7 DESIGN FLOOD RESULTS

A range of design flood events were modelled, the results of which are presented and discussed below. The simulated design events included the 2 year ARI, 5 year ARI, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.2% AEP and PMF events for catchment derived flooding and the 1 year ARI Harbour level for the tidal inundation mapping.

A range of design event storm durations have been simulated for each event. The design results presented in the remainder of the report represent the maximum values across all durations (peak envelope) for each design event simulated.

A series of design flood maps are provided in Appendix A. Supplementary to mapped results output, tabular results of peak flood behaviour have been provided for all design events in Table 7-1 and Table 7-2. The locations of flooding behaviour reported in Table 7-1 and Table 7-2 are shown in Figure 7-1 and Figure 7-2, respectively. Results presented in Appendix A, Table 7-1 and Table 7-2 result are discussed herein.

Table 7-1 Peak Design Flood Levels

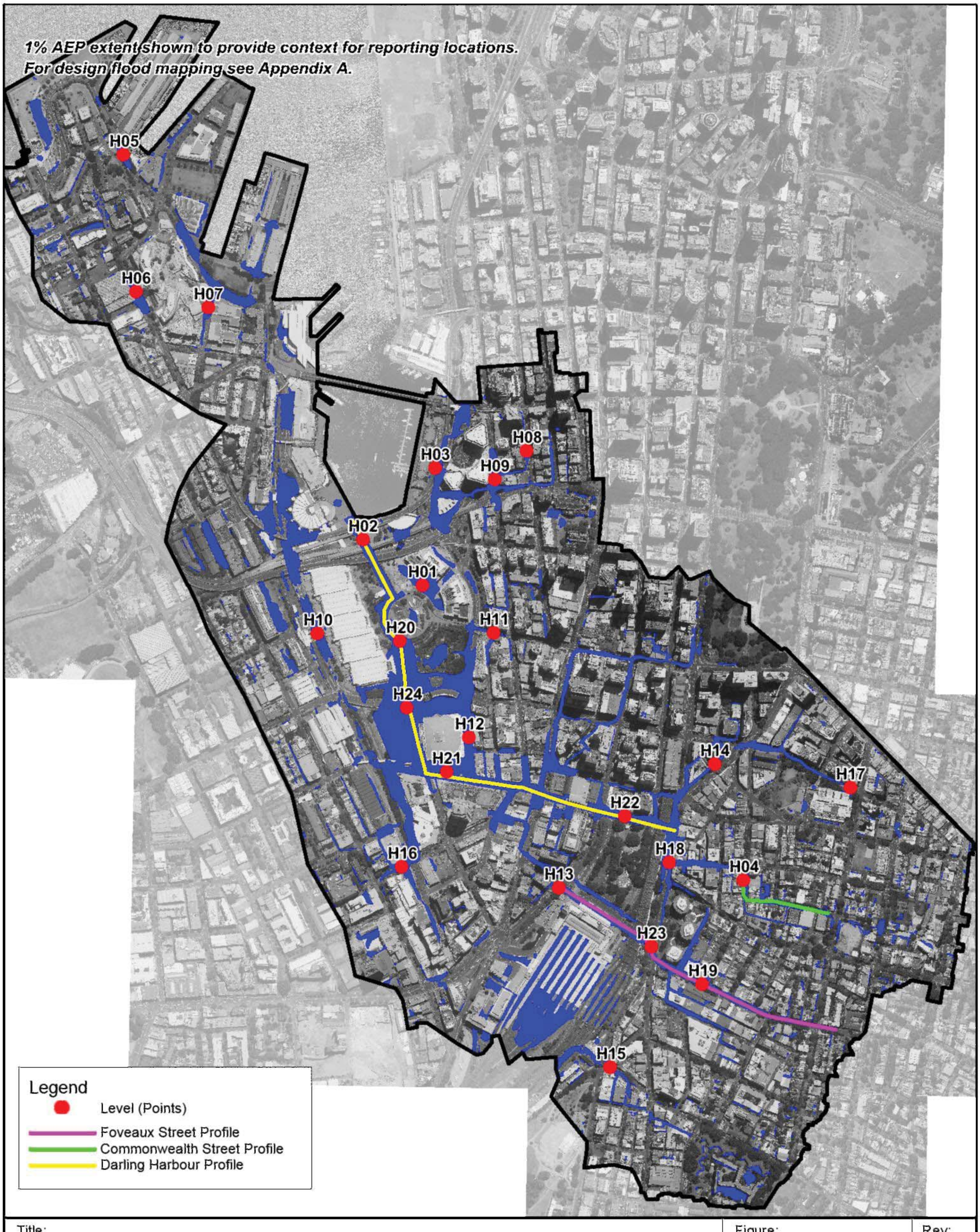
Location#	2yr ARI	5yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
H01	3.38	3.40	3.42	3.42	3.43	3.44	3.45	4.29
H02	2.43	2.44	2.45	2.46	2.60	2.69	2.83	3.50
H03	2.76	2.76	2.76	2.77	2.82	2.87	2.95	3.34
H04	16.54	16.60	17.23	17.32	17.39	17.45	17.57	18.09
H05	2.60	2.63	2.68	2.73	2.76	2.79	2.85	3.00
H06	6.47	6.55	7.23	7.32	7.42	7.53	7.77	10.81
H07	2.54	2.60	2.75	2.79	2.82	2.85	2.90	3.16
H08	11.34	11.36	11.37	11.38	11.39	11.40	11.42	11.57
H09	5.40	5.51	5.62	5.69	5.73	5.77	5.87	6.24
H10	2.77	2.85	2.89	2.95	3.02	3.09	3.18	4.47
H11	6.82	6.83	6.85	6.88	6.89	6.90	6.92	6.99
H12	2.88	3.01	3.08	3.14	3.18	3.23	3.43	4.62
H13	11.49	11.52	11.53	11.54	11.55	11.56	11.58	11.72
H14	17.06	17.09	17.10	17.11	17.12	17.13	17.14	17.31
H15	24.37	24.39	24.40	24.42	24.42	24.43	24.46	24.66
H16	4.45	4.52	4.57	4.60	4.63	4.67	4.74	5.22
H17	35.06	35.07	35.07	35.09	35.09	35.10	35.11	35.25
H18	11.24	11.28	11.35	11.41	11.45	11.49	11.59	12.33
H19	19.50	19.53	19.55	19.57	19.58	19.61	19.65	19.90
H20	2.67	2.67	2.68	2.85	3.03	3.16	3.40	4.54
H21	3.15	3.21	3.28	3.34	3.38	3.43	3.53	4.68
H22	7.61	7.64	7.66	7.69	7.72	7.75	7.83	8.28
H23	16.25	16.27	16.29	16.30	16.30	16.31	16.33	16.54
H24	2.48	2.48	2.74	2.91	3.06	3.19	3.43	4.63

Refer to Figure 7-1 for the reporting locations

Table 7-2 Peak Design Flood Flows – Pipe (P) and Overland (Q)

Location#	2yr ARI	5yr ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
Q01	0.0	0.1	0.1	0.7	2.9	5.3	10.6	91.6
Q02	0.5	0.7	1.0	1.2	1.3	1.6	2.1	7.7
Q03	0.4	1.5	2.9	3.9	4.9	6.1	8.8	34.1
Q04	0.7	1.6	2.4	3.4	4.0	5.0	6.9	21.7
Q05	1.9	4.0	5.5	8.1	10.5	13.9	21.3	92.2
Q06	0.7	1.1	1.4	1.8	2.0	2.3	3.0	9.3
Q07	1.6	2.7	3.2	4.0	4.4	5.2	6.9	25.2
Q08	2.5	5.7	9.1	14.0	18.9	24.3	36.1	154.6
Q09	0.2	0.2	0.3	0.4	0.4	0.4	0.6	2.0
Q10	0.0	0.0	0.0	0.2	0.3	0.3	0.6	27.4
Q11	0.3	2.4	3.9	5.5	6.8	8.2	10.5	20.7
Q12	0.2	0.8	3.4	6.5	9.8	13.4	21.5	99.6
P01	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.7
P02	1.7	2.2	1.6	1.5	1.7	2.0	1.9	2.6
P03	0.2	0.3	0.0	0.1	0.1	0.1	0.1	0.1
P04	2.9	3.8	4.1	4.8	5.2	5.6	6.3	9.1
P05	1.8	2.7	3.1	3.4	3.7	3.9	4.4	7.4
P06	4.8	5.6	6.1	6.5	6.8	7.1	7.6	10.1
P07	7.3	8.7	8.6	9.0	9.3	9.5	9.9	11.4
P08	12.4	14.8	14.7	15.5	15.9	16.3	16.9	19.5
P09	2.2	2.8	3.0	3.3	3.5	3.7	4.0	5.5
P10	3.9	4.6	4.9	5.3	5.5	5.7	6.1	8.2
P11	2.9	3.4	2.1	2.3	2.5	2.7	2.9	3.9

Refer to Figure 7-2 for the reporting locations



Title:

Darling Harbour Result Locations
Level Recording - Points and Profiles

Figure: 7-1

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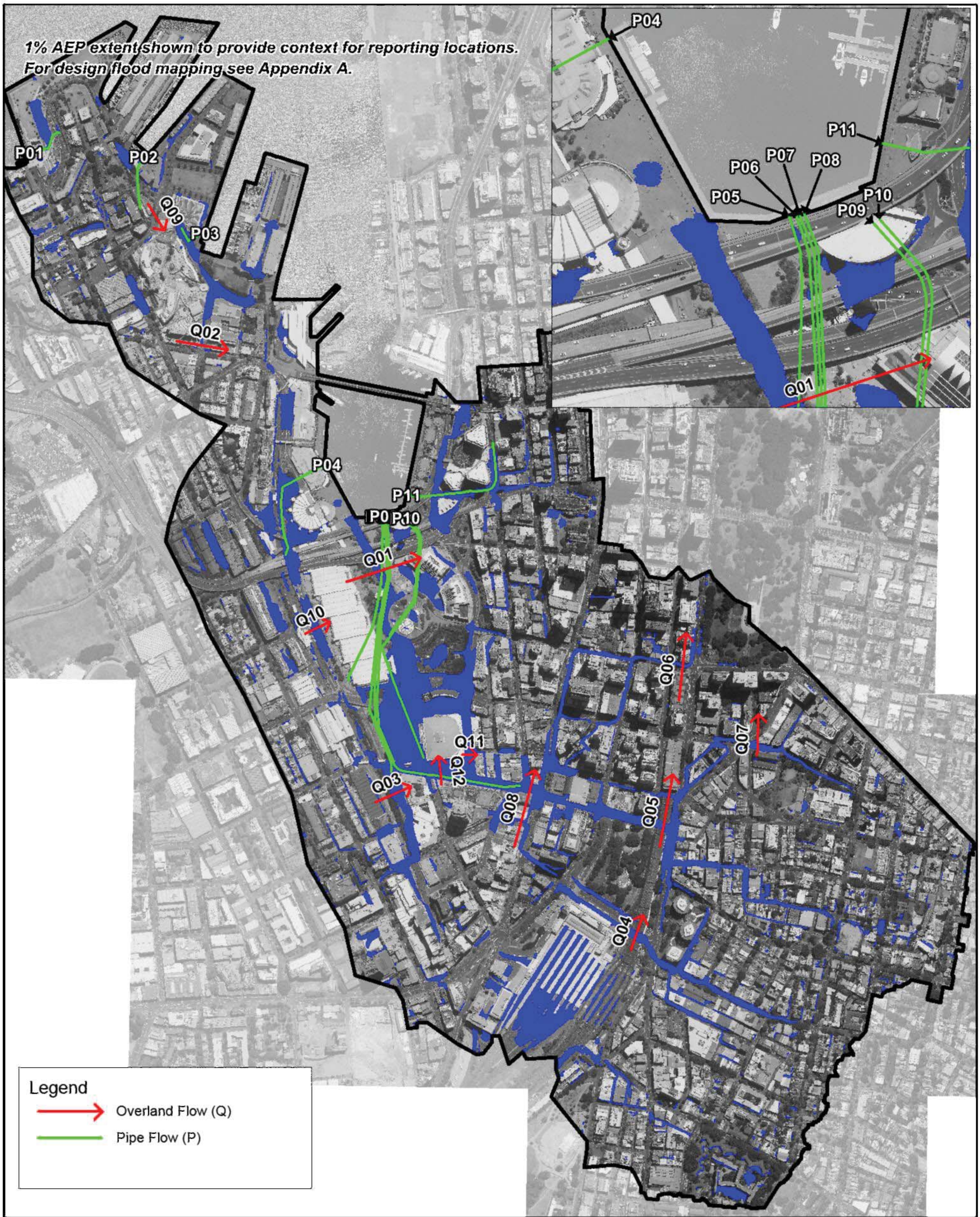

Title:

Darling Harbour Result Locations
Flow Recording - Overland and Pipe Flow

Figure: 7-2

Rev: -

0 375 750m
Approx. Scale

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7.1 Peak Flood Conditions

7.1.1 Flooding Behaviour

7.1.1.1 Overview

Section 2.1 provides a general overview of the layout of the drainage network infrastructure and major flow paths. The trunk drainage network across the study area is comprised of predominantly pipe reaches. Overland flow routes are generally confined to the road network which is typical of urban environments, but even more pronounced in the Darling Harbour catchment.

The Darling Harbour catchment has two distinct catchments areas with the Western Distributor being the divide. Flows underneath the western distributor arrive from the Surry Hills area to the south-east. North of the Western Distributor, flood waters have very small catchment areas and flow quickly to Cockle Bay/Sydney Harbour by the shortest distance.

High in the catchment upstream of the western distributor (south east Surry Hills area), steep streets quickly convey flows downstream to the Darling Harbour area. Figure 7-4 shows the peak flood level profile at Foveaux Street for all modelled design events and demonstrates the limited flood level sensitivity to the event exceedance probability. A noted exception to the limited sensitivity in upper catchment reaches is at Commonwealth Street. Commonwealth Street has a trapped low point which was identified in the community consultation stage of the study. Figure 7-5 shows the peak flood level profile for the Commonwealth Street trapped low point for all modelled design events. Figure 7-5 shows the limited flood level sensitivity to event recurrence interval in Ann Street which feeds the trapped low point and Reservoir Street which drains overflow. The flood level in the trapped low point however increases by 0.9m from the 2 year ARI event to the 1% AEP event and is further sensitive to pit blockage assumptions.

Downstream of Elizabeth Street (and the railway line), the catchment slope starts to reduce. Buried conduits become very important in the in relieving downstream flood waters. Overland flow at Q01 (see Figure 7-2) first initiates in the 5% AEP (20 year ARI) event. For events more frequent than the 5% AEP event, pipes P05, P06, P07, P08, P09 and P10 drained catchment flows. For the 5% AEP event, these 6 pipes convey a peak flow of $43m^3/s$. In the 1% AEP event, overland flow at Q01 is $5.3m^3/s$, representing 10% of the flow from the catchment at this location.

North of the Western Distributor, flooding in the catchment is from localised catchments with small upstream catchment areas. These catchments may drain to trapped low points such as Pyrmont Road (point H06) where piped infrastructure in critical in relieving flooding.

Peak flood behaviour for design modelling is best interpreted by reviewing the extensive series of design flood mapping figures presented in Appendix A.

FIGURE 7-3
DARLING HARBOUR PROFILE - DESIGN EENT RESULTS

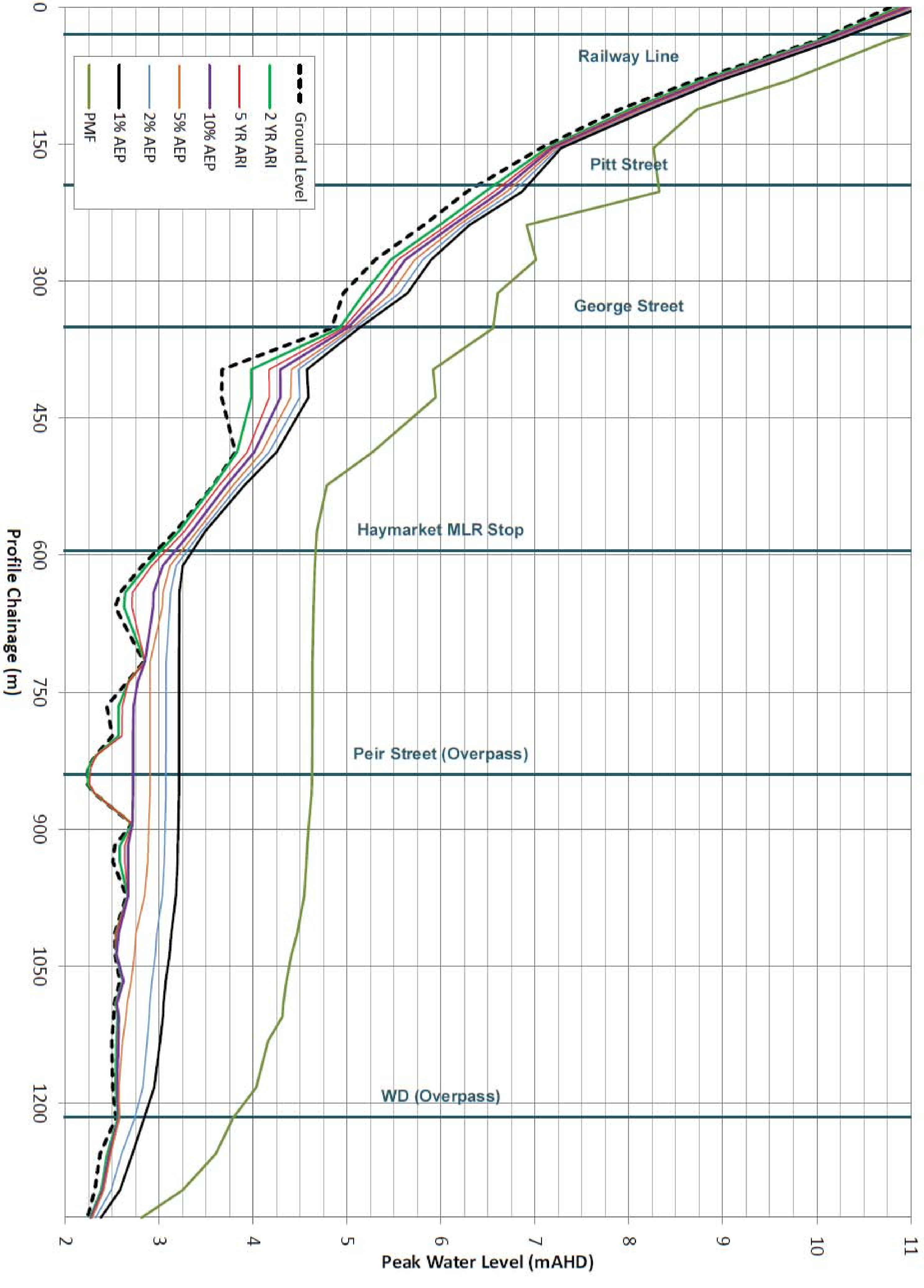


FIGURE 7-4

FOVEAUX STREET PROFILE - DESIGN EENT RESULTS

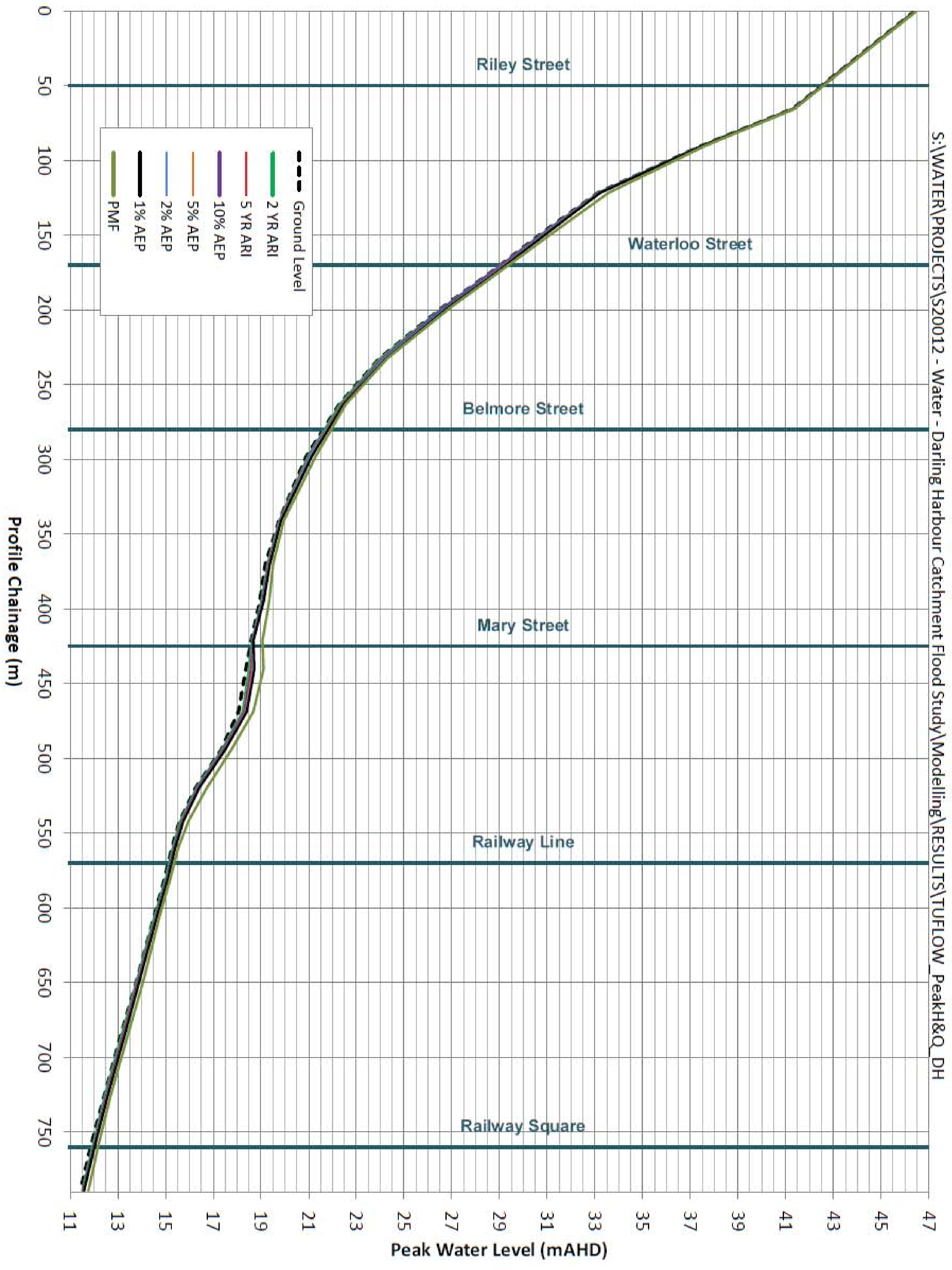
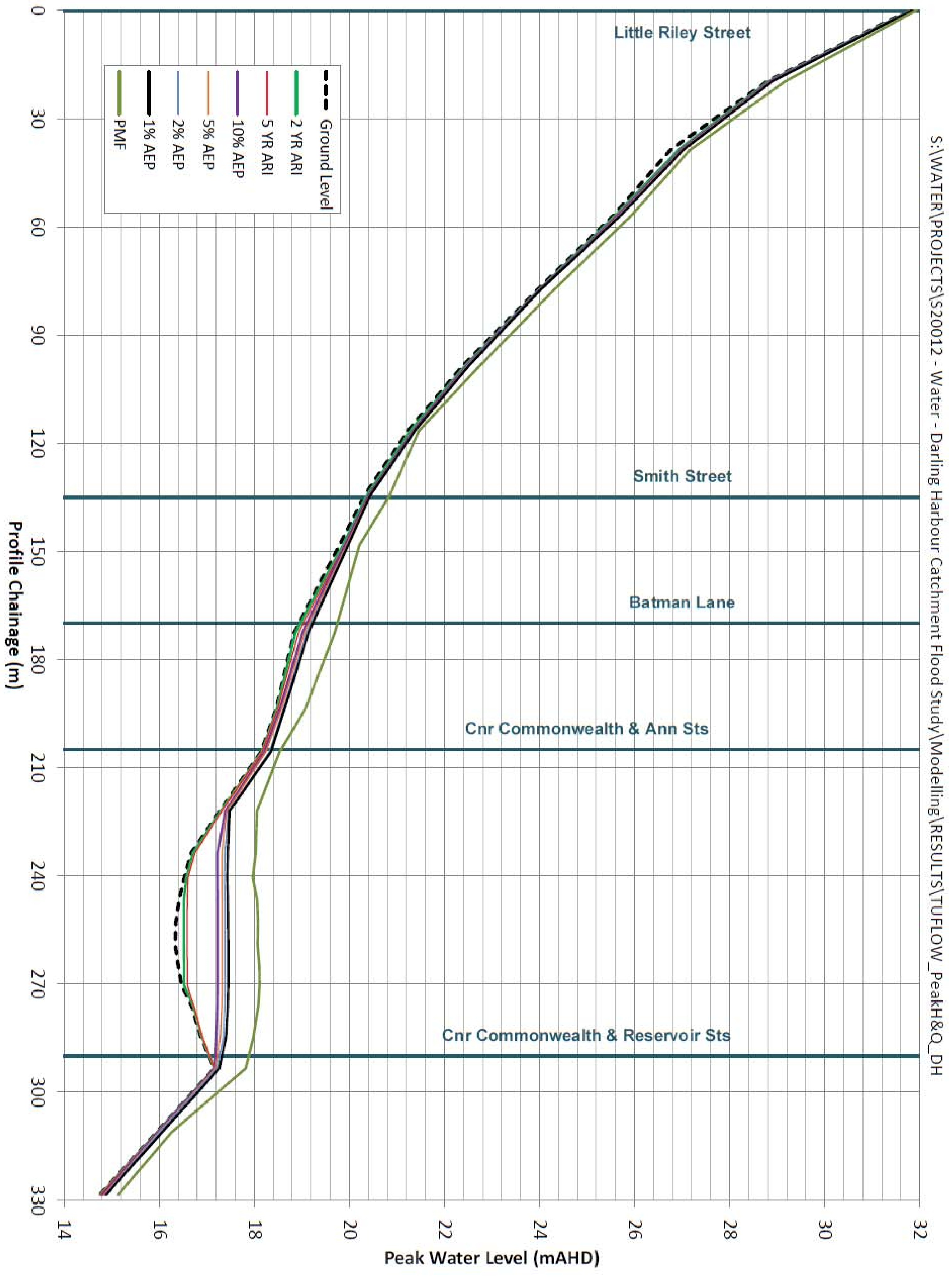


FIGURE 7-5
COMMONWEALTH STREET PROFILE - DESIGN EENT RESULTS



7.1.2 Catchment-Derived Flood Events

As presented in Section 6, a range of durations has been modelled and enveloped for each annual exceedance probability modelled. For complete catchment modelling, it is common for different durations to produce critical flood levels at different locations. Upper catchment reaches or isolated areas with small catchments will likely respond to a shorter duration event. Lower catchment reaches, catchment areas with large upstream detention volumes or large upstream areas will likely respond to longer storms with greater volume. For the utmost confidence in model results, a single duration is not identified as an approximate critical duration but rather all durations are modelled and the results of each combined to form an envelope grid.

Figure 7-6 shows the 1% AEP critical duration assessment for the Darling Harbour catchment. As shown, the majority of the catchment is critical for the 25 minute, 60 minutes and 90 minute storm durations.

Table 7-3 shows the differences in flood level for individual storm durations compared with the maximum flood level envelope which combines all durations. The single storm duration which most represents the maximum flood levels across the study area is the 90 minute storm. This duration has therefore been selected as the critical duration and adopted for the sensitivity analysis and climate change modelling. For all design event modelling however, all storm durations have been modelled to most accurately produce a peak flood envelope.

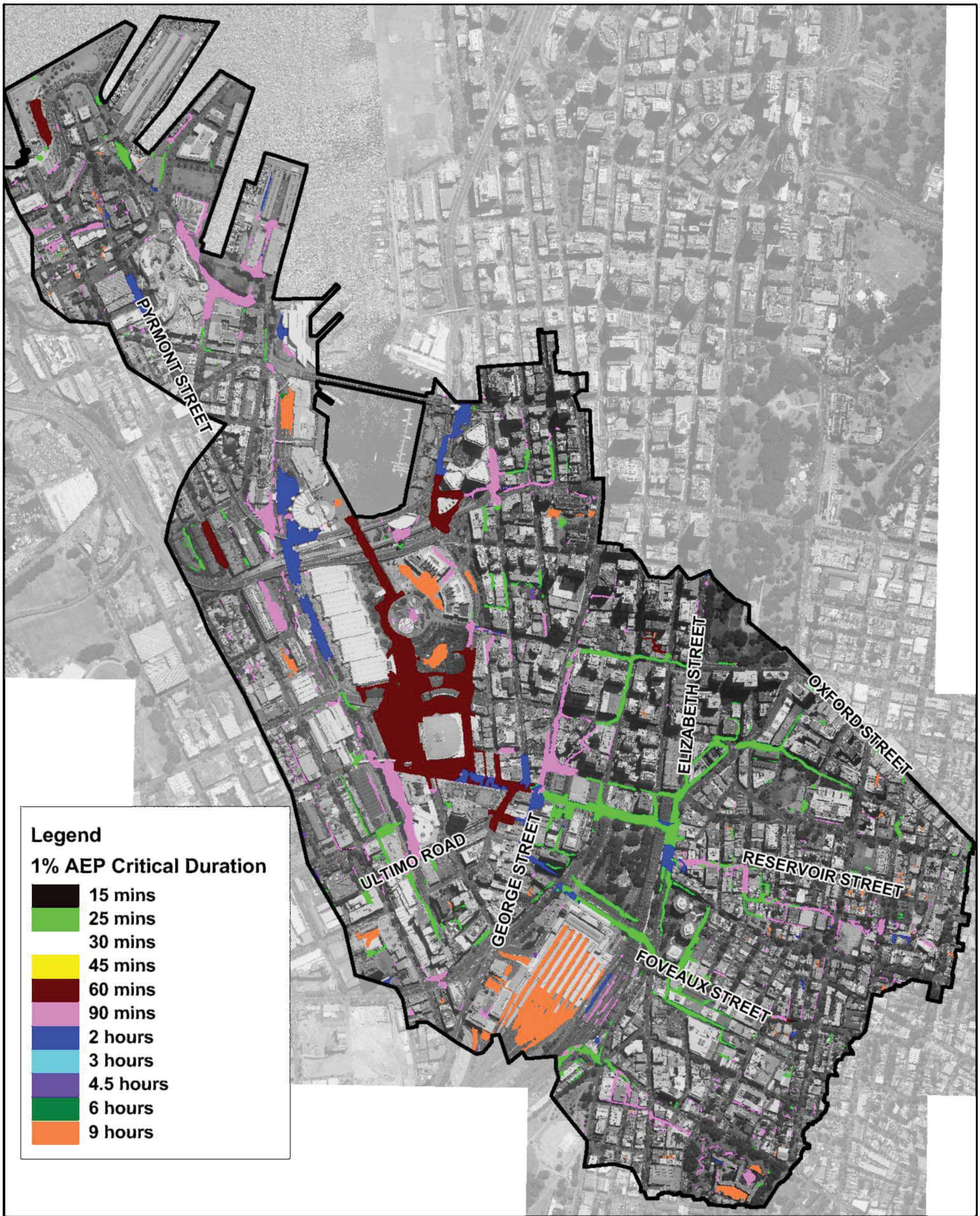
Table 7-3 Critical Duration Assessment (difference from maximum envelope)

Location#	015min	025min	030min	045min	060min	090min	120min	180min	270min	360min	540min
H01	-0.25	-0.17	-0.15	-0.09	-0.05	-0.03	-0.02	-0.02	-0.02	-0.02	+0.00
H02	-0.19	-0.15	-0.12	-0.05	+0.00	-0.01	-0.02	-0.20	-0.23	-0.24	-0.25
H03	-0.07	-0.06	-0.07	-0.02	+0.00	+0.00	+0.00	-0.03	-0.03	-0.05	-0.04
H04	-0.09	+0.00	-0.02	-0.06	-0.02	+0.00	-0.02	-0.19	-0.24	-0.34	-0.38
H05	-0.03	+0.00	-0.01	-0.02	-0.01	-0.01	-0.02	-0.14	-0.19	-0.23	-0.24
H06	-0.25	-0.13	-0.15	-0.10	-0.02	-0.01	+0.00	-0.19	-0.29	-0.36	-0.44
H07	-0.05	-0.02	-0.03	-0.03	-0.01	+0.00	-0.01	-0.06	-0.10	-0.13	-0.15
H08	+0.00	+0.00	-0.01	-0.01	-0.01	+0.00	-0.01	-0.05	-0.06	-0.08	-0.09
H09	-0.08	-0.01	-0.03	-0.05	-0.01	+0.00	-0.01	-0.13	-0.19	-0.26	-0.30
H10	-0.16	-0.10	-0.10	-0.06	-0.01	-0.01	+0.00	-0.12	-0.14	-0.19	-0.23
H11	+0.00	+0.00	+0.00	-0.01	+0.00	+0.00	+0.00	-0.07	-0.08	-0.09	-0.09
H12	-0.08	-0.01	-0.02	-0.03	+0.00	-0.01	+0.00	-0.12	-0.18	-0.26	-0.30
H13	-0.01	+0.00	+0.00	+0.00	+0.00	-0.01	+0.00	-0.03	-0.04	-0.06	-0.07
H14	-0.01	+0.00	+0.00	-0.01	-0.01	+0.00	-0.01	-0.05	-0.06	-0.08	-0.09
H15	-0.01	+0.00	+0.00	-0.01	+0.00	+0.00	-0.00	-0.04	-0.05	-0.07	-0.08
H16	-0.05	+0.00	-0.01	-0.03	-0.01	+0.00	-0.02	-0.11	-0.14	-0.18	-0.20
H17	-0.01	+0.00	+0.00	-0.01	+0.00	+0.00	-0.01	-0.04	-0.04	-0.05	-0.05
H18	-0.05	+0.00	-0.01	-0.02	-0.01	-0.01	+0.00	-0.11	-0.16	-0.22	-0.25
H19	+0.00	-0.01	-0.02	-0.02	-0.01	-0.01	-0.02	-0.10	-0.11	-0.13	-0.14
H20	-0.42	-0.17	-0.14	-0.07	+0.00	-0.02	-0.04	-0.29	-0.40	-0.51	-0.51
H21	-0.08	-0.01	-0.02	-0.02	+0.00	-0.01	+0.00	-0.12	-0.17	-0.24	-0.28
H22	-0.04	+0.00	-0.01	-0.02	-0.01	-0.01	+0.00	-0.08	-0.11	-0.14	-0.15

H23	-0.01	+0.00	+0.00	-0.01	+0.00	+0.00	-0.01	-0.03	-0.05	-0.07	-0.07
H24	-0.36	-0.15	-0.13	-0.06	+0.00	-0.02	-0.04	-0.27	-0.36	-0.51	-0.62

Refer to Figure 7-1 for the reporting locations

The design flood results, as presented in a flood mapping series in Appendix A, are the maximum condition for all of the modelled durations. For each of the simulated design events, a map of peak flood level, depth and velocity is presented covering the study area.



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CRITICAL DURATION ASSESSMENT
1% AEP (100 year ARI)

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7.1.3 Tidal Inundation

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.

7.1.4 Potential Flooding Problem Areas

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

- **Commonwealth Street Trapped Low Point (near Ann and Reservoir Streets)**
  Through the community consultation it was identified that Commonwealth Street has a trapped point between Ann Street and Reservoir Street which is sensitive to pit blockage. In standard design modelling, the existing pit and pipe network has capacity to convey the 2 year and 5 year ARI events. The rise in the peak flood level (0.6 m) in the 10% AEP event from the 5 year ARI event indicates that the stormwater capacity is first exceeded in the 10% AEP event. The peak depth in this trapped point exceeds 0.9 m for the 1% AEP event.

- **Pyrmont Road Trapped Low Point (near Jones Bay Road and Union Street)**
  Pyrmont Road between Jones Bay Road and Union Street (near The Star), has a trapped low point which is sensitivity to pit blockage. In standard design modelling, the existing pit and pipe network has capacity to convey the 2 year and 5 year ARI events. The rise in the peak flood level (0.7 m) in the 10% AEP event from the 5 year ARI event indicates that the stormwater capacity is first exceeded in the 10% AEP event. The peak depth in this trapped point exceeds 1.0 m for the 1% AEP event.

- **Elizabeth Street**
  The Railway line along Elizabeth Street only allows flood water from the Surry Hills area to pass through to the lower catchment at the under rail bridges Eddy Avenue, Hay Street and to a lesser extent Campbell Street.

  In the 1% AEP event, a peak flood depths 0.5 m occurs on Elizabeth Street upstream of Hay Street and Campbell Street as a peak flow of 14 m^3/s is conveyed downstream (flow line Q05).

  In the 1% AEP event, a peak flood depth of 0.2 m upstream of Eddy Avenue as a peak flow of 5m^3/s is conveyed downstream. Upstream of Eddy Avenue the flood water has a peak velocity of 3 m/s.

  At both locations upstream of railway, a significant risk is posed to the safety of pedestrians and motorists.

- **Hay Street (from Elizabeth Street to Haymarket)**
  Hay Street from Elizabeth Street downstream to Haymarket and Sydney Entertainment Centre has a peak depth of 0.7 m and a peak flow velocity of almost 3 m/s. This reach has a high provisional hydraulic hazard for the 1% AEP event and presents a significant potential risk to pedestrians, motorists and property.

- **Darling Harbour near Tumbalong Park and Chinese Gardens**
  At the Haymarket Tram station, the concentrated flow path along Hay Street spreads out and reduced velocity. This flat area is the upper limit of the catchment which is demonstrated to be sensitive to sea level rise. In some sections, flood water depths exceed 1m in the 1% AEP. In the 2 year and 5 year ARI, there is very little flooding present in this area though the flood extent and flood depth starts to increase for the 10% AEP event.

It should be noted that there are numerous underground car parks across the Darling Harbour Area catchment. Whilst car parks have not explicitly been considered in this Flood Study, the flooding risk does exist for many of these car parks.

7.2 Comparison with Previous Studies

Section 2.2.2 presents previous studies in the catchment and presents the Flooding and Stormwater report prepared by Hyder for the SICEEP area (Hyder, 2013). Table 7-4 presents a comparison of peak flood levels and flows between the current study and the SICEEP study.

Table 7-4 Comparison of Design Results to Hyder Study

Location	5 yr ARI		5% AEP		1% AEP		PMF	
	Current Study	SICEEP Study	Current Study	SICEEP Study	Current Study	SICEEP Study	Current Study	SICEEP Study
OVERLAND FLOW (m^3/s)								
Hay Street (US Harbour St) OL Flow	3.9	0.0	12.2	0.9	21.8	10.6	120.9	102.0
Harbour Street OL Flow	2.4	0.0	5.5	0.7	8.2	5.0	20.7	35.0
Hay Street (US Quay St) OL Flow	0.8	0.0	6.5	0.0	13.4	4.9	99.6	73.0
Darling Quarter OL Flow to Cockle Bay	0.0	0.0	0.6	0.0	5.1	0.1	62.8	65.0
PIPE FLOW (m^3/s)								
Harbourside (Conduit Y)	3.8	6.8	4.8	8.8	5.6	10.5	9.1	19.7
Imax Theatre (Conduit F)	4.6	8.1	5.3	10.1	5.7	12.0	8.2	19.4
Imax Theatre (Conduit G)	2.8	7.5	3.3	9.0	3.7	10.4	5.5	15.7
Cockle Bay Outlet (Conduit M)	14.8	9.1	15.5	11.5	16.3	13.8	19.5	23.7
Cockle Bay Outlet (Conduit N)	8.7	9.1	9.0	11.4	9.5	14.0	11.4	23.3
Cockle Bay Outlet (Conduit Q)	5.6	13.6	6.5	15.9	7.1	17.1	10.1	20.5
Cockle Bay Outlet (Conduit U)	2.7	6.8	3.4	8.4	3.9	9.6	7.4	16.2
FLOOD LEVEL (mAHD)								
Tumbalong Green	2.64	2.70	2.89	2.80	3.18	2.80	4.57	4.20
Cnr Little Hay and Harbour Sts	3.15	3.05	3.26	3.10	3.34	3.25	4.63	4.60
Tram Station (Exhibition Centre)	2.85	2.80	2.95	2.80	3.09	2.80	4.47	4.00
Flow Path Under Anzac Bridge	2.44	2.40	2.46	2.40	2.69	2.50	3.50	3.50
Tram Station (Haymarket)	2.92	2.90	3.10	2.90	3.21	3.20	4.66	4.80

Peak flood levels from Hyder modelling are approximate only. They have been interpreted from peak flood level contours on design results mapping figures.

As presented in Table 7-4 the general trend between SICEEP study and current Flood Study results indicates that the current study has reduced pipe flow and increased overland flow and therefore higher flood levels. This trend is expected due to key differences in model assumptions as presented in Table 7-5. The difference in flood levels typically range from 0.1 m to 0.2 m for the 1% AEP event. The discrepancy is higher for the 1% AEP event as the SICEEP study (which effectively has increased pipe capacity compared with this Flood Study) largely conveys the 1% AEP flow with minimal overland flow to Darling Harbour, whilst pipe capacities for this Flood Study are reduced due to pit blockage and higher tailwater conditions such that overland flow paths are inundated in the 1% AEP event (note the increased flow measured for Q01 in Table 7-2 for the 1% AEP event).

Table 7-5 Key differences in modelling assumptions

Location	Current Study	SICEEP Study
Pit Blockage <= 5 yr ARI	20% on-grade, 50% sag.	30% on-grade, 50% sag
Pit Blockage <= 5% AEP	50% on-grade, 100% sag.	30% on-grade, 50% sag
5 yr ARI Tailwater (mAHD)	1.28	0.9
1% AEP Tailwater (mAHD)	1.38	0.9

7.3 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 flood impact categories across Darling Harbour 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 (sometimes referred to as unit discharge);
- Cumulative volume conveyed during the flood event; and
- Combinations of the above.

The definition of flood impact categories that was considered to best fit the application within the Darling Harbour catchment was based on a combination of velocity, velocity*depth and depth parameters. The adopted hydraulic categorisation is defined in Table 7-6 and is consistent with similar 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 7-6 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.

7.4 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 often 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 7-7. 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).

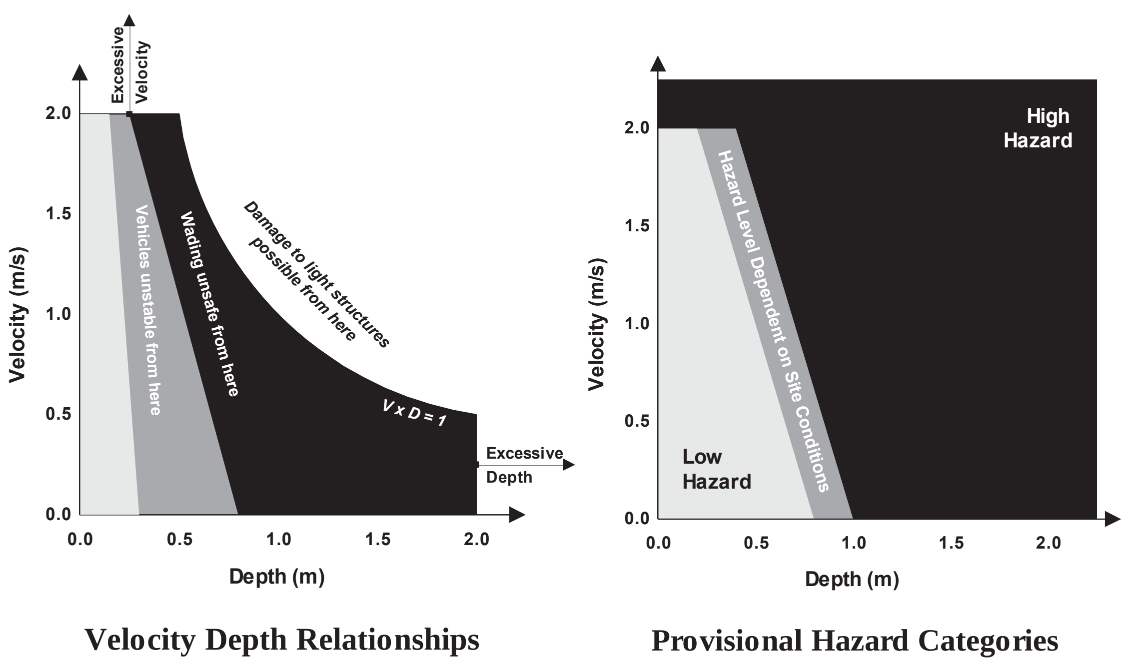


Figure 7-7 Provisional Flood Hazard Categorisation

7.5 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:

- **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).

7.6 Conclusion

The TUFLOW hydraulic model has been applied to derive design flood conditions within the Darling Harbour 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 Darling Harbour 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 sea 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 7.1.2 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 buried 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 buried 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.

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.

Variation of the hydraulic roughness of the pipe network results in changes to peak flood levels of less than or equal to 0.05 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 Flood Levels 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	+0.01	-0.01	+0.00	+0.00
H02	-0.07	+0.04	+0.03	-0.03
H03	-0.01	+0.04	+0.01	-0.01
H04	-0.01	+0.06	+0.01	+0.00
H05	-0.01	+0.02	+0.01	-0.01
H06	-0.02	+0.03	+0.04	-0.04
H07	+0.01	-0.03	+0.01	-0.01
H08	+0.03	-0.07	+0.00	+0.00
H09	+0.02	+0.02	+0.01	+0.00
H10	-0.01	+0.01	+0.02	-0.02
H11	-0.01	+0.09	+0.00	+0.00
H12	+0.05	-0.03	+0.02	-0.02
H13	-0.01	+0.02	+0.00	+0.00
H14	+0.03	-0.04	+0.00	+0.00
H15	+0.01	+0.10	+0.00	+0.00
H16	+0.02	+0.11	+0.01	+0.00
H17	+0.01	-0.01	+0.00	+0.00
H18	+0.00	+0.03	+0.00	+0.00
H19	+0.02	+0.02	-0.01	+0.00
H20	-0.05	+0.04	+0.05	-0.05
H21	+0.02	+0.02	+0.02	-0.01
H22	+0.05	+0.02	+0.00	+0.00
H23	+0.01	-0.01	+0.00	+0.00
H24	-0.04	+0.04	+0.05	-0.04

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%
- 10% AEP and less frequent: 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. Points H06 and H04 for example are trapped low points on Pyrmont Street and Commonwealth Street respectively, these points exhibit a high sensitivity to pit blockage.

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. Upper catchment peak flood levels typically increase by less than 0.1 m. A much higher sensitivity is exhibited lower in the catchment. For the standard 1% AEP design event only 3.6 m^3/s overland flow drains from the catchment at flow line Q01 while a combined flow of 46 m^3/s is conveyed into Cockle Bay via pipes P5 to P10. This peak flow of 46m^3/s which is forced overland (since pits unrealistically 100% blocked) contributes to increased flood depths in the lower Darling Harbour area of approximately 0.6 m highlighting the importance of the stormwater infrastructure in the area.

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	+0.32
H02	+0.00	+0.53
H03	+0.00	+0.26
H04	+0.56	+0.18
H05	+0.00	+0.12
H06	+0.62	+1.48
H07	+0.12	+0.10
H08	+0.00	+0.05
H09	+0.06	+0.11
H10	+0.00	+0.59
H11	+0.00	+0.02
H12	+0.01	+0.64
H13	+0.00	+0.03
H14	+0.00	+0.03
H15	+0.00	+0.06
H16	+0.01	+0.12
H17	+0.00	+0.03
H18	+0.02	+0.18
H19	+0.00	+0.05
H20	+0.00	+0.69

H21	+0.03	+0.46
H22	+0.00	+0.15
H23	+0.00	+0.04
H24	+0.01	+0.70

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.

Table 8-3 Changes in Flood Levels for Rainfall Loss Sensitivity Tests

Location	+ 50% Rainfall Losses	- 50% Rainfall Losses
H01	-0.01	+0.01
H02	-0.01	+0.01
H03	-0.01	+0.01
H04	+0.00	+0.00
H05	+0.00	+0.00
H06	-0.01	+0.01
H07	+0.00	+0.00
H08	+0.00	+0.00
H09	+0.00	+0.00
H10	-0.01	+0.01
H11	+0.00	+0.00
H12	+0.00	+0.00
H13	+0.00	+0.00
H14	+0.00	+0.00
H15	+0.00	+0.00
H16	+0.00	+0.00
H17	+0.00	+0.00
H18	+0.00	+0.00
H19	-0.01	+0.00
H20	-0.01	+0.01
H21	+0.00	+0.00
H22	+0.00	+0.00
H23	+0.00	+0.00
H24	-0.01	+0.01

8.4 Conclusion

A series of sensitivity tests have been undertaken on the modelled flood behaviour of the Darling Harbour 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; and
- Design rainfall losses.

Results were shown to be generally insensitive to the values adopted for deriving the design flood levels and extents for the 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 0.70 m in the 1% AEP design event in the lower catchment reaches. This exceeds the standard 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 (SLR) 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 Darling Harbour 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 Darling Harbour 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 Darling Harbour 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%	1.24 (5% ARI Harbour Level)
1% AEP 90 min duration	20%	1.24 (5% ARI Harbour Level)
1% AEP 90 min duration	30%	1.24 (5% ARI 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. Further discussion on relative increases from existing peak flood levels is provided herein.

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 0.10 m. Figure 9-1 shows the peak flood level profile for Darling Harbour (for the profile location refer to Figure 7-1). As shown, impacts on peak flood levels are minimal in the upper catchment, whilst higher increases are likely in areas toward the lower catchment near the Haymarket Tram stop and downstream to Cockle Bay.

Figure A- 36 shows the results of Climate Change sea level rise on tidal inundation extent. Result of sea level rise on tidal inundation extent is minimal with a very limited extent.

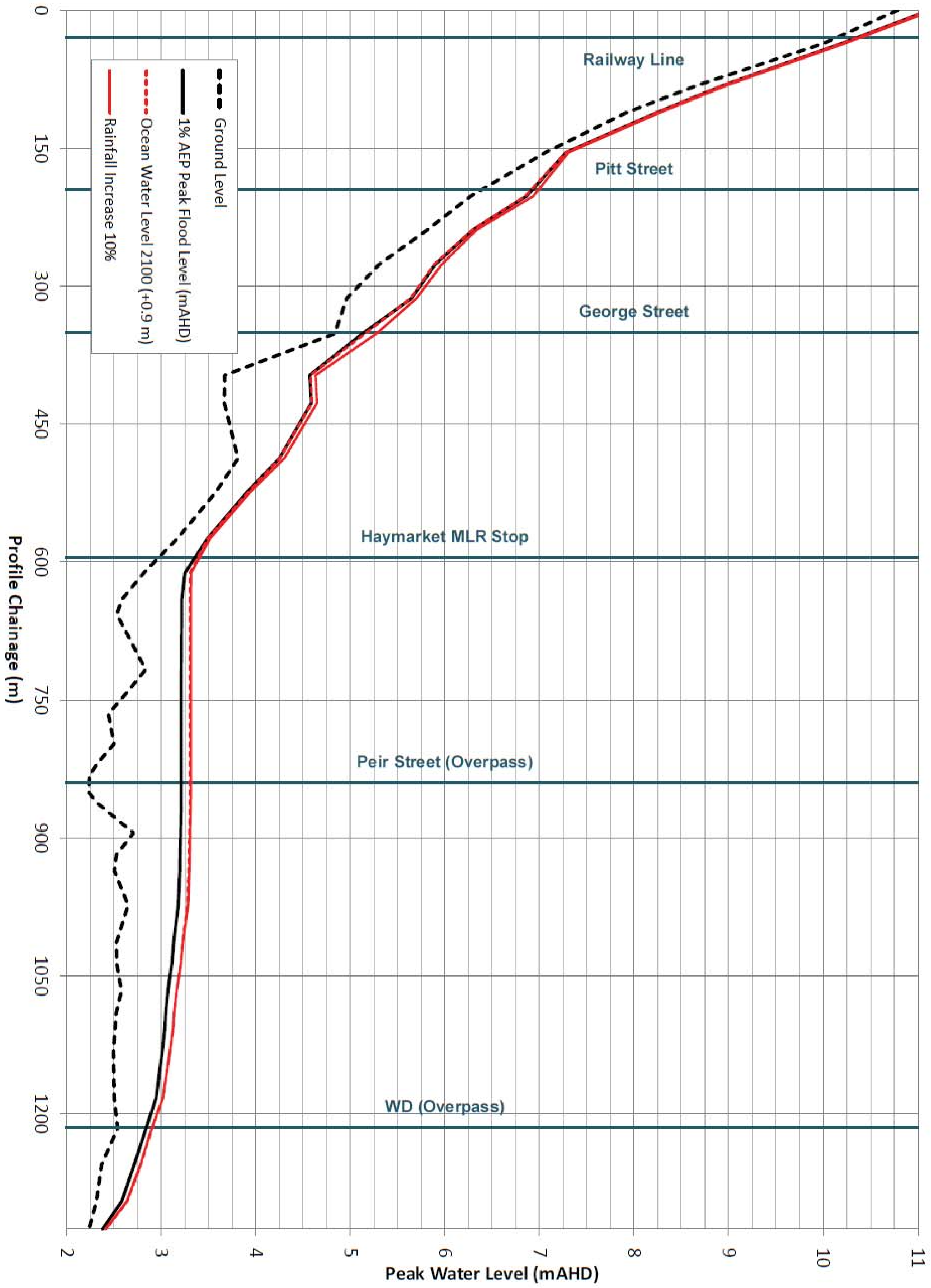
Table 9-3 Changes in Flood Levels for Climate Change Scenarios

Location	10% Rainfall	20% Rainfall	30% Rainfall	2050 Harbour	2100 Harbour
H01	+0.01	+0.02	+0.03	+0.00	+0.00
H02	+0.07	+0.13	+0.22	+0.03	+0.07
H03	+0.04	+0.08	+0.11	+0.01	+0.08
H04	+0.05	+0.10	+0.14	+0.00	+0.00
H05	+0.03	+0.06	+0.08	+0.04	+0.07
H06	+0.10	+0.20	+0.31	+0.00	+0.00
H07	+0.02	+0.04	+0.06	+0.01	+0.02
H08	+0.01	+0.02	+0.03	+0.00	+0.00
H09	+0.04	+0.08	+0.11	+0.00	+0.00
H10	+0.05	+0.09	+0.13	+0.03	+0.06
H11	+0.00	+0.00	+0.01	+0.00	+0.00
H12	+0.07	+0.17	+0.27	+0.01	+0.06
H13	+0.01	+0.02	+0.02	+0.00	+0.00
H14	+0.01	+0.02	+0.02	+0.00	+0.00

Location	10% Rainfall	20% Rainfall	30% Rainfall	2050 Harbour	2100 Harbour
H15	+0.01	+0.02	+0.03	+0.00	+0.00
H16	+0.03	+0.06	+0.09	+0.00	+0.00
H17	+0.01	+0.01	+0.02	+0.00	+0.00
H18	+0.04	+0.08	+0.12	+0.00	+0.00
H19	+0.02	+0.04	+0.05	+0.00	+0.00
H20	+0.12	+0.23	+0.32	+0.04	+0.11
H21	+0.04	+0.09	+0.13	+0.01	+0.02
H22	+0.03	+0.05	+0.09	+0.00	+0.00
H23	+0.01	+0.02	+0.02	+0.00	+0.00
H24	+0.12	+0.22	+0.32	+0.04	+0.11

FIGURE 9-1

DARLING HARBOUR 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 Darling Harbour 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 FLOOD DAMAGE ASSESSMENT

To be prepared upon completion of floor level survey.

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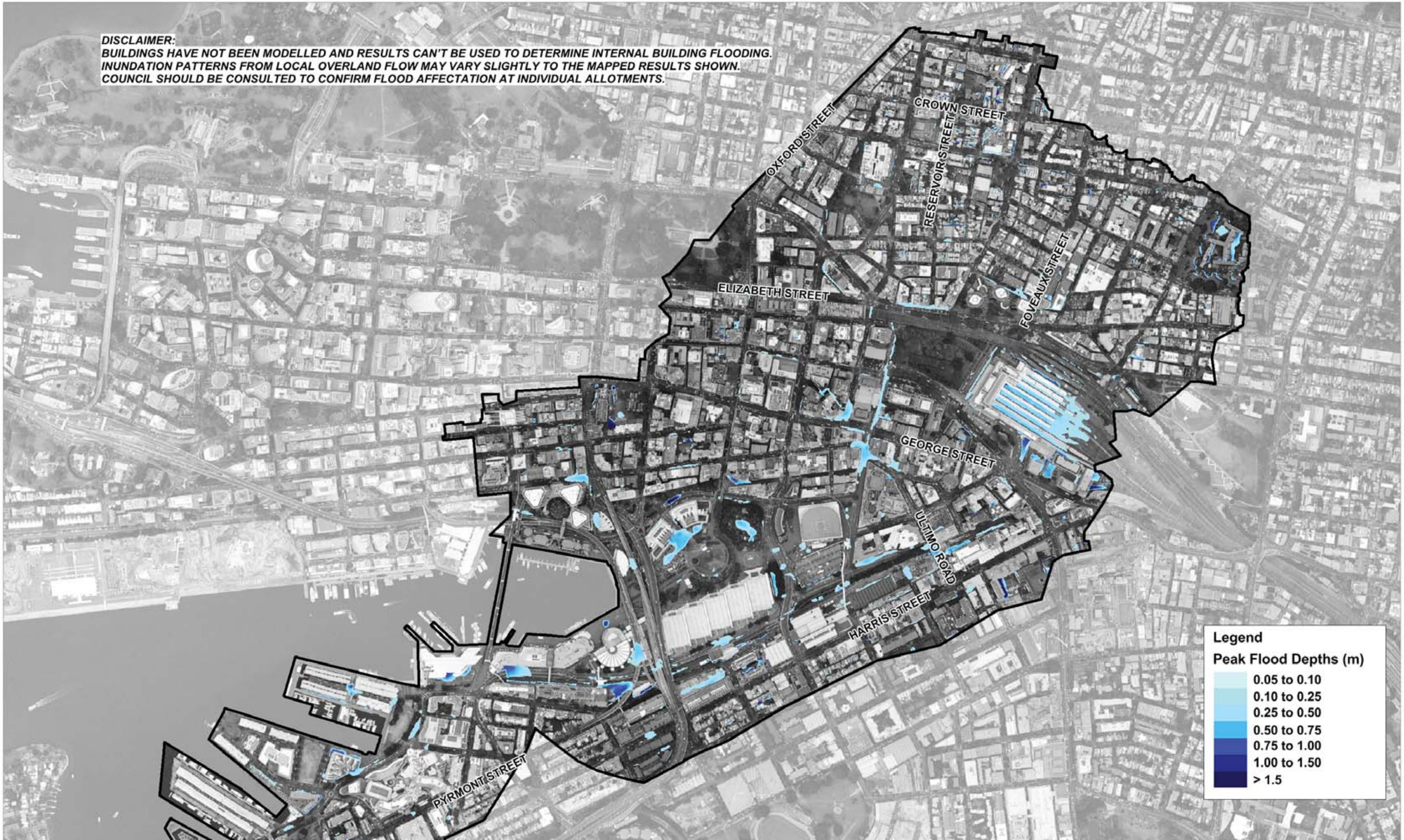
APPENDIX A: DESIGN FLOOD MAPPING



Title:
Peak Flood Depth
2 year ARI

Figure: A-1

Rev: -

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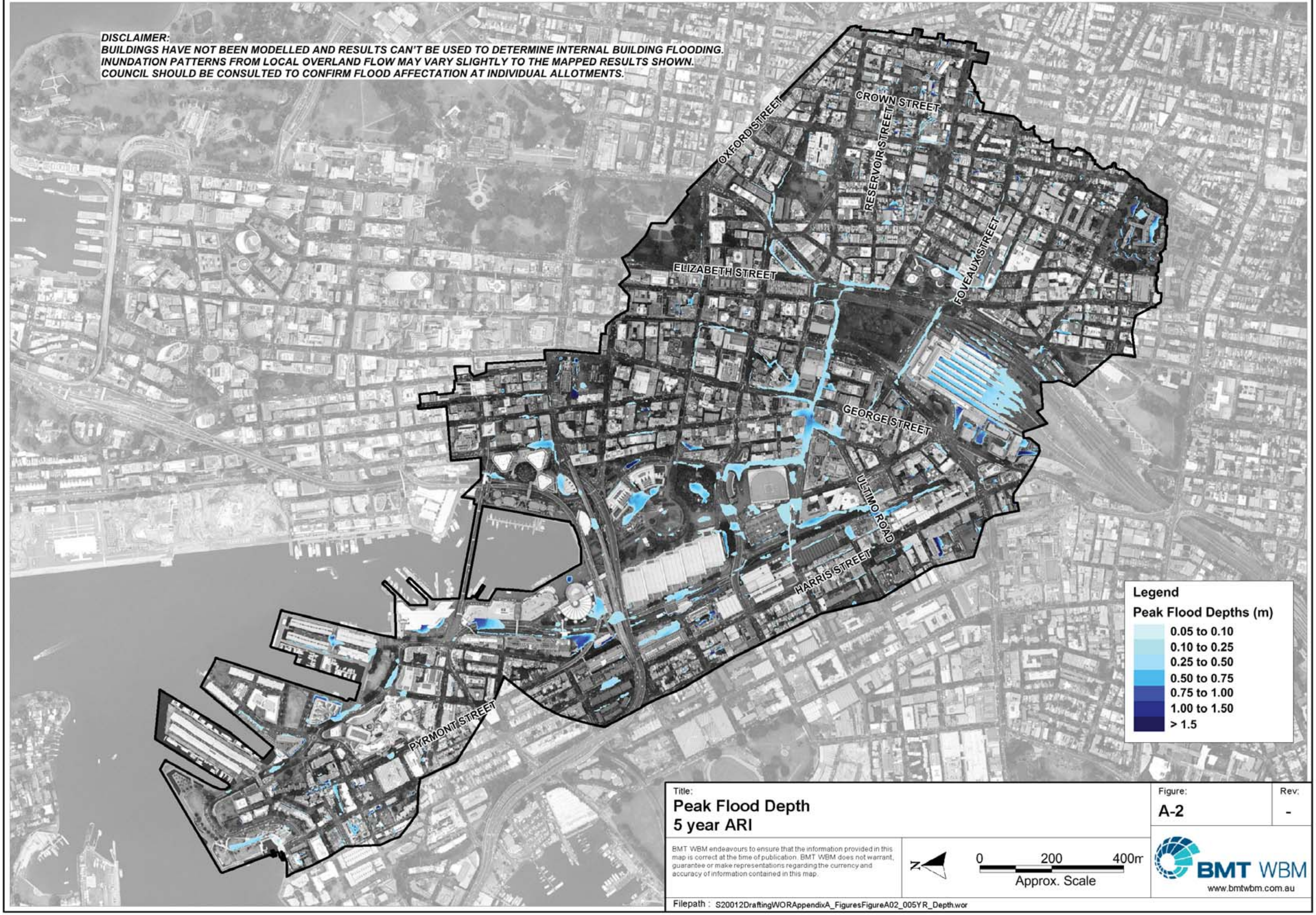

Title:
Peak Flood Depth
5 year ARI

Figure: A-2

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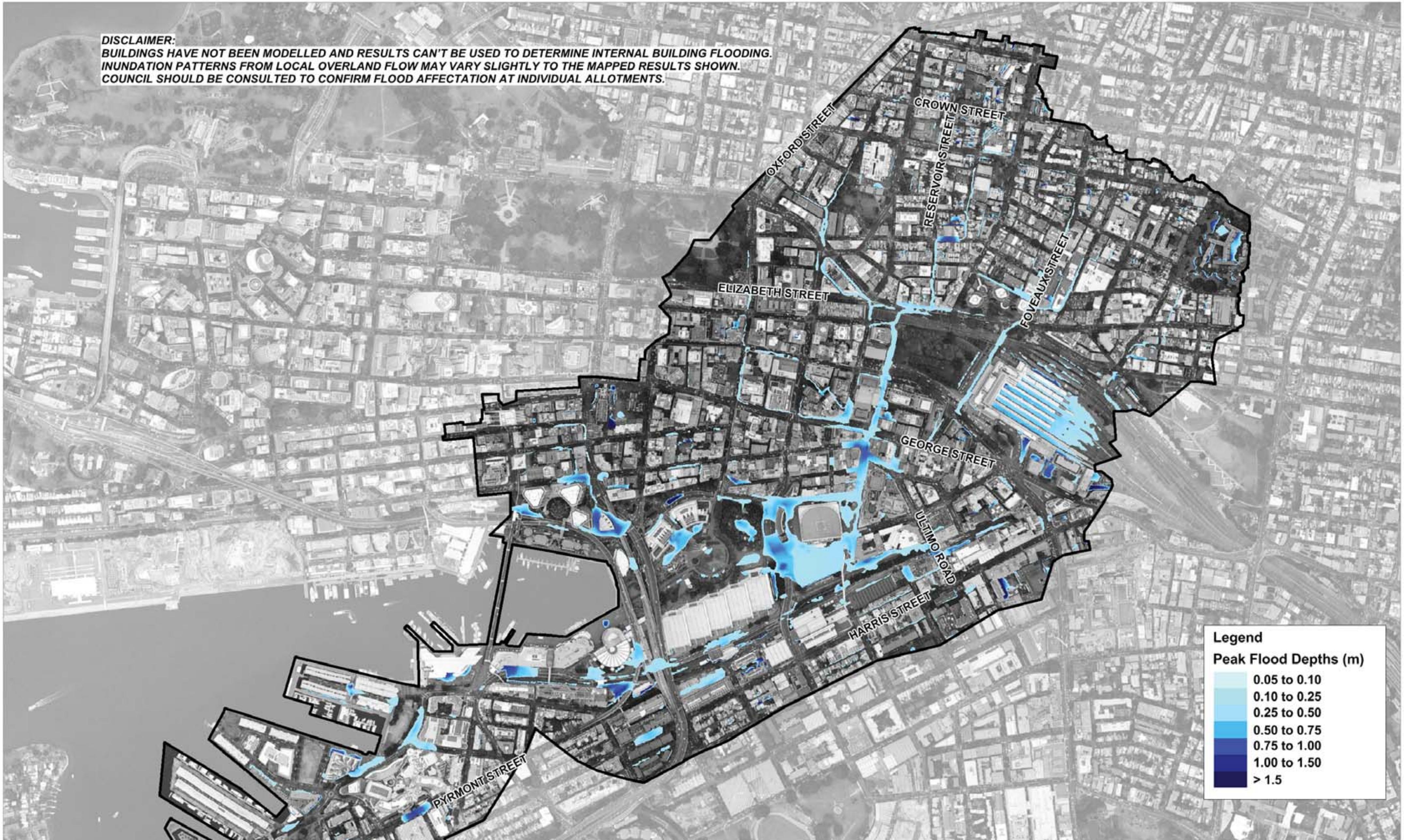

Title:
Peak Flood Depth
10% AEP (10 yr ARI)

Figure: A-3

Rev: -

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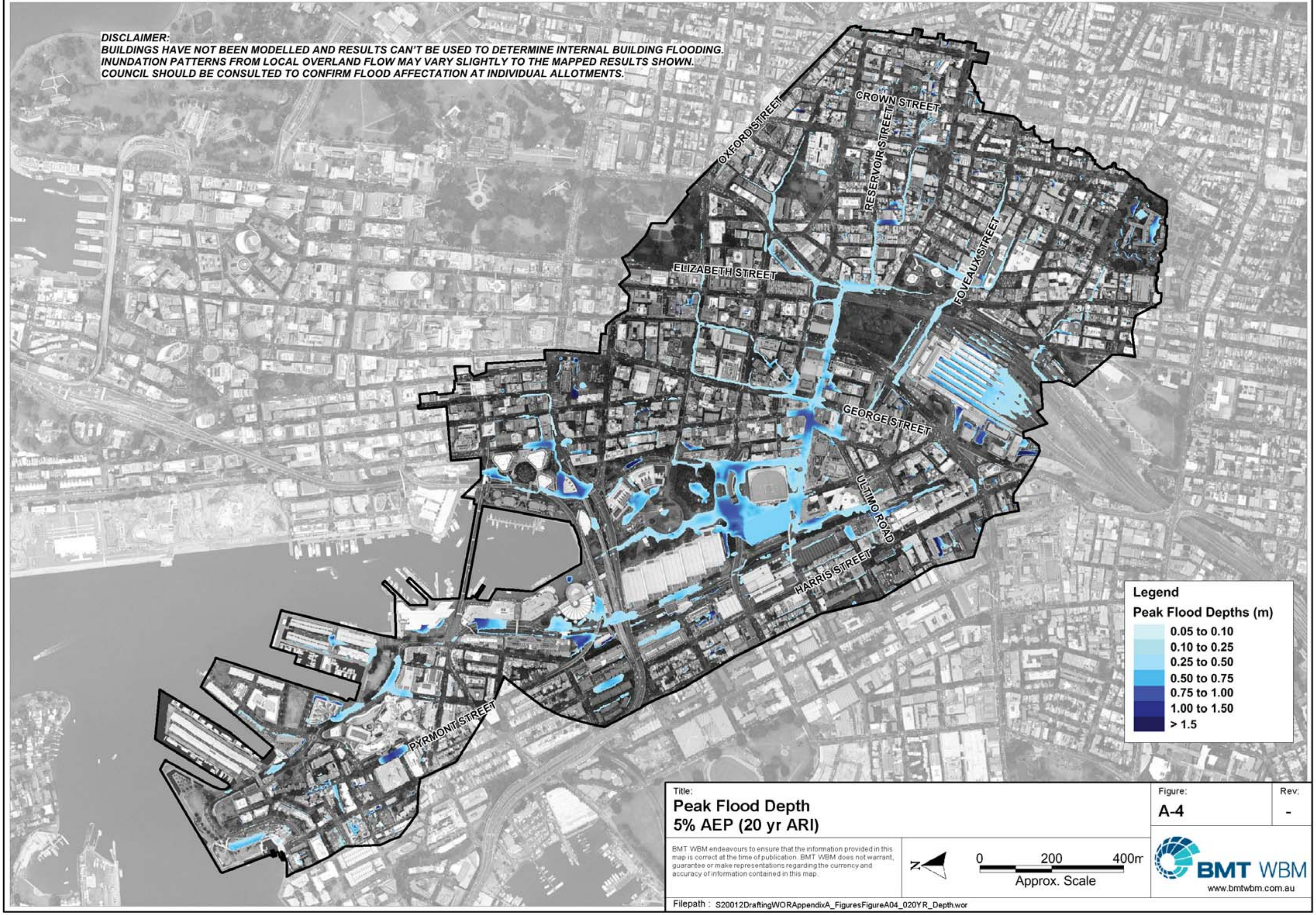

Title:
Peak Flood Depth
5% AEP (20 yr ARI)

Figure: A-4

Rev: -

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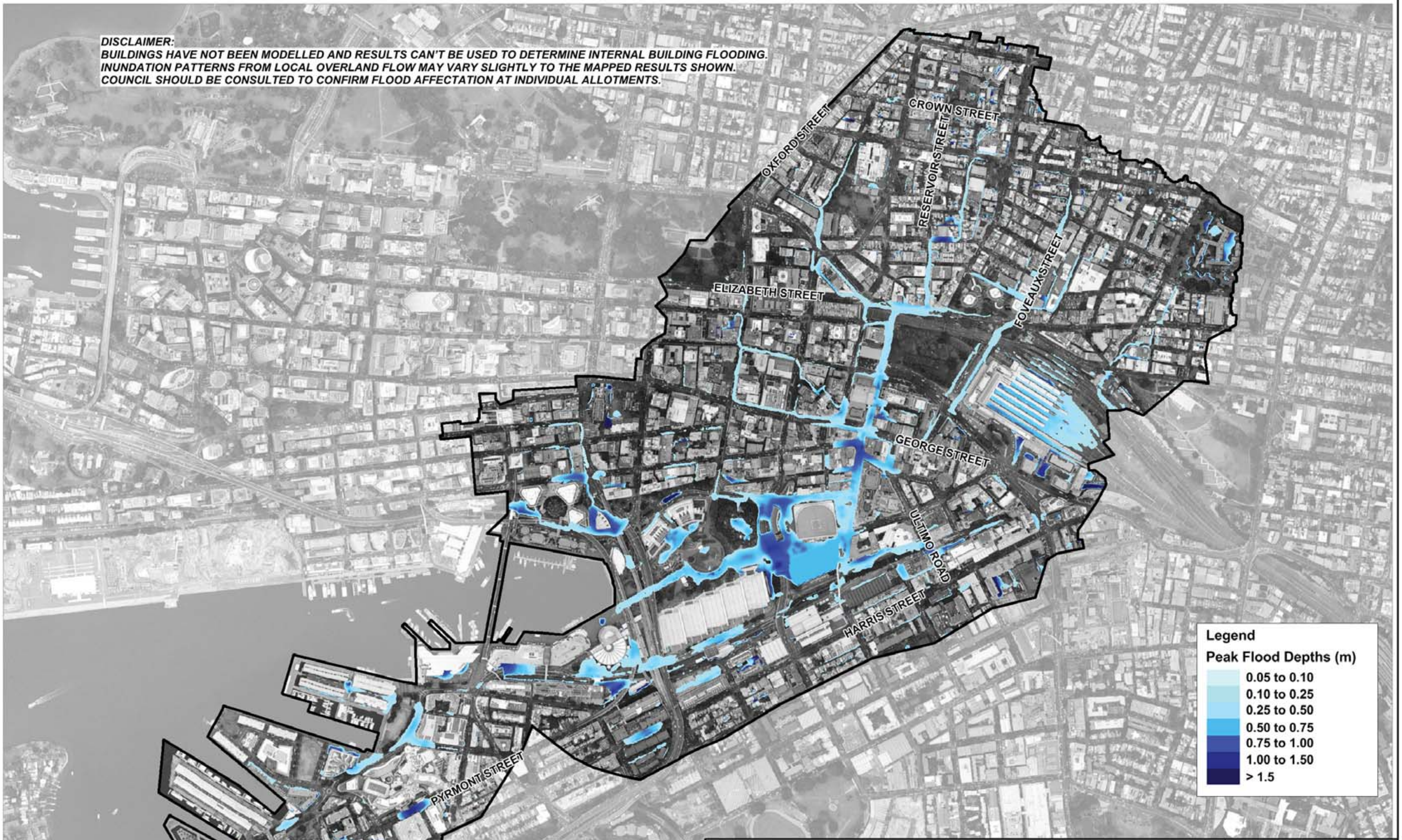

Title:
Peak Flood Depth
2% AEP (50 yr ARI)

Figure: A-5

Rev: -

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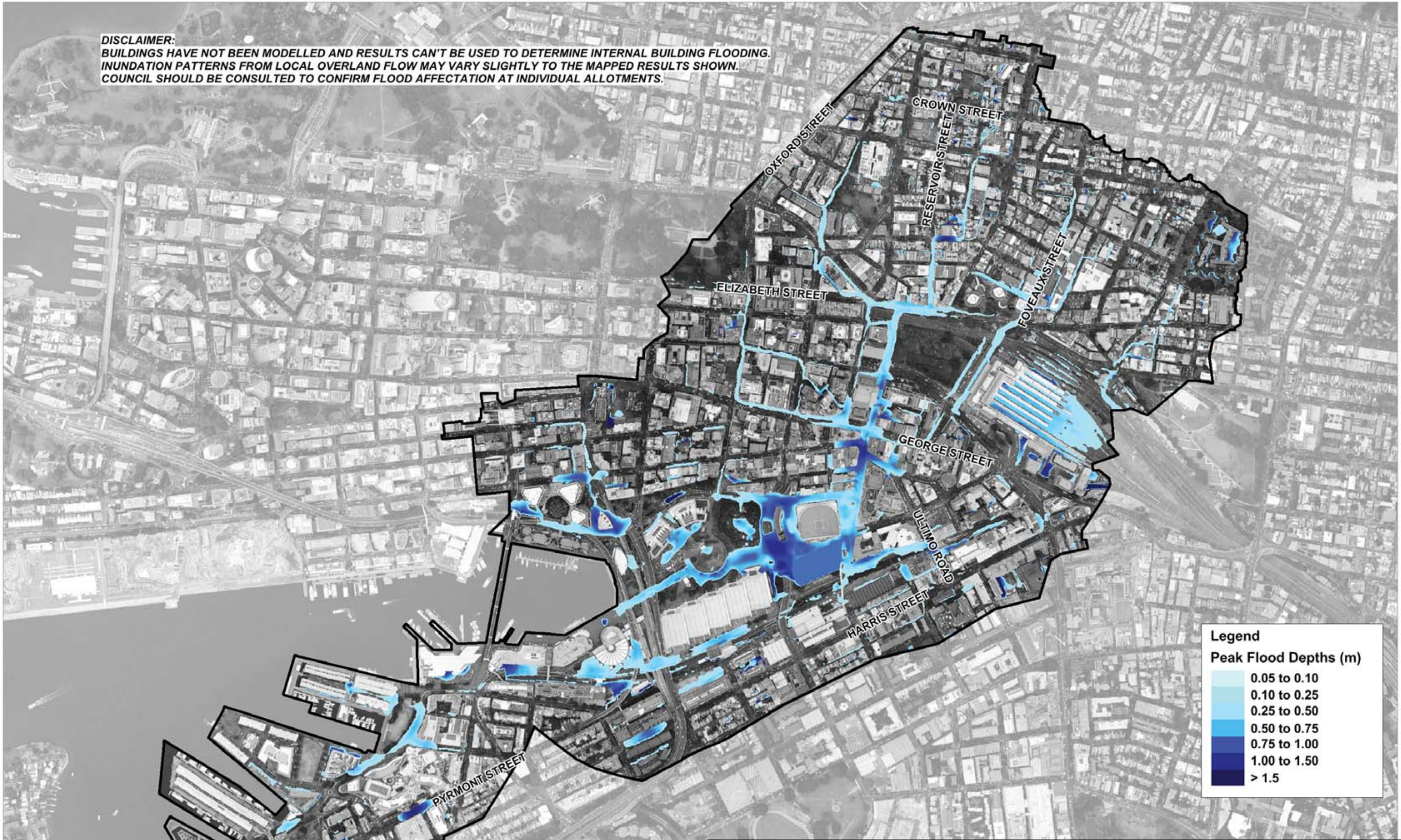
Filepath : S20012DraftingWORAppendixA_FiguresFigureA05_050YR_Depth.wor



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

Figure: A-6

Rev: -

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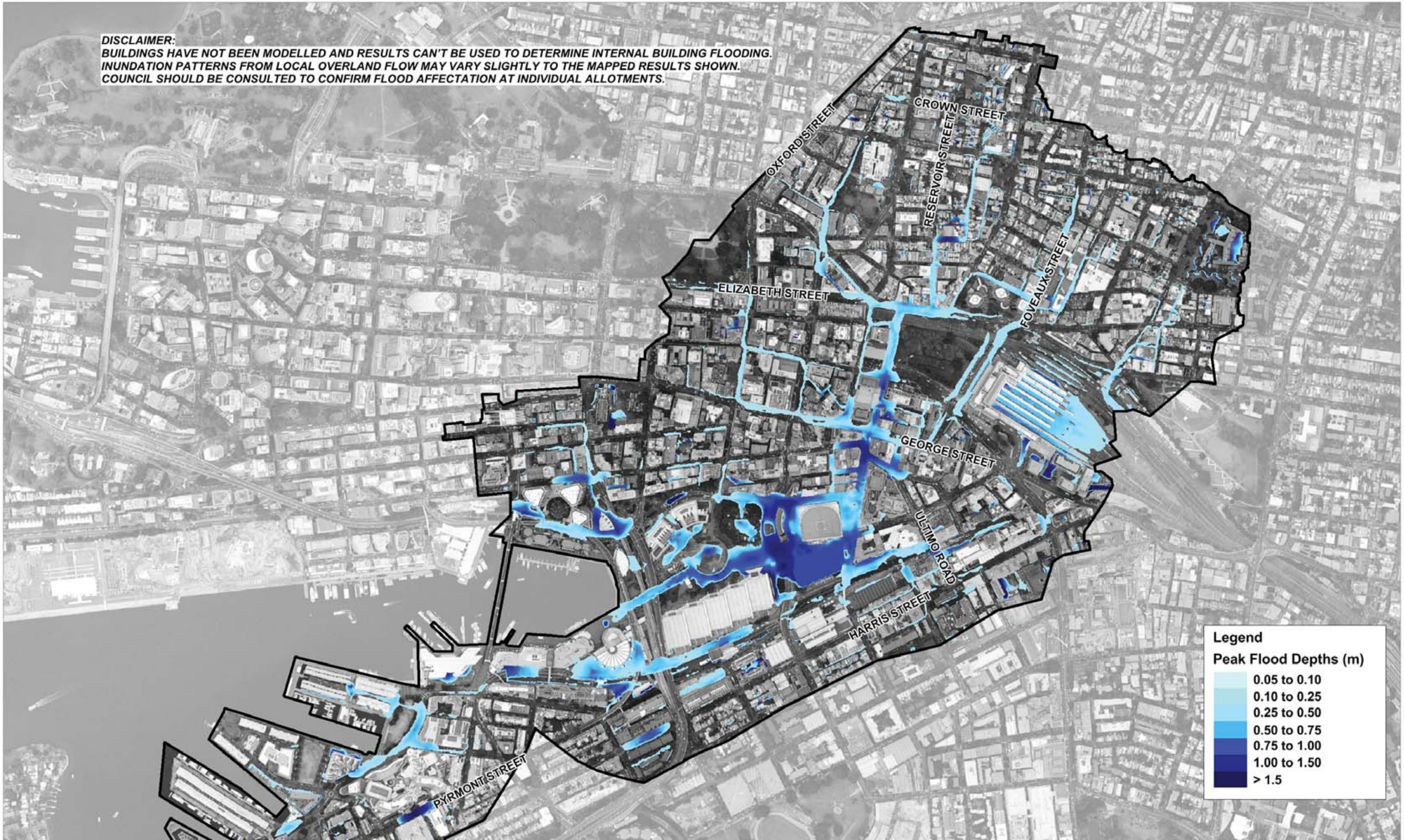
Filepath : S20012DraftingWORAppendixA_FiguresFigureA06_100YR_Depth.wor



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

Figure: A-7

Rev: -

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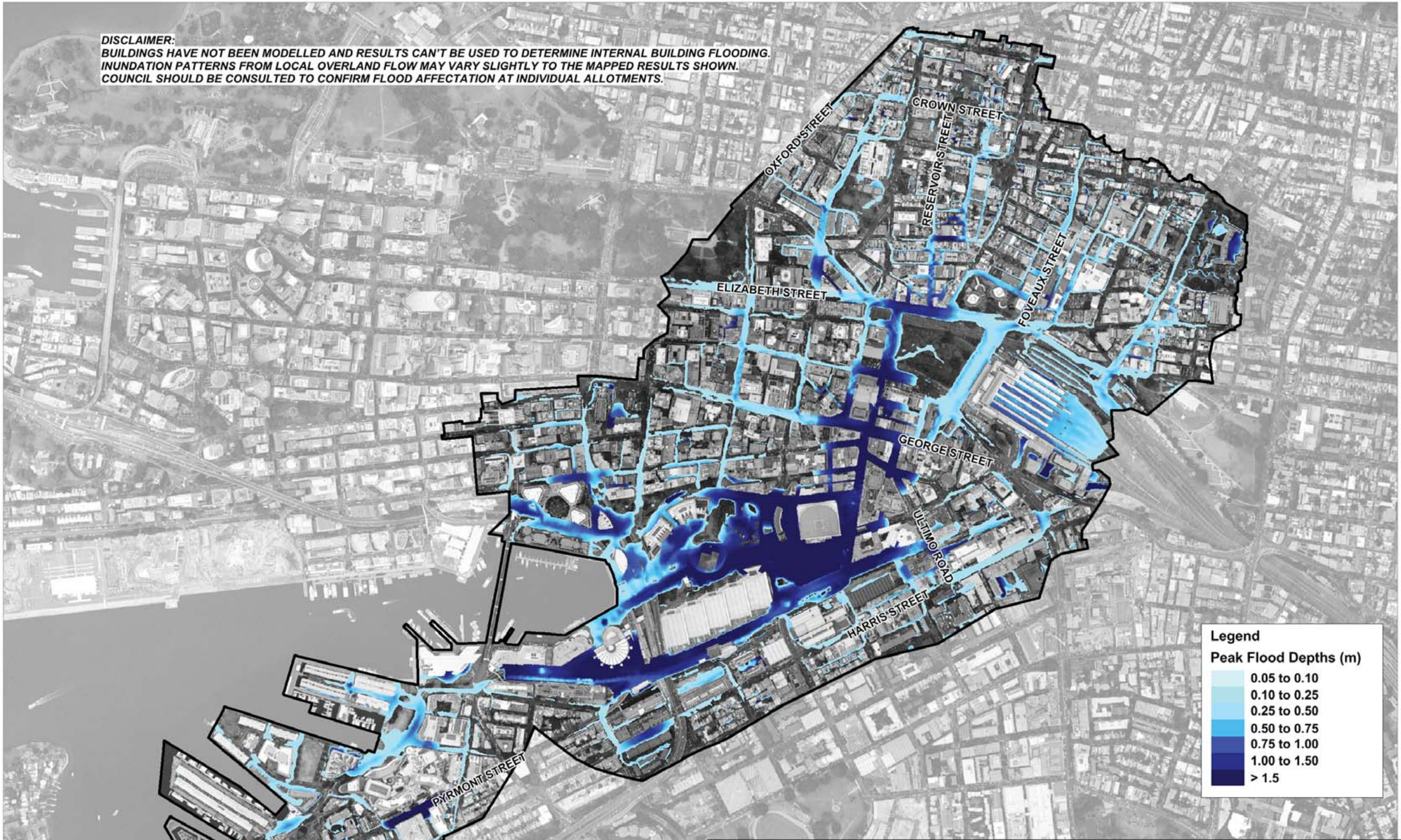
Filepath : S20012DraftingWORAppendixA_FiguresFigureA07_500YR_Depth.wor



Title:
Peak Flood Depth
Probable Maximum Flood (PMF)

Figure: **A-8**

Rev: **-**

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N

0 200 400m
Approx. Scale

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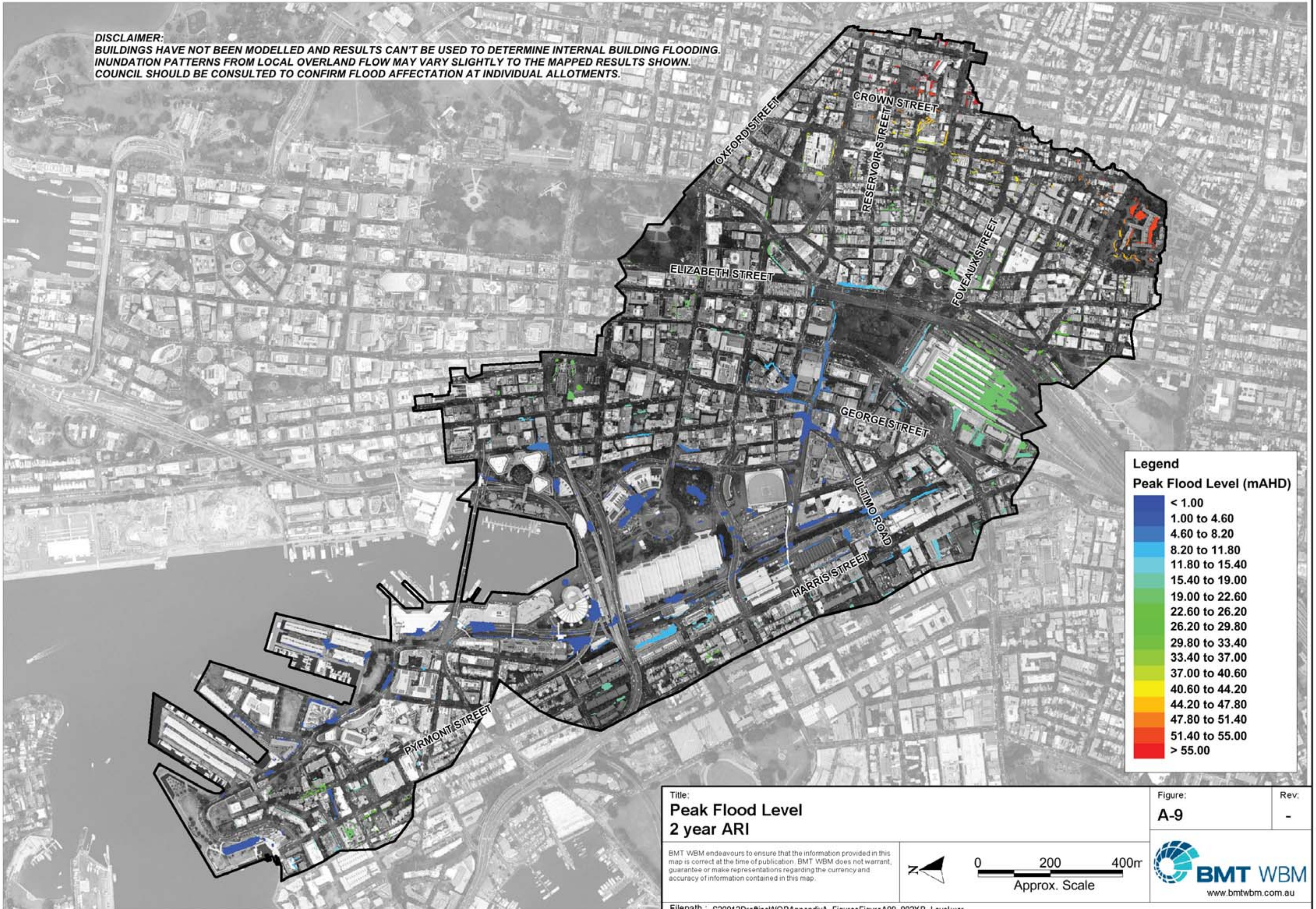
Filepath : S20012DraftingWORAppendixA_FiguresFigureA08_PMF_Depth.wor



Title:

Peak Flood Level
2 year ARI

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Figure: A-9

Rev: -

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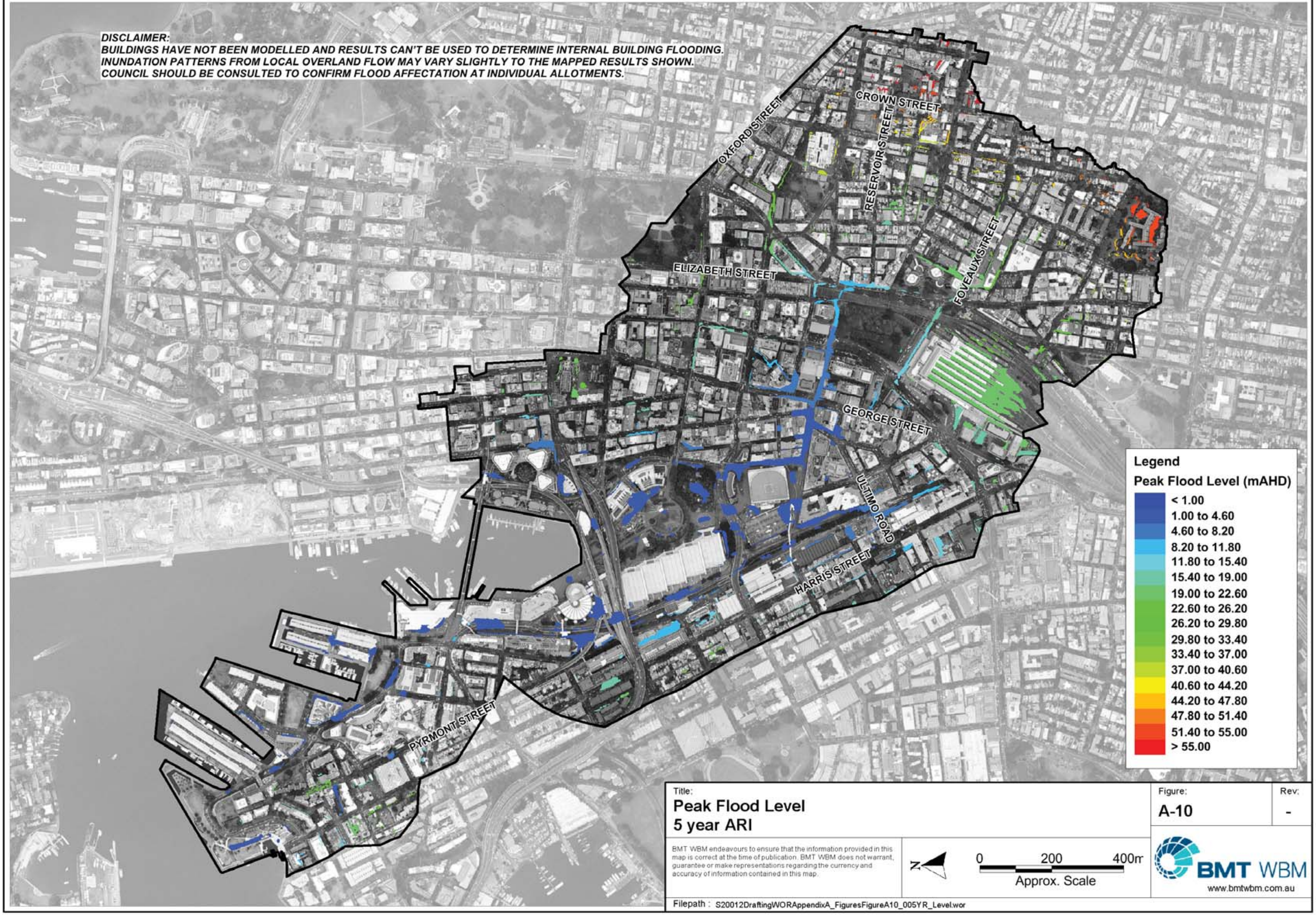
Filepath : S20012DraftingWORAppendixA_FiguresFigureA09_002YR_Level.wor



Title:
Peak Flood Level
5 year ARI

Figure: A-10

Rev: -

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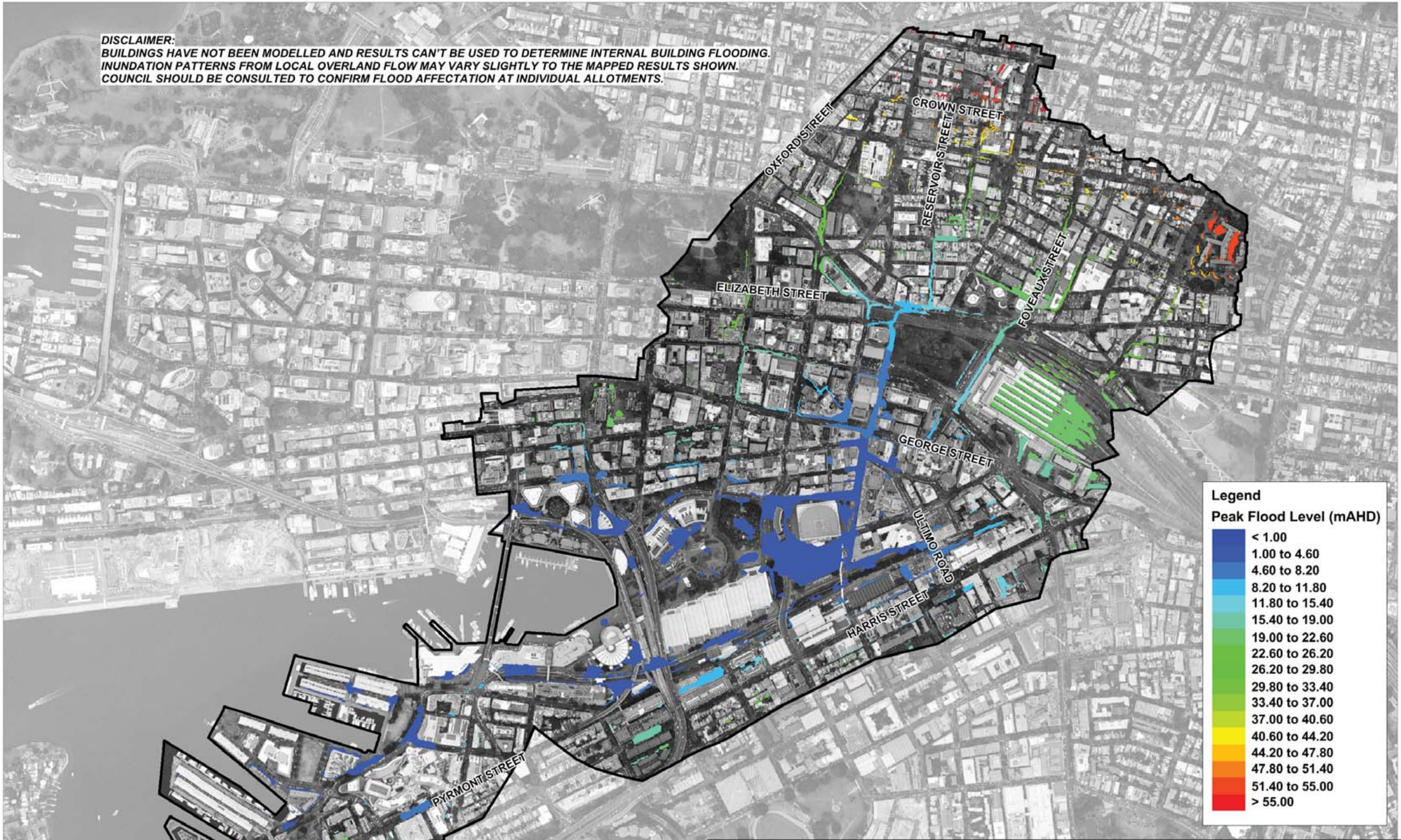

Title:
Peak Flood Level
10% AEP (10 yr ARI)

Figure: **A-11**

Rev: **-**

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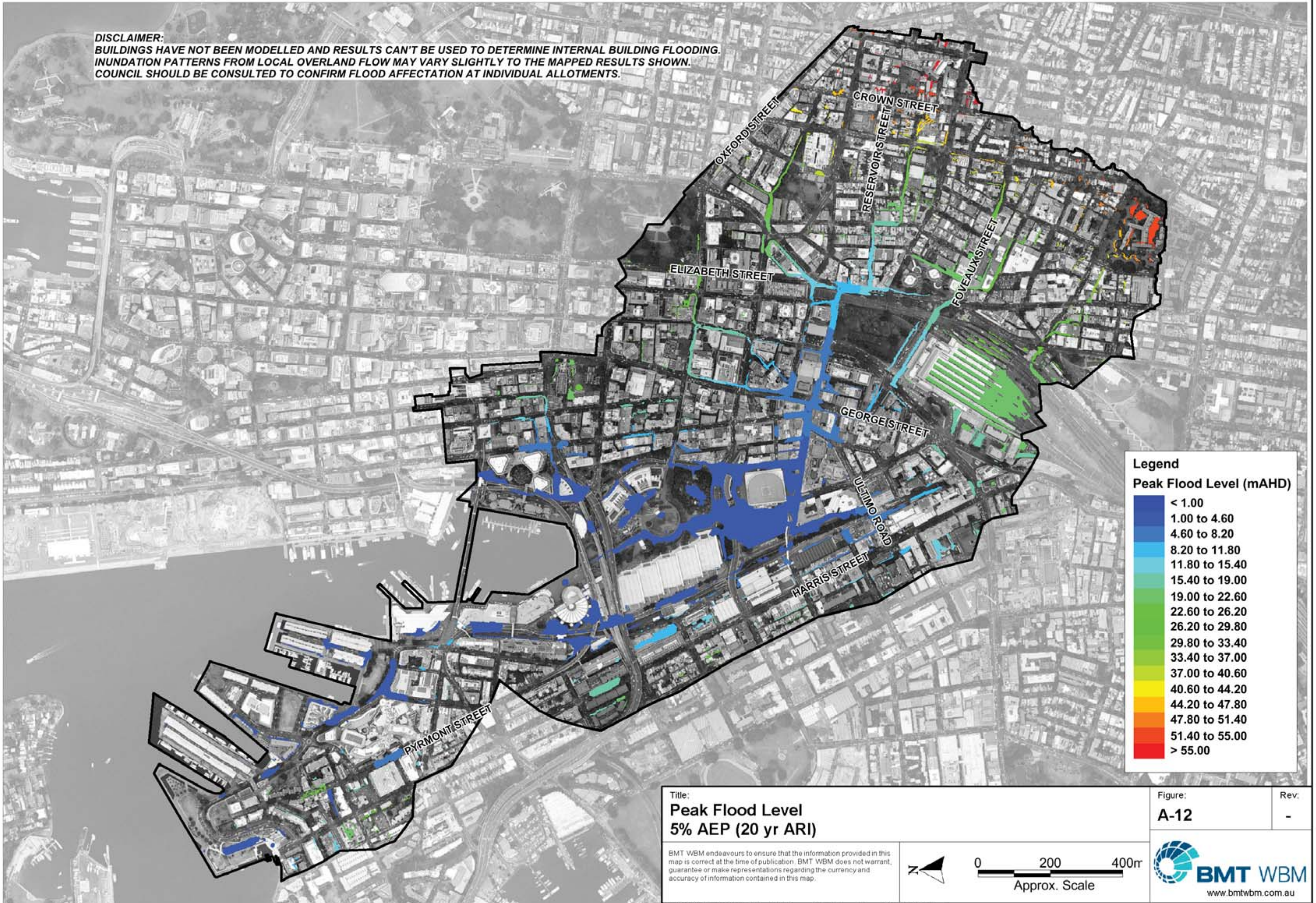
Filepath : S20012DraftingWORAppendixA_FiguresFigureA11_010YR_Level.wor



Title:
Peak Flood Level
5% AEP (20 yr ARI)

Figure: **A-12**

Rev: -

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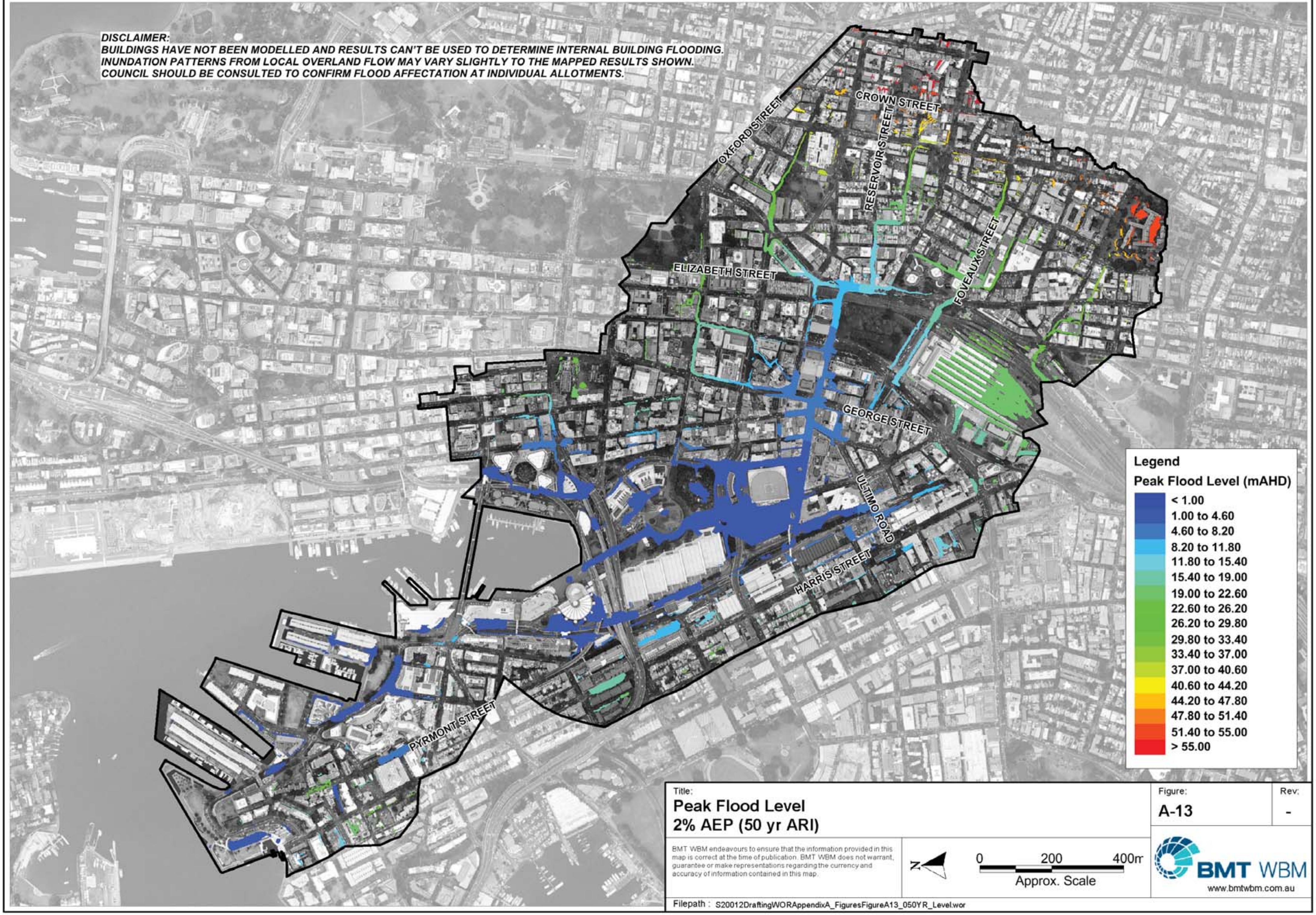
Filepath : S20012DraftingWORAppendixA_FiguresFigureA12_020YR_Level.wor



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

Figure: A-13

Rev: -

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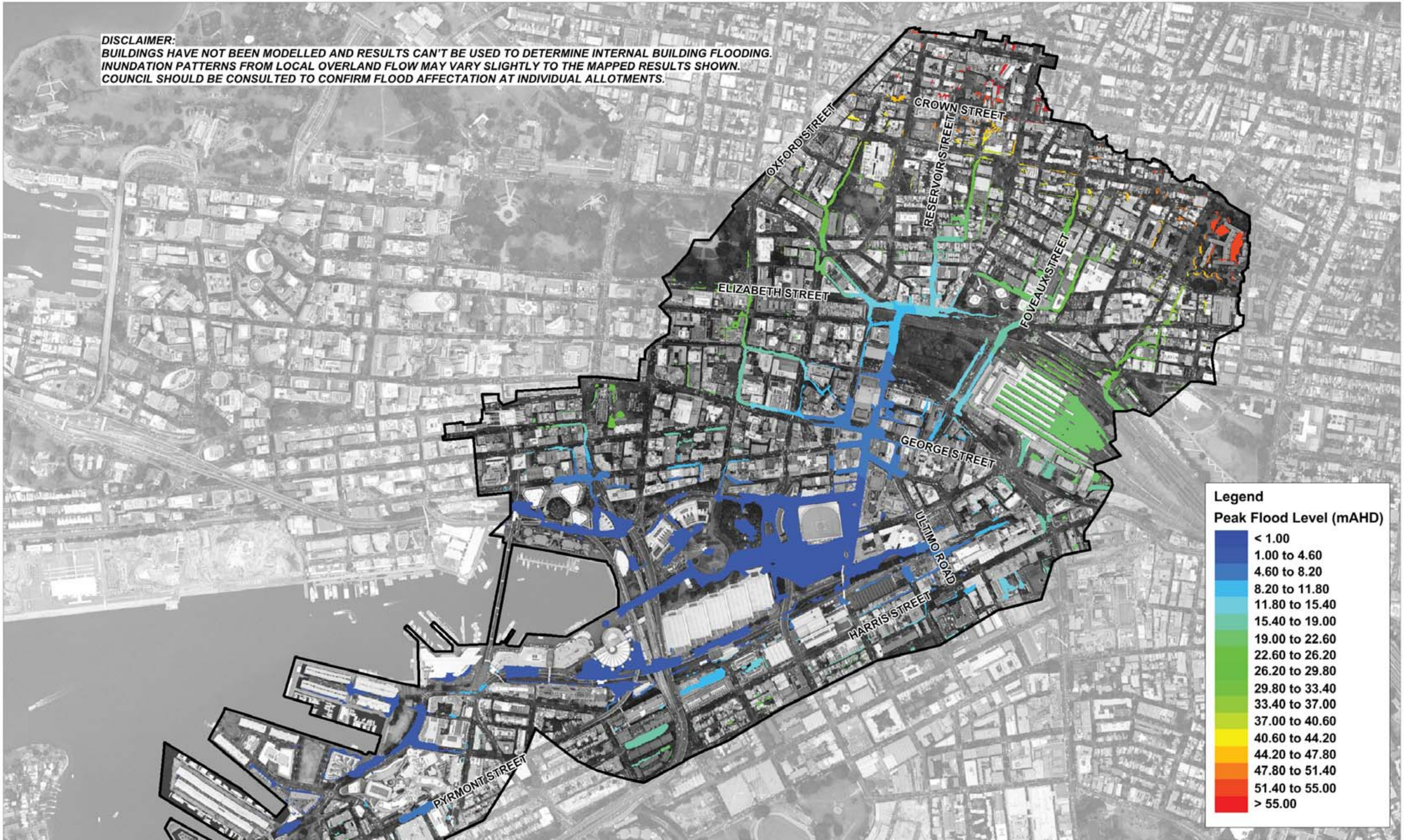

Title:
Peak Flood Level
1% AEP (100 yr ARI)

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N

0 200 400m
Approx. Scale

Figure: A-14

Rev: -

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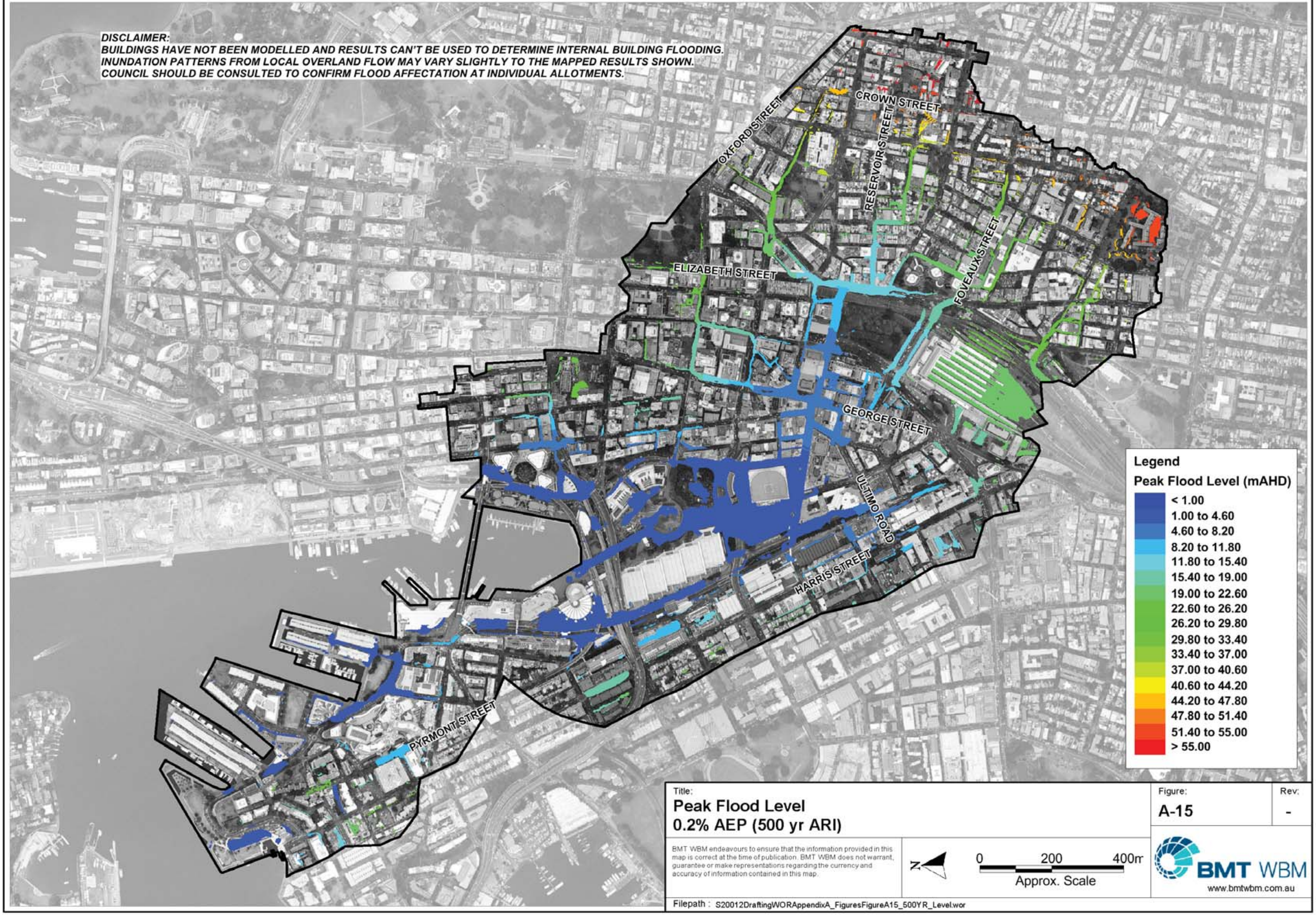
COUNCIL SHOULD BE CONSULTED TO CONFIRM FLOOD AFFECTATION AT INDIVIDUAL ALLOTMENTS.



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

Figure: A-15

Rev: -

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