7. CALIBRATION

7.1. Overview

The Woolloomooloo catchment has experienced a number of large changes throughout its recent history. These include installation of large trunk drainage culverts in 1987 extending from Palmer Street to Woolloomooloo Bay and the recent construction of the Eastern Distributor in 1997, which has altered the catchment response significantly.

Historic flood levels at 60-72 Sir John Young Crescent and 24 Crown Street are affected by the construction of the Eastern Distributor to the east, changes to Sir John Young Crescent and recent construction works (currently being undertaken in 2012) within 60-72 Sir John Young Crescent, which used to be a car park of the old Sydney Eye Hospital prior to 1995.

Construction of the SWC Western Main Drain In 1987 has also increased drainage capacity in the lower reaches of the catchment and will have an effect on all locations with recorded flood levels.

The Eastern Distributor was completed in 1997 and overland flow which would have otherwise contributed to flooding within the most downstream areas of the catchment such as the Bourke Street low point are now routed through the Cowper Wharf underpass. Photo 12 shows the Cahill Expressway in 1978 prior to construction of the Eastern Distributor, with aerial photography taken in June 1983 shown in Photo 13. Photo 14 shows the Cahill Expressway and Eastern Distributor in October 2012 with the Eastern Distributor raised significantly above previous road levels.

Photo 12: 1978 with 1-7 Bourke Street seen top at right and The Domain on the left.

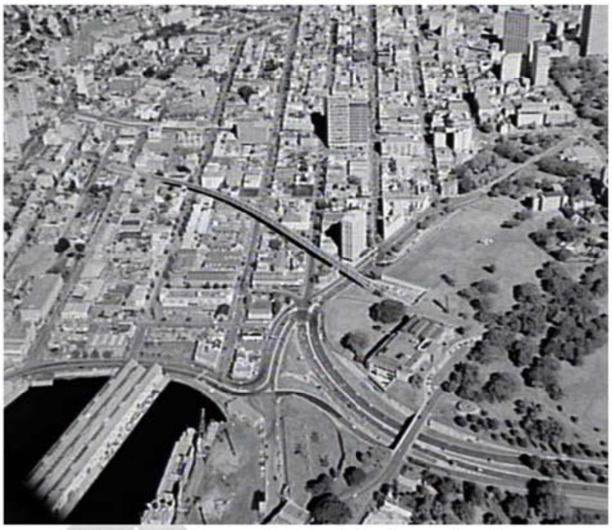


Photo 13: June 1983 Aerial photo showing Woolloomooloo Bay, Cahill Expressway

Photo 14: September 2012 looking north towards Eastern Distributor

Given that the many of historic flood levels recorded in the catchment were surveyed prior to 1987 and the many changes to the catchment since that time, the historical data prior to the year 2000 mentioned in Section 3.6 are of little value for use in calibration.

As a result of catchment changes, very limited calibration data is available and what calibration is available will need to be supplemented with model verification.

7.2. Calibration – 12 February 2010 Event

The February 2010 rainfall event had a recurrence interval of approximately 20 years and consisted of short burst rainfall over a 30 minute period, typical of that required to cause flooding within the Woolloomooloo catchment. Two flood marks were recorded for the event along with anecdotal information.

The flood event occurred at between 11:00pm and 12:00am on 12/13 February 2010. Given the event occurred at night, there were no photographs of flooding and levels recorded were based upon water marks and mud marks the next morning. A comparison of modelled peak flood levels for the 12/13 February 2010 event against recorded levels is made in Table 17 and on Figure 12.

Table 17 –12 February 2010 Flood Levels – Modelled vs Recorded

Location	Date	Observed Level (mAHD)	Modelled Level (mAHD)
18 Crown Street	regularly	4.2	4.4
108 Cathedral Street	12/2/2010	3.9	4.3
123 Victoria Street	12/2/2010	30.5	30.5

Flood levels taken at 18 Crown Street and 108 Cathedral Street are affected by flooding in the Crown Street low point. In order for excess water to exit the low point it must pass through Bossley Terrace which has a crest elevation of 3.8 mAHD.

The timing of the flood event means there is some uncertainty with regards to recorded flood levels. Model sensitivity to the width of the overland flow path through Bossley Terrace, hydrologic flows and assumptions regarding the construction site at 60-72 Sir John Young Crescent were investigated and it was found that the representation of the crest elevation and width of the overland flow path along Bossley Terrace had the most significant effect on flood levels within the Crown Street low point.

Given the uncertainty of the recorded flood levels, the limited accuracy of the LiDAR survey, the resolution of the hydraulic model and the low flood depths involved, the precision required in this area of the model is outside of the bounds of uncertainty of the hydraulic modelling and no further adjustments to the hydraulic model were made.

7.3. Model Verification

Given the limited calibration data, verification of modelled results was necessary. Recorded flood levels in Table 18 have been assessed and compared against design flood levels.

Table 18 – Comparison of Recorded Flood Levels against Design Flood Levels

Location	Date	Observed Level (mAHD)	Modelled Flood Level (mAHD)			
			2Y ARI	10Y ARI	20Y ARI	100Y ARI
10 Bourke Street	5/8/1986	2.1	1.5	1.7	2.1	2.3
12 Bourke Street	5/8/1986	2.0	1.5	1.7	2.1	2.3
60-72 Sir John Young Crescent	5/8/1986	4.0	4.1	4.3	4.4	4.8
24 Crown Street	5/8/1986	4.0	4.1	4.3	4.4	4.8
18 Crown Street	Regularly	4.2	4.1	4.3	4.4	4.8
108 Cathedral Street	12/2/2010	3.9	4.1	4.3	4.4	4.7
137 Victoria Street	14/6/2007	30.7	30.6	30.7	30.7	30.7
123 Victoria Street	12/2/2010	30.5	30.5	30.5	30.6	30.6

The location at which the flood level at 60-72 Sir John Young Crescent for the 1986 event was surveyed is uncertain and therefore an accurate comparison to modelled results cannot be made. In general flood levels taken during the 1986 event are not comparable to current day conditions due to catchment changes.

Flood levels along Victoria Street were found to have little variation between events of different frequency of occurrence with 100 Year ARI flooding only causing marginally higher flood levels than that of a 2 Year ARI event. Modelled results compare well to observed flood behaviour and therefore results within this area of the catchment are considered robust.

Modelled peak flood levels near the Crown Street low point are generally higher compared to recorded levels, however as discussed previously there is some uncertainty in the underlying data.

8. DESIGN FLOOD MODELLING

8.1. Critical Duration

To determine the critical storm duration for various parts of the catchment, modelling of the 100 year ARI event was undertaken for a range of design storm durations from 15 minutes to 12 hours, using temporal patterns from Reference 2. An envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

It was found that the 60, 90 and 120 minute storms were critical for the majority of the catchment, with downstream areas near Bourke Road and Palmer Street having a critical duration of 60 minutes. The peak flood depths produced for these storm events were generally found to be within ±0.02 m throughout the catchment, with levels varying by ±0.02 near the Palmer Street depression and by ±0.01 m along Victoria Street. Given the small differences in peak flood levels, the 60 minute duration was taken to be the critical storm duration.

For the PMF event the critical duration was found to be 15 minutes for the upper areas of the catchment, with the 30 minute duration event critical for areas downstream of Cathedral Street. Flood levels vary by up to 0.2 m in areas where the 15 minute event is critical, whereas in the lower areas of the catchment where the 30 minute event dominates flood levels vary by 0.07 m between the two events. Due to these differences, a peak envelope of the 15 minute and 30 minute event was used to define the PMF flood extent.

8.2. Overview of Results

Design results are influenced by both rainfall driven events and ocean tailwater levels. For design events greater than 20 year ARI the adopted tailwater level generally reduces the pipe capacity within the study are due to backwater effects. Details of boundary condition assumptions with regards to ocean tailwater levels may be found in Section 6.5.

The results from this study are provided in the following forms:

- Peak flood depths and levels on Figure 13 to Figure 19,
- Provisional flood hazard on Figure 20 to Figure 23,
- Preliminary hydraulic categorisation on Figure 24 to Figure 27.

Results have been provided to Council in digital format compatible with Council's Geographic Information System (GIS).

8.3. Results at Key Locations

The results at key locations for peak flows, levels and depths are shown on Table 19 and Table 20 (refer to Figure 11 for locations).

Table 19 – Peak Flows (m^3/s) at Key Locations

ID	Location	Name	Type	2y ARI	5y ARI	10y ARI	20y ARI	50y ARI	100y ARI	PMF
1	Wiliam Street D/S Stream Street	WilliamParal	Overland	0.0	0.0	0.0	0.1	6.2	8.7	55.5
		pRS_015	Piped	0.0	0.0	0.0	0.0	0.0	0.1	0.1
		pWestMD_036	Piped	3.9	4.3	4.5	5.0	3.3	3.3	3.3
2	Crown Street D/S Cathedral Street	CrownSt_03	Overland	1.0	1.9	2.5	3.2	6.9	8.4	14.1
		pCrown_008	Piped	0.2	0.2	0.2	0.2	0.1	0.1	0.1
3	The Domain flow into Cahill Expressway	Domain_Out_01	Overland	0.0	0.0	0.0	0.1	0.1	0.1	0.3
		pDRAP15584B	Piped	0.3	0.5	0.6	0.7	0.9	1.0	1.6
		pDRAP15585	Piped	0.3	0.5	0.6	0.8	1.0	1.1	1.9
		pHR_011	Piped	0.5	0.6	0.7	0.8	0.9	0.9	1.4
4	Cowper Wharf Road D/S Eastern Distributor	Cowper01	Overland	0.4	0.9	1.3	2.1	3.1	3.7	23.0
		pHR_001	Piped	0.5	0.6	0.7	0.7	0.7	0.8	1.0
		pSJY_001	Piped	1.8	1.9	2.0	2.1	1.6	1.6	1.8
5	Bourke Street	Bourke	Overland	0.4	0.9	1.3	2.0	2.2	2.4	4.4
		pWestMD_001A	Piped	3.3	4.6	5.4	6.5	5.1	5.2	5.8
		pWestMD_001B	Piped	3.4	5.0	5.9	6.6	5.1	5.2	5.8
6	Forbes Street	Forbes	Overland	0.0	0.0	0.0	0.3	1.1	1.2	10.7
		pEastMC_004	Piped	3.3	4.0	4.3	4.4	3.3	3.4	4.0
		pDRAP13622	Piped	0.0	0.1	0.1	0.2	0.8	0.8	0.9
7	Dowling Street	Dowling_01	Overland	0.5	0.9	1.2	1.7	2.2	2.6	5.5
		pDRAP13611E	Piped	0.8	0.8	0.9	0.9	0.7	0.7	0.9
8	141 Victoria Street	Vic_01A	Overland	0.2	0.3	0.4	0.5	0.6	0.8	4.9
		pVic_022	Piped	0.2	0.2	0.2	0.2	0.2	0.2	0.2
9	Butlers Stairs	Butlers_W	Overland	0.0	0.0	0.0	0.0	0.0	0.0	1.2
10	Orwell Street	Orwell_001	Overland	0.4	0.6	0.7	1.0	1.4	1.5	5.7
		pDRAP14217	Piped	0.0	0.0	0.0	0.0	0.0	0.0	0.1
		pDRAP14216A	Piped	0.1	0.1	0.1	0.1	0.1	0.1	0.2
11	Hughes Street	HughesSt02	Overland.	0.3	0.3	0.4	0.5	0.5	0.6	3.4
12	102 Victoria Street	Vc001	Overland	0.7	1.1	1.3	1.4	1.6	1.8	6.3
		pDRAP14879A	Piped	0.3	0.3	0.3	0.3	0.3	0.3	0.3
13	75 Victoria Street	Vc002	Overland	0.6	1.4	1.7	2.1	2.5	2.8	10.9
		pVic_017	Piped	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		pDRAP14877A	Piped	0.6	0.6	0.6	0.6	0.5	0.5	0.6
14	Victoria Street U/S McElhone Stairs	Vic_004	Overland	0.7	1.5	1.9	2.3	2.8	3.1	12.6
		pVic_016	Piped	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		pDRAP14269	Piped	0.6	0.6	0.6	0.7	0.6	0.6	0.6

Table 20 – Peak Flood Levels (mAHD) and Depths (m) at Key Locations

ID	Location	2 year ARI		5 year ARI		10 year ARI		20 year ARI		50 year ARI		100 year ARI		PMF	
		Level	Depth	Level	Depth	Level	Depth	Level	Depth	Level	Depth	Level	Depth	Level	Depth
1	Francis Street	16.8	0.2	17.0	0.4	17.1	0.5	17.2	0.5	17.2	0.6	17.3	0.6	17.5	0.9
2	Francis Lane	15.3	0.4	15.9	1.1	16.4	1.6	16.5	1.7	16.7	1.9	16.7	1.9	17.2	2.3
3	Yurong Lane	10.7	0.8	11.8	1.9	12.3	2.4	12.9	3.0	13.2	3.3	13.3	3.4	14.1	4.2
4	Busby Lane	7.0	0.9	7.1	1.0	7.1	1.0	7.2	1.0	7.4	1.2	7.4	1.3	8.3	2.1
5	Crown Street	4.1	0.5	4.2	0.6	4.3	0.7	4.4	0.8	4.7	1.1	4.7	1.2	5.6	2.0
6	Palmer Street	2.5	0.4	2.7	0.5	2.7	0.6	2.8	0.7	3.4	1.2	3.4	1.3	3.8	1.7
7	Cowper Wharf Road underpass	2.7	0.4	2.8	0.5	2.8	0.6	2.9	0.6	2.9	0.7	3.0	0.7	3.5	1.3
8	Bourke Street	1.5	0.1	1.6	0.2	1.7	0.3	2.1	0.7	2.3	0.9	2.3	0.9	2.8	1.4
9	The Domain	19.1	0.2	19.2	0.3	19.2	0.3	19.2	0.4	19.3	0.4	19.3	0.4	20.2	1.3
10	137 Victoria Street	30.5	0.2	30.5	0.2	30.6	0.3	30.6	0.3	30.7	0.4	30.7	0.4	31.1	0.8

8.4. Provisional Flood Hazard and Preliminary Hydraulic Categorisation

Maps of provisional hydraulic hazard are presented on Figure 20 and Figure 23. Hazard categories were determined in accordance with Appendix L of the NSW Floodplain Development Manual (Reference 11).

Preliminary hydraulic categorisations for the 10, 20, 100 year ARI and PMF events are provided on Figure 24 to Figure 27. There is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study catchment in question.

For this study, hydraulic categories were defined by the following criteria:

- Floodway is defined as areas where:
    - the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s **AND** peak velocity > 0.25 m/s, **OR**
    - peak velocity > 1.0 m/s **AND** peak depth > 0.15m

  The remainder of the floodplain is either Flood Storage or Flood Fringe,
- Flood Storage comprises areas outside the Floodway where peak depth is > 0.5 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth is < 0.5 m.

8.5. Preliminary Flood ERP Classification of Communities

The Floodplain Development Manual, 2005 (Reference 11) requires flood studies to address the management of continuing flood risk to both existing and future development areas. As continuing flood risk varies across the floodplain so does the type and scale of emergency response problem and therefore the information necessary for effective Emergency Response Planning (ERP). Classification provides an indication of the vulnerability of the community in flood emergency response and identifies the type and scale of information needed by the SES to assist in emergency response planning (ERP).
action can be taken prior to the flood.

Table 21: Response Required for Different Flood ERP Classifications

Classification	Response Required		
	Resupply	Rescue/Medivac	Evacuation
High Flood Island	Yes	Possibly	Possibly
Low Flood Island	No	Yes	Yes
Area with Rising Road Access	No	Possibly	Yes
Areas with Overland Escape Routes	No	Possibly	Yes
Low Trapped Perimeter	No	Yes	Yes
High Trapped Perimeter	Yes	Possibly	Possibly
Indirectly Affected Areas	Possibly	Possibly	Possibly

Table 21 (taken from Reference 12) provides an indication of the response required for areas with different classifications. However, these may vary depending on local flood characteristics and resultant flood behaviour i.e. in flash flooding or overland flood areas. The criteria for classification of floodplain communities outlined in Reference 12 are generally more applicable to riverine flooding where significant flood warning time is available and emergency response.

In urban areas like the Woolloomooloo catchment, flash flooding from local catchment and overland flow will generally occur as a direct response to intense rainfall without significant warning. At most (if not all) flood affected properties in the catchment, remaining inside the home or building is likely to present less risk to life than attempting to drive or wade through floodwaters, as flow velocities and depths are likely to be greater in the roadway.

ERP Classification for the Woolloomooloo catchment is shown on Figure 28. Areas near the Stream Street low point have been classified as low flood island due to the very high depths in the road in more frequent events. Other areas have been classified as high flood island as they are only isolated in PMF flooding.

9. SENSITIVITY ANALYSIS

9.1. Overview

Due to lack of historical data suitable for undertaking a thorough model calibration, a number of assumptions have been made for the selection of the design approach/parameters, primarily relying on default parameter values or values used in similar (and proximate) studies. The following sensitivity analyses were undertaken for the 100y ARI event to establish the variation in design flood level that may occur if different assumptions were made:

- Routing Lag: The hydrologic routing length values were adjusted by ± 20% for all sub-catchments;
- Manning's "n": The roughness values were increased and decreased by 20% within areas of overland flow;
- Inflows / Climate Change: Sensitivity to rainfall/runoff estimates was assessed by increasing the rainfall intensity by 10%, and
- Pipe Blockage: Sensitivity of blocking all pipes by 50% was considered.

9.2. Results of Sensitivity Analyses

Table 23 and Table 22 provide a summary of peak flood level and flow changes at various locations for the sensitivity scenarios. Overall results were shown to be relatively insensitive to routing, roughness and blockage with results tending to be within ± 0.2 m which can generally be accommodated within the freeboard (typically 0.5 m) applied to the 100 year ARI results to determine the Flood Planning Levels.

The sensitivity testing thus provides confidence that as long as the model emulates ground conditions and hydraulic structures, within a range of typical values for parameters, the model will produce accurate and reliable design flood levels.

Table 22 – Results of Sensitivity Analyses – 100 Year ARI Event Depths (m)

ID	Location	100 Year ARI Peak Flood Depth (m)	Decrease in routing by 20%	Increase in routing by 20%	Roughness decreased by 20%	Roughness increased by 20%	Increase in rainfall by 10%	Pipe Blockage 50%
			Difference with 100 Year ARI base case (m)					
1	Francis Street	0.6	-	-	-	-	0.02	-0.02
2	Francis Lane	1.9	-	-	-0.02	0.02	0.03	-
3	Yurong Lane	3.4	-	-	-	-	0.06	0.02
4	Busby Lane	1.3	-	-	-	-	0.07	0.02
5	Crown Street	1.2	-	-	-	-	0.07	0.02
6	Palmer Street	1.3	-	-	-	-0.02	0.04	0.04
7	Cowper Wharf Road underpass	0.7	-	-	0.14	-	0.03	0.04
8	Bourke Street	0.9	-	-	-	-	0.03	0.03
9	The Domain	0.4	-	-	-	-	0.03	0.07
10	137 Victoria Street	0.4	-	-	-	-	0.02	-

Table 23 – Results of Sensitivity Analyses – 100 Year ARI Event Flows (m^3/s)

ID	Location	Name	Type	100 Year ARI Peak Flood Flow (m^3/s)	Decrease in routing by 20%	Increase in routing by 20%	Roughness decreased by 20%	Roughness increased by 20%	Increase in rainfall by 10%	Pipe Blockage 50%
					Difference with 100 Year ARI base case (m^3/s)					
1	Wiliam Street D/S Stream Street	WilliamParal	Overland	8.7	0.07 (1%)	-0.10 (-1%)	0.19 (2%)	-0.27 (-3%)	2.37 (27%)	0.88 (10%)
		pRS_015	Piped	0.1	0.00 (3%)	0.00 (-4%)	0.00 (-1%)	0.00 (0%)	0.03 (28%)	-0.04 (-41%)
		pWestMD_036	Piped	3.3	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	-0.33 (-10%)
2	Crown Street D/S Cathedral Street	CrownSt_03	Overland	8.4	0.04 (1%)	-0.06 (-1%)	-0.24 (-3%)	0.05 (1%)	1.12 (13%)	0.36 (4%)
		pCrown_008	Piped	0.1	0.00 (-1%)	0.00 (1%)	-0.01 (-4%)	0.01 (4%)	0.00 (-1%)	-0.08 (-55%)
3	The Domain flow into Cahill Expressway	Domain_Out_01	Overland	0.1	-0.02 (-19%)	-0.01 (-15%)	0.01 (13%)	-0.02 (-20%)	0.04 (41%)	0.00 (0%)
		pDRAP15584B	Piped	1.0	0.02 (2%)	-0.03 (-3%)	0.00 (0%)	0.01 (1%)	0.10 (10%)	-0.32 (-32%)
		pDRAP15585	Piped	1.1	0.02 (2%)	-0.03 (-3%)	-0.01 (-1%)	0.01 (1%)	0.13 (11%)	-0.33 (-30%)
		pHR_011	Piped	0.9	0.01 (1%)	-0.01 (-1%)	-0.07 (-7%)	0.04 (5%)	0.06 (6%)	-0.28 (-30%

ID	Location	Name	Type	100 Year ARI Peak Flood Flow (m^3/s)	Decrease in routing by 20%	Increase in routing by 20%	Roughness decreased by 20%	Roughness increased by 20%	Increase in rainfall by 10%	Pipe Blockage 50%
					Difference with 100 Year ARI base case (m^3/s)					
4	Cowper Wharf Road D/S Eastern Distributor	Cowper01	Overland	3.7	0.09 (2%)	-0.06 (-2%)	0.16 (4%)	-0.15 (-4%)	0.67 (18%)	0.86 (23%)
		pHR_001	Piped	0.8	0.01 (1%)	-0.01 (-1%)	-0.05 (-7%)	0.04 (5%)	0.05 (6%)	-0.30 (-37%)
		pSJY_001	Piped	1.6	0.00 (0%)	0.00 (0%)	0.01 (0%)	-0.02 (-1%)	0.03 (2%)	-0.87 (-54%)
5	Bourke Street	Bourke	Overland	2.4	0.06 (3%)	-0.11 (-5%)	-0.02 (-1%)	-0.07 (-3%)	0.18 (7%)	0.00 (0%)
		pWestMD_001A	Piped	5.2	0.00 (0%)	0.00 (0%)	0.00 (0%)	-0.01 (0%)	0.06 (1%)	-0.24 (-5%)
		pWestMD_001B	Piped	5.2	0.00 (0%)	0.00 (0%)	0.00 (0%)	-0.01 (0%)	0.07 (1%)	-1.18 (-23%)
6	Forbes Street	Forbes	Overland	1.2	0.00 (0%)	0.01 (0%)	0.08 (6%)	-0.06 (5%)	0.31 (25%)	0.06 (5%)
		pEastMC_004	Piped	3.4	0.00 (0%)	0.00 (0%)	-0.01 (0%)	0.02 (1%)	0.08 (2%)	-0.56 (-17%)
		pDRAP13622	Piped	0.8	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	-0.43 (-55%)
7	Dowling Street	Dowling_01	Overland	2.6	0.00 (0%)	-0.01 (0%)	0.17 (7%)	-0.05 (-2%)	0.40 (15%)	0.32 (12%)
		pDRAP13611E	Piped	0.7	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.01 (2%)	-0.20 (-28%)
8	141 Victoria Street	Vic_01A	Overland	0.8	0.01 (1%)	-0.01 (-1%)	0.02 (2%)	-0.02 (-3%)	0.09 (12%)	0.01 (1%)
		pVic_022	Piped	0.2	0.00 (0%)	0.00 (0%)	0.00 (1%)	0.00 (1%)	0.00 (0%)	-0.11 (-58%)
9	Butlers Stairs	Butlers_W	Overland	0.0	0.00 (10%)	0.00 (-14%)	-0.01 (-62%)	0.01 (67%)	0.03 (124%)	0.01 (38%)
10	Orwell Street	Orwell_001	Overland	1.5	0.01 (1%)	-0.03 (-2%)	0.13 (9%)	-0.01 (-1%)	0.22 (15%)	0.04 (3%)
		pDRAP14217	Piped	0.0	0.00 (0%)	0.00 (0%)	0.00 (-7%)	0.00 (7%)	0.00 (11%)	0.01 (52%)
		pDRAP14216A	Piped	0.1	0.00 (0%)	0.00 (0%)	0.00 (-1%)	0.00 (1%)	0.00 (1%)	-0.04 (-39%)
11	Hughes Street	HughesSt02	Overland.	0.6	0.00 (0%)	-0.01 (-2%)	0.02 (4%)	0.00 (0%)	0.04 (7%)	-0.01 (-1%)
12	102 Victoria Street	Vc001	Overland	1.8	0.02 (1%)	-0.02 (-1%)	0.08 (5%)	-0.11 (-6%)	0.12 (7%)	0.03 (2%)
		pDRAP14879A	Piped	0.3	0.00 (0%)	0.00 (0%)	0.00 (1%)	0.00 (0%)	0.00 (1%)	-0.15 (53%)
13	75 Victoria Street	Vc002	Overland	2.8	0.01 (0%)	-0.08 (-3%)	0.16 (6%)	-0.17 (-6%)	0.26 (9%)	0.18 (6%)
		pVic_017	Piped	0.2	0.00 (0%)	0.00 (0%)	0.00 (-1%)	0.00 (1%)	0.00 (0%)	-0.11(-56%)
		pDRAP14877A	Piped	0.5	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	-0.31 (-58%)
14	Victoria Street U/S McElhone Stairs	Vic_004	Overland	3.1	0.09 (3%)	0.04 (1%)	0.16 (5%)	-0.09 (-3%)	0.43 (14%)	0.36 (11%)
		pVic_016	Piped	0.2	0.00 (0%)	0.00 (0%)	0.00 (-1%)	0.00 (1%)	0.00 (0%	-0.11 (-56%)
		pDRAP14269	Piped	0.6	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (1%)	0.00 (0%)	-0.34 (-56%)

9.3. Climate Change

9.3.1. Rainfall Increase

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even a similar magnitude decrease); however this information is not of sufficient accuracy for use as yet (Reference 13).

Any change in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation (IPO) index (Reference 14). Although mean daily rainfall intensity is not observed to differ significantly between IPO phases, runoff is significantly reduced during periods with fewer rain days. Although given high levels of urbanisation of the study catchment, any such impact will be minimal.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the Woolloomooloo catchment under warmer climate scenarios.

In light of this uncertainty, the NSW State Government advice (Reference 13) recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

9.3.2. Sea Level Rise

In October 2009 the NSW Government issued its Policy Statement on Sea Level Rise (Reference 15) which states"

"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed.

Sea level rise is an incremental process and will have medium to long-term impacts. The best national and international projections of sea level rise along the NSW coast are for a rise relative to 1990 mean sea levels of 40 cm by 2050 and 90 cm by 2100. However, the 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible";

In August 2010, the former NSW Department of Environment, Climate Change and Water issued the:

- Flood Risk Management Guide (Reference 8): Incorporating sea level rise benchmarks in flood risk assessments.

In addition an accompanying document *Derivation of the NSW Government's sea level rise planning benchmarks* provided technical details on how the sea level rise assessment was undertaken.

Although there are some minor variations in the sea levels predicted in these studies, policies, and guides, they all agree on an ocean level rise on the NSW coast of around 0.9 metre by the year 2100 relative to 1990 levels.

The previous guideline, the NSW Sea Level Rise Policy Statement (2010) (Reference 15) and associated guides, indicated a metre sea level rise by the year 2100 and a 0.4 metre rise by the year 2050. It should be noted that climate change and the associated rise in sea levels will continue beyond 2100. Recent changes have NSW State Government endorsement of sea level rise predictions. Unless specific Councils adopt an alternative policy, predicted sea level rises as per NSW 2010 will continue to be used.

9.3.3. Results

The effect of increasing the design rainfalls by 10%, 20% and 30% has been evaluated for the 100 year ARI event; resulting in a relatively significant impact on peak flood levels in the study area. Generally speaking, each incremental 10% increase in flow results in a 0.1 m to 0.2 m increase in peak flood levels at most of the locations analysed.

The 100 year ARI event with a rainfall increase of 30% is approximately equivalent to a 500 year ARI event in present day conditions and an impact on flood levels particularly in flow paths/storage areas is not unexpected.

Sea level rise scenarios have very little impact on flood levels within the catchment except for within Bourke Street where a 0.9 m sea level increase by 2100 will increase peak flood levels by 0.1m.

Table 24 and Table 25 show the change in peak flows and flood levels due to the effect of climate change induced rainfall increases and sea level rise.

Table 24 – Results of Climate Change Analyses – 100 Year ARI Event Depths (m)

ID	Location	100 Year ARI Peak Flood Flow (m^3/s)	Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	2050 Sea Level +0.4 m	2100 Sea Level +0.9 m
			Difference with 100 Year ARI Base Case (m^3/s)				
1	Francis Street	0.6	0.02	0.03	0.04	-	-
2	Francis Lane	1.9	0.03	0.06	0.08	-	-
3	Yurong Lane	3.4	0.06	0.12	0.17	-	-
4	Busby Lane	1.3	0.07	0.12	0.19	-	-
5	Sir John Young Crescent	1.2	0.07	0.12	0.17	-	-
6	Palmer Street	1.3	0.04	0.07	0.11	-	0.02
7	Cowper Wharf Road underpass	0.7	0.03	0.07	0.10	-	-
8	Bourke Street	0.9	0.03	0.06	0.09	0.05	0.13
9	The Domain	0.4	0.03	0.06	0.09	-	-
10	137 Victoria Street	0.4	0.02	0.05	0.07	-	-

Table 25 – Results of Climate Change Analyses – 100 Year ARI Event Flows (m^3/s)

ID	Location	Name	Type	100 Year ARI Peak Flood Flow (m^3/s)	Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	2050 Sea Level +0.4 m	2100 Sea Level +0.9 m
					Difference with 100 Year ARI Base Case (m)				
1	Wiliam Street D/S Stream Street	WilliamParal	Overland	8.7	2.37 (27%)	5.06 (58%)	7.64 (88%)	0.01 (0%)	0.00 (0%)
		pRS_015	Piped	0.1	0.03 (28%)	0.03 (30%)	0.03 (28%)	0.00 (0%)	0.00 (0%)
		pWestMD_036	Piped	3.3	0.00 (0%)	0.00 (0%)	0.01 (0%)	0.00 (0%)	0.00 (0%)
2	Crown Street D/S Cathedral Street	CrownSt_03	Overland	8.4	1.12 (13%)	2.14 (26%)	2.90 (35%)	0.01 (0%)	0.01 (0%)
		pCrown_008	Piped	0.1	0.00 (-1%)	0.00 (-1%)	0.00 (-1%)	0.00 (0%)	0.00 (-3%)
3	The Domain flow into Cahill Expressway	Domain_Out_01	Overland	0.1	0.04 (41%)	0.01 (13%)	0.03 (36%)	0.00 (0%)	0.00 (0%)
		pDRAP15584B	Piped	1.0	0.10 (10%)	0.19 (19%)	0.27 (27%)	0.00 (0%)	0.00 (0%)
		pDRAP15585	Piped	1.1	0.13 (11%)	0.23 (20%)	0.33 (29%)	0.00 (0%)	0.00 (0%)
		pHR_011	Piped	0.9	0.06 (6%)	0.11 (12%)	0.15 (16%)	0.00 (0%)	0.00 (0%)
4	Cowper Wharf Road D/S Eastern Distributor	Cowper01	Overland	3.7	0.67 (18%)	1.36 (37%)	2.09 (57%)	0.06 (2%)	0.33 (9%)
		pHR_001	Piped	0.8	0.05 (6%)	0.10 (12%)	0.14 (17%)	0.00 (0%)	0.00 (0%)
		pSJY_001	Piped	1.6	0.03 (2%)	0.06 (4%)	0.08 (5%)	-0.19 (-12%)	-0.47 (-30%)
5	Bourke Street	Bourke	Overland	2.4	0.18 (7%)	0.36 (15%)	0.53 (22%)	-0.81 (-34%)	-2.39 (-100%)
		pWestMD_001A	Piped	5.2	0.06 (1%)	0.12 (2%)	0.16 (3%)	-0.79 (-15%)	-2.07 (-40%)
		pWestMD_001B	Piped	5.2	0.07 (1%)	0.13 (3%)	0.18 (4%)	-0.87 (-17%)	-2.30 (-44%)
6	Forbes Street	Forbes	Overland	1.2	0.31 (25%)	0.76 (61%)	1.25 (101%)	0.46 (37%)	2.14 (173%)
		pEastMC_004	Piped	3.4	0.08 (2%)	0.15 (5%)	0.21 (6%)	-0.57 (-17%)	-1.45 (173%)
		pDRAP13622	Piped	0.8	0.00 (0%)	0.00 (0%)	0.00 (0%)	-0.23 (-29%)	-0.49 (-62%)
7	Dowling Street	Dowling_01	Overland	2.6	0.40 (15%)	0.76 (29%)	1.02 (39%)	-0.05 (-2%)	-2.50 (-96%)
		pDRAP13611E	Piped	0.7	0.01 (2%)	0.03 (4%)	0.04 (6%)	-0.12 (-16%)	-0.32 (-44%)

ID	Location	Name	Type	100 Year ARI Peak Flood	Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	2050 Sea Level +0.4 m	2100 Sea Level +0.9 m
8	141 Victoria Street	Vic_01A	Overland	0.8	0.09 (12%)	0.28 (38%)	0.39 (52%)	0.00 (0%)	0.00 (0%)
		pVic_022	Piped	0.2	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
9	Butlers Stairs	Butlers_W	Overland	0.0	0.03 (124%)	0.06 (290%)	0.09 (433%)	0.00 (0%)	0.00 (0%)
10	Orwell Street	Orwell_001	Overland	1.5	0.22 (15%)	0.37 (25%)	0.55 (37%)	0.04 (3%)	-0.01 (0%)
		pDRAP14217	Piped	0.0	0.00 (11%)	0.01 (19%)	0.01 (30%)	0.00 (0%)	0.00 (0%)
		pDRAP14216A	Piped	0.1	0.00 (1%)	0.00 (2%)	0.00 (3%)	0.00 (0%)	0.00 (0%)
11	Hughes Street	HughesSt02	Overland.	0.6	0.04 (7%)	0.14 (23%)	0.22 (36%)	-0.01 (0%)	0.00 (0%)
12	102 Victoria Street	Vc001	Overland	1.8	0.12 (7%)	0.25 (14%)	0.38 (21%)	0.00 (0%)	0.00 (0%)
		pDRAP14879A	Piped	0.3	0.00 (1%)	0.00 (1%)	0.00 (1%)	0.00 (0%)	0.00 (0%)
13	75 Victoria Street	Vc002	Overland	2.8	0.26 (9%)	0.54 (19%)	0.88 (31%)	-0.03 (-1%)	-0.05 (-2%)
		pVic_017	Piped	0.2	0.00 (0%)	0.00 (1%)	0.01 (2%)	0.00 (0%)	0.00 (0%)
		pDRAP14877A	Piped	0.5	0.00 (0%)	0.00 (1%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
14	Victoria Street U/S McElhone Stairs	Vic_004	Overland	3.1	0.43 (14%)	0.72 (23%)	1.10 (35%)	0.01 (0%)	0.07 (2%)
		pVic_016	Piped	0.2	0.00 (0%)	0.00 (1%)	0.00 (2%)	0.00 (0%)	0.00 (0%)
		pDRAP14269	Piped	0.6	0.00 (1%)	0.00 (1%)	0.00 (0%)	0.00 (1%)	0.00 (0%)

10. DAMAGES ASSESSMENT

The cost of flood damages and the extent of the disruption to the community depend upon many factors including:

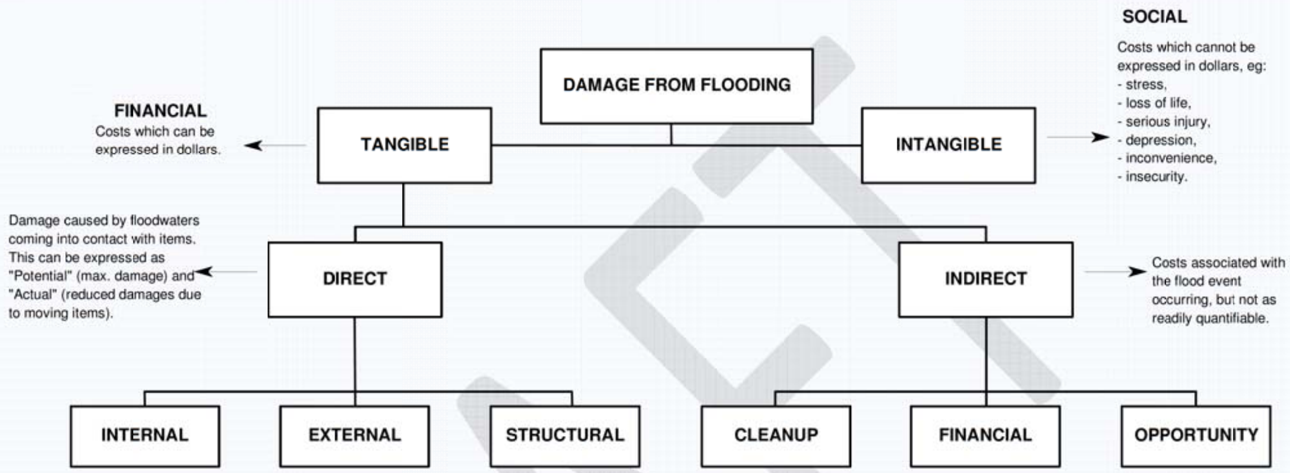
- the magnitude (depth, velocity and duration) of the flood,
- land usage and susceptibility to damage,
- awareness of the community to flooding,
- effective warning time,
- the availability of an evacuation plan or damage minimisation program,
- physical factors such as failure of services (pits and pipes), flood borne debris, sedimentation, and
- the types of asset and infrastructure affected.

The estimation of flood damages tends to focus on the physical impact of damages on the human environment but there is also a need to consider the ecological cost and benefits associated with flooding. Flood damages can be defined as being tangible or intangible. Tangible damages are those to which a monetary value cannot easily be attributed. Types of flood damages are shown on Table 26.

While the total likely damages in a given flood are useful to get a “feel” for the magnitude of the flood problem, it is of little value for absolute economic evaluation. When considering the economic effectiveness of a proposed mitigation measure, the key question is what are the total damages prevented over the life of the measure? This is a function not only of the high damages which occur in large floods but also of the lesser but more frequent damages which occur in small floods.

The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by taking into the account the probability of a flood occurrence. By this means, the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

Table 26 – Breakdown of Flood Damages Categories



	INTERNAL	EXTERNAL	STRUCTURAL	CLEANUP	FINANCIAL	OPPORTUNITY
RESIDENTIAL	Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances	External Items: Vehicles, Laundries, Caravans, Sheds, Tools, Gardens, Fences	Physical Damage to Buildings: Gyprock, Cupboards, Scour of Footings, Houses becoming buoyant (floating off footings)	Clean Carpets, Walls, Clothes; Re-instate Furniture; Remove Mud and Debris	Loss of wages, Living costs (temporary accomodation and food), Time to repair/replace damaged items	Not Applicable
RURAL	Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances	External Items: Vehicles, Sheds (stables/barns), Machinery, Tools, Fences, Feed storage, Saddles, Crops &/or Stock, Irrigation Systems	Physical Damage to Structures: Damage to Homestead, Sheds, Access tracks, Protection levees	Clean Homestead and Out-buildings; Remove Debris; Dispose of affected crops &/or stock	Loss of Farm Production and Income, Re-instatement of Pastures, Supplementary feeding of stock (by hand or outside agistment), Stock movement/ transport, Living costs (temporary accomodation and food)	Sowing or harvesting of Crops, Sale of Stock (at depreciated value or dependent on market influences)
COMMERCIAL	Contents of Buildings: Products, Stock, Fittings, Tools, Machinery, Raw Materials	External Items: Vehicles, Machinery, Display, Raw Materials/Stockpiles, Fences	Physical Damage to Buildings	Dispose of damaged products, stock, materials; Cleaning and Re-instatement	Loss of Productivity and Income, Bank Interest Charges	Loss of existing &/or Potential Trade
PUBLIC AUTHORITIES	Contents of Public Buildings and Facilities	Public Property and Facilities: Parks, Signs, Machinery, Equipment	Physical Damage to Infrastructure: Electricity, Water, Telephone, Gas, Road & Rail Transport Links	Remove Mud & Debris from Facilities, Public & Private Property Repairs (temporary & permanent)	Disruption of Services, Community Service Relief Grants	Provision of Public Service

A flood damages assessment was undertaken for existing development for overland flooding within the Woolloomooloo catchment. This was based on a detailed floor level survey which was undertaken for properties considered flood liable. The study area contains a total of 2844 cadastral lots of which 241 were surveyed or approximately 8% of the study area. Only properties which have surveyed floor levels have been included in the flood damages assessment.

A number of properties within the study area have below ground floors or basement car parking. In the case of below ground floors it was assumed that 50% would be inhabited and the maximum depth of flooding would be 1m. For basement car parking, if water could access the car park damages were assumed to be $10,000 (assumed 50% have a car at a cost of $20,000 per car park).

Damages to public structures have not been assessed. A summary of flood damages for the catchment is provided in Table 27 and Table 28 and with the building floors inundated shown on Figure 29.

Table 27 – Summary of Flood Damages

Design Flood Event	Residential Properties Flooded Above Floor Level	Commercial Properties Flooded Above Floor Level	Total Properties Flooded Above Floor Level
2 Year ARI	35	16	51
5 Year ARI	56	21	77
10 Year ARI	58	29	87
20 Year ARI	77	40	117
50 Year ARI	105	51	156
100 Year ARI	106	54	160
PMF	142	65	207

Note: * Excludes all damages to public assets

Table 28 – Summary of Flood Damages

Design Flood Event	Residential Properties Tangible Flood Damages	Commercial Properties Tangible Flood Damages	Total Tangible Flood Damages*
2 Year ARI	$ 2,330,000	$ 621,000	$ 2,950,000
5 Year ARI	$ 3,090,000	$ 746,000	$ 3,840,000
10 Year ARI	$ 3,550,000	$ 890,000	$ 4,440,000
20 Year ARI	$ 4,420,000	$ 1,140,000	$ 5,580,000
50 Year ARI	$ 5,800,000	$ 2,390,000	$ 8,190,000
100 Year ARI	$ 6,410,000	$ 3,000,000	$ 9,410,000
PMF	$ 9,480,000	$ 7,070,000	$ 16,600,000
	Average Annual Damages		$ 2,840,000

Note: * Excludes all damages to public assets

Data was provided in terms of cadastral lots and in many cases there were a number of properties within each cadastral lot. For an individual building floor levels may vary, with multiple levels, and only the lowest floor level was surveyed. Nevertheless the damages provide the best indicative assessment of the annual cost of flooding to residents.

10.1. Discussion

Overall 160 buildings were flooded over floor level in the 100 year ARI event, approximately 6% of properties in the study area. Further work during the Floodplain Risk Management Study (FRMS) will address these flood liable properties. It may be that a recommendation be made as part of the subsequent FRMS that some buildings be altered (raised or limited works) in order to reduce overall flood risk in the catchment.

STREAM STREET AREA

Flooding within the Printers Lane and Seale Lane low point appear to be affected frequently with above flood flooding identified in the 2 year ARI event. Properties near the Stream Street hot spot in Stanley Lane are also affected.

CROWN STREET AREA

Properties in this area are mixed residential and commercial. Of these residential buildings most of the buildings were not flooded until a 5 year ARI event.

BOURKE STREET AREA

Flood affectation of properties in the lower Woolloomooloo catchment area near Bourke and Forbes Streets is fairly infrequent with the majority of properties unaffected by flooding above floor level until the PMF event.

One property along Bourke Street is affected by above floor flooding in a 10 year ARI event and further nine properties are flood affected in a 20 year ARI event. Along Forbes Street there are two properties affected by flooding above floor level in a 2 year ARI event.

On the eastern end of Bland Street near its intersection with Dowling Street four properties are affected above floor level in flood events larger than 5 Year ARI.

VICTORIA STREET AREA

Properties along Victoria Street are flood affected in events as frequent as the 2 year ARI including several below street level.

11. DISCUSSION

11.1. Flooding Hot Spots

Historically flooding problems occur throughout the catchment, with seven instances of reported above floor flooding (as documented in Section 3.6). Some of the areas where flooding is problematic are described herein as "hotspots" and are discussed in some detail.

11.1.1. Stream Street

Stream Street, as the name suggests, is along a natural depression and was once a major overland flow-path within the Woolloomooloo catchment. With the construction of William Street and buildings along Yurong Lane, this flow path is effectively blocked and water ponds which has historically caused above floor flooding to nearby properties.

Flooding Behaviour

The contributing catchment area is approximately 23 ha. The main culvert draining through Stream Street is the SWC's Western Main Drain (910 mm x 1370 mm under William Street) which ultimately drains to Woolloomooloo Bay. Two branches of the CoS pipes drain through Stream Street along Stanley Lane and Yurong Lane connecting to the Western Main Drain (details of pipe sizes shown on Figure 30).

The low point shown on Figure 30 receives overland flow from William Street, Riley Street, Stanley Lane and Yurong Lane. Downstream, William Street acts as a weir with the lowest road crest level at 12.7 mAHD. During flood events equal to or greater than 20 Year ARI peak flood levels within the Stream Street low point exceed the crest level of William Street and excess flows are conveyed overland via Riley Street to the northern part of the catchment.

Table 29 lists peak design flood levels and depths within Stream Street and Yurong Lane and Table 30 lists peak flows for the locations marked on Figure 30.

Table 29 – Stream Street Peak Design Flood Levels, Depths and Flows across William Street (m^3/s) (refer Figure 30)

Design Event	Peak Flood Level (mAHD)	Peak Flood Depth (m)	William St Overflow (m^3/s)
2Y ARI	10.7	0.9	0.0
5Y ARI	11.8	2.0	0.0
10Y ARI	12.3	2.5	0.0
20Y ARI	12.9	3.1	0.1
50Y ARI	13.2	3.4	6.2
100Y ARI	13.3	3.5	8.7
PMF	14.1	4.3	55.5

Table 30 – Stream Street Peak Flows (refer Figure 30)

Peak Overland Flow (m^3/s)							
Location	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50Y ARI	100Y ARI	PMF
1	0.4	0.8	1.0	1.7	3.0	3.5	17.9
2	0.0	0.1	0.2	0.4	0.6	0.7	1.5
3	0.3	0.5	0.7	1.2	3.4	4.8	18.5
4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5
5	0.5	1.0	1.3	1.6	2.2	2.5	13.3
6 (1)	0.0 (-0.4)	0.0 (-0.7)	0.0 (-0.9)	0.0 (-1.2)	0.2 (-1.6)	0.6 (-1.9)	15.7 (-3.9)
7	0.0	0.0	<0.1	0.7	6.0	7.9	33.5
8	0.0	0.0	0.0	0.1	6.2	8.7	55.5

Note (1)**:** In events smaller than or equal to the 20 Year ARI event runoff travel south from William Street through Yurong Street into the low point (denoted by negative values). In events greater than 20 Year ARI peak water levels in the low point are high enough that excess flows from the low point travel north through Yurong Street into William Street.

Peak PipeFlow (m^3/s)									
Location	Size (mm)	Capacity	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50YARI	100Y ARI	PMF
2	1370 x 910 (ovoid)	< 2y ARI	2.6	2.8	2.8	2.8	1.7	1.7	1.8
4	300	2y ARI	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
5	525	< 2y ARI	0.2	0.2	0.2	0.2	0.2	0.2	0.1
8	1830 x 1220 (ovoid)	2y ARI	3.9	4.3	4.5	5.0	3.3	3.3	3.3

11.1.2. Busby Lane Low Point

Busby Lane is located on the northern side of William Street and branches off from Riley Street, providing access to a number of commercial properties then re-joining Riley Street to the north. Council has indicated flooding issues have occurred in the past.

Flooding Behaviour

Figure 31 shows the trunk drainage and peak design flood depths for the 100 Year ARI event within the lane. Ground elevations are significantly lower than the adjoining Riley Street. Busby Lane has a low point of 7.0 mAHD which is approximately 1.1 m lower than the Riley Street exit and any excess overland flow which cannot be conveyed by the underground drainage system will pond.

Table 31 lists the peak flood levels and depths in the low point and Table 32 lists peak flows for the locations marked on Figure 31.

Table 31 – Busby Lane Peak Design Flood Levels and Depths (refer Figure 31)

Design Event	Level (mAHD)	Depth (m)
2Y ARI	7.0	1.0
5Y ARI	7.1	1.1
10Y ARI	7.1	1.1
20Y ARI	7.2	1.2
50Y ARI	7.4	1.4
100Y ARI	7.4	1.4
PMF	8.3	2.3

Table 32 – Busby Lane Peak Flows (refer Figure 31)

Peak Overland Flow (m^3/s)							
Location	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50Y ARI	100Y ARI	PMF
3	<0.1	<0.1	<0.1	0.1	0.5	0.5	3.8
4	0.0	0.2	0.3	0.4	0.9	1.0	3.8

Peak Pipe Flow (m^3/s)									
Location	Size (mm)	Capacity	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50YARI	100Y ARI	PMF
1	1830 x 1220 (ovoid)	20y ARI	0.5	0.5	0.5	0.1	0.3	0.3	0.3
2	450	< 2y ARI	4.3	4.7	4.9	5.6	4.1	4.1	4.3
5	1830 x 1220 (ovoid)	20y ARI	4.6	5.0	5.2	5.3	4.1	4.1	4.3

11.1.3. Crown Street Low Point

The Crown Street low point is located at the intersection of Crown Street and Bossley Terrace and is adjacent to a site which was previously a car park and is now under development. Overflow from the Crown Street low point continues to the adjacent Palmer Street (see Section 11.1.4).

Flooding Behaviour

Table 33 lists the peak flood levels and depths within Crown Street and Table 34 lists the peak flows for the locations marked on Figure 32.

Table 33 – Crown Street Peak Design Flood Levels and Depths (refer Figure 32)

Design Event	Level (mAHD)	Depth (m)
2Y ARI	4.1	0.5
5Y ARI	4.2	0.6
10Y ARI	4.3	0.7
20Y ARI	4.4	0.8
50Y ARI	4.6	1.1
100Y ARI	4.7	1.1
PMF	5.6	2.0

Table 34 – Crown Street Peak Flows (refer Figure 32)

Peak Overland Flow (m^3/s)							
Location	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50Y ARI	100Y ARI	PMF
1	1.0	1.9	2.5	3.2	6.9	8.4	14.1
2	0.4	0.5	0.7	0.8	1.0	1.2	29.8
3 (1)	0.0 (-0.2)	0.0 (-0.4)	0.0 (-0.4)	0.0 (-0.5)	0.3 (-0.5)	1.2 (-0.6)	20.3 (-2.1)
5	<0.1	0.1	0.1	0.6	0.6	1.5	22.0
6	0.0	0.0	0.0	0.0	<0.1	0.2	3.7
7	0.0	0.0	0.0	0.0	<0.1	0.1	4.2
8	1.1	2.1	2.9	3.8	6.8	7.8	19.1
9	1.1	2.1	2.8	3.7	6.6	7.6	18.1

Note (1)**:** In events smaller than or equal to the 20 Year ARI event runoff travels south into the low point (denoted by negative values). In events greater than 20 Year ARI peak flow travels north out of the low point.

Peak Pipe Flow (m^3/s)									
Location	Size (mm)	Capacity	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50YARI	100Y ARI	PMF
1	375	< 2y ARI	0.2	0.2	0.2	0.2	0.1	0.1	0.1
3	600	< 2y ARI	0.4	0.3	0.3	0.3	0.3	0.3	0.4
4	1830 x 1220 (ovoid)	< 2y ARI	5.2	5.5	5.6	5.6	4.1	4.1	4.2
5	1830 x 1220 (ovoid)	< 2y ARI	5.3	5.6	5.7	5.8	4.6	4.6	4.2

Overland flow enters the low point from Cathedral Street to the south and Sir John Young Crescent from the west and to the north. Excess water is drained via Bossley Terrace and in larger events via Sir John Young Crescent to the north.

11.1.4. Palmer Street Low Point

The Palmer Street low point is located below the Eastern Railway line alongside Palmer Street and the Eastern Distributor (Photo 15). Adjacent properties are primarily commercial and although there is no record of past flooding there is considerable drainage infrastructure at the low point. Many physical changes to the catchment have occurred in the past 20 years which have directly affected drainage from the low point. Firstly in 1987 a twin culvert line was constructed which starts at the low point via a large inlet pit seen in Photo 16. Secondly in 1997 the Eastern Distributor was completed, with wall barriers varying in height from 0.8 ~ 1.3 m adjacent to the low point. Additional inlet capacity was added within Palmer Street as seen in Photo 17 and Photo 18.

Photo 15: Palmer Street Low Point

Photo 16: 4 m by 4 m inlet pit

Photo 17: 7.2m lintel and 7x0.6x1.0 m grated inlets

Photo 18: 4x0.6x1.0 m grated inlets

Flooding Behaviour

Pipe sizes of the trunk drainage system through Palmer Street and the adjacent Sir John Young Crescent are shown on Figure 33. Table 35 lists the peak flows for the locations marked on Figure 33.

Table 35 – Palmer Street Peak Flows (refer Figure 33)

Peak Overland Flow (m³/s)							
Location	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50Y ARI	100Y ARI	PMF
1	<0.1	0.1	0.2	0.2	1.0	2.2	6.5
2	1.1	2.1	2.8	3.7	6.6	7.6	18.1
3	0.0	0.0	0.0	0.0	0.2	0.6	14.0
4	<0.1	<0.1	<0.1	0.1	0.4	1.0	10.0
5	0.0	0.0	0.0	0.0	3.4	7.2	44.5

Peak Pipe Flow (m³/s)									
Location	Size (mm)	Capacity	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50YARI	100Y ARI	PMF
1	675	2y ARI	0.3	0.4	0.5	0.6	0.5	0.5	0.7
4	1520 x 2440 (irregular)	10y ARI	4.1	4.6	4.8	4.7	3.5	3.5	3.8
6	2 x 840 x 1830 BC	< 2y ARI	3.8	5.1	5.7	6.3	5.4	5.4	5.6
7	2 x 1520 x 2440 BC	< 2y ARI	1.6	2.3	2.6	2.9	2.8	2.9	3.0

Modelling shows that floodwater enters the low point from Cathedral Street via Palmer Street to the south and from the Crown Street low point (Section 11.1.3) from the west via Bossley Terrace and north via Sir John Young Crescent and through adjacent properties.

During large storm events, water levels in the low point overtop the barrier dividing Palmer Street and the Eastern Distributor and overflows enter the north-bound Eastern distributor tunnel exit. Site survey of the barrier indicated a crest level of 3.1 mAHD. Table 36 lists peak flood levels and depths within the low point and peak flows overtopping the barrier.

Table 36 – Palmer Street Peak Design Flood Levels, Depths and Flows across the Eastern Distributor Barrier (m^3/s) (refer Figure 33)

Design Event	Level (mAHD)	Depth (m)	Barrier Overflow (m^3/s)
2Y ARI	2.4	0.4	0.0
5Y ARI	2.6	0.6	0.0
10Y ARI	2.7	0.7	0.0
20Y ARI	2.8	0.8	0.0
50Y ARI	3.4	1.3	3.4
100Y ARI	3.5	1.4	7.2
PMF	3.8	1.8	44.5

11.1.5. Victoria Street

Victoria Street consists of mainly residential and small commercial properties and is located on the eastern side of the Woolloomooloo catchment. The top of the catchment is located near the intersection of Surrey Street and Victoria Street and the catchment area contributing to pipe flows through Victoria Street is larger than that contributing to overland flow. In recent events, flood waters have been observed to travel through the street at the western side of the street in the gutter at depths between 0.3 to 0.5 m.

Photo 19: Victoria Street looking north from Butlers Stairs.

Photo 20: Examples of flood barriers located at commercial premises on Victoria Street.

Flooding Behaviour

Pipe sizes of the trunk drainage system are shown on Figure 34. Table 37 lists the peak flood flows for the locations marked on Figure 34.

Table 37 – Victoria Street Peak Flows (refer Figure 34)

Peak Overland Flow (m^3/s)							
Location	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50Y ARI	100Y ARI	PMF
1	0.2	0.3	0.4	0.5	0.6	0.8	4.9
2	0.0	<0.1	<0.1	<0.1	<0.1	0.1	2.6
3	0.4	0.6	0.7	1.0	1.4	1.5	5.7
4	0.3	0.3	0.4	0.5	0.5	0.6	3.4
5	0.7	1.1	1.3	1.4	1.6	1.8	6.3
6	0.2	0.3	0.4	0.5	0.7	0.8	3.0
7	0.6	1.4	1.7	2.1	2.5	2.8	10.9

Peak Pipe Flow (m^3/s)									
Location	Size (mm)	Capacity	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50YARI	100Y ARI	PMF
1	450	< 2y ARI	0.2	0.2	0.2	0.2	0.2	0.2	0.2
3 (1)	300	100y ARI	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
3 (1)	375	100y ARI	0.1	0.1	0.1	0.1	0.1	0.1	0.2
5	450	< 2y ARI	0.2	0.2	0.2	0.2	0.2	0.2	0.2
5	600	< 2y ARI	0.3	0.3	0.3	0.3	0.3	0.3	0.3
6	300	< 2y ARI	0.1	0.1	0.1	0.1	0.1	0.1	0.1
7	450	< 2y ARI	0.2	0.2	0.2	0.2	0.2	0.2	0.2
7	600	< 2y ARI	0.6	0.6	0.6	0.6	0.5	0.5	0.6

Note (1): Limited pit inlet capacity along Orwell Street means that drainage pipes are under-utilised – despite this we still get surcharging occurring at the corner of Orwell and Victoria Streets.

Piped and overland flow from Orwell Street, Hughes Street and Tusculum Lane easement join flows from Victoria Street from the east. The percentage of piped and overland flow contributed to the Victoria Street overland and sub-surface drainage system is described in Table 38.

Table 38 – Victoria Street system flow distribution (m^3/s) (refer Figure 34)

Location	2 Year ARI	20 Year ARI	100 Year ARI
Victoria Street U/S of Orwell Street	0.4	0.7	0.9
Orwell Street	0.5	1.1	1.6
Hughes Street	0.3	0.5	0.6
Tusculum Lane easement	0.3	0.6	0.9
Victoria Street D/S of easement	1.5	2.9	3.6

Sub-surface drainage within Victoria Street reaches full capacity in less than a 2 year ARI event. The largest peak inflow into the Victoria Street system is from Orwell Street. In flood events with a 2 year ARI or greater intensity any additional flows delivered from adjoining streets such as Orwell Street must surcharge at the intersection with Victoria Street, contributing to the existing overland flows and exacerbating flooding issues, albeit downstream of Butlers Stairs and some of the worst affected residences.

Within Orwell Street pit inlet capacity is limited with approximately 50~60% of the 300 mm pipe capacity being used in all design events and approximately 90% of the 375 mm pipe capacity being used in all design events (Location 3 – Figure 34). Given that downstream pipes within Victoria Street are at capacity in a 2 Year ARI event having Orwell Street pipes at full capacity will provide no additional benefit to Victoria Street properties.

At the Victoria Street and Orwell Street intersection the topography naturally grades from east to west and prior to the construction of properties along Victoria Street, a large proportion of overland flow would continue from Orwell Street and flow full due west down to Brougham Street. In existing conditions, water is diverted down Victoria Street via the gutter and footpath causing inundation of properties.

The road surface gradient along Victoria Street varies. From the top of the catchment to approximately 165 Victoria Street, the grade is typically 3% and this changes to approximately 1% until just south of the Tusculum Lane easement where the road gradient becomes approximately 4% (Figure 35). Past the Tusculum Lane easement the increase in grade results in reduced peak flood depths and generally lower flood hazard. The low road and pipe grades upstream of the Tusculum Lane easement are part of the reason for the low pipe capacity within this section of Victoria Street.

11.1.6. Cowper Wharf Road underpass

The underpass is below the Eastern Distributor and connects traffic from the Cahill Expressway and Sir John Young Crescent to Cowper Wharf Road and Woolloomooloo Bay.

Pipe sizes of the trunk drainage system are shown on Figure 36. The underpass represents a low point and any excess overland flow which cannot be conveyed by the underground drainage system will pond with depths of up to 0.8 m in the 100 year ARI event. Table 39 lists the peak flood depths within the low point and Table 40 lists peak flows for the locations marked on Figure 36.

Table 39 – Cowper Wharf Road underpass Design Peak Depths (refer Figure 36)

Design Event	Depth (m)
2Y ARI	0.5
5Y ARI	0.6
10Y ARI	0.6
20Y ARI	0.7
50Y ARI	0.7
100Y ARI	0.7
PMF	1.3

Table 40 – Cowper Wharf Road underpass Peak Flows (refer Figure 36)

Peak Overland Flow (m^3/s)							
Location	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50Y ARI	100Y ARI	PMF
1	0.5	1.0	1.2	1.5	2.0	2.1	12.6
2	1.0	1.7	2.0	2.4	3.0	3.7	12.0
3	1.0	2.1	2.7	3.6	4.6	5.4	26.7

Peak Pipe Flow (m^3/s)									
Location	Size (mm)	Capacity	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50YARI	100Y ARI	PMF
1	375	< 2y ARI	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2	750	5y ARI	0.5	0.6	0.7	0.7	0.8	0.8	1.1
3	750	< 2y ARI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	600	< 2y ARI	0.5	0.6	0.7	0.7	0.7	0.8	1.0

11.1.7. Bourke Street Low Point

Bourke Street and Bland Street consist of a mix of residential and commercial properties and are located at the downstream and northern end of the catchment adjacent to Cowper Wharf Road. Past flooding has been reported within the low point in August 1986 with reported levels of approximately 2.1 mAHD corresponding to depths of approximately 0.5 m in the road.

Flooding Behaviour

A significant portion of catchment flows are routed through Bourke Street which is a result of the conjunction of the Western Main Drain with Bourke Street and Palmer Street SWC trunk drainage systems. Excess overland flow from the Eastern Main Channel system along Forbes Street also contributes to flooding within the low point.

Flooding behaviour within the low point has changed significantly with the construction of the SWC Western Main Drain in 1987 and the Eastern Distributor in 1993 and overland flows which would have otherwise contributed to flooding within the low point are now routed through the Cowper Wharf underpass (see Section 11.1.6).

Pipe sizes of the trunk drainage system are shown on Figure 36. Table 41 lists the peak flood levels and Table 42 lists the peak flood flows for the locations marked on Figure 36.

Table 41 – Bourke Street Design Flood Levels (refer Figure 37)

Design Event	Level (mAHD)	Depth (m)
2Y ARI	1.5	<0.1
5Y ARI	1.6	<0.1
10Y ARI	1.7	0.2
20Y ARI	2.1	0.6
50Y ARI	2.3	0.8
100Y ARI	2.3	0.8
PMF	2.8	1.3

Table 42 – Bourke Street Peak Flows (refer Figure 37)

Peak Overland Flow (m^3/s)							
Location	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50Y ARI	100Y ARI	PMF
1	0.1	0.1	0.2	0.8	1.9	2.3	11.0
2	0.0	0.0	0.0	0.6	1.1	1.2	2.7
3	0.0	0.0	<0.1	0.2	0.5	0.6	2.2
4	0.0	0.0	<0.1	0.3	0.6	0.7	2.2
5	0.0	0.0	0.0	0.0	0.1	0.4	2.2
7	1.0	2.1	2.7	3.6	4.6	5.4	26.7
8	0.0	0.0	0.0	<0.1	2.0	3.4	28.0

Peak Pipe Flow (m^3/s)									
Location	Size (mm)	Capacity	2Y ARI	5Y ARI	10Y ARI	20Y ARI	50YARI	100Y ARI	PMF
1	1520x2440 BC	< 2y ARI	3.8	5.1	5.7	6.3	5.4	5.4	5.6
1	1520x2440 BC	< 2y ARI	2.4	3.3	3.7	3.8	2.8	2.9	3.0
6	1350	< 2y ARI	1.3	1.4	1.4	1.6	1.2	1.2	1.4
7	750	< 2y ARI	0.5	0.6	0.7	0.7	0.7	0.8	1.0
7	600	< 2y ARI	0.3	0.3	0.3	0.3	0.2	0.2	0.2
8	1650 x 2770 BC	< 2y ARI	1.8	1.9	2.0	2.1	1.6	1.6	1.8
8	1660 x 2770 BC	< 2y ARI	3.3	4.6	5.4	6.5	5.1	5.2	5.8
8	1200	< 2y ARI	3.4	5.0	5.9	6.6	5.1	5.2	5.8

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Figures

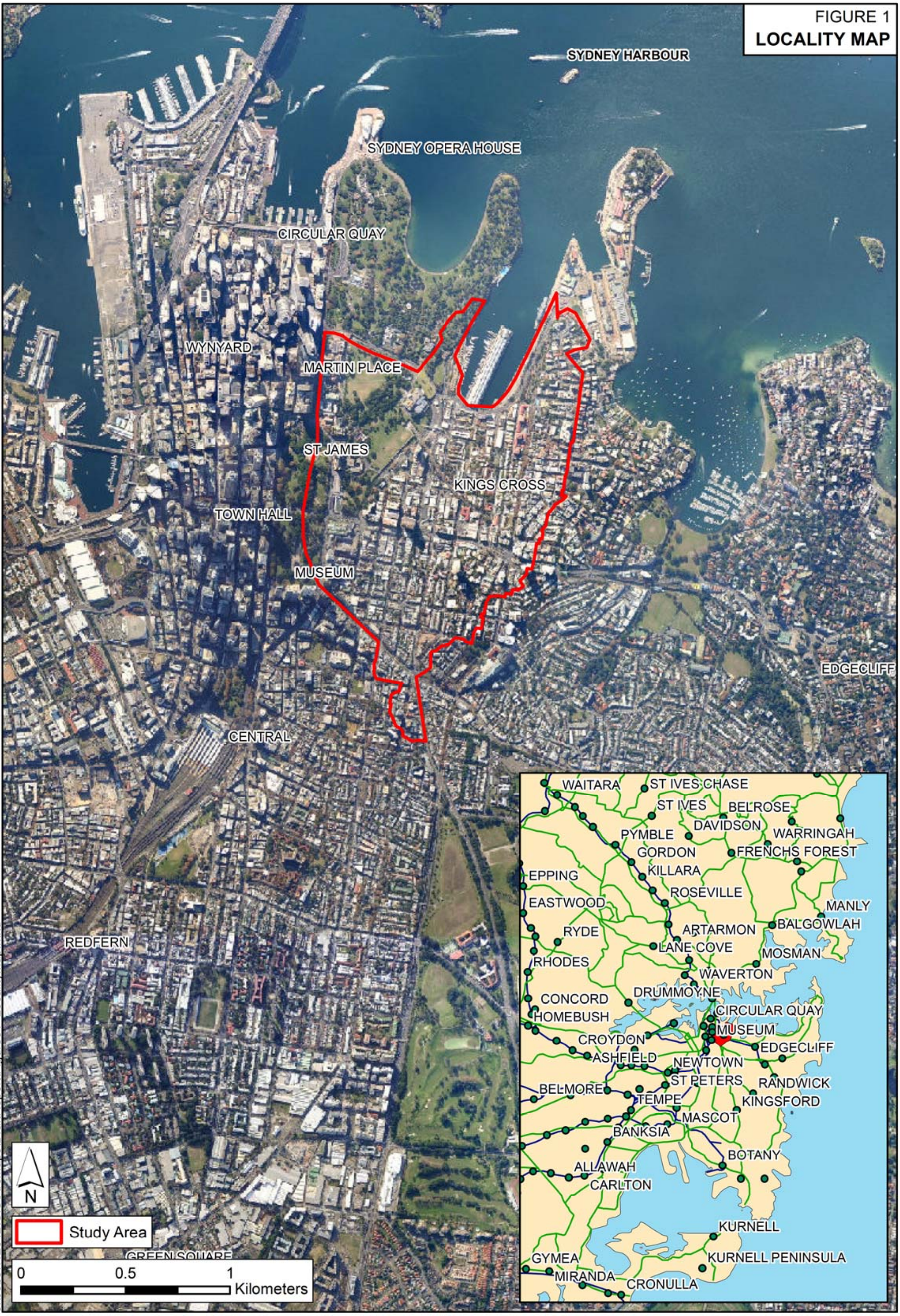

FIGURE 1
LOCALITY MAP

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