10% AEP event. Belmore Park lies adjacent to the catchment's main flowpath and is on the few areas of green space in the catchment. The ground surface in approximately the north third of the park was lowered by up to 0.8 m to a level of 6.5 mAHD. The area is approximately 6500 $m^2$, which creates a volume of approximately 5000 $m^3$. It should be noted that the depth and area of excavation is based on a 'first-pass' assessment where only the effect on flooding is determined. If there is shown to be a benefit, the environmental and social constraints would be carefully considered. The option does not involve changes to the sub-surface drainage (although more detailed design would likely involve drainage of the lowered area to the existing trunk system). The Elizabeth Street hotspot's flood behaviour is shown on Figure 27 while Figure 28 shows the location of the lowered area.

**Modelled Impacts**

The proposed works achieve significant reduction in flood level on Hay Street and no reduction on Elizabeth Street. The impact of the proposed works on the 10% AEP flood level is shown on Figure 28. The reduction shown on the figure is 0.1 – 0.2 m on Hay Street between Elizabeth Street and George Street, with less reduction downstream of George Street. The reduction results in the majority of Hay Street having 0.1 – 0.2 m of depth in the 10% AEP event. As shown on the figure, the peak overland flow on Hay Street is reduced from 4.9 $m^3/s$ to 1.2 $m^3/s$. There is also a minor increase on Elizabeth Street which is a result of the changed flow behaviour on Hay Street slightly reducing the flow onto Hay Street from Elizabeth Street. The reduction in flow and level is due to the lowered park area acting as a retarding basin which captures a portion of the overland flow and attenuates the flow downstream. The reduction in level also corresponds to some reduction in property affectation; however, it is generally small as most affected properties on Hay Street are downstream of George Street.

**Evaluation**

The lowered park would provide only minor benefit to the area's flood risk and would have significant social and environmental costs. The volume of storage captures only a percentage of the 10% AEP runoff and so there is still significant road affectation on Hay Street, while Elizabeth Street has no benefit. The affected section of Hay Street (mostly upstream of George Street) has little traffic relative to the surrounding area with only light rail access between Pitt Street and George Street. The social and environmental costs of the option are as follows:

- Significant impact on the visual amenity and pedestrian function of the park, which rises as it moves towards Central Station and contains a busy pedestrian path. The lowered park would involve walking down into the park and then back out and would involve large-scale re-landscaping of the park;
- Impact on well-established trees that are part of City of Sydney's 'Significant Trees' register. The basin has been located in an area that is generally free of trees but there is not enough cleared space to place a basin that does not affect at least some trees. The 'Significant Trees' register lists 7 species of trees in the area and lists their age and location in a historically-significant park as being factors in the trees' value; and
- Possible contamination issues with excavating land. The extent of possible contamination issues is not known for Belmore Park but experience of other parks in inner Sydney suggest there may be contaminated fill.

Overall, the benefits resulting from the lowered park are not large enough to offset the significant social and environmental impacts resulting from the works. The benefit is a reduction in flood level on Hay Street that removes part of the road flood risk in a 10% AEP event. Given that the road inundation on Elizabeth Street is not addressed, which has a much higher volume of traffic than Hay Street, and the likely social and environmental impacts are significant, the option is not considered viable.

### 9.3.5. Drainage Upgrade – Elizabeth Street to Outlet (FM – DH05)

**Option Description**

Option FM – DH-05 describes a trunk upgrade between Elizabeth Street and the outlet with the goal of mitigating flooding in the 1% AEP event. The 1% AEP event is used as the existing flood behaviour inundates many commercial premises and mitigation works may be able to offset the requirements of an FPL in the catchment that is set at the 1% AEP level. The proposed upgrade consists of an approximately 1.3 km long 1.8 m diameter pipe between Elizabeth Street and the outlet at Darling Harbour, following the existing trunk drainage line. The pipe only drains runoff at Elizabeth Street so as to avoid drainage pits along its length that reduce its hydraulic pressure. Although it only drains runoff at Elizabeth Street, the pipe is designed to benefit Hay Street and Darling Harbour downstream, by reducing flow into these areas from Elizabeth Street. As the pipe is full from its drainage on Elizabeth Street, this is essentially the same as having a series of drainage points along Elizabeth Street and Hay Street. The additional hydraulic pressure is designed to offset the flat gradient of the catchment through Hay Street and Darling Harbour, which inhibits pipe peak flow rates. The Elizabeth Street and Hay Street hotspots' flood behaviour is shown on Figure 23 and Figure 27 while Figure 29 shows the location of the raised section.

**Modelled Impacts**

The proposed works achieve significant reduction in flood level on Hay Street and on Elizabeth Street. The impact of the proposed works on the 1% AEP flood level is shown on Figure 29. The reduction shown on the figure is around 0.2 m on Hay Street between Elizabeth Street and Harbour Street, while Elizabeth Street also has around 0.2 m reduction. The reduction results in a depth on Hay Street of around 0.1 m at Belmore Park, 0.3 m upstream of George Street and 0.4 – 0.8 m downstream of George Street, while Elizabeth Street has less 0.1 m depth. As shown on the figure, the overland flow reduces by 5.8 $m^3/s$ near Belmore Park and by 1.5 $m^3/s$ at the downstream end of Hay Street. The reduction in flow and level corresponds to increased road serviceability, particularly on Elizabeth Street, and reduced overfloor flooding, particularly downstream of George Street. However, the reduction in flood level and property affectation in 1% AEP event is limited downstream of George Street, as a significant depth of flow remains. In general, the pipe has more limited effect in the downstream areas where there is more contributing catchment from the CBD area, while the pipe takes flow from the Surry Hills part of the catchment.

Figure 30 shows the change in hydraulic hazard in the 1% AEP event due to the upgrade. The figure shows that the upgrade's reduction in overland flow significantly changes the area's

hydraulic hazard. The main area of change is on Hay Street between Pitt Street and Elizabeth Street where the high hazard flowpath is reduced to low hazard. There are also areas of reduction in parts of Darling Harbour. The high hazard flowpath downstream George Street on Hay Street is largely unchanged.

**Evaluation**

The upgraded trunk drainage would provide significant benefit to the area's flood risk but would have significant constructability issues and would not completely relieve 1% AEP flooding on Hay Street. The new drainage pipe drains a significant portion of runoff on Elizabeth Street, which in turn reduces flow downstream on Hay Street and into Darling Harbour. This corresponds to increased serviceability for Elizabeth Street, which would be largely flood free up to a 1% AEP event, and Hay Street, while also improving property flooding along Hay Street. The large contributing catchment at the west end of Hay Street means that the inundation at this location is only partially mitigated by the option. The proposed works are extensive and would likely involve significant constructability issues in two main areas: incorporating the 1.8 m diameter pipe into the high density of existing services (including stormwater drainage) and design of the additional pit inlet capacity on Elizabeth Street and surrounds. Economic assessment of the option is given in Section 9.3.9.

### 9.3.6. Drainage Upgrade – Pyrmont Street to Outlet (FM – DH06)

**Option Description**

Option FM – DH-06 describes a trunk upgrade from Pyrmont Street to the outlet with the goal of reducing road affectation in the 10% AEP event. The 10% AEP event is used as it corresponds with Council's objective to mitigate road flooding up to a 10% AEP event. The proposed upgrade includes the following elements:

- Additional pit capacity at the topographic sag on Pyrmont Street to drain an additional 0.2 m³/s into the existing drainage line towards Jones Bay Road;
- Additional drainage on Jones Bay Road to the outlet consisting of a 1.5 m x 1.5 m pipe on Jones Bay Road which becomes 2 x 1.5 m x 1.5 m where the drainage turns north, until the outlet into Jones Bay; and
- No additional drainage line on Pyrmont Street as the existing system has capacity to drain the 10% AEP runoff.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 23. Figure 32 shows the new drainage elements.

**Modelled Impacts**

The proposed works achieve a significant reduction in flood level for the topographic sag on Pyrmont Street. The impact of the proposed works on the 10% AEP flood level is shown on Figure 32. The reduction in flood level shown on the figure is 0.2 – 0.3 m on Pyrmont Street, which reduces the flooding to below 0.1 m in that event. The new drainage downstream on Jones Bay Road ensures that there is no adverse impact downstream due to the increased pipe flow from Pyrmont Street.

**Evaluation**

The proposed upgrade would provide minor benefit to the area's flood risk, largely through mitigating the road flooding. The inundated section of Pyrmont experiences localised flooding to a depth large enough to disable cars driving through it. The upgrade would mean the road is serviced by the drainage for up to a 10% AEP event. This would have significant benefit to the road users and pedestrians that use Pyrmont Street. Although there is benefit to the road serviceability, it is a relatively minor road and, compared to other flood-affected roads in the catchment, would not cause significant delays if blocked for 1-3 hours. There is also negligible benefit to property flooding in the hotspot, with only one property identified as benefitting from the reduced flood level.

The works involve large-scale pipe upgrades and therefore may face constructability issues. The upgraded pipes are over 3 m in width towards the outlet and would take up a significant portion of the roadway, which likely already has many services beneath it. The upgrade may be unable to be incorporated into these existing services. The hotspot itself could be serviced by relatively minor works involving additional drainage pits on Pyrmont Street; however, this would cause unacceptable adverse impacts downstream. Furthermore, the benefit of the option largely relates to improves road serviceability, which is not measured by the standard flood damages assessment, and the flooding poses relatively minimal risk to life. These factors make it less justifiable under a multi-criteria matrix assessment (see Section 9.5).

### 9.3.7. Drainage Upgrade – Black Wattle Place (FM – DH07)

**Option Description**

Option FM – DH-07 describes a drainage upgrade on Black Wattle Place and Harbour Street with the goal of reducing property affectation in the 5% AEP event. The 5% AEP event is used as it corresponds with Council's objective upgrade the stormwater network to the 5% AEP event. The proposed upgrade includes the following elements:

- Additional pit capacity at the topographic sag Harbour Street where it passes beneath the freeway south of Black Wattle Place, and at Black Wattle Place adjacent to the existing Ausgrid electricity substation; and
- Additional drainage from these two locations consisting of a 0.6 m diameter pipe connected to the existing system beneath Cockle Bay Wharf, which discharges into Darling Harbour.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 27. Figure 33 shows the new drainage elements.

**Modelled Impacts**

The proposed works achieve a significant reduction in flood level for the topographic sag on Black Water Place and Harbour Street. The impact of the proposed works on the 5% AEP flood level is shown on Figure 33. The reduction in flood level shown on the figure is 0.2 – 0.4 m on the two streets, which reduces the flooding to below 0.1 m in that event. The new drainage

elements ensure the two topographic sags are drained and that affectation at the building and on the road is reduced.

**Evaluation**

The proposed upgrade would provide minor benefit to the area's flood risk, through both reducing affectation around the substation and improving road serviceability. The building is currently surrounded by around 0.5 m in the 5% AEP event. It is not known what property damage this corresponds to as the internal floor level of the building is not known, or whether there are internal features that can be damaged by inundation. The road flooding is relatively minor except for localised inundation on Harbour Street south-west of the substation.

The construction feasibility of the two 0.6 m pipes is high relative to other options, which require much larger works. The main issues would relate to managing any impact of the construction on the road, which is a major thoroughfare, and secondly to incorporating the drainage into existing services.

### 9.3.8. Data Collection – Catchment Specific Flood Damages Assessment (FM – DH08)

**Description**

Option FM-DH08 consists of a catchment specific flood damages assessment of properties in the Sydney CBD and review of cost/benefit analysis of recommended flood modification measures. The catchment specific flood damages assessment would investigate the various property types in the Darling Harbour 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 both the estimation of flood damages across the catchment and cost/benefit analysis of recommended flood modification measures.

The measure has been included as a site-specific flood modification measure, as it would largely inform the construction of site-specific measures 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 options involving large scale drainage upgrades have been evaluated for the Darling Harbour Catchment that have costs in the order of $10 million. The cost/benefit ratios of these options have been estimated at less than 0.6, 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 Darling Harbour 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 catchment. 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 Darling Harbour catchment and provide a more reliable assessment of the benefits of flood mitigation options, potentially providing a greater economic justification for the large-scale pit and pipe works in the catchment.

### 9.3.9. Economic Assessment of Site Specific Options

The cost effectiveness of the site specific management options in reducing flood liability within the catchment was determined using the benefit/cost (B/C) approach. A costing was estimated for each option and this was compared, where appropriate, to the option's reduction in AAD. Where no significant benefit to AAD was found, the option's cost effectiveness was assessed qualitatively.

**Costing**

Detailed cost estimates have been prepared for each option and these are summarised in

Table 21, 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 options to obtain a more accurate costing. For the trunk drainage upgrade options, 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.

Table 21: Costings of Management Options

| Option | Capital | Maintenance per year |
|---|---|---|
| **FM-DH01** Drainage Upgrade – Commonwealth Street | $ 1,200,000 | $ 12,540 |
| **FM-DH02** Drainage Upgrade – Elizabeth Street | $ 8,096,900 | $ 4,920 |
| **FM-DH03** Road Adjustment – Elizabeth Street | ND* | ND |
| **FM-DH04** Park Adjustment – Belmore Park | ND | ND |
| **FM-DH05** Drainage Upgrade – Elizabeth Street to Outlet | $ 10,454,900 | $ 12,810 |
| **FM-DH06** Drainage Upgrade – Pyrmont Street to Outlet | $ 3,897,500 | $ 4,860 |
| **FM-DH07** Drainage Upgrade – Black Wattle Place | $ 894,500 | $ 1,730 |

*Not Determined. Option not costed as produced no significant benefit to flood behaviour (DH03) or has large social and environmental impacts (DH04)

Table 21 shows that the drainage capacity upgrade Option FM – DH05 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 options.

**Damage Assessment of Options**

The total damage costs were evaluated for two of the options and compared against the existing base case, as shown in Table 22. The assessment for the two options 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-DH02, FM-DH03, FM-DH06 and FM-DH07 do not produce significant reduction in overfloor inundation; and
- FM-DH04 has some benefit to property flooding but has unacceptable social and environmental impacts.

Table 22: Average Annual Damage Reduction of Management Options

| Option | AAD | Reduction in AAD due to Option |
|---|---|---|
| **FM-DH01** Drainage Upgrade – Commonwealth Street | $ 2,749,241 | $ 48,241 |
| **FM-DH05** Drainage Upgrade – Elizabeth Street to Outlet | $ 2,702,986 | $ 94,496 |

The results show that the pressurised pipe from Elizabeth Street to the outlet has the greatest reduction in AAD, but that both options have little change to the catchment's economic damages. The Commonwealth Street upgrade reduces flooding for around 13 properties; however, they are still flood affected in events greater than the 5% AEP and the reduction is small relative to the catchment's overall property damage. The large pipe upgrade mostly benefits Elizabeth Street and Hay Street upstream of George Street, while property inundation is more concentrated downstream of George Street. It should be noted that all of the options 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.

**Benefit Cost Ratio of Options**

Following estimation of the option's cost and AAD, the benefit/cost ratio (B/C) of two of the options 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 23 lists the reduction in AAD due to the options, and compares this to the works' capital and maintenance costs to produce a B/C. The options' B/C was between 0.1 and 0.6, with values above 1 indicating that the economic benefit of the option is greater than its cost.

Table 23: Benefit/Cost Ratio for Management Options

| Options | Benefit | | | Cost Estimate | | | |
|---|---|---|---|---|---|---|---|
| | AAD | Reduction in AAD | NPW of AAD Reduction* | Capital | Maintenance (Annual) | NPW of Costs* | B/C Ratio |
| **FM-DH01** | $2,749,241 | $48,241 | $ 712,368 | $ 1,200,000 | $ 12,540 | $ 1,214,900 | 0.6 |
| **FM-DH05** | $2,702,986 | $94,496 | $ 1,395,399 | $ 10,454,900 | $ 12,810 | $ 10,644,100 | 0.1 |

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

The two options presented in Table 23 have a B/C of less than 1, indicating they are not economically feasible. 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.

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 options.

## 9.4. Catchment Wide Management Options

### 9.4.1. Property Modification - Flood Planning Levels (PM – DH01)

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 – DH02)

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 – DH03)

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 measures 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.

With regards to commercial properties in the catchment, responsibility for flood-proofing should fall to property owners, and should be initiated by the City. The majority of buildings in these areas 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 measures 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. Property Modification – Feasibility Study for City of Sydney Flood Proofing (PM – DH04)

**DESCRIPTION**

As discussed in the previous option, flood proofing involves modifications to a building's exterior in order to prevent the ingress of floodwater. The option recommended that for most of the catchment, flood proofing should be the responsibility of property owners. For residential houses in the catchment (largely in Surry Hills and Pyrmont), where flood proofing is not undertaken by property owners, it may be possible for City of Sydney to undertake mitigation works if the property is put up for sale. That is, for a severely flood affected properties, City of Sydney may purchase the property so that works on it can be undertaken, and then the property is put up for sale soon after. Such a scheme would be most suited to areas with significant overfloor flood

affectation where structural measures (for example, drainage upgrades) are not feasible.

**DISCUSSION**

A Council-led program that involves the purchase, renovation and selling of flood-affected land is a straightforward variation on other Council-led property modification measures, and will provide benefit to properties that do not have other available options. The nature of the flood issue in the catchment is that although there is significant overfloor flood affectation, it is concentrated in several localised areas. This makes structural options difficult to justify, and it is possible that a property's flood risk will remain indefinitely.

As the option can only be implemented when an affected property is put on sale, such a program's implementation would be very gradual and would be undertaken over a long period of time. In this sense, the option is an extension of Council's FPL policy, whereby minimum floor levels are required when a flood-affected property is re-developed. A Council-led flood proofing program would account for the flood affected properties that are not re-developed and therefore would not otherwise have their floor levels raised.

Although such a program has some similarity to a voluntary purchase scheme, it would be markedly less obtrusive and would not reduce the number of dwellings in the catchment. Voluntary purchase involves returning severely-affected land on a floodway to the floodplain, whereas in the Darling Harbour catchment, affected properties are not necessarily on a floodway and restoring an area's natural flowpath (for example, in a trapped depression) would adversely impact downstream properties and may impact an area's streetscape and character. Most significantly, a flood proofing program would only involve properties that are available for purchase, meaning there would be no disruption to the existing property market. This would be further ensured by having no publicly available information on which properties would be targeted by such a program.

**EVALUATION**

A flood proofing program undertaken by the City of Sydney could significantly alleviate property affectation and give Council an alternative to drainage upgrades in areas where they are prohibitively expensive and not cost-effective. It would also allow Council to extend their objective of raising flood affected properties (via an FPL) to affected properties by improving properties that may not otherwise have their floor level raised. Although such a program has several apparent benefits, its feasibility should be investigated further to determine whether it can be cost-effective (based on the cost of purchasing, flood-proofing and re-selling a property compared to the existing economic cost of flooding) and what social impacts may exist.

### 9.4.5. Response Modification - Flood Warning and Evacuation (RM – DH01)

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 and the SES is disseminating these warning 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).

### 9.4.6. Response Modification - Flood Emergency Management (RM – DH02)

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, and
- People (residents and visitors) do not appreciate the dangers of crossing floodwaters.
- In dense urban areas (such as the Darling Harbour 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 Darling Harbour 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;
- Organise 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.

### 9.4.7. Response Modification - Community Awareness Programme (RM – DH03)

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 in the adjacent catchment. 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 social media account 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 set up for the area.

## 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 24 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 24: 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 25, with each of the assessed management options scored against the range of criteria. Also, 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 option, and the subsequent rank, is only an indicator to be used for general comparison.

Table 25: 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-DH01** | Pit and Pipe Upgrade – Commonwealth Street | 9.4.1 | 5% | 2 | 3 | -2 | -1 | 2 | -2 | 0 | 2 | -2 | 1 | 2 | 5 | 7 |
| **FM-DH02** | Trunk Upgrade – Elizabeth Street | 9.4.2 | 10% | 2 | 2 | -3 | -1 | 1 | -3 | 0 | 2 | -3 | 1 | 1 | -1 | 11 |
| **FM-DH03** | Road Adjustment – Elizabeth Street | 9.4.3 | 10% | 0 | 0 | -1 | -1 | 0 | -1 | 0 | 0 | -2 | 2 | 0 | -3 | 14 |
| **FM-DH04** | Park Adjustment – Belmore Park | 9.4.4 | 10% | 2 | 1 | 0 | -1 | 1 | -1 | -3 | 1 | -3 | 1 | 0 | -2 | 12 |
| **FM-DH05** | Trunk Upgrade – Elizabeth Street to Outlet | 9.4.5 | 1% | 3 | 3 | -3 | -1 | 2 | -3 | -1 | 2 | -3 | 1 | 1 | 1 | 9 |
| **FM-DH06** | Trunk Upgrade – Pyrmont Street to Outlet | 9.4.6 | 10% | 1 | 1 | -2 | -1 | 1 | -2 | -1 | 1 | -2 | 1 | 1 | -2 | 12 |
| **FM-DH07** | Drainage Upgrade – Black Wattle Place | 9.4.7 | 5% | 2 | 1 | -1 | -1 | 1 | -2 | 0 | 1 | -2 | 1 | 0 | 0 | 10 |
| ***Property Modification Measures*** | | | | | | | | | | | | | | | | |
| **PM-DH01** | Property Modification - Flood Planning Levels | 9.5.1 | N/A | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 1 | 0 | 3 | 1 | 9 | 2 |
| **PM-DH02** | Property Modification - Development Control Planning | 9.5.2 | N/A | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 1 | 1 | 3 | 1 | 10 | 1 |
| **PM-DH03** | Property Modification - Flood Proofing | 9.5.3 | N/A | 0 | 0 | -1 | 0 | 2 | 1 | 0 | 1 | -1 | 2 | 1 | 5 | 7 |
| **PM-DH04** | Property Modification - Feasibility Study for City of Sydney Flood Proofing | 9.5.4 | N/A | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 2 | 1 | 1 | 8 | 3 |
| ***Response Modification Measures*** | | | | | | | | | | | | | | | | |
| **RM-DH01** | Response Modification - Flood Warning and Evacuation | 9.5.5 | N/A | 0 | 0 | -1 | 0 | 1 | 2 | 0 | 2 | 2 | 0 | 2 | 8 | 3 |
| **RM-DH02** | Response Modification - Flood Emergency Management | 9.5.6 | N/A | 0 | 0 | -1 | 0 | 2 | 2 | 0 | 2 | 1 | 0 | 1 | 7 | 6 |
| **RM-DH03** | Response Modification - Community Awareness Programme | 9.5.7 | N/A | 0 | 0 | 2 | 0 | 2 | 2 | 0 | 2 | 1 | -2 | 1 | 8 | 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

Voluntary purchase is difficult to justify as it is has issues with its technical feasibility, in that it would be very different to a typical VP scheme, and the political/administrative issues associated with buying flood-affected houses.

Based on the matrix, the options for future implementation are ranked in the order as tabulated in Table 26.

Table 26: Ranking of Management Options

| Rank | Ref | Options | Score |
|---|---|---|---|
| 10 | PM-DH02 | Property Modification - Development Control Planning | 0 |
| 10 | PM-DH01 | Property Modification - Flood Planning Levels | 0 |
| 3= | PM-DH04 | Property Modification - Feasibility Study for City of Sydney Flood Proofing | 0 |
| 3= | RM-DH01 | Response Modification - Flood Warning and Evacuation | 8 |
| 3= | RM-DH03 | Response Modification - Community Awareness Programme | 8 |
| 6 | RM-DH02 | Response Modification - Flood Emergency Management | 7 |
| 7= | FM-DH01 | Pit and Pipe Upgrade – Commonwealth Street | 5 |
| 7= | PM-DH03 | Property Modification - Flood Proofing | 0 |
| 9 | FM-DH05 | Trunk Upgrade – Elizabeth Street to Outlet | 1 |
| 10 | FM-DH07 | Drainage Upgrade – Black Wattle Place | 0 |
| 11 | FM-DH02 | Trunk Upgrade – Elizabeth Street | -1 |
| 12= | FM-DH04 | Park Adjustment – Belmore Park | -2 |
| 12= | FM-DH06 | Trunk Upgrade – Pyrmont Street to Outlet | -2 |
| 14 | FM-DH03 | Road Adjustment – Elizabeth Street | -3 |

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 Darling Harbour Catchment Floodplain Risk Management Plan. The three discarded options are FM-DH04, DM-DH06 and FM-DH03. These options have very minor benefit (FM-DH06), have adverse impacts (FM-DH03) or have significant social and environmental impacts (FM-DH04).

# 10. ACKNOWLEDGEMENTS

WMAwater wish to acknowledge the assistance of the City of Sydney Council staff and the Floodplain Management Committee in carrying out this study as well as the NSW Government (Office of Environment and Heritage) and the residents and business operators of the Darling Harbour catchment. This study was jointly funded by the City of Sydney Council and the NSW Government. The cover page image is used courtesy of Wikimedia Commons user Adam.J.W.C.

# 11. REFERENCES


1. NSW Government
**Floodplain Development Manual**
April 2005

2. BMT-WBM
**Darling Harbour Flood Study**
Final Report, 2014

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

4. City of Sydney
**Interim Floodplain Management Policy**
May 2014

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

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

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


DRAFT

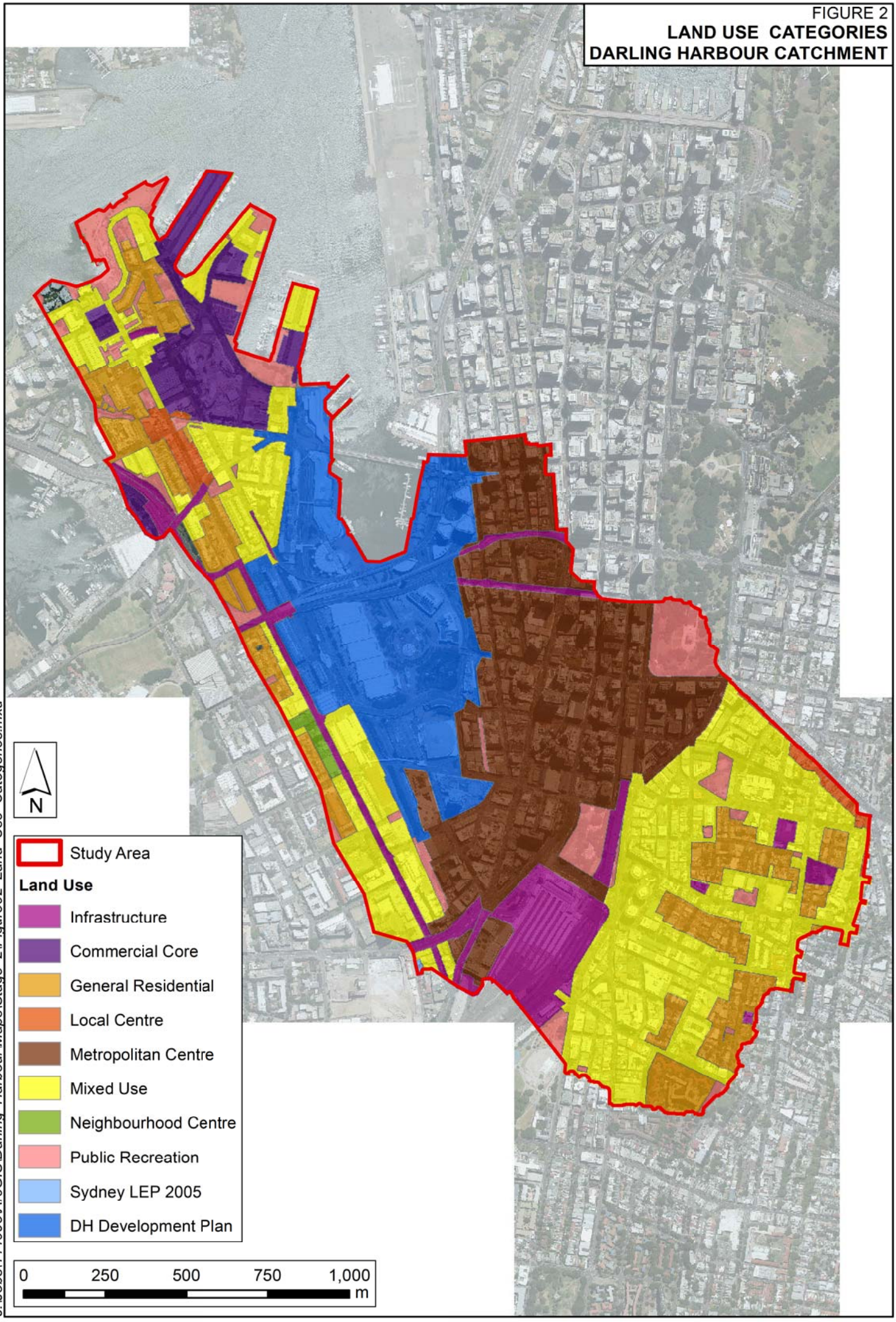
DRAFT

# Figures


FIGURE 1
STUDY AREA
DARLING HARBOUR CATCHMENT
Pyrmont
Union St
Sussex St
Town Hall
Bathurst St
George St
Museum
Harris St
Haymarket
Hay St
Pitt St
Commonwealth St
Quay St
George St
Albion St
Ann St
Ultimo
Central
Surry Hills
N
Study Area
0
250
500
750
1,000
m
J:\Jobs\114095\ArcGIS\Darling_HarbourMaps\Stage_2\Figure01_StudyArea.mxd

FIGURE 2

**LAND USE CATEGORIES**
**DARLING HARBOUR CATCHMENT**




J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure02_Land_Use_Categories.mxd

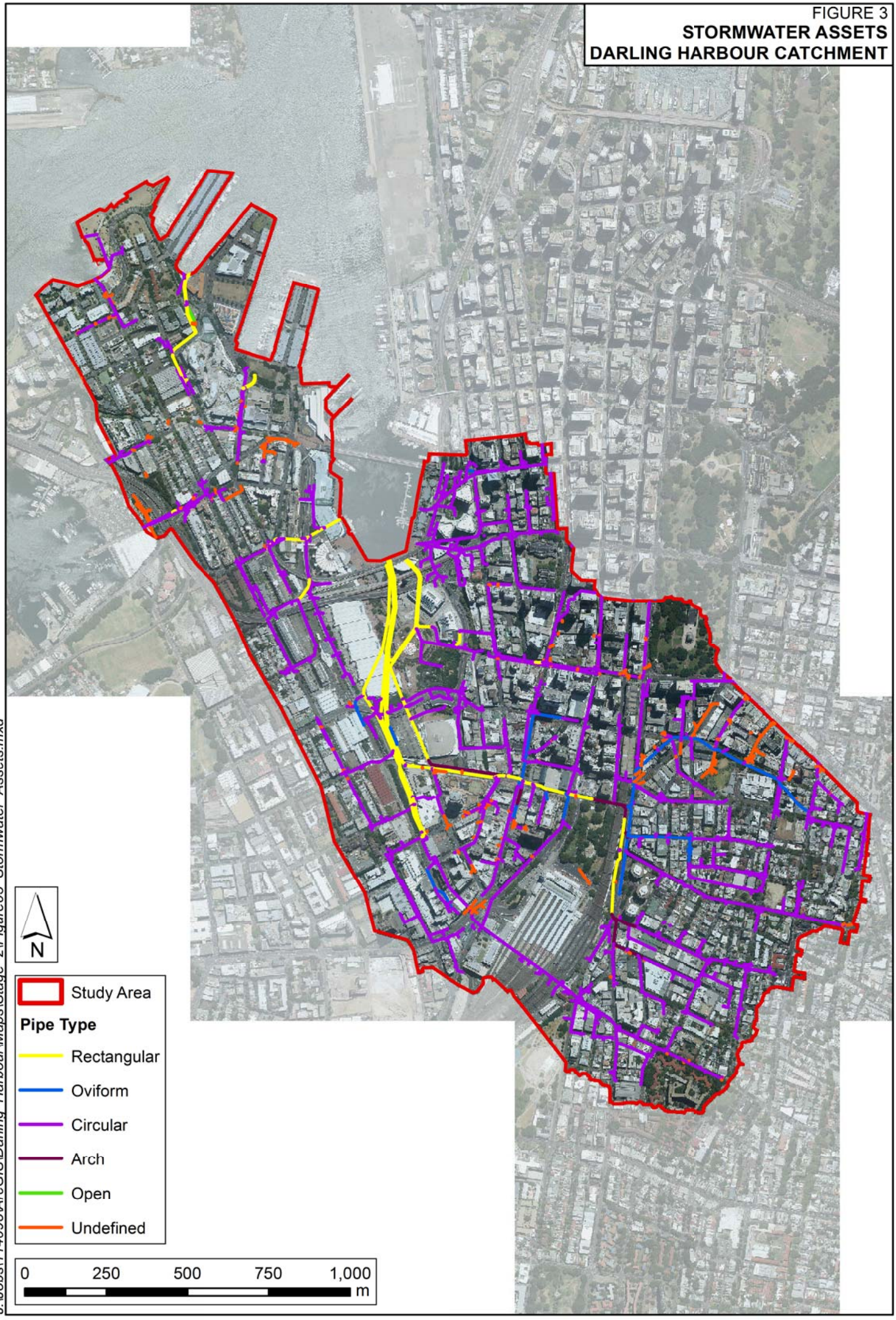


FIGURE 3
STORMWATER ASSETS
DARLING HARBOUR CATCHMENT
N
Study Area
Pipe Type
Rectangular
Oviform
Circular
Arch
Open
Undefined
0
250
500
750
1,000
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure03_Stormwater_Assets.mxd

FIGURE 4
**HOTSPOT LOCATIONS**
**DARLING HARBOUR CATCHMENT**





Union St
Western Distributor Freeway
George St
Hay St
Pitt St
George St
Commonwealth St

N

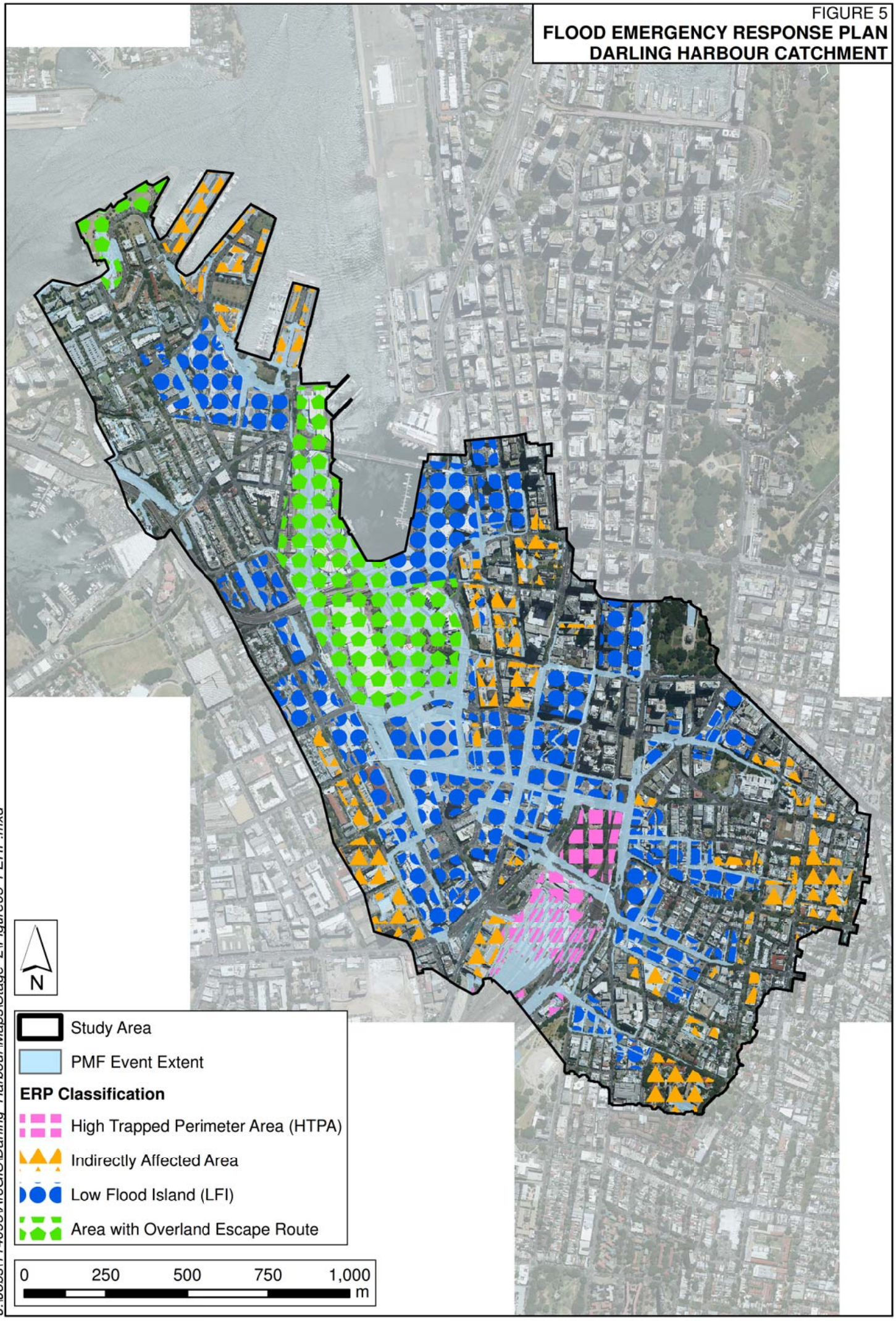
Approx. 1% AEP Flood Level
Study Area
Hotspot Locations

0 250 500 750 1,000
m

J:\Jobs\114095\ArcGIS\Darling_HarbourMaps\Stage_2\Figure04_Hotspots_Locations.mxd

FIGURE 5

**FLOOD EMERGENCY RESPONSE PLAN**
**DARLING HARBOUR CATCHMENT**




J:\Jobs\1140951\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure05_FERP.mxd