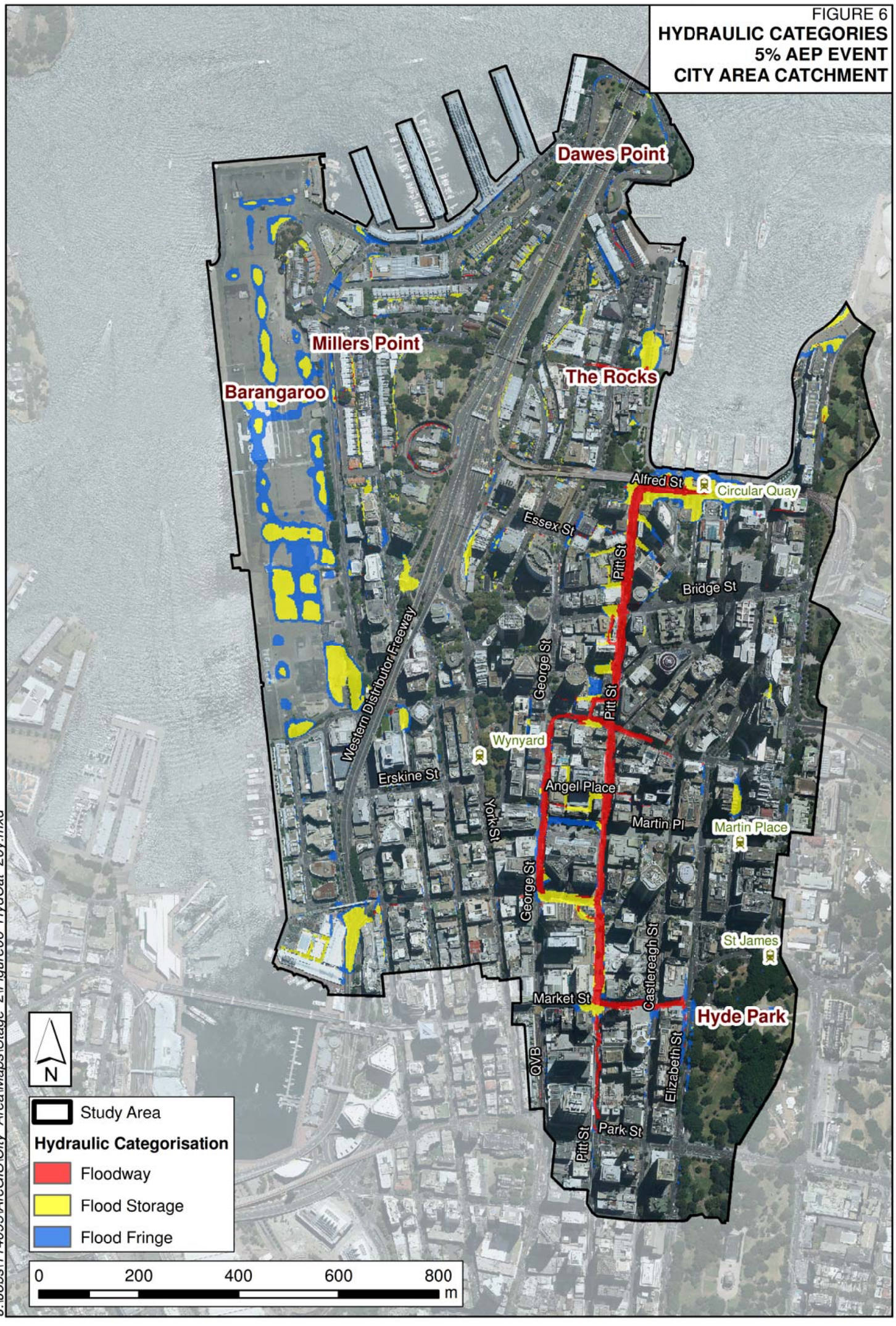
FIGURE 6
HYDRAULIC CATEGORIES
5% AEP EVENT
CITY AREA CATCHMENT
Dawes Point
Millers Point
Barangaroo
The Rocks
Alfred St
Circular Quay
Essex St
Pitt St
Bridge St
George St
Western Distributor Freeway
Wynyard
Erskine St
Angel Place
York St
Martin Pl
Martin Place
George St
St James
Castlereagh St
Market St
Hyde Park
QVB
Elizabeth St
Park St
Pitt St
N
Study Area
Hydraulic Categorisation
Floodway
Flood Storage
Flood Fringe
0
200
400
600
800
m
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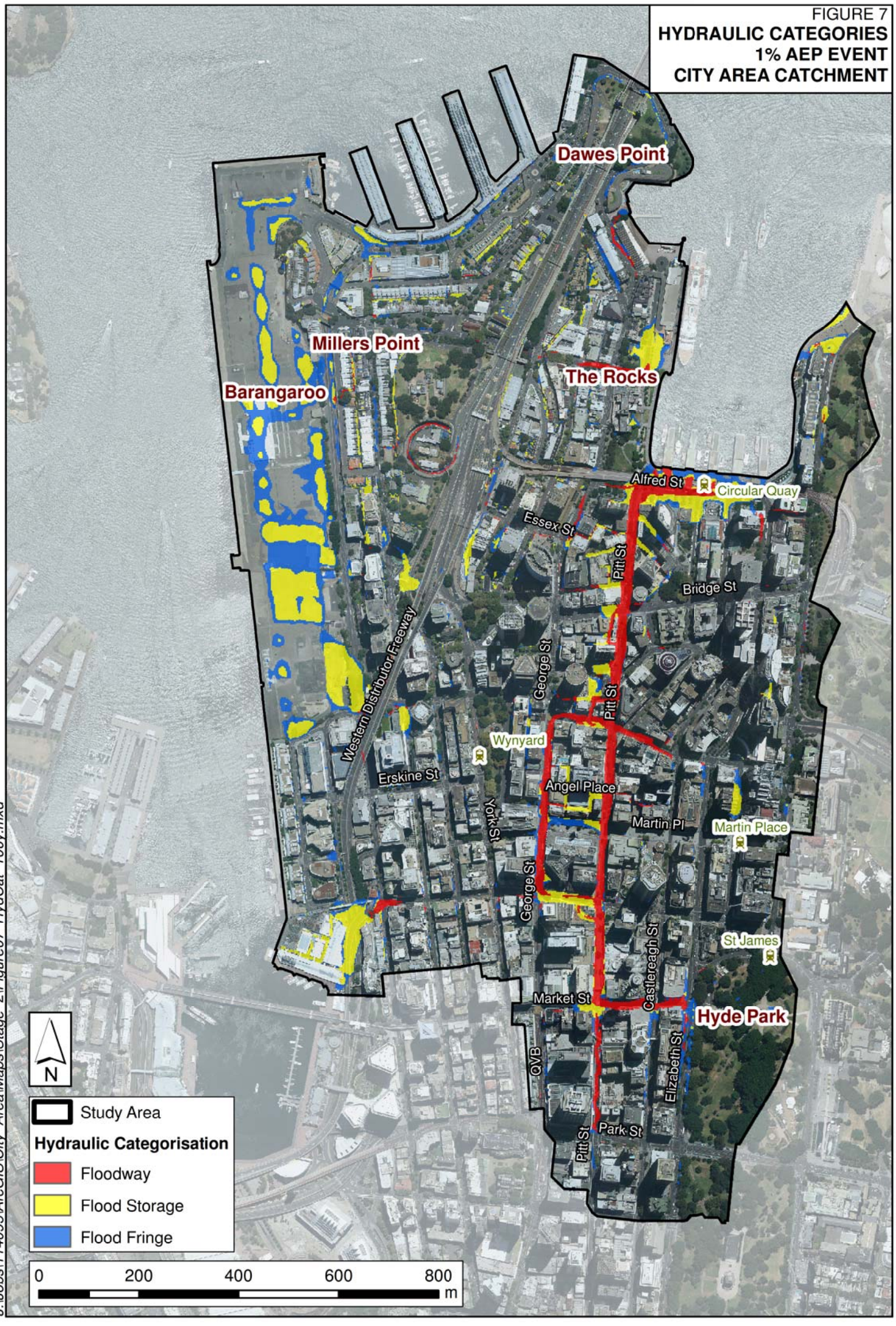
FIGURE 7
HYDRAULIC CATEGORIES
1% AEP EVENT
CITY AREA CATCHMENT
Dawes Point
Millers Point
Barangaroo
The Rocks
Alfred St
Circular Quay
Essex St
Pitt St
Bridge St
George St
Western Distributor Freeway
Wynyard
Erskine St
Angel Place
York St
Martin Pl
Martin Place
George St
St James
Castlereagh St
Market St
Hyde Park
QVB
Elizabeth St
Park St
Pitt St
N
Study Area
Hydraulic Categorisation
Floodway
Flood Storage
Flood Fringe
0
200
400
600
800
m
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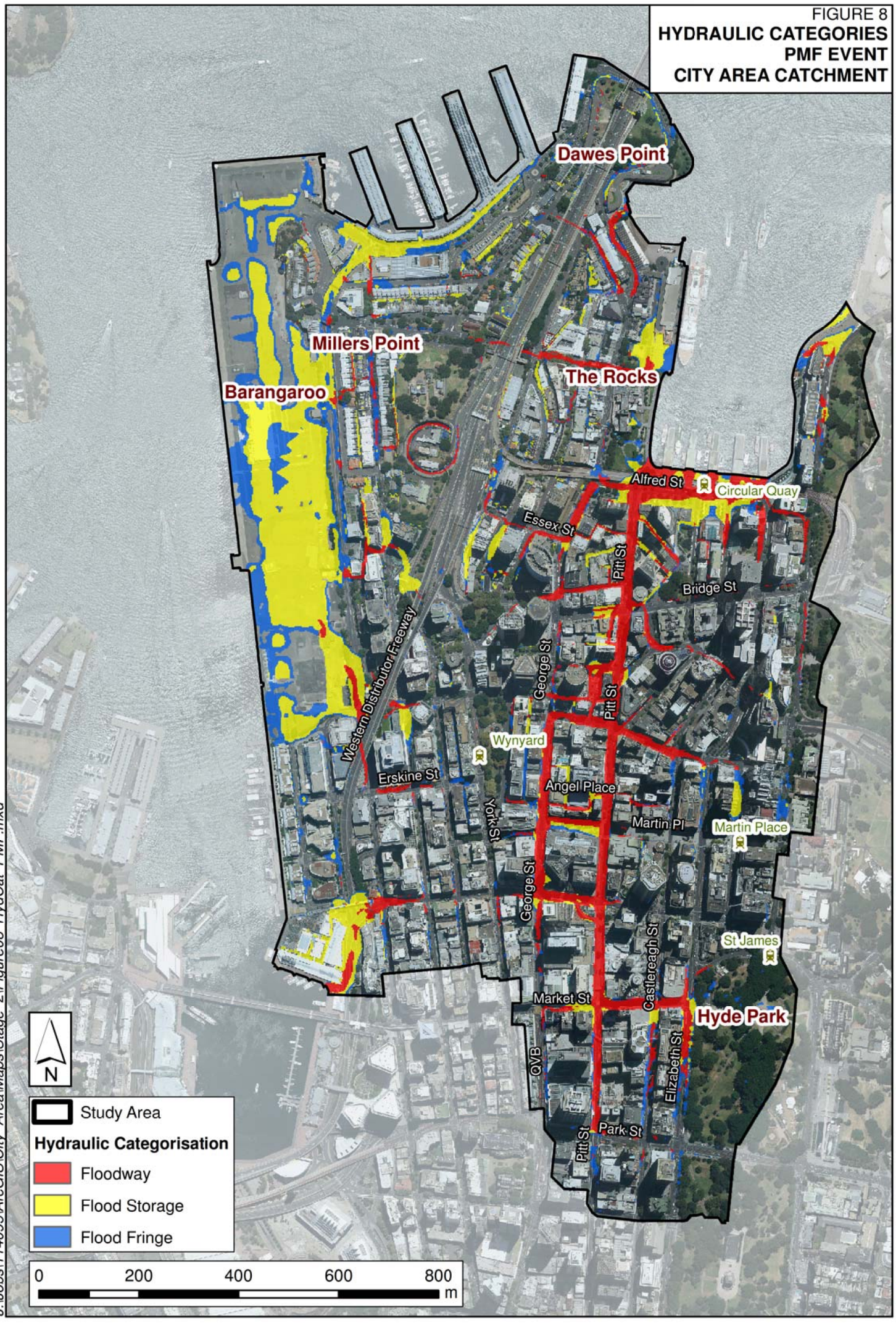
FIGURE 8
HYDRAULIC CATEGORIES
PMF EVENT
CITY AREA CATCHMENT
Dawes Point
Millers Point
Barangaroo
The Rocks
Alfred St
Circular Quay
Essex St
Pitt St
Bridge St
George St
Western Distributor Freeway
Wynyard
Erskine St
Angel Place
York St
Martin Pl
Martin Place
St James
Castlereagh St
Market St
Hyde Park
QVB
Elizabeth St
Park St
N
Study Area
Hydraulic Categorisation
Floodway
Flood Storage
Flood Fringe
0
200
400
600
800
m
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