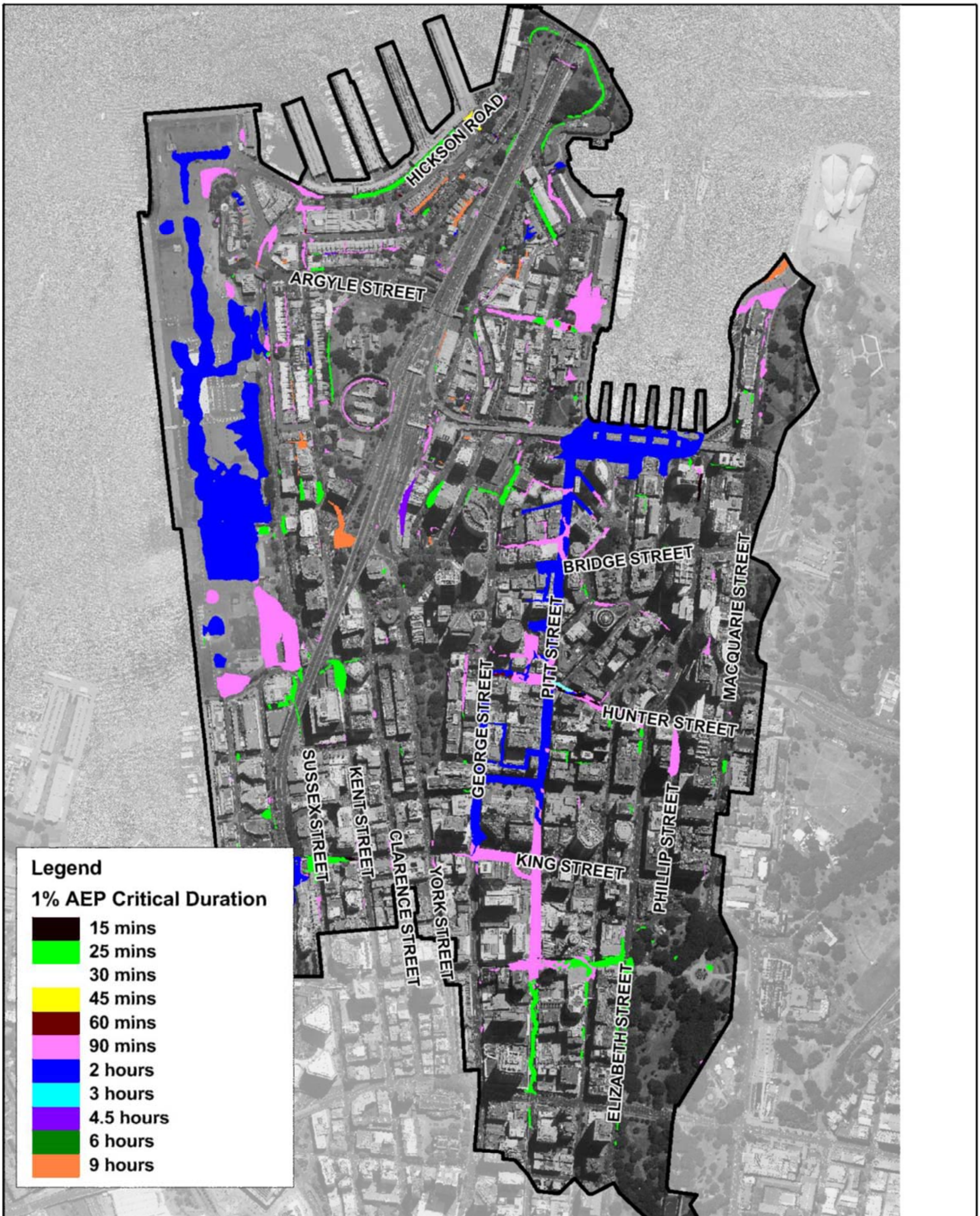


Title:

Critical Duration Assessment
1% AEP (100 year ARI)

Figure: 7-4

Rev: A

0 250 500m
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : S:\WATER\PROJECTS\S20022 - Water - Sydney CBD Catchment Flood Study\Drafting\WOR\Figures\FIGURE07-4_CriticalDuration.wor

7.1.3 Tidal Inundation

Limited tidal inundation modelling was undertaken for the 1 year ARI level for Sydney Harbour, which has a level of 1.2 m AHD. This tidal event does not directly pose any flood risk to locations within the study area. It is noted that there is limited sensitivity in Harbour water levels to frequency of design water level. The 1% AEP (100 year ARI) harbour water level is only 0.2 m higher than the 1 year ARI water level (Section 2.2.5, Table 2-3).

7.1.4 Potential Flooding Problem Areas

In simulating the design flood conditions for the Sydney City Area catchment, the following locations have been identified as potential problem areas in relation to flood inundation:

- **Pitt Street**
  As discussed in Section 7.1.1, Pitt Street acts as the primary overland flow path for most of the Sydney City Area catchment. In the 1% AEP event, approximately 20m^3/s is conveyed along Pitt Street at a depth of up to 0.5 m and velocity up to 2.5 m/s. These flooding characteristics represent a significant risk to pedestrians, motorists and property along the majority of Pitt Street within this catchment from Park Street in the south to Alfred Street/Circular Quay in the north.

- **George Street (between King Street and Hunter Street)**
  For a limited length of George Street between King Street and Hunter Street, there is a concentration of overland flow with depths up to 0.3m and velocity up to 2.0 m/s.

- **King Street (between Pitt Street and George Street)**
  A trapped low point exists at this location which is significantly flooded in all design flood events including the 2 year ARI event. Flood levels in the 1% AEP design event are up to 0.5m higher than those in the 2 year ARI event at this location. Responses from the consultation exercise indicated that flooding has occurred at this location in the past.

- **Martin Place (between Pitt Street and George Street)**
  At this location George Street and Pitt Street act as overland flow paths. In the 10% AEP event, water from George Street breaks out and flows through Martin Place to Pitt Street with a velocity of less than 0.5 m/s and a depth of 0.1 m. In the 1% AEP event this flow path has depths up to 0.2 m whilst the velocity remains less than 0.5 m/s.

- **Angel Place**
  Flood depths in the vicinity of Angel Place exceed 1.0m in the 1% AEP design event, resulting in an automatic classification as a high hazard area. Flood depths are up to 0.50m at this location in a 2 year ARI event.

- **Curtin Place**
  A trapped low point exists at this location which is significantly flooded in all design flood events including the 2 year ARI event. Flood levels in the 1% AEP design event are up to 1.0m higher than those in the 2 year ARI event at this location. Responses from the consultation exercise indicated that flooding has occurred at this location in the past.

- **Bond Street**
  A trapped low point exists at this location which is significantly flooded in all design flood events including the 2 year ARI event. Flood levels in the 1% AEP design event are up to 0.5m higher than those in the 2 year ARI event at this location. Responses from the consultation exercise indicated that flooding has occurred at this location in the past. There is an entrance to an underground car park at this location.

- **Phillip Street**
  Flooding occurs at this location for all design events modelled. Whilst the contributing catchment area to this location is relatively small, there is insufficient drainage infrastructure to alleviate flooding. Some water may actually spill into and flood an underground car park, however, such car parks have not been modelled as part of this study.

- **Hickson Road, Walsh Bay**
  Whilst there is a relatively small and localised catchment contributing flow to Hickson Road in the Walsh Bay area, modelling shows that flooding occurs in the 5 year ARI design event (reporting location H13). Furthermore, responses received during the community consultation exercise indicated that flooding has occurred here in the past. At this location the roadway is relatively flat and does not promote efficient drainage. Flooding is relatively shallow with depths less than 0.20m, but these depths may still impede pedestrian and vehicle access and possibly inundate car parks.

7.1.5 Supercritical Flows and Conjugate Depths

As described, sections of the catchment have high velocity flow due to the low hydraulic roughness of the roads which convey the main flow paths and the steepness of the catchment. A catchment of this nature has a tendency to convey supercritical flow which may under-represent the maximum peak water level possible if a hydraulic jump is activated.

For the 1% AEP event, the conjugate depths were calculated for supercritical flow areas. Impact mapping was undertaken to determine the sensitivity of reported model results from the standard depths to the conjugate depths. It was found that conjugate flood levels rarely exceed the standard levels by more than 0.3 m.

Mapping and further discussion of conjugate depth analysis is found in Appendix E.

7.2 Preliminary Hydraulic Categorisation

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the Floodplain Development Manual (NSW Government, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

The hydraulic categories as defined in the Floodplain Development Manual are:

- Floodway - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.

- Flood Storage - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.

- Flood Fringe - Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

A number of approaches were considered when attempting to define hydraulic categories across City Area catchment. Approaches to define hydraulic categories that were considered for this assessment included partitioning the floodplain based on:

- Peak flood velocity;
- Peak flood depth;
- Peak velocity-depth product (sometimes referred to as unit discharge);
- Cumulative volume conveyed during the flood event; and
- Combinations of the above.

The definition of hydraulic categories that was considered to best fit the application within the City Area catchment was based on a combination of velocity, velocity-depth product and depth parameters. The adopted hydraulic categorisation is defined in Table 7-4 and is consistent with similar study catchments in the City of Sydney LGA (WMAwater, 2012a and 2012b).

Preliminary hydraulic category mapping for the 1% AEP and PMF design events is included in Appendix A (Figure A- 25 to Figure A- 26). It is also noted that mapping associated with the flood hydraulic categories may be amended in the future, at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts (e.g. if it is to change from floodway to flood storage).

Table 7-4 Provisional hydraulic categories

Hydraulic Category	Definition	Description
Floodway	Velocity * Depth > 0.25 m^2/s AND Velocity > 0.25 m/s OR Velocity > 1.0 m/s.	Areas and flowpaths where a significant portion of floodwaters are conveyed during a flood.
Flood Storage	NOT Floodway AND Depth > 0.2 m	Floodplain areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	NOT Floodway AND Depth < 0.2 m	Areas that are low velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

7.3 Provisional Hazard Categories

The NSW Government's Floodplain Development Manual (NSW Government, 2005) defines flood hazard categories as follows:

- **High hazard** – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and
- **Low hazard** – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

- Size of the Flood
- Rate of Rise - Effective Warning Time
- Community Awareness
- Flood Depth and Velocity
- Duration of Inundation
- Obstructions to Flow
- Access and Evacuation

The provisional flood hazard level is determined on the basis of the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities have no major threat.

Figures L1 and L2 in the Floodplain Development Manual (NSW Government, 2005) are used to determine provisional hazard categorisations within flood liable land. These figures are reproduced in Figure 7-5. The provisional hydraulic hazard is included in the mapping series provided in Appendix A for the 10%, 5%, 1% AEP and PMF events (Figure A- 27 to Figure A- 30).

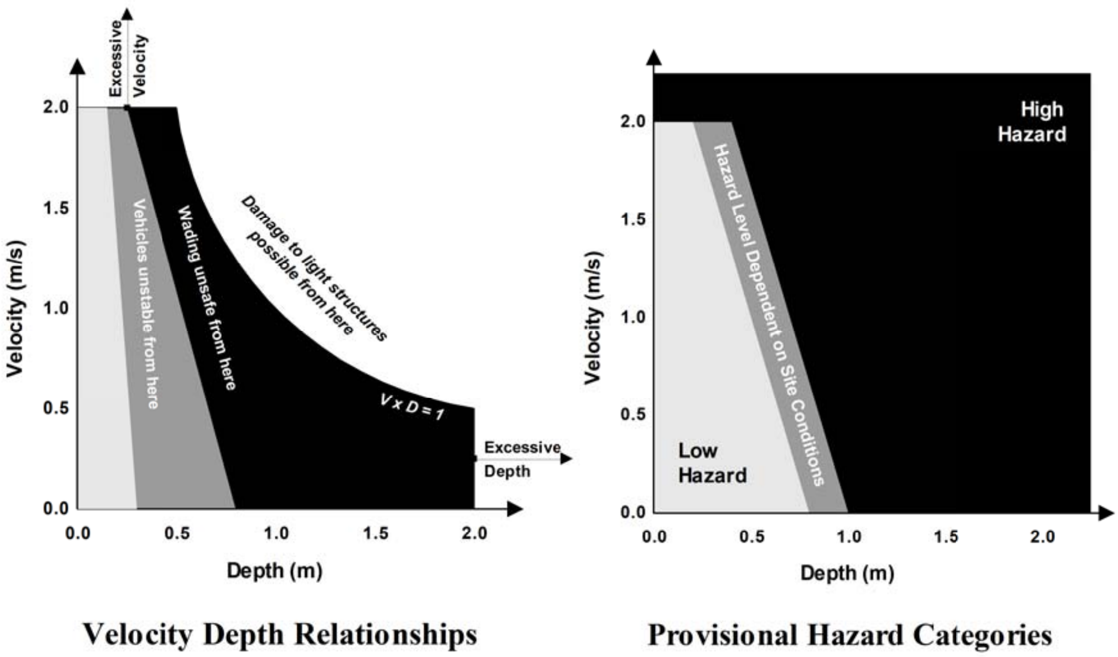


Figure 7-5 Provisional flood hazard categorisation

7.4 Flood Emergency Response Classification

The NSW Government's Floodplain Development Manual (NSW Government, 2005) requires flood studies and subsequent floodplain risk management studies to address the management of continuing flood risk to both existing and future development areas. Continuing flood risk may vary across a floodplain and as such the type and scale of emergency response does also. To assist the state emergency services with emergency response planning floodplain communities may be classified into the following categories (DECC, 2007):

- **High Flood Island** – high ground within a floodplain. Road access may be cut by floodwater creating an island. The flood island includes enough land higher than the limit of flooding to provide refuge.
- **Low Flood Island** – high ground within a floodplain. Road access may be cut by floodwater creating an island. The flood island is lower than the limit of flooding.
- **High Trapped Perimeter** – fringe of the floodplain. Road access may be cut by floodwater. The area includes enough land higher than the limit of flooding to provide refuge.
- **Low Trapped Perimeter** – fringe of the floodplain. Road access may be cut by floodwater. The flood island is lower than the limit of flooding.
- **Areas with Overland Escape Routes** – areas available for continuous evacuation. Access roads may cross low lying flood prone land but evacuation can take place by walking overland to higher ground.
- **Areas with Rising Road Access** – areas available for continuous evacuation. Access roads may rise steadily uphill away from rising floodwaters. Evacuation can take place vehicle and communities cannot be completely isolated before inundation reaches its maximum ;and

- **Indirectly Affected Areas** – areas outside the limit of flooding and therefore will not be inundated or lose road access. They may be indirectly affected as a result of flood damaged infrastructure or due to loss of services.

The flood emergency response classification is included in the mapping series provided in Appendix A for the full range of design events simulated (Figure A- 37 to Figure A- 43).

7.5 Conclusion

The TUFLOW hydraulic model has been applied to derive design flood conditions within the City Area catchment using the design rainfall and tidal conditions described in Section 6. The design events considered in this study include the 2 year ARI, 5 year ARI, 10% AEP (10-year ARI), 5% AEP (20-year ARI), 2% AEP (50-year ARI), 1% AEP (100-year ARI), 0.2% AEP (500-year ARI) and Probable Maximum Flood (PMF) events. The model results for the design events considered have been presented in a detailed flood mapping series for the catchment. The flood data presented includes design flood inundation, peak flood water levels and peak flood depths.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped for the 10% AEP, 5% AEP 1% AEP and the PMF events, in addition to the hydraulic categories (floodway, flood fringe and flood storage) for all modelled design events.

The flood inundation extents derived from the hydraulic modelling are shown in Appendix A.

8 SENSITIVITY ANALYSIS

A number of sensitivity tests have been undertaken on the modelled flood behaviour in the City Area catchment. In defining sensitivity tests, consideration has been given to the most appropriate tests taking into account catchment properties and simulated design flood behaviour. The tests undertaken have included:

- Hydraulic roughness;
- Blockage of the stormwater drainage system;
- Change in rainfall losses; and
- Changed tailwater level.

The rationalisation for each of these sensitivity tests along with adopted model configuration/parameters and results are summarised in the following sections.

As outlined in Section 7 the critical duration varies across the catchment. For the purpose of sensitivity testing the 1% AEP, 90-minute duration, design storm event has been used as the design base case.

8.1 Hydraulic Roughness

Sensitivity tests on the hydraulic roughness (Manning's 'n') were undertaken separately for the 1D stormwater network and for the 2D overland flow paths. Whilst adopted design parameters are within typical ranges, the inherent variability/uncertainty in hydraulic roughness warrants consideration of the relative impact on adopted design flood conditions. The potential uncertainty in selected parameter choice is different between sub-surface conduits which has much firmer guidance in literature versus overland flow paths which could feasible have greater variation.

Sensitivity analysis for the TUFLOW 2D overland flow path Manning's '*n*' values was assessed by applying a 50% increase and a 50% decrease in the adopted values for the baseline design conditions. Sensitivity analysis for the 1D sub-surface pipe network was assessed by applying a 20% increase and a 20% decrease in the adopted values for the baseline design conditions.

The results of the sensitivity tests on hydraulic roughness are summarised in Table 8-1 for the reporting locations indicated in Figure 7-1 and Figure 7-2.

With regard to the TUFLOW 2D overland flow path hydraulic roughness, the model simulations show minor change (generally <0.05 m) in peak flood level for the variation in roughness values. It should be noted that the reduction in hydraulic roughness does not always reduce flood levels and conversely an increase in hydraulic roughness does not always increase peak flood levels which can be attributed to the timing of flows at the confluences of difference flow paths. Of particular interest is Pitt Street which is the main flow path for the catchment, where changes in simulated peak flood levels are less than 0.10 m.

Variation of the hydraulic roughness of the pipe network results in changes to peak flood levels of less than or equal to 0.02 m. In the scenario where pipe roughness is increased, the pipe has a reduced capacity and more flow is conveyed via overland flow paths. In the scenario where the pipe roughness is reduced, the pipe is able to convey a higher flow reducing overland flows and overland flood levels.

Table 8-1 Changes in peak flood levels (m) for Manning's '*n*' sensitivity tests

Location	+ 50% Manning's '*n*´ (2D Domain)	- 50% Manning's '*n*´ (2D Domain)	+ 20% Manning's '*n*´ (1D Domain)	- 20% Manning's '*n*´ (1D Domain)
H01	-0.02	+0.09	+0.01	-0.01
H02	+0.01	+0.01	+0.00	+0.00
H03	+0.02	-0.07	+0.01	-0.01
H04	-0.05	+0.12	+0.02	-0.02
H05	+0.03	+0.01	+0.01	-0.01
H06	+0.02	-0.03	+0.01	-0.01
H07	+0.03	-0.09	+0.00	+0.00
H08	+0.01	+0.00	+0.00	+0.00
H09	-0.01	-0.01	+0.01	-0.01
H10	-0.02	+0.02	+0.01	-0.01
H11	+0.01	-0.03	+0.00	+0.00
H12	+0.00	+0.00	+0.01	-0.02
H13	+0.01	-0.01	+0.00	+0.00
H14	+0.01	-0.02	+0.00	+0.00

8.2 Stormwater Drainage Blockage

Structure blockages have the potential to substantially increase the magnitude and extent of property inundation through local increases in water level, redistribution of flows on the floodplain, and activation of additional flow paths. As outlined in Section 6, different pit blockages were considered for different magnitude storms, summarised as follows:

- 5 year ARI and more frequent: Grade Blockage 20%, Sag Blockage 50%
- Rarer than the 5 year ARI: Grade Blockage 50%, Sag Blockage 100%

Pit inlet blockage sensitivity was therefore separately assessed for 5 year ARI design event and also the 1% AEP design event. The blockage scenarios modelled are shown below:

- 5 year ARI: Grade Blockage 50%, Sag Blockage 100%
- 1% AEP: Grade Blockage 100%, Sag Blockage 100%.

The results of the sensitivity tests on blockages are summarised in Table 8-2 for the reporting locations indicated in Figure 7-1.

For the 5 year ARI event, if the level of pit blockage was used, the modelled peak water level would increase typically by less than 0.05 m. A higher sensitivity is exhibited in isolated trapped low points which are more reliant on the drainage network.

For the 1% AEP event, blockage sensitivity analysis assumes a very extreme scenario where no water is allowed into the stormwater system via on-grade or sag pits. Peak water levels for this scenario typically increase by less than 0.1 m though increase higher in isolated locations. Given the extreme sensitivity analysis scenario and the limit of sensitivity analysis modelled confidence can be relied upon the 1% AEP design results used to derive the Flood Planning Level.

Table 8-2 Changes in flood levels for pit inlet blockage sensitivity Tests

Location	5yr ARI Blockage - Grade 50%, Sag 100%	1% AEP Blockage - Grade 100%, Sag 100%
H01	-0.01	+0.10
H02	+0.06	+0.08
H03	+0.04	+0.13
H04	+0.00	+0.10
H05	+0.08	+0.15
H06	+0.04	+0.11
H07	+0.04	+0.05
H08	+0.00	+0.01
H09	+0.03	+0.09
H10	+0.00	+0.25
H11	+0.01	+0.04
H12	+0.00	+0.03
H13	+0.00	+0.16
H14	+0.03	+0.04

8.3 Rainfall Losses

Sensitivity analysis has been undertaken for rainfall losses by assessing both a 50% increase and decrease in rainfall losses (initial loss and infiltration). The fraction impervious parameter was not adjusted. The results of the sensitivity tests on rainfall losses are summarised in Table 8-3 for the reporting locations indicated in Figure 7-1.

The change in flood levels from rainfall loss changes is typically less than 0.01 m. The limited sensitivity to rainfall losses is due to the highly impervious nature of the catchment, whereby there is little opportunity for rainfall infiltration which translates to a negligible change in the amount of rainfall lost via pervious surfaces. Accordingly for the base case condition, losses are already relatively low across the catchment given the extent of impervious areas.

Table 8-3 Changes in peak flood levels (m) for rainfall loss sensitivity tests

Location	+ 50% Rainfall Losses	- 50% Rainfall Losses
H01	+0.00	+0.00
H02	+0.00	+0.00
H03	+0.00	+0.00
H04	+0.00	+0.01
H05	-0.01	+0.01
H06	-0.01	+0.00
H07	+0.00	+0.00
H08	+0.00	+0.00
H09	-0.01	+0.01
H10	+0.00	+0.00
H11	+0.00	+0.00
H12	+0.00	+0.00
H13	+0.00	+0.00
H14	+0.00	+0.00

8.4 Tailwater Level

Sensitivity analysis has been undertaken for tailwater by assessing both a 0.5m increase and decrease in the Harbour water level. The results of the sensitivity tests on tailwater are summarised in Table 8-4 for the reporting locations indicated in Figure 7-1.

Changes in flood levels from tailwater changes are limited indicating little sensitivity to tailwater assumptions.

Table 8-4 Changes in peak flood levels (m) for tailwater sensitivity tests

Location	+ 0.5m Tailwater	- 0.5m Tailwater
H01	+0.00	+0.00
H02	+0.00	+0.00
H03	+0.00	+0.00
H04	+0.00	+0.00
H05	+0.00	+0.00
H06	+0.01	+0.00
H07	+0.00	+0.00
H08	+0.00	+0.00
H09	+0.01	-0.02
H10	+0.00	+0.00
H11	+0.00	+0.00
H12	+0.02	-0.01
H13	+0.01	+0.00
H14	+0.00	+0.00

8.5 Conclusion

A series of sensitivity tests have been undertaken on the modelled flood behaviour of the Sydney CBD catchment. The tests provide a basis for determining the relative sensitivity of modelling results to adopted parameter values. The parameters assessed include:

- Hydraulic roughness;
- Stormwater drainage blockage;
- Design rainfall losses; and
- Tailwater level.

Results were shown to be generally insensitive to the values adopted for deriving the design flood levels and extents for the tailwater, hydraulic roughness and rainfall losses tests, with the magnitude changes in flood level less than 0.10m.

The stormwater drainage blockage sensitivity tests represent an extreme scenario whereby there is 100% blockage applied to the drainage network, effectively eliminating all sub-surface drainage. The 100% blockage scenario indicates that flood levels may increase by up to 0.25m in the 1% AEP design event. This could be considered to be contained within the 0.50m freeboard (if adopted) applied to the 1% AEP results to determine the Flood Planning Levels (FPL).

9 CLIMATE CHANGE ANALYSIS

In 2009, the NSW Government incorporated consideration of potential climate change impacts into relevant planning instruments. The NSW Sea Level Rise Policy Statement (DECCW, 2009) was prepared to support consistent adaptation to projected sea level rise impacts. The policy statement incorporates sea level rise planning benchmarks for use in assessing potential impacts of sea level rise in coastal areas, as well as in flood risk and coastal hazard assessments. The benchmarks are a projected rise in sea level, relative to the 1990 mean sea level, of 0.4 metres by 2050 and 0.9 metres by 2100.

The NSW Government announced its Stage One Coastal Management Reforms in September 2012. As part of these reforms, the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils, but instead provides councils with the flexibility to consider local conditions when determining future hazards within their LGA.

It was agreed between Council and BMT WBM that the sea level rise benchmarks from the 2009 NSW Sea level Rise Policy Statement be adopted based on the conclusion that it was the best available information at the time of preparation of this report.

Worsening coastal flooding impacts as a consequence of sea level rise are of concern for the future. Regional climate change studies (e.g. CSIRO, 2004) indicate that aside from sea level rise, there may also be an increase in the maximum intensity of extreme rainfall events. This may include increased frequency, duration and height of flooding and consequently increased number of emergency evacuations and associated property and infrastructure damage.

The NSW Floodplain Development Manual (2005) requires consideration of climate change in the preparation of Floodplain Risk Management Studies and Plans, with further guidance provided in:

- Floodplain Risk Management Guideline – Practical Consideration of Climate Change (DECC, 2007); and
- Flood Risk Management Guide - Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW, 2010).

Key elements of future climate change (e.g. sea level rise, rainfall intensity) have been incorporated into the assessment of future flooding conditions in the City Area catchment for consideration in the ongoing floodplain risk management.

9.1 Potential Climate Change Impacts

The impacts of future climate change are likely to lead to a wide range of environmental responses in receiving waters such as Sydney Harbour. These are likely to manifest throughout the physical, chemical and ecological processes that drive local estuarine ecosystems.

The following changes in the physical characteristics of the City Area catchment have potential influence on the flood behaviour of the system and implications for medium and long term floodplain management:

- Increase in ocean boundary water level – sea level projections provide for a direct increase in tidal and storm surge water level conditions; and
- Increase in rainfall intensity – the frequency and severity of extreme rainfall events is expected to increase.

The model configuration and assumptions adopted for these potential climate change impacts are discussed in the following sections.

9.1.1 Ocean Water Level

As discussed in Section 1.3.1, the sea level rise planning benchmarks provided in the NSW Sea Level Rise Policy Statement (DECCW, 2009) have been adopted for this Flood Study.

The benchmarks are a projected rise in sea level, relative to the 1990 mean sea level, of 0.4 metres by 2050 and 0.9 metres by 2100 (DECCW, 2009). Based on these guidelines, design ocean boundary conditions were raised by 0.4 m and 0.9 m to assess the potential impact of sea level rise on flood behaviour in the City Area catchment for the year 2050 and 2100 respectively.

The sea level rise allowances provide for direct increases in these ocean water levels. Table 9-1 presents a summary of the adopted peak ocean water levels for 1% AEP design modelling for existing water level conditions and the 2050 and 2100 sea level rise benchmarks.

Table 9-1 Design peak Sydney Harbour water levels incorporating sea level rise

Existing (5% AEP Tide)	2050 (+0.4m)	2100 (+0.9m)
1.38 m AHD	1.78 m AHD	2.28 m AHD

9.1.2 Design Rainfall Intensity

Current research predicts that a likely outcome of future climatic change will be an increase in flood producing rainfall intensities. Climate Change in New South Wales (CSIRO, 2007) provides projected increases in 2.5% AEP 24h duration rainfall depths for Sydney Metropolitan catchments of up to 12% and 10%, for the years 2030 and 2070 respectively.

The NSW Government has also released a guideline (DECC, 2007) for Practical Consideration of Climate Change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. In line with this guidance note, additional tests incorporating 10%, 20% and 30% increases in design rainfall have been undertaken.

9.2 Climate Change Model Conditions

A range of design event simulations have been undertaken incorporating combinations of increases in rainfall intensities and ocean water levels. A summary of the modelled scenarios for the 1% AEP design event is provided in Table 9 2.

Table 9-2 Summary of model runs for climate change consideration

Design Flood	Rainfall Intensity Increase	Sydney Harbour Peak Water Level (mAHD)
1% AEP 90 min duration	10%	1.38 (5% AEP Harbour Level)
1% AEP 90 min duration	20%	1.38 (5% AEP Harbour Level)
1% AEP 90 min duration	30%	1.38 (5% AEP Harbour Level)
1% AEP 90 min duration	0%	1.78 mAHD (+0.4m to 2050)
1% AEP 90 min duration	0%	2.28 mAHD (+0.9m to 2050)

9.3 Climate Change Results

The modelled peak flood levels for the climate change scenarios are presented in Table 9-3 for the reporting locations indicated in Figure 7-1. The impact of potential climate change scenarios on the standard design flood condition is presented in Figure A- 31 to Figure A- 35 as a series of maps showing increase in peak flood inundation extents from the baseline (existing) conditions.

The model simulation results show a general increase in peak flood levels along the major and some minor overland flow paths within the study area with increasing rainfall intensity, with increased peak flood levels particularly evident along the major overland flow paths. The 10% rainfall increase scenario which is closest to the regional estimate of future rainfall intensity increases for the Sydney region typically results in flood level increases of less than 0.05 m. Figure 9-1 shows the peak flood level profile along Pitt Street (for the profile location refer to Figure 7-1) and highlights the limited impact from the Climate Change scenarios.

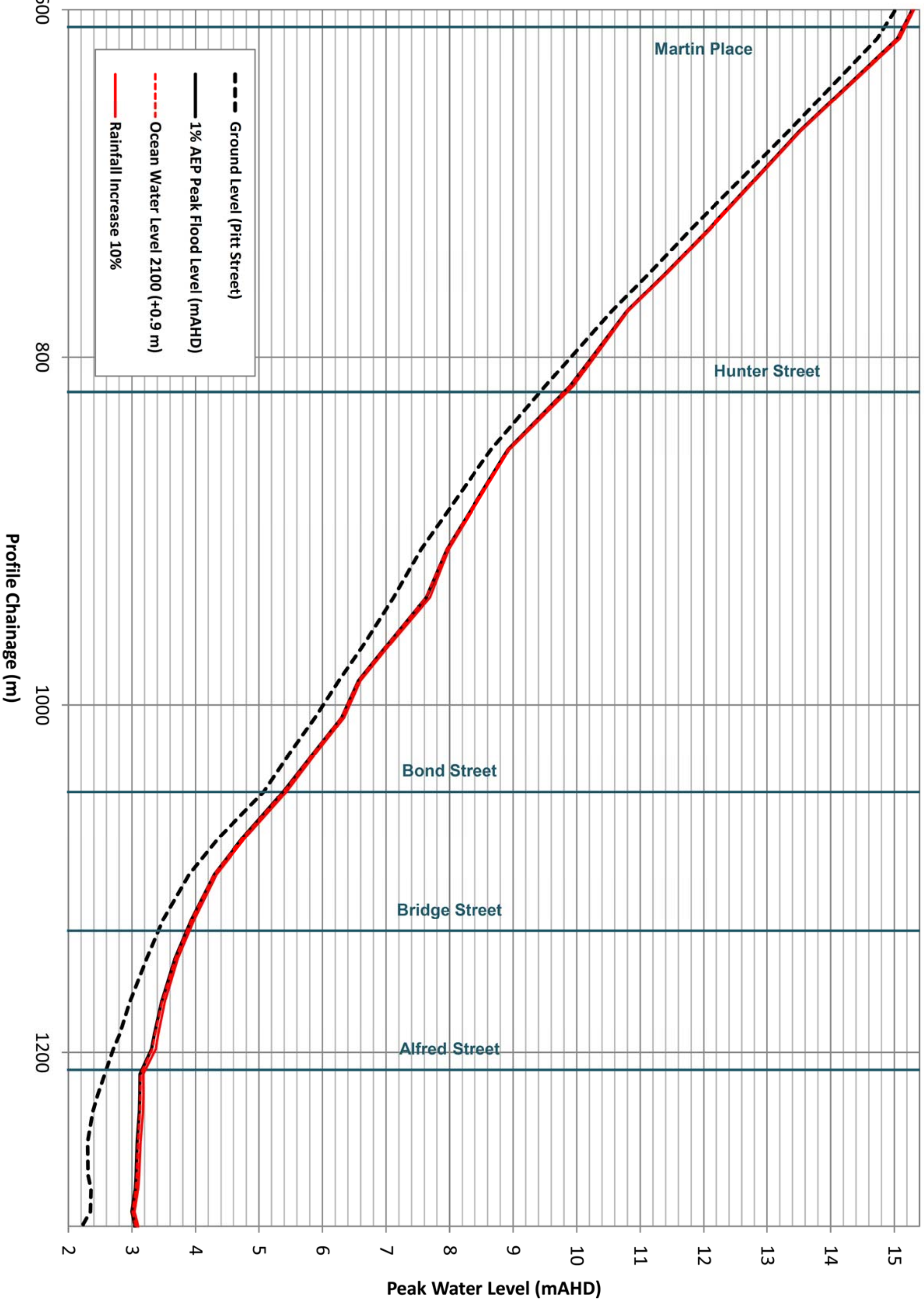
Figure A- 36 shows the tidal inundation extents due to future sea level rise. These results show that future sea level rise has minimal effect on flooding.

Table 9-3 Changes in peak flood levels (m) for climate change scenarios

Location	10% Rainfall	20% Rainfall	30% Rainfall	2050 Harbour	2100 Harbour
H01	+0.04	+0.07	+0.10	+0.00	+0.00
H02	+0.03	+0.06	+0.08	+0.00	+0.00
H03	+0.04	+0.09	+0.13	+0.00	+0.00
H04	+0.03	+0.08	+0.12	+0.00	+0.00
H05	+0.05	+0.10	+0.15	+0.00	+0.00
H06	+0.03	+0.06	+0.09	+0.00	+0.01
H07	+0.02	+0.04	+0.06	+0.00	+0.00
H08	+0.01	+0.02	+0.04	+0.00	+0.00
H09	+0.02	+0.04	+0.06	+0.02	+0.04
H10	+0.03	+0.06	+0.10	+0.00	+0.00
H11	+0.01	+0.02	+0.02	+0.00	+0.00
H12	+0.02	+0.03	+0.03	+0.02	+0.03
H13	+0.01	+0.03	+0.04	+0.00	+0.03
H14	+0.01	+0.03	+0.04	+0.00	+0.01

FIGURE 9-1

PITT STREET PROFILE - CLIMATE CHANGE SENSITIVITY



9.4 Conclusions

The potential impacts of future climate change have been considered for a range of design event scenarios as defined in Table 9-2. The impact of climate change scenarios on the standard design flood condition us presented in Appendix A as a series of maps showing the increase in peak flood inundation extents from the baseline (existing) conditions. The most significant impacts of climate change within the study area are associated with increased rainfall intensities.

The results of the climate change analysis highlight the sensitivity of the peak flood level conditions in the City Area catchment to potential impacts of climate change. Future planning and floodplain risk management in the catchment will need to take due consideration of the increasing flood risk under possible future climate conditions.

10 PROPERTY INUNDATION AND FLOOD DAMAGE ASSESSMENT

A flood damage assessment has been undertaken to identify flood affected property, to quantify the extent of damages in economic terms for existing flood conditions and to enable the future assessment of the relative merit of potential flood mitigation options by means of benefit-cost analysis. As part of the flood damage assessment a property database has been developed detailing individual buildings subject to flood inundation.

The general process for undertaking a flood damages assessment incorporates:

- Identifying properties subject to flooding;
- Determining depth of inundation above floor level for a range of design event magnitudes;
- Defining appropriate stage-damage relationships for various property types/uses;
- Estimating potential flood damage for each property; and
- Calculating the total flood damage for a range of design events.

10.1 Property Data

10.1.1 Location

Property locations have been derived from Council's cadastre information and associated detailed aerial photography of the catchment. Linked within a GIS system, this data enables rapid identification and querying of property details. A property database has been developed detailing individual properties subject to flood inundation.

10.1.2 Land Use

For the purposes of the flood damage assessment, property was considered as either residential or commercial. Commercial properties have been identified from the property survey. Public infrastructure and utility assets have been excluded from the damages assessment. Figure 10-1 shows the breakdown of residential versus commercial properties.

10.1.3 Ground and Floor Level

During the course of the flood study, a surveyor was engaged to survey the building floor levels for the cadastral parcels flagged from the preliminary PMF inundation assessment. Approximately 1400 cadastral parcels were flagged as requiring inclusion in the flood damage assessment for both the Darling Harbour and City Area studies. The floor level was surveyed for the lowest entrance level to the property. Properties with basement levels had the crest level of the basement surveyed. No internal building survey was undertaken.

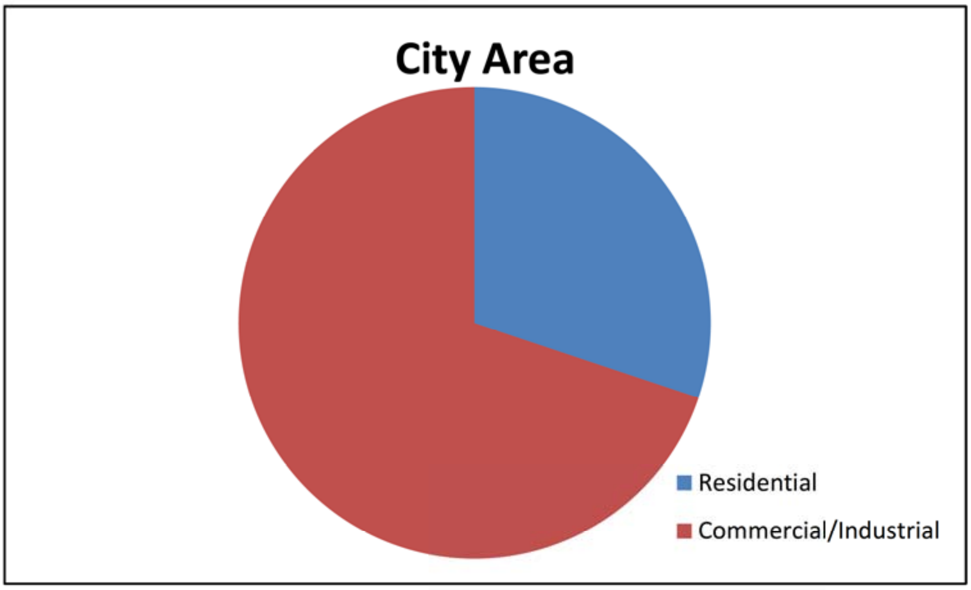


Figure 10-1 Proportion of residential and commercial properties in the City Area catchment

10.1.4 Flood Level

Design flood levels have been obtained for each property for the full range of design events modelled. Topography in the catchment can rapidly change meaning the flood level across a property may vary considerably. The flood level closest to the location of the lowest entrance was used as the critical flood level defining potential flood damages.

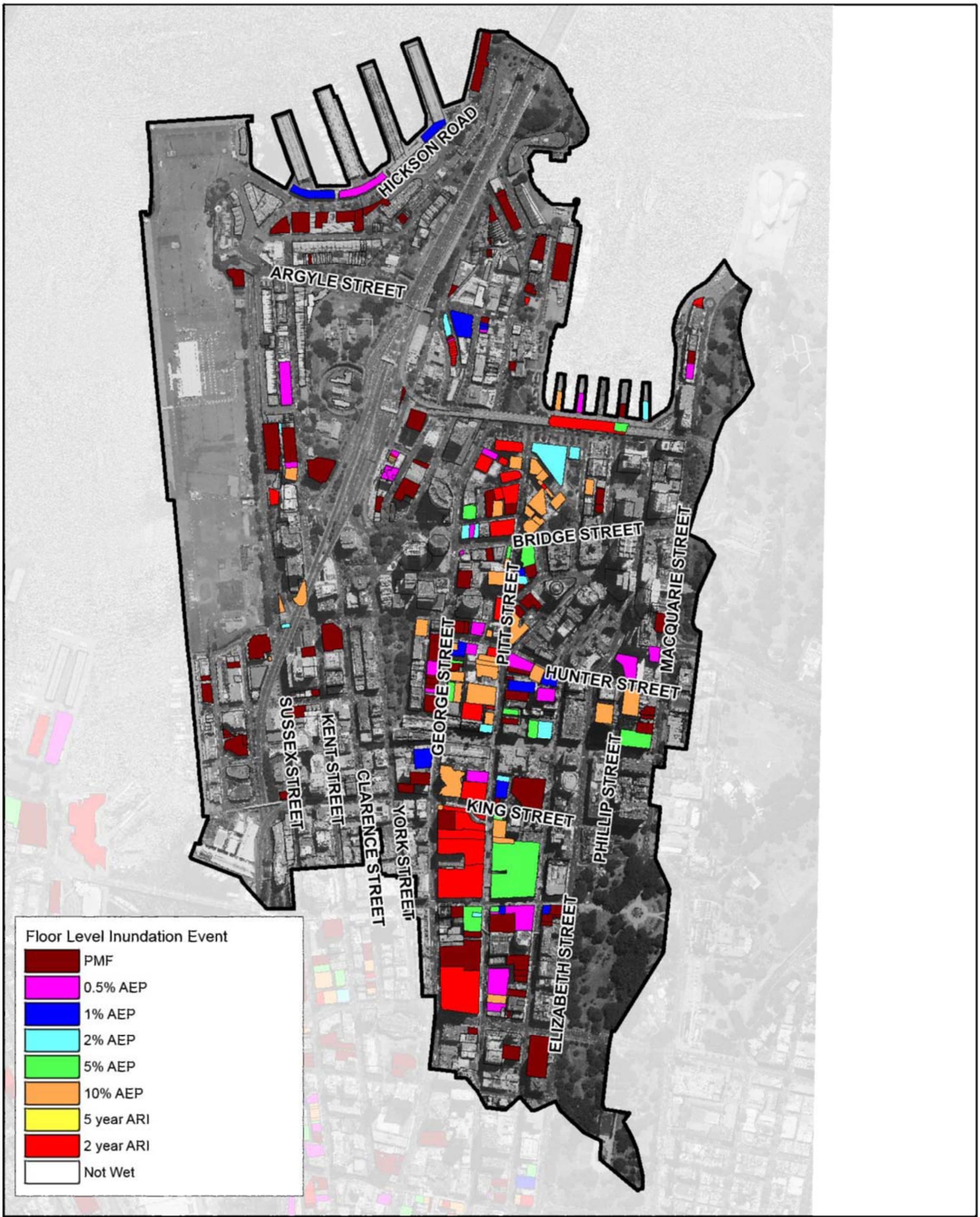
10.2 Property Inundation

A summary of the number of properties potentially affected by above floor flooding for a range of flood magnitudes is shown in Table 10-1.

Figure 10-2 shows the spatial distribution of properties potentially affected by above floor flooding and the design event which first results in above floor flooding for individual properties. The distribution of the affected properties for each design flood event is shown in Figure 10-2.

Table 10-1 Number of properties affected by above floor flooding for various design flood events.

Design Flood	Residential	Commercial	Total
2 yr ARI	9	31	40
5 yr ARI	17	51	68
10% AEP	17	72	89
5% AEP	20	85	105
2% AEP	21	96	117
1% AEP	30	107	137
0.2% AEP	35	125	160
PMF	72	206	278



Title:

Flood Damage Assessment Floor Level Inundation Event

Figure: 10-2

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0 250 500m

Approx. Scale

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10.3 Flood Damages Assessment

10.4 Types of Flood Damage

The definitions and methodology used in estimating flood damage are summarised in the Floodplain Development Manual. Figure 10-3 summarises the “types” of flood damages typically considered. The two main categories are 'tangible' and 'intangible' damages. Tangible flood damages are those that can be more readily evaluated in monetary terms, while intangible damages relate to the social cost of flooding and therefore are much more difficult to quantify.

Tangible flood damages are further divided into direct and indirect damages. Direct flood damages relate to the loss, or loss in value, of an object or a piece of property caused by direct contact with floodwaters. Indirect flood damages relate to loss in production or revenue, loss of wages, additional accommodation and living expenses, and any extra outlays that occur because of the flood.

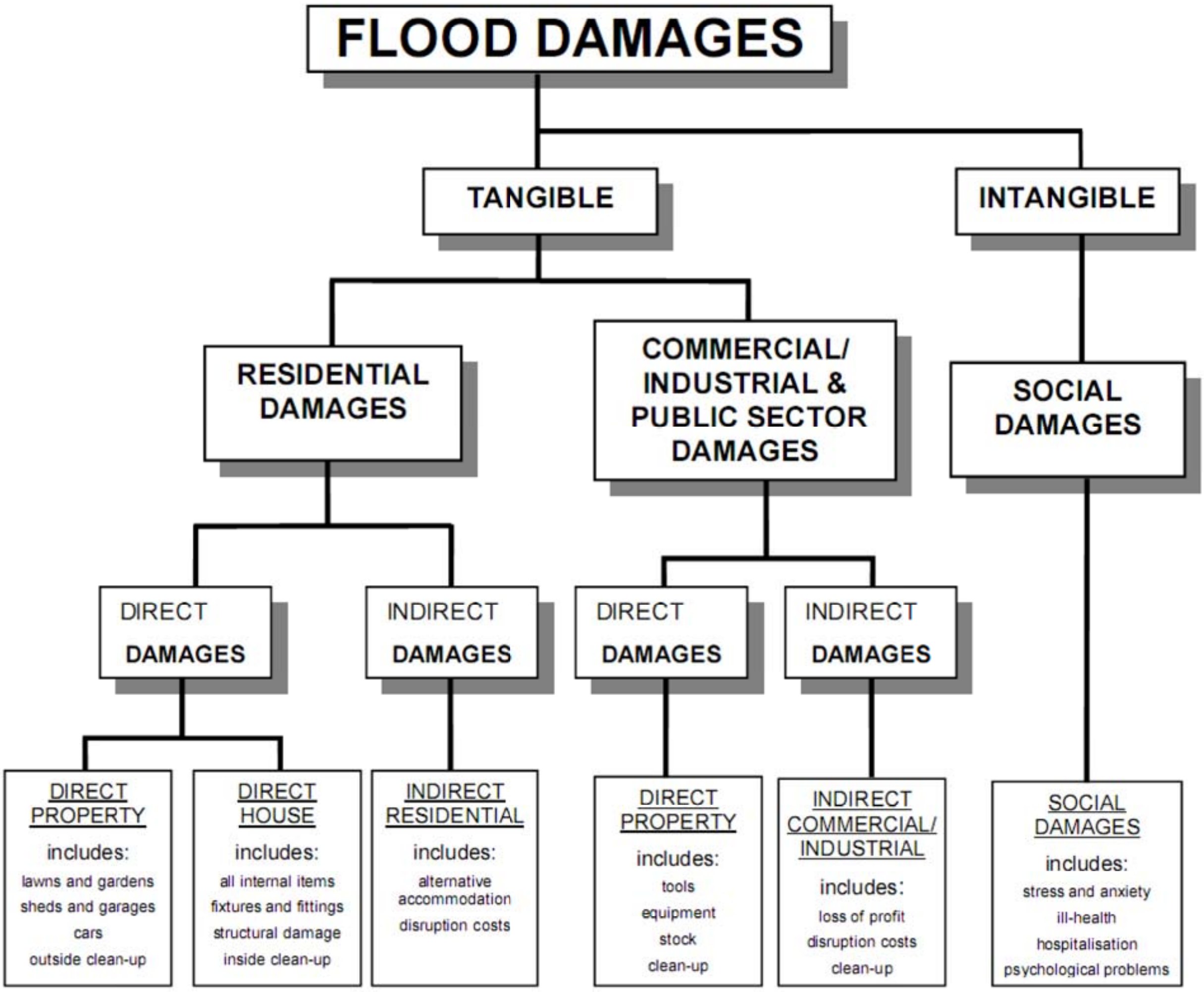

Figure 10-3 Types of Flood Damage

10.4.1 Basis of Flood Damage Calculations

Flood damages have been calculated using the data base of potentially flood affected properties and a number of stage-damage curves derived for different types of property within the catchment. These curves relate the amount of flood damage that would potentially occur at different depths of inundation, for a particular property type. Residential damage curves are based on the OEH guideline stage-damage curves for residential property. Commercial damage curves are based upon Queensland Government Guidance on the Assessment of Tangible Flood Damages (DNRM, 2002)

Different stage-damage curves for direct property damage have been derived for:

- Residential dwellings (categorised into small, typical or raised categories); and
- Commercial premises (categorised by size [small, medium, large] and damage class [1-5]).

Apart from the direct damages calculated from the derived stage-damage curves for each flood affected property, other forms of flood damage include:

- Indirect residential, commercial and industrial damages, taken as a percentage of the direct damages;
- Infrastructure damage, based on a percentage of the total value of residential and business flood damage; and
- Intangible damages relate to the social impact of flooding and include:
    - inconvenience,
    - isolation,
    - disruption of family and social activities,
    - anxiety, pain and suffering, trauma,
    - physical ill-health, and
    - psychological ill-health.

The damage estimates derived in this study are for the tangible damages only. Whilst intangible losses may be significant, these effects have not been quantified due to difficulties in assigning a meaningful dollar value.

The Average Annual Damage (AAD) is the average damage in dollars per year that would occur in a designated area from flooding over a very long period of time. In many years there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there will be major flood damage (caused by large, rare flood events). Estimation of the AAD provides a basis for comparing the effectiveness of different floodplain management measures (i.e. the reduction in the AAD).

Table 10-2 Estimated flood damages

Design Flood	Properties	Event Damage	Contribution to AAD
2 yr ARI	40	$1,880,467	$224,388
5 yr ARI	68	$3,000,370	$517,857
10% AEP	89	$4,112,054	$306,214
5% AEP	105	$5,025,749	$211,961
2% AEP	117	$5,849,570	$157,525
1% AEP	137	$6,876,224	$62,682
0.2% AEP	160	$8,833,531	$62,463
PMF	278	$27,582,892	$36,378
		Total AAD	**$1,579,467**

The total estimated flood damage to occur in a 1% AEP local catchment flood event is $6.9 million, increasing to an estimated $28 million worth of damage for the PMF. The annual cost of flooding is estimated to be approximately $1.6 million.

The sensitivity of the damage estimate to climate change has been assessed for the 1% AEP event. Table 10-3 shows the increased number of properties affected and the increase in estimated event damage for the climate change scenarios assessed in Section 9.

Table 10-3 Flood damages sensitivity to climate change

Design Flood	Properties	Event Damage
1% AEP	137	$6,876,224
10% Rainfall	+ 7	+ 13%
20% Rainfall	+ 20	+ 25%
30% Rainfall	+ 31	+ 39%
2050 Harbour	+ 0	+ 1%
2100 Harbour	+ 2	+ 2%

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APPENDIX A: DESIGN FLOOD MAPPING

DISCLAIMER:
BUILDINGS HAVE NOT BEEN MODELLED AND RESULTS CAN'T BE USED TO DETERMINE INTERNAL BUILDING FLOODING.
INUNDATION PATTERNS FROM LOCAL OVERLAND FLOW MAY VARY SLIGHTLY TO THE MAPPED RESULTS SHOWN.
COUNCIL SHOULD BE CONSULTED TO CONFIRM FLOOD AFFECTATION AT INDIVIDUAL ALLOTMENTS.

Title:
Peak Flood Depth
2 year ARI

Figure: A-1

Rev: -

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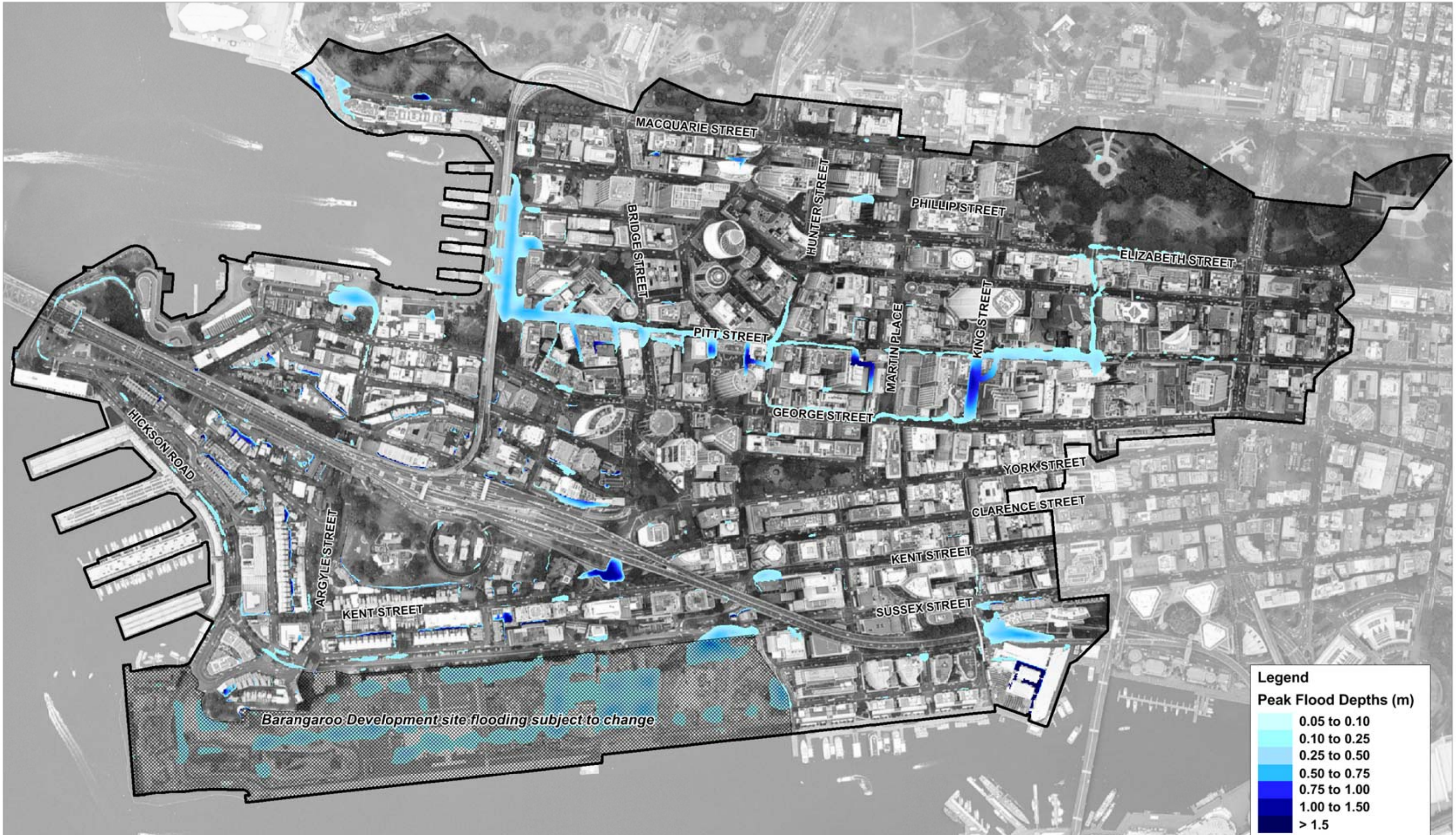

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Title:
Peak Flood Depth
5 year ARI

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Title:
Peak Flood Depth
10% AEP (10 yr ARI)

Figure: A-3

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Title: Peak Flood Depth 5% AEP (20 yr ARI)	Figure: A-4	Rev: -

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Title:
Peak Flood Depth
2% AEP (50 yr ARI)

Figure: A-5

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Title:
Peak Flood Depth
1% AEP (100 yr ARI)

Figure: A-6

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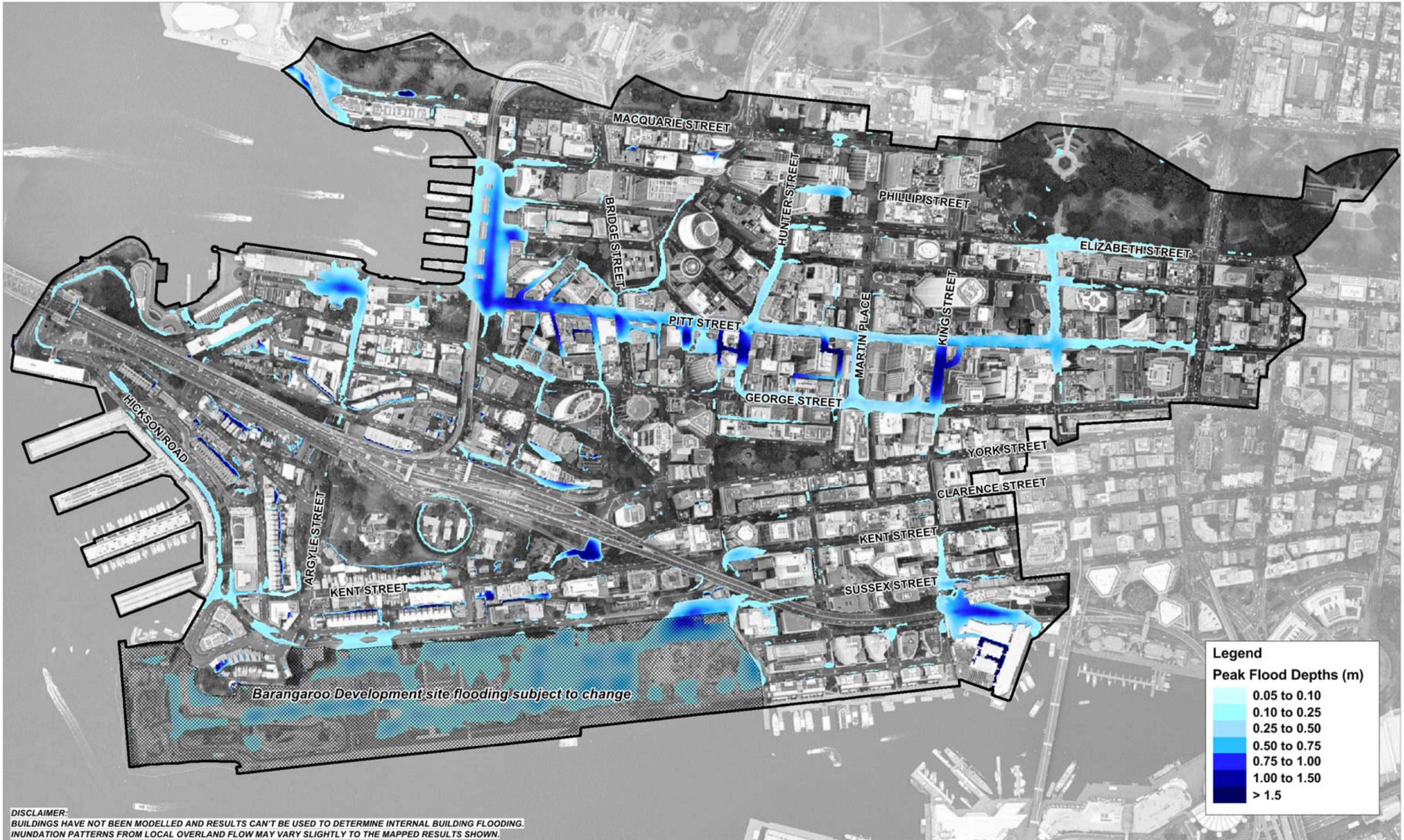

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COUNCIL SHOULD BE CONSULTED TO CONFIRM FLOOD AFFECTATION AT INDIVIDUAL ALLOTMENTS.

Title:
Peak Flood Depth
0.2% AEP (500 yr ARI)

Figure: A-7

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