ATTACHMENT H

CENTENNIAL PARK CATCHMENT FLOOD STUDY (DRAFT REPORT)

CITY OF SYDNEY

CENTENNIAL PARK

FLOOD STUDY

FINAL DRAFT REPORT

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JUNE 2013

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CENTENNIAL PARK FLOOD STUDY

FINAL DRAFT REPORT
JUNE 2013

Project **Centennial Park Flood Study**	Project Number **112022**
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Date 28 June 2013	**Verified by** TO BE SIGNED FOR FINAL REPORT

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CENTENNIAL PARK FLOOD STUDY

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FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

1. Flood Study
- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management
- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan
- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan
- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

EXECUTIVE SUMMARY

The Centennial Park catchment area within the City of Sydney local government area (LGA) includes the suburbs of Paddington, Moore Park and Centennial Park (Figure 1). The catchment is drained by a series of Sydney Water pipes and overland flow-paths into Busby's Pond in the Centennial Parklands and Anzac Parade.

The key objective of this Flood Study is to develop a suitable hydraulic model that can be used as a basis for a Floodplain Risk Management Plan for the Study area, and to assist City of Sydney to undertake flood-related planning decisions for existing and future developments. Previous hydraulic modelling of the study area was limited in extent, and did not estimate flood levels in the catchment.

The primary objectives of the study are:

- to determine the flood behaviour including design flood levels and velocities over the full range of flooding up to and including the PMF from storm runoff in the study area;
- to provide a model that can establish the effects of future development on flood behaviour;
- to assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise; and
- to assess the hydraulic categories and undertake provisional hazard mapping.

This report details the results and findings of the Flood Study investigations. The key elements include:

- a summary of available flood related data;
- establishment and validation of the hydrologic and hydraulic models;
- sensitivity analysis of the model results to variation of input parameters;
- potential implications of climate change projection;
- the estimation of design flood behaviour for existing catchment conditions; and
- a flood damages assessment.

A glossary of flood related terms is provided in Appendix A.

FLOODING HISTORY

The drainage characteristics of the catchment have been significantly altered as a result of urbanisation, particularly in the past 100 years.

Frequent flooding occurs in areas of the catchment including along Lang Road at localised depression storages which collect excess overland flow which is unable to be transported by the underground drainage network.

Historical records indicate flooding within the catchment at many locations for events in excess of the 1 in 2 year ARI. June 1949, November 1961, March 1975, November 1984, January

1991 and February 2001 were some of the major storm events in which the catchment experienced extensive flooding. Section 3.3.1 provides details on a number of these past rainfall events responsible for the above mentioned floods.

OUTCOMES

The hydrological and hydraulic modelling undertaken for this study has defined flood behaviour for the 2 year, 5 year, 10 year, 20 year, 50 year and 100 year ARI design floods, as well as the Probable Maximum Flood (PMF). Due to the limited available data for calibration, a limited verification of the models to anecdotal historical information was undertaken. Sensitivity analyses were undertaken to assess the influences of modelling assumptions on key outputs, and the potential impacts of future climate change. Provisional hazard mapping has been completed for the 10 year, 20 year and 100 year and PMF events. Hydraulic category mapping has been completed for the 100 year ARI event.

The design flood modelling indicates that significant flood depths may occur in a number of locations such as Stewart Street, Leinster Street, Poate Road, Driver Avenue and Lang Road which is supported by anecdotal reports of flooding.

1. INTRODUCTION

1.1. Background

The Centennial Park catchment within the City of Sydney local government area (LGA) includes the suburbs of Paddington, Moore Park and Centennial Park (Figure 1). The catchment is drained by a series of Sydney Water pipes and overland flow-paths into Busby's Pond in the Centennial Parklands and Anzac Parade.

The present Flood Study has been commissioned by City of Sydney (CoS), with assistance from the NSW Office of Environment and Heritage (OEH). This study considers flooding in the Centennial Park catchment within the City of Sydney's LGA from local storm runoff and continued development means it is important that appropriate tools and information to assess flood risks are available to City of Sydney for planning future development in the area.

1.2. Objectives

The key objective of this Flood Study is to develop a suitable hydraulic model that can be used as a basis for a Floodplain Risk Management Plan for the Study area (Figure 2), and to assist City of Sydney to undertake flood-related planning decisions for existing and future developments. Previous hydraulic modelling of the study area was limited in extent, and did not estimate flood levels in the City of Sydney portions of the catchment.

The primary objectives of the study are:

- to determine the flood behaviour including design flood levels and velocities over the full range of flooding up to and including the PMF from storm runoff in the study area;
- to provide a model that can establish the effects of flood behaviour of future development;
- to assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise; and
- to assess the hydraulic categories and undertake provisional hazard mapping.

This report details the results and findings of the Flood Study investigations. The key elements include:

- a summary of available flood related data;
- establishment and validation of the hydrologic and hydraulic models;
- sensitivity analysis of the model results to variation of input parameters;
- potential implications of climate change projection;
- the estimation of design flood behaviour for existing catchment conditions; and
- a flood damages assessment.

A glossary of flood related terms is provided in Appendix A.

2. BACKGROUND

2.1. Catchment Description

The Centennial Park catchment is located in the suburbs of Paddington, Moore Park and Centennial Park. This region lies within the City of Sydney Local Government Area (LGA) and has been extensively developed for urban usage. The catchment is fully urbanised and consists predominantly of medium to high-density housing and commercial development with some large open recreational spaces and facilities that include Moore Park, Sydney Cricket Grounds, Aussie Stadium, Fox Studios and Heritage Park.

The catchment covers an area of approximately 150 hectares draining to Sydney Water's major trunk drainage systems (known as SWC 58, 59 and 89) to route flows from the upper regions of the catchment. The trunk drainage system is linked to Council's local drainage system consisting of covered channels, in-ground pipes, culverts and kerb inlet pits. Further information on the drainage system is presented in Section 3.2.

The topography of the catchment is steep with the greatest relief occurring at the top of the catchment along Oxford Street at elevations of 60 to 70 mAHD which slopes south to the Fox Studios site with grades of approximately 4%. Anzac Parade, extending along the western side of the study area, has a grade of approximately 1% from north to south. The downstream end of the study area is also the flattest part of the catchment; within the Parklands Tennis club, which has a relatively gentle ground gradient of 1% draining south towards Anzac Parade.

2.1.1. Flooding History

The drainage characteristics of the catchment have been significantly altered as a result of urbanisation, particularly in the past 100 years.

Frequent flooding occurs in areas of the catchment including along Lang Road at localised depression storages which collect excess overland flow which is unable to be transported by the underground drainage network.

Historical records indicate flooding within the catchment at many locations for events in excess of the 1 in 20 year ARI. June 1949, November 1961, March 1975, November 1984, January 1991 and February 2001 were some of the major storm events in which the catchment experienced extensive flooding. Section 3.3.1 provides details on a number of these past rainfall events responsible for the above mentioned floods.

2.2. Previous Studies

2.2.1. Kensington – Centennial Park Flood Study (Reference 1)

The Kensington – Centennial Park Flood Study defined the flood behaviour for design flood events up to the Probable Maximum Flood (PMF) within Randwick City Council's LGA and included hydrology using MIKE-STORM and DRAINS modelling within Moore Park, Fox Studios and Centennial Park catchments.

A hydraulic model was established to convert hydrologic inflows into water levels. The TUFLOW model was verified against historic flood information within Randwick City Council.

3. AVAILABLE DATA

3.1. Topographic Survey

Airborne Light Detection and Ranging (LiDAR) survey of the catchment and its immediate surroundings was provided for the study by City of Sydney and is shown on Figure 3. The data was a combination of data collected in 2007 and 2008 with a 1.3m average point separation. For hard flat surfaces these data typically have accuracy in the order of:

- ±0.15m in the vertical direction (to one standard deviation); and
- ±0.25m in the horizontal direction (to one standard deviation).

When interpreting the above, it should be noted that the accuracy of the ground definition can be adversely affected by the nature and density of vegetation and/or the presence of steeply varying terrain.

3.2. Pit and Pipe Data

The catchment is serviced by a major/minor drainage system. Property drainage is directed to the kerb and gutter system where it is then able to enter the Council owned minor street drainage network. Flow is then routed into the Sydney Water Corporation (SWC) owned and maintained SW58&59 and SW89 trunk drainage systems draining Driver Avenue and the Fox Studios Site through Centennial Park and Moore Park respectively.

When the capacity of the drainage system is exceeded, flow occurs along road reserves and other overland flow paths, with the potential for velocities and/or flow depths combining to generate high hazard flood conditions in some places.

City of Sydney provided an asset database including dimensions and invert elevations for the majority of stormwater conduits within the study area. The following datasets were used to define stormwater infrastructure in modelling for this study:

- pipe asset database "WMA_DataSupply.gdb: Pipes_Survey" (received 16/03/2012);
- pit asset database "WMA_DataSupply.gdb: Pits_Survey" (received 16/03/2012);

A summary of pit and pipe survey data used within the study is provided in Table 1.

Table 1: Modelled Pipe and Pipe Network

Pit Type	Number
Outlet	6
Kerb or Grate Inlets	312
Junctions	224

Pipe Diameter (mm)	Number	Total Length (m)
< 450	336	5164
450 - 750	95	2446
750 - 1000	15	863
1000 - 2400	49	2008
2400 - 3800	14	1232

3.3. Rainfall

3.3.1. Historical Rainfall

Table 2 presents a summary of the official rainfall gauges (provided by the Bureau of Meteorology located close to or within the catchment. These gauges are operated either by Sydney Water (SW) or the Bureau of Meteorology (BoM). There may also be other private gauges in the area (bowling clubs, schools) but data from these has not been collected as there is no public record of their existence. Of the 45 gauges listed in Table 2 over 58% (26) have now closed. The gauge with the longest record is Observatory Hill, operating from 1858 to the present. The closest pluviometer gauge to the study area catchment is Paddington, which has been in operation from 1968. Locations of rainfall stations are shown on Figure 4.

Table 2: Rainfall Stations with a 6km Radius of Paddington Gauge

Station No	Owner	Station	Elevation (mAHD)	Distance from Paddington (km)	Date Opened	Date Closed	Type
66139	BOM	Paddington	5	0.0	Jan-1968	Jan-1976	Daily
566041	SW	Crown Street Reservoir	40	0.8	Feb-1882	Dec-1960	Daily
566032	SW	Paddington (Composite Site)	45	1.0	Apr-1961		Continuous
566032	SW	Paddington (Composite Site)	45	1.0	Apr-1961		Daily
566009	SW	Rushcutters Bay Tennis Club	-	1.3	May-1998		Continuous
566042	SW	Sydney H.O. Pitt Street	15	1.5	Aug-1949	Feb-1965	Continuous
66015	BOM	Crown Street Reservoir		1.5	Feb-1882	Dec-1960	Daily
66006	BOM	Sydney Botanic Gardens	15	1.9	Jan-1885		Daily
66160	BOM	Centennial Park	38	2.1	Jun-1900		Daily
566011	SW	Victoria Park @ Camperdown	-	2.4	May-1998		Continuous
66097	BOM	Randwick Bunnerong Road		2.4	Jan-1904	Jan-1924	Daily
66062	BOM	Sydney (Observatory Hill)	39	2.7	??		Continuous
66062	BOM	Sydney (Observatory Hill)	39	2.7	Jul-1858	Aug-1990	Daily
66033	BOM	Alexandria (Henderson Road)	15	2.8	May-1962	Dec-1963	Daily
66033	BOM	Alexandria (Henderson Road)	15	2.8	Apr-1999	Mar-2002	Daily
66073	BOM	Randwick Racecourse	25	2.9	Jan-1937		Daily
566110	SW	Erskineville Bowling Club	10	3.4	Jun-1993	Feb-2001	Continuous
566010	SW	Cranbrook School @ Bellevue	-	3.4	May-1998		Continuous
566015	SW	Alexandria	5	3.5	May-1904	Aug-1989	Daily
66066	BOM	Waverley Shire Council		3.6	Sep-1932	Dec-1964	Daily
66149	BOM	Glebe Point Syd. Water Supply	15	3.6	Jun-1907	Dec-1914	Daily
566099	SW	Randwick Racecourse	30	3.7	Nov-1991		Continuous
66052	BOM	Randwick Bowling Club	75	3.7	Jan_1888		Daily
566141	SW	SP0057 Cremorne Point	-	4.0			Continuous
66021	BOM	Erskineville	6	4.0	May-1904	Dec-1973	Daily
	SW	Gladstone Park Bowling Club	-	4.1	Jan-1901		Continuous
566114	SW	Waverley Bowling Club	-	4.1	Jan-1995		Continuous

Station No	Owner	Station	Elevation (mAHD)	Distance from Paddington (km)	Date Opened	Date Closed	Type
566043	SW	Randwick (Army)	30	4.3	Dec-1956	Sep-1970	Continuous
566077	SW	Bondi (Dickson Park)	60	4.4	Dec-1989	Feb-2001	Continuous
566065	SW	Annandale	20	4.5	Dec-1988		Continuous
66098	BOM	Royal Sydney Golf Club	8	4.5	Mar-1928		Daily
66005	BOM	Bondi Bowling Club	15	4.6	Jul-1939	Dec-1982	Daily
66178	BOM	Birchgrove School	10	4.8	May-1904	Dec-1910	Daily
66075	BOM	Waverton Bowling Club	21	5.1	Dec-1955	Jan-2001	Daily
66187	BOM	Tamarama (Carlisle Street)	30	5.1	Jul-1991	Mar-1999	Daily
66179	BOM	Bronte Surf Club	15	5.2	Jan-1918	Jan-1922	Daily
566130	SW	Mosman (Reid Park)	-	5.3	Jan-1998	Jun-1998	Continuous
566030	SW	North Sydney Bowling Club	80	5.5	Apr-1950	Sep-1995	Daily
66007	BOM	Botany No.1 Dam	6	5.5	Jan-1870	Jan-1978	Daily
66067	BOM	Wollstonecraft	53	5.8	Jan-1915	Jan-1975	Daily
66061	BOM	Sydney North Bowling Club	75	5.8	Apr-1950	Dec-1974	Daily
566027	SW	Mosman (Bradleys Head)	85	5.8	Jun-1904		Continuous
566027	SW	Mosman (Bradleys Head)	85	5.8	Jun-1904		Daily
566006	BOM	Bondi (Sydney Water)	10	5.9	Jun-1997		Operational
66175	BOM	Schnapper Island	5	5.9	Mar-1932	Dec-1939	Daily

BOM = Bureau of Meteorology
SW = Sydney Water

3.4. Analysis of Daily Read Data

For the purposes of this study, an analysis of daily rainfall data was undertaken to identify and place past storm events in some context. All daily rainfall depths greater than 150 mm recorded at Centennial Park (112 years of record), Randwick Bowling Club (124 years of record) and Randwick Racecourse (75 years of record) have been ranked and shown in Table 3.

The main points regarding these data are:

- February 1990 was in the top 10 for all gauges, showing very similar rainfalls at each gauge (between 220 and 245 mm);
- August 1986 looks like the most significant widespread daily rainfall event;
- March 1942 and August 1986 were the largest daily events recorded for the Centennial Park and Randwick Bowling Club gauges with approximately 300 mm. Randwick Racecourse also recorded high rainfall for these days, although some spatial variation is shown;
- February 1992 showed a significant difference between the three gauges (151 mm, 162 mm and 294 mm). Analysis of the Botanic Gardens and Observatory Hill gauges show rainfalls of 264 mm and 190 mm for this day, implying a wide spatial range of rainfall depths;
- Data for the November 1984 event, which was known to produce flooding in the study area, is available at the Randwick Racecourse gauge and the Paddington gauge where it

ranked 10th for total daily rainfall.

Table 3: Daily Rainfall greater than 150 mm

Centennial Park Records since 1900		
Rank	Date	Rainfall (mm)
1	28/03/1942	302
2	06/08/1986	236
3	03/02/1990	222
4	12/08/1975	221
5	13/10/1975	205
6	31/01/1938	201
7	30/04/1988	193
8	10/02/1956	192
9	23/01/1933	189
10	09/02/1958	185
11	11/10/1975	184
12	07/07/1931	177
13	09/04/1945	177
14	07/08/1998	162
15	17/05/1943	159
16	04/02/1990	156
17	10/07/1957	155
18	14/11/1969	155
19	01/05/1955	154
20	09/02/1992	151
21	28/07/2008	150
22	13/01/2011	150

Randwick Bowling Club (66052) Records since Jan 1888		
Rank	Date	Rainfall (mm)
1	06/08/1986	297
2	29/10/1959	265
3	28/03/1942	243
4	03/02/1990	225
5	10/02/1956	213
6	31/01/1938/	213
7	11/03/1975	201
8	17/01/1988	178
9	12/10/1902	178
10	28/04/1966	177
11	04/02/1990	175
12	19/11/1900	164
13	09/02/1992	162
14	28/07/1908	161
15	09/02/1958	158
16	29/05/1906	155
17	30/08/1963	152
18	27/04/1901	150

Randwick Racecourse (66073) Records since Jan 1937		
Rank	Date	Rainfall (mm)
1	10/02/1992	294
2	20/11/1961	270
3	30/10/1959	267
4	06/08/1986	263
5	11/03/1975	261
6	14/05/1962	258
7	10/02/1958	256
8	05/02/1990	248
9	03/02/1990	244
10	09/11/1984	240
11	20/03/1978	237
12	06/11/1984	223
13	28/03/1942	213
14	31/01/1938	211
15	10/02/1956	195
16	30/04/1988	175
17	30/08/1963	174
18	07/08/1967	171
19	10/01/1949	170
20	14/11/1969	160
21	05/02/2002	157
22	16/06/1952	156
23	04/03/1977	155
24	03/05/1948	154
25	04/04/1988	152
26	28/04/1966	151
27	05/03/1979	151

3.5. Analysis of Pluviometer Data

Pluviometer records provide a more detailed description of temporal variations in rainfall for sub-daily durations. Table 4 lists the maximum storm intensities for the four largest recent rainfall events from both the pluviometers and the daily read gauges.

Table 4: Maximum Recorded Storm Depths (in mm)

Station Location	5 Nov 1984		8/9 Nov 1984		6 Jan 1989		26 Jan 1991	
	30 min	60 min	30 min	60 min	30 min	60 min	30 min	60 min
Paddington	36	51	54	91	53	54	52	53
Observatory Hill	20	32	90	119	42	42	60	65
UNSW (Avoca Street)(1)	65	112	41	58	-	-	-	-
UNSW (Storey Street) (1)	65	90	33	46	-	-	-	-

Station Location	5 Nov 1984	8 Nov 1984	9 Nov 1984	6 Jan 1989	26 Jan 1991
Royal Botanic Gardens (daily)	-	37	248	49	59
Observatory Hill (daily)	121	44	234	47	65
Paddington (daily)	108	71	208	63	54

Notes:

(1) From Reference 1.

The above data indicate that for January 1989, March 1989 and January 1991 the peak 30 minute rainfall comprised the majority of the daily rainfall. However, for November 1984 the 30 minute peak was part of a much larger rainfall event, for both the storms investigated.

Storm intensities and durations recorded at the Paddington gauging station for significant historical storm events are given in Table 5.

Table 5: Paddington Pluviometer Storm Intensities (mm/h)

Duration	6 min	10 min	20 min	30 min	60 min	120 min
12 Aug 1983	175	156	106	84	48	28
(approx. ARI)	*(10)*	*(20)*	*(10)*	*(10)*	*(5)*	*(2)*
5 Nov 1984	120	108	84	72	52	39
(approx. ARI)	*(2)*	*(2)*	*(5)*	*(5)*	*(5)*	*(10)*
8-9 Nov 1984	125	123	114	108	91	74
(approx. ARI)	*(2)*	*(5)*	*(10)*	*(25)*	*(75)*	*(>100)*
6 Jan 1989	215	195	155	108	56	30
(approx. ARI)	*(50)*	*(50)*	*(50)*	*(25)*	*(5)*	*(5)*
9 Mar 1989	140	138	114	85	54	28
(approx. ARI)	*(5)*	*(10)*	*(15)*	*(10)*	*(5)*	*(2)*
21 Apr 1989	140	120	78	54	29	14
(approx. ARI)	*(5)*	*(5)*	*(2)*	*(2)*	*(1)*	*(1)*
26 Jan 1991	190	162	138	103	53	27
(approx. ARI)	*(20)*	*(2)*	*(40)*	*(20)*	*(5)*	*(2)*

Data taken from Reference 3.

3.5.1. Design Rainfall Data

Table 6: Rainfall Intensity-Frequency Duration Data

Duration	Design rainfall Intensity (mm/hr)						
	1 Year	2 Years	5 Years	10 Years	20 Years	50 Years	100 Years
5 minute	106	134	168	188	213	247	272
10 minute	80.9	103	131	146	167	194	214
20 minute	59.5	76.5	98.1	111	127	149	165
30 minute	48.5	62.5	80.9	91.7	106	124	138
1 hour	32.7	42.4	55.4	63	73	86.2	96.2
2 hour	21.1	27.3	35.8	40.8	47.4	56	62.6
3 hour	16	20.8	27.3	31.1	36	42.6	47.6
6 hour	10	13	17	19.3	22.4	26.4	29.5
12 hour	6.35	8.21	10.7	12.2	14.1	16.6	18.5
24 hour	4.11	5.31	6.93	7.87	9.1	10.7	12
48 hour	2.64	3.41	4.45	5.06	5.85	6.9	7.69
72 hour	1.96	2.54	3.3	3.74	4.33	5.1	5.69

Design rainfall depths and temporal patters for various storm durations at the study area were obtained from Australian Rainfall and Runoff 1987 (ARR87), for events up to and including the 100 Year ARI event. Probable Maximum Precipitation estimates were derived according to Bureau of Meteorology (BoM) guidelines (Reference 4). A summary of the design rainfall depths is provided in Table 6 and a comparison of the design rainfall Intensity-Frequency Duration (IFD) data and significant historic storms in the catchment is shown on Figure 5.

3.6. Historical Flood Information

A data search was carried out to identify the dates and magnitudes of historical floods. The search concentrated on the period since approximately 1970 as data prior to this date would generally be of insufficient quality and quantity for model calibration. Unfortunately there were no stream height gauges in the catchment. The following sources were used:

- City of Sydney records,
- previous reports,
- questionnaire issued in November 2012,
- follow-up conversations with local residents.

Flooding at Lang Road was reported as part of the Community Consultation process and pictures showing the location of flooding are shown on Figure 8. Historical flood data collected and collated as part of this study is presented in Table 7 with locations shown on Figure 9

Table 7: Historic Flood Data

ID	Location	Description	Flood Event	Observed Depth (m)	Comments	Source
1	More Park Road south of Victoria Barracks	Road flooded	-	0.4	Depth in the road	CoS Database
2	Driver Avenue	Road flooded	5 November 1984	-	Flooded for 1 week with spill from Kippax Lake a factor	CoS Database
3	Corner of Stewart Street and little Steward Street	Road flooded	-	-	Historical reports of road flooding	CoS Database
4	Stewart Street	Property flooded	6 January 1989	-	Yard flooding experienced	CoS Database
			9 March 1989	-		CoS Database
			21 April 1989	-		CoS Database
5	Moore Park Road	Garage flooding	-	-	Garage flooding experienced in all heavy rain events	CoS Database
6	Lang Road	Road flooding leading to minor flooding on raised front lawn	14 June 2007	-	Lawn is approximately 0.9m above pavement surface.	Community Consultation
7	Moore Park Road	Flooding at rear of property	February 2001	1.0	Depth in rear Lane	Community Consultation
8	Robertson Road	Road Flooding	February 2012	0.45	Depth in Oxley Lane	Community Consultation
		Property Inundation	February 2012	0.15	In building at rear of property	

4. COMMUNITY CONSULTATION

In collaboration with CoS, a questionnaire and newsletter were distributed to residents and owners of property within the study area by post, describing the role of the Flood Study in the floodplain risk management process, and requesting records of historical flooding. A total of 560 surveys were distributed with reply paid envelopes, and 47 responses were received (a return rate of 8%).

The information requested in the survey included details about length of residency in the catchment, descriptions of any experiences of flooding, and evidence of flood heights or extents such as photographs of flood marks.

The occasions when respondents recalled being affected by flooding are summarised in Table 8. The most frequently recalled flood related to the June 2007 storm, although other events were also mentioned by a significant number of respondents. A summary of responses received is shown on Figure 6 and Figure 7.

Table 8: Summary of Reported Incidents of Flooding

Flood Event	Total Reponses	House Flooded (above floor)	Other Buildings Flooded (above floor)	Other Descriptions of Flooding
January 1991	1	0	0	1
April 1998	1	0	0	1
February 2001	1	0	0	1
June 2007	5	0	0	5
February 2012	1	1	0	1

The flood experiences described in the survey responses generally related to nuisance flooding, such as ponding of stormwater in roadways or gardens, although instances of above floor flooding in both residential and non-residential properties were also reported. February 2012 was the only storm with reported above floor inundation of residential property. Photographs detailing flooding within Lang Road are shown on Figure 8.

A copy of the questionnaire and newsletter is provided in Appendix B.

5. STUDY METHODOLOGY

5.1. General Approach

The approach adopted in flood studies to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc). High quality survey datasets were available for this study, which enabled a detailed topographic model of the catchment to be established. However the historical hydrologic data (such as rainfall patterns and stream-flows) were relatively limited.

The estimation of flood behaviour in a catchment is often conducted as a two-stage process, consisting of:

1. <u>hydrologic modelling</u> to convert rainfall estimates to overland flow and stream runoff; and
2. <u>hydraulic modelling</u> to estimate overland flow distributions, flood levels and velocities.

When historical flood data is available it can be used to allow calibration of the models, and increase confidence in the estimates. The calibration process is undertaken by altering model input parameters to improve the reproduction of observed catchment flooding. Recorded rainfall and stream-flow data area required for calibration of the hydrologic model, while historic records of flood levels, velocities and inundation extents can be used for the calibration of hydraulic model parameters.

There are no stream-flow records in the catchment, so the use of a flood frequency approach for the estimation of design floods is not possible.

Flood estimation in urban catchments generally presents challenges for the integration of the hydrologic and hydraulic modelling approaches, which have been treated as two distinct tasks as part of traditional flood modelling methodologies. As the main output of a hydrologic model is the flow at the outlet of a catchment or sub-catchment, it is generally used to estimate inflows from catchment areas upstream of an area of interest, and the approach does not lend itself well to estimating flood inundation in mid- to upper-catchment areas, as required for this study. The aim of identifying the full extent of flood inundation can therefore be complicated by the separation of hydrologic and hydraulic processes into separate models, and these processes are increasingly being combined in a joint modelling approach.

In view of the above, the broad approach adopted for this study was to use a widely utilised and well-regarded hydrologic model to conceptually model the rainfall concentration phase (including runoff from roof drainage systems, gutters, etc.). The hydrologic model used design rainfall patterns specified in Reference 5, and the runoff hydrographs were then used in a hydraulic model to estimate flood depths, velocities and hazard in the study area.

The sub-catchments in the hydrologic model were kept small (less than a typical residential block) such that the overland flow behaviour for the study was generally defined by the hydraulic model. This joint modelling approach was calibrated against observed historical flood levels.

Additionally, the estimated flows at various points in the catchment were validated against previous studies and alternative methods.

5.2. Hydrologic Model

DRAINS is a hydrologic/hydraulic model that can simulate the full storm hydrograph and is capable of describing the flow behaviour of a catchment and pipe system for real storm events, as well as statistically based design storms. It is designed for analysing urban or partly urban catchments where artificial drainage elements have been installed.

The DRAINS model is broadly characterised by the following features:

- the hydrological component is based on the theory applied in the ILSAX model which has seen wide usage and acceptance in Australia,
- its application of the hydraulic grade line method for hydraulic analysis throughout the drainage system,
- the graphical display of network connections and results.

DRAINS generates a full hydrograph of surface flows arriving at each pit and routes these through the pipe network or overland, combining them where appropriate. Consequently, it avoids the "partial area" problems of the Rational Method and additionally it can model detention basins (unsteady flow rather than steady state).

Runoff hydrographs for each sub-catchment area are calculated using the time area method and the conveyance of flow through pipe and open channels is calculated using unsteady flow hydraulics. Open channel flow uses the simpler Hydraulic Grade Line method. This provides improved prediction of hydraulic behaviour, consistency in design, and greater freedom in selecting pipe slopes. It requires more complicated design procedures, since pipe capacity is influenced by upstream and downstream conditions.

It should be noted that the version of DRAINS used in this study is not a true unsteady flow model as it does not account for the attenuation effects of routing through temporary floodplain storage in overland areas (down streets or in yards).

5.3. Hydraulic Model

The availability of high quality ALS data means that the study area is suitable for two-dimensional (2D) hydraulic modelling. Various 2D software packages are available (SOBEK, TUFLOW, Mike FLOOD) and the TUFLOW package (Reference 6) was adopted as it is widely used in Australia and was considered most suitable for use in this study.

The Centennial Park study area consists of a wide range of development, with residential, commercial and open space areas. Overland flood behaviour in the catchment is generally two-dimensional, with flooding along road reserves and areas prone to ponding (e.g. Lang Road). For this catchment, the study objectives required accurate representation of the overland flow system including kerbs and gutters and defined drainage controls.

The 2D model is capable of dynamically simulating complex overland flow regimes and interactions with sub-surface drainage systems. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short-duration events and a combination of underground piped and overland flow behaviour.

For the hydraulic analysis of complex overland flow paths (such as the present study area where overland flow occurs between and around buildings), an integrated 1D/2D model such as TUFLOW provides several key advantages when compared to a 1D only model. For example, a 2D approach can:

- provide localised detail of any topographic and /or structural features that may influence flood behaviour,
- better facilitate the identification of the potential overland flow paths and flood problem areas,
- dynamically model the interaction between hydraulic structures such as culverts and complex overland flow-paths, and
- inherently represent the available flood storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into Council's planning activities. The model developed for the present study provides a flexible modelling platform to properly assess the impacts of any overland flow management strategies within the floodplain (as part of the ongoing floodplain management process).

In TUFLOW the ground topography is represented as a uniformly-spaced grid with a ground elevation and a Manning's "n" roughness value assigned to each grid cell. The grid cell size is determined as a balance between the model result definition required and the computer run time (which is largely determined by the total number of grid cells).

5.4. Design Flood Modelling

Following validation of the hydrologic model against previous studies with similar catchment characteristics and alternative calculation methods, the following steps were undertaken:

- design runoff hydrographs for localised sub-catchments were obtained from the DRAINS hydrologic model and applied as inflows to the TUFLOW model;
- sensitivity analysis was undertaken to assess the relative effect of changing various modelling parameters; and
- design floods were modelled in TUFLOW using parameters selected to provide a sensible match between design flood levels and available recorded peak flood levels from historical events.

6. HYDROLOGIC MODELLING

6.1. Sub-catchments

A hydrological model of the study catchment was established using the DRAINS software package (Reference 7).

Sub-catchment areas were delineated based on ALS survey and making the assumptions that:

- properties generally drain to streets or inlet pits; and
- flow in streets is along gutters and uni-directional.

The DRAINS hydrologic runoff-routing model was used to determine hydraulic model inflows for the local sub-catchments within the study area. The catchment layout for the model is shown on Figure 10.

6.2. Key Model Parameters

6.3. Impervious Areas

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete aprons occurs significantly faster than from natural surfaces, resulting in a faster concentration of flow at the bottom of a catchment, and increased peak flow in some situations. It is therefore necessary to estimate the proportion of a catchment area that is covered by such surfaces.

For each sub-catchment the proportion of pervious (grassed and landscaped), impervious (paved) and supplementary areas (paved not directly connected to pipe system) were determined from field and aerial photographic inspections. The adopted values are summarised in Table 9.

Table 9: Summary of Catchment Imperviousness values used in DRAINS

Area	Area (ha)	%
Paved Area	68.8	45
Grassed Area	77.3	50
Supplementary	7.7	5
TOTAL	153.8	100

6.4. Rainfall Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in AR&R. The methods are of varying complexity, with the more complex options only suitable if sufficient data are available (such as detailed soil properties). An industry accepted method used for design flood estimation is the Horton Infiltration loss model used within DRAINS software.

Losses from a paved or impervious area are considered to comprise only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed areas are comprised of an initial loss and a continuing loss. The continuing loss was calculated from infiltration curves based on work by Horton in the 1930's which decreases as the storm duration progresses and is determined using the estimated representative soil type and antecedent moisture condition.

It has been shown that soil in the catchment has a high infiltration rate potential (Reference 2) and the antecedent moisture condition was considered to be rather wet. The latter was justified by the fact that the peak rainfall burst can typically occur within a longer rainfall event that has a duration lasting days. The adopted parameters are summarised in Table 10.

Table 10: Adopted Hydrologic Loss Parameters

RAINFALL LOSSES	
Paved Area Depression Storage (Initial Loss)	1.0 mm
Grassed Area Depression Storage (Initial Loss)	5.0 mm
SOIL TYPE	3
Moderate infiltration rates and moderately well drained. This parameter, in conjunction with the Antecedent Moisture Condition, determines the continuing loss (defined by Horton's infiltration equation).	
ANTECENDENT MOISTURE CONDITIONS	3
Description	Rather Wet
Total Rainfall in 5 Days Preceding the Storm	12.5 to 25 mm

6.5. Time of Concentration

The surface runoff from each sub-area contributing to a pit has a particular *time of concentration*. This is defined as the time it takes for runoff from the upper part of a sub-area to start contributing as inflow to the pit. It is mainly related to the flow path distance, slope and surface type over which the runoff has to travel.

The time of concentration was defined as overland flow time based on the Kinematic wave equation. The flow time was defined using a flow length based on the sub-catchment slope and the size and shape of the contributing catchment. The relationship was developed based on a catchment of similar characteristics within the Sydney region and is generally suitable for application in the present investigation.

Time of concentration can have a significant bearing upon the accumulated peak flows achieved further downstream. Sensitivity to these assumptions was assessed in Section 10.

6.6. Verification of Methodology

Ideally hydrologic models are calibrated and validated against observed stream flow information; however for the study area no such data is available. Thus verification was undertaken in which results from the current study were compared with similar studies in adjacent catchments and specific and general expectations of catchment flooding behaviour.

Flow results from the Kensington – Centennial Park Flood Study, June 2011 (Reference 1) and the Rushcutters Bay Flood Study, October 2007 (Reference 3) were compared to those used in the current study for individual sub-catchments.

Table 11 provides the model comparisons for 3 random sub-catchments from each model.

Table 11: Comparison of 20 and 100 Year ARI DRAINS Results with References 1 and 3

Model	Catchment Name	Area (ha)	Impervious %	20 Year ARI		100 Year ARI	
				Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)
Current Study	CP089	1.4	93	0.7	0.5	0.9	0.7
Current Study	CP028	4.8	17	1.9	0.4	2.4	0.5
Current Study	CP139	0.6	87	0.3	0.5	0.4	0.6
Reference 1	F-G	3.3	95	1.8	0.5	2.3	0.7
Reference 1	E1-E2	2.3	80	1.0	0.5	1.3	0.6
Reference 1	AN2Det	3.5	83	1.6	0.5	2.1	0.6
Reference 3	aP24AA2	14.7	90	8.2	0.6	10.1	0.7
Reference 3	aP7Z7	0.4	90	0.2	0.6	0.3	0.7
Reference 3	aP3A1	2.7	90	1.5	0.5	1.9	0.7

Discrepancies between the compared specific yields can be attributed to a number of reasons such as the variance in loss parameters, differences in land use and difference in the applied routing method (peak flow also correlates to catchment area, but not linearly).

Specific yield for the 100 year ARI event in the current study was found to vary from 0.5 to 0.7 m^3/s per hectare and averaging at 0.6 m^3/s per hectare. The range of values is largely dependent on land use with more urbanised sub-catchments producing higher specific yields. The results are comparable for the studies considered.

7. HYDRAULIC MODELLING

7.1. Model Extents and Boundary Conditions

A hydraulic model was established for the study using the TUFLOW package. The model schematisation is illustrated on Figure 11, including the location of the sub-catchment inflow boundary conditions.

Downstream boundary conditions were located at key overland flow points and following areas of steep terrain and pipe gradients. Busby's pond was set as the outflow location for trunk drainage flows, whereas overland flow boundary conditions were applied using an automatic stage-flow calculation boundary (based on water surface slope of upstream model cells) sufficiently distanced from the study area so as to not impact upstream flow and water level conditions.

Downstream boundary conditions within Busby Pond and Kensington Pond were set as a low constant tailwater level (Table 12). Sensitivity of model results within the study area to the tailwater conditions were tested by applying PMF levels from Reference 1 within Busby's and Kensington Ponds. The tailwater condition was found to have no influence on water levels within the study area.

Table 12 – Centennial Park Tailwater Levels

Location	Adopted Tailwater Level	PMF Level from Reference 1
Busby Pond	35.0	36.5
Kensington Pond	29.0	32.3

7.2. Terrain Model

A computational grid cell size of 2 m by 2 m was adopted, as it provided an appropriate balance between providing sufficient detail for roads and overland flow paths, while still resulting in workable computational run-times. The model grid was established by sampling from a triangulation of filtered ground points from the LiDAR dataset.

Permanent buildings and other significant structures likely to act as significant flow obstructions were incorporated into the terrain model. These features were identified from the available aerial photography and modelled as impermeable obstructions to the flood flow (i.e. they were removed from the model grid).

7.3. Hydraulic Roughness

The adopted roughness values are consistent with typical values in the literature (References 5, 8, and 9) and previous experience with modelling similar catchment conditions. The sensitivity of model results to changes the roughness values is discussed in Section 10.

Table 13 - Mannings 'n' values

Surface Type	Manning's "n" value
Very short grass or sparse vegetation	0.035
General overland areas, gardens, roadside verges, low density residential lots etc. (default)	0.045
Medium density vegetation	0.060
Heavy vegetation	0.100
Roads, paved surfaces	0.025
Concrete pipes	0.013

Culvert Type	Manning's "n" value
Concrete pipes	0.013
Clay Pipes	0.025
Brick	0.014
PVC	0.011

7.4. Blockage Assumptions

Blockage of hydraulic structures is an important issue in the design and management of drainage systems. Blockage is produced by a range of different processes and can reduce the capacity of drainage systems by partially or completely closing the drainage structure.

Inlet pits are critical parts of drainage systems, and collect the runoff from the streets and other parts of the urban catchment and convey these to the piped underground system. Stormwater inlets are especially prone to blockage and temporary blockage may occur during a storm due to a range of issues. All materials that may occur naturally on the road can end up in the pit inlets; the most common material is leaves and other small vegetation as well as general litter. Other obstructions include parked cars or trucks.

Much of the catchment includes parks (Moore Park and areas near Lang Road) with a large amount of vegetative debris which has the potential to end up in the stormwater system. The biggest impact will occur in trapped low points, which can only be drained by the pit and pipe system. Most of the trapped low points such as Stewart Street, Leinster Street and Poate Road are serviced by pipes with a diameter larger than 450 mm and the potential for blockage within these locations is considered low. Generally,

It is impossible to accurately estimate the degree of blockage during a storm. The trunk drainage system within the study area often had no direct connections to inlet pits and most roads have multiple pits. Therefore, all pipes in the study area were assumed to be clear of blockage and blockage factors were applied to inlet pits rather than pipes.

Blockage to inlet pits was applied as per the Queensland Urban Drainage Manual (Reference

10) and Project 11 of the AR&R revision project (Table 14).

Table 14 – Theoretical capacity of inlet pits based on blockage assumptions

Sag Inlet Pit	
Kerb Inlet	80%
Grated Inlet	50%
Combination	grate assumed 100% blocked
On-Grade Inlet Pit	
Kerb Inlet	80%
Grated Inlet	60%
Combination	90%

The sensitivity of the catchment's drainage response to blockage of assumptions within the underground drainage network is assessed in Section 10.

8. MODEL VERIFICATION

Ideally the overall modelling system should be calibrated to one historical event and validated using at least one other historical event. To facilitate this work there should be sufficient historical flood height data, preferably for multiple historical events.

For the study area the insufficient quality and quantity of historical data means that this process was not possible. Thus verification was undertaken in which results from the current work were compared with:

- anecdotal reports of flooding in the November 1984 event, various events in 1989, the June 2007 event and the February 2012 event,
- specific and general descriptions of catchment flooding behaviour

8.1. Verification Results

A comparison of recorded flooding observations is made against design flood depths and levels in Table 15. Given the lack of surveyed flood levels and the general paucity of data the modelled results correspond reasonably well with anecdotal flooding observations and general catchment behaviour.

Table 15 – Comparison of Observed Flooding Behaviour against Design Flood Results

ID	Location	Description	Flood Event	Observed Depth (m)	Peak Modelled Flood Depth (m)						Comments
					2Y ARI	5Y ARI	10Y ARI	20Y ARI	50Y ARI	100Y ARI	
1	Moore Park Road (South of Victoria Barracks)	Depth in the road	-	0.4	0.6	0.6	0.6	0.6	0.6	0.6	Modelled depths based on gutter break-lines
2	Driver Avenue	Flooding for 1 week with spill from Kippax Lake a factor	5/11/1984	-	1.3	1.5	1.6	1.7	1.8	1.9	Modelled results show extensive flooding
3	Stewart Street / Little Stewart Street	Reported flooding at intersection of Stewart Street / Little Stewart Street	-	-	1.0	1.1	1.2	1.2	1.3	1.3	Runoff from Little Stewart Street enters the low point with no overland flow path
4	Stewart Street	Yard Flooding	6/1/1989 9/3/1989 21/4/1989	- - -	1.0	1.1	1.2	1.2	1.3	1.3	Low points in Stewart and Leinster Streets contribute to property inundation
5	Moore Park Rd	Garage flooding in all heavy rain events	-	-	1.2	1.3	1.4	1.4	1.5	1.5	Depth of up to 1.5 m in Leinster Street
6	Moore Park Rd	Flooding at lane rear of property	Feb 2001	>1.0	1.2	1.3	1.3	1.3	1.4	1.4	
7	Robertson Rd	Road flooded	Feb 2012	0.45	0.3	0.3	0.3	0.3	0.4	0.4	Modelled results replicate observed behaviour
		Property inundation	Feb 2012	0.15	0.1	0.1	0.1	0.1	0.1	0.1	Property flooded by approximately 0.1 m in all events.
8	Lang Road (East)	Road flooding leading to minor flooding on front lawn	14/6/2007	-	0.6 in road	0.6 in road	0.7 in road	0.7 in road	0.7 in road	0.7 in road	Peak flood levels vary between 47.3 and 47.4 mAHD for design events. A wall adjacent to the property is the control.

8.1.1. Comparison to Similar Studies

Two DRAINS models were constructed as part of the Kensington-Centennial Park Flood Study (Reference 1) and include modelling of the Moore Park and Fox Studios catchments (known as SWC 58 & 59 and SWC 94). A comparison between results from References 1 against those in the current study is given in Table 16.

Table 16 – Comparison of peak flows (m^3/s) at various locations with Reference 1.

Location	Type	2 Year ARI		20 Year ARI		100 Year ARI	
		DRAINS	TUFLOW	DRAINS	TUFLOW	DRAINS	TUFLOW
Driver Avenue adjacent to John Hargreaves Ave (SWC 89)	Overland	0.0	0.0	0.0	0.0	0.0	0.0
	Piped	4.1	1.4	4.2	2.0	4.3	2.4
Lottie Lyell Ave west of the SCG (SWC 58 & 59)	Overland	0.0	0.0	0.0	0.0	1.4	0.0
	Piped	6.6	1.4	8.5	1.8	9.0	2.0
Lang Road (SWC 89 and SWC 58 & 59)	Overland	11.2	1.9	1.4	9.7	4.7	15.1
	Piped	11.2	3.0	13.6	3.5	14.6	3.8

Reference 1 has used an embedded storm approach for design hydrology for a 1 hour event embedded in the longer 12 hour event. In addition, overland flow-paths must be defined explicitly in DRAINS and are better represented in a 2D model such as within the current study which represents them implicitly.

Reference 1 assumed that the Centennial Park catchment (within the CoS LGA) comprised of two separate drainage areas, with no interaction of overland flow from one model to the other. Previously it was assumed that all flow (piped and overland) from the Moore Park catchment eventually discharged into Busbys Pond. Inspection of the LiDAR data has identified a crest near the Lang Road and Robertson Road which is higher than ground levels within the Parklands Sports Centre. As a result, the current study shows the majority of overland flow combining within Lang Road and travelling through the Parklands Sports Centre to ANZAC Parade, with minimal overland flow entering Busby Pond.

TUFLOW produces much lower piped flows than DRAINS and this may be attributed to model schematisation. In DRAINS all overland flow routes are connected to the pits and if the pit or downstream pipe capacity is reached, any excess flow is stored above the pit (sag pit), directed out of the model (on-grade pit) or directed along the downstream overland flow path (on-grade pit). Pit inlet capacity in DRAINS was assumed to be unlimited whereas the current study assumes pit blockages. In the current study not all overland flow will be routed to the inlet pits, therefore the drainage system will not necessarily be at capacity. Additionally, DRAINS cannot take into account backwater effects within the overland domain therefore any additional driving head (or level ponding) is not accounted for in pipe flow hydraulics and this also effects catchment attenuation and therefore total flows.

It is considered that the modelling methodology used for this study provides a more accurate and detailed representation of the relevant physical process than previous studies using only DRAINS.

9. DESIGN FLOOD MODELLING

9.1. 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 5. 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 minute storm was critical for the majority of the catchment, with Kippax Lake having a critical duration greater than 3 hours due to additional storage volume. Upstream areas of the catchment near Stewart Street had a shorter critical duration of 30 minutes however peak flood depths produced by various storm events were generally found to be within ±0.05 m. As a result the 60 minute duration was taken to be the critical storm duration.

Modelling of the PMF indicated that the 15 minute duration and the 60 minute duration produced the highest flood levels throughout the catchment. In upper areas of the catchment the 15 minute event was dominant, with flood levels approximately 0.2 m higher in Stewart Street than in the 60 minute event. Near Kippax Lake and lower areas of the catchment, the 60 minute event produced flood levels up to 0.5 m higher than that of the 15 minute event. As a result, the 60 minute duration event was assessed as the critical duration.

9.2. Overview of Results

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

- Peak flood level profiles on Figure 12 to Figure 14,
- Peak flood depths and levels on Figure 15 to Figure 20,
- Provisional flood hazard on Figure 22 to Figure 25,
- Preliminary hydraulic categorisation on Figure 26.

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

9.3. Peak Outflows from Sub-catchments

There are three major outflow locations within the catchment, which are to Busby's Pond, Kensington Ponds and via Anzac Parade. Table 17 indicates the peak catchment outflows for all design storm events.

Table 17 – Comparison of peak outflows for all design storm events

Outlet	Type	2 Year ARI	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	PMF
Busby's Pond	Piped	1.9	2.1	2.3	2.5	2.6	2.7	3.6
	Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Kensington Ponds	Piped	1.1	1.3	1.4	1.4	1.5	1.5	1.6
	Overland	1.1	1.3	1.4	1.4	1.4	1.5	1.8
Anzac Parade	Piped	2.2	2.2	2.2	2.3	2.3	2.3	2.6
	Overland	2.5	6.7	9.7	13.1	17.6	21.2	117

9.4. Results at Key Locations

The results at key locations for peak flood flows, velocities, levels and depths are shown on Table 18 and Table 19 (refer to Figure 11 for locations).

Table 18 – 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	Driver Avenue (North)	Q027	Overland	0.6	0.9	1.1	1.4	1.7	2.0	7.0
		DRAP6151B	Piped	0.2	0.3	0.3	0.3	0.3	0.3	0.3
2	Football Stadium Car-park	Q031	Overland	2.1	3.5	4.3	5.4	6.5	8.0	29.9
		DRAP6159	Piped	0.4	0.4	0.4	0.4	0.4	0.4	0.4
3	Football Stadium Entrance at Regent St	Q026	Overland	0.3	0.5	0.7	0.8	0.8	0.9	2.5
4	Poate Road	Q041	Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		DRAP5967	Piped	0.9	0.9	0.9	0.9	0.9	0.9	0.9
5	Entertainment Quarter Show Ring	Q076	Overland	1.1	1.5	1.7	2.0	2.3	2.6	6.1
6	Errol Flynn Boulevard	Q061	Overland	2.6	4.0	4.8	5.8	6.9	8.1	51.6
7	Lang Road (West)	Q073	Overland	1.9	5.7	7.6	10.0	12.8	15.1	88.3
		DRAP5897G	Piped	3.4	3.7	3.8	3.9	4.0	4.1	5.3
8	Parklands Sports Centre at Busway	Q072	Overland	0.9	4.9	7.3	10.2	13.8	16.7	84.1
		DRAP6120	Piped	3.4	3.7	3.9	4.0	4.2	4.3	5.4
9	Anzac Parade near Robertson Road	Q071	Overland	0.9	4.9	7.4	10.3	13.9	16.7	100.2
		PW8A	Piped	2.5	2.7	2.8	2.9	3.1	3.3	4.7
		DRAP5883A	Piped	1.1	1.2	1.3	1.3	1.4	1.4	2.2
10	Centennial Park (East of Lang Rd)	Q018	Overland	0.8	1.2	1.5	1.8	2.1	2.3	7.3
11	Centennial Park (East of Mitchell St)	Q089	Overland	0.1	0.1	0.1	0.1	0.1	0.1	0.2
		DRAP5828B	Piped	0.2	0.3	0.3	0.3	0.3	0.3	0.4

Table 19 – Peak flood levels (m AHD) and depths (m) at key locations for all design events

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	Stewart Street	49.4	0.2	49.7	0.5	49.8	0.7	49.9	0.8	50.0	0.9	50.0	0.9	50.4	1.3
2	Leinster Street	47.4	1.1	47.5	1.3	47.5	1.3	47.6	1.4	47.7	1.4	47.7	1.4	48.2	1.9
3	Poate Road	52.1	0.9	52.4	1.2	52.6	1.4	52.7	1.5	52.8	1.6	52.9	1.7	53.6	2.4
4	Driver Avenue	38.5	0.9	38.7	1.1	38.8	1.2	38.9	1.3	39.0	1.4	39.1	1.5	40.1	2.5
5	John Hargraves Ave	-	-	-	-	-	-	37.8	0.0	38.2	0.5	38.4	0.6	39.4	1.6
6	Erol Flynn Boulevard	37.4	0.2	37.4	0.2	37.5	0.3	37.5	0.3	37.5	0.3	37.6	0.4	38.0	0.8
7	Lang Road/ Driver Ave	35.9	0.7	36.0	0.8	36.0	0.8	36.1	0.9	36.1	0.9	36.1	0.9	36.6	1.4
8	Parklands adjacent Lang Road / Driver Ave	35.9	0.7	36.0	0.8	36.0	0.8	36.1	0.9	36.1	0.9	36.1	0.9	36.6	1.4
9	Lang Road (East)	47.3	0.5	47.3	0.5	47.3	0.5	47.4	0.5	47.4	0.6	47.4	0.6	47.6	0.8
10	Anzac Parade	34.8	0.1	35.0	0.3	35.1	0.4	35.1	0.4	35.2	0.5	35.2	0.5	35.6	0.9