OVERFLOW CONSENTING AND DESIGN STORM SELECTION BASED ON HISTORICAL RAINFALL

Joel Wilson (WCS Engineering), Andrew Rickert (WCS Engineering), Bridget O'Brien (Christchurch City Council), Tyler McMillan (Christchurch City Council)

ABSTRACT

Christchurch City Council (CCC) has a large wastewater network serving approximately 373,000 people with a single wastewater treatment plant capable of treating 650 megalitres/day. This paper outlines the innovative approach to assessing overflow compliance used by CCC. Continuous simulation of long-term rainfall data is utilised to assess overflow compliance rather than a synthetic rainfall pattern representing the target return period. Network planning is based on a design storm generated using statistical analysis of the 25-year rainfall continuous model simulation results. The paper demonstrates that overflow frequencies are sometimes not well represented by rainfall events that have an equivalent return period and that antecedent rainfall conditions and hydrologic and hydraulic routing of flows unique to each collection system can help to select a better design storm to simulate overflow return periods of interest.

Christchurch has two main river systems: Avon and Heathcote. CCC holds a resource consent that allows an overflow frequency to each of these receiving environments which decreases over time to a 2-year ARI, based on 15 years of long timeseries modelling. Additionally, no site may overflow more than every six months on average, based on the same long timeseries modelling.

The objective of the wet weather overflow compliance assessment was to determine wastewater overflow compliance with the consent conditions stipulated by the environmental protection agency, Environment Canterbury (ECAN). This was undertaken using the calibrated hydraulic model to simulate system performance based on continuous rainfall data from the period of 1995 to 2020. To determine whether the rainfall window could have an impact on the consent compliance results, the assessment of overflow frequency and volume was performed for four time periods: 1995-2020, 1995-2010, 2000-2015 and 2005 2020. The compliance assessment results showed a significant level of variation in overflow response dependent on the rainfall window chosen; however, the compliance outcomes were not affected.

The objective of the design storm review was to ensure the design storm used for wastewater infrastructure planning is representative of a 2-year return period based on the continuous simulation results as the previous synthetic event did not provide a good representation of actual overflows. The assessment was based on overflow volume, peak and spatial distribution. Due to a high degree of rainfall spatial variance in the historical events close to a 2-year return period, it was

decided to complete the overflow statistical analysis by receiving environment rather than system-wide.

Based on the results from the overflow statistical analysis, several 2-year design storm alternatives were shortlisted. The preferred 2-year design storm was a composite event made up of August 5, 1995 (northern basins) and April 17, 2014 (southern basins). This event provided the best representation of 2-year ARI overflow volumes, peaks and spatial distribution and comprised events of sufficiently short duration to be convenient for planning.

The results from this study demonstrate a novel and improved approach to developing design storms to ensure investments made in new infrastructure and rehabilitation programs are targeted in the relevant area of the collection system to meet compliance targets.

KEYWORDS

Sanitary sewer overflows, consent compliance, environmental regulations, continuous rainfall simulation, composite synthetic design storms.

PRESENTER PROFILE

Andrew Faulkner is a water and wastewater infrastructure planning engineer with over 12 years of experience in water distribution and collection systems modeling, strategic planning, and alternatives analysis. He has worked extensively with high-profile water utilities and engineering consultants.

INTRODUCTION

Christchurch City Council provides drinking water, stormwater, and wastewater across five council areas in the South Island, New Zealand. Christchurch has a large and complex wastewater network serving approximately 373,000 people with a single wastewater treatment plant capable of treating 650 megaliters/day (MLD).

Christchurch has two main river systems: the Avon River and the Heathcote River, which both flow into the Avon-Heathcote Estuary which then flows into the Pacific Ocean (see Figure 1). Christchurch City Council (CCC) holds a resource consent (permit) for the overflows to waterways. The resource consent allows an overflow frequency to each of these receiving environments which decreases over time to a 2-year ARI, based on 15 years of long time series modelling. In addition, no overflow site may overflow more than every six months on average, based on the same long time series modelling.

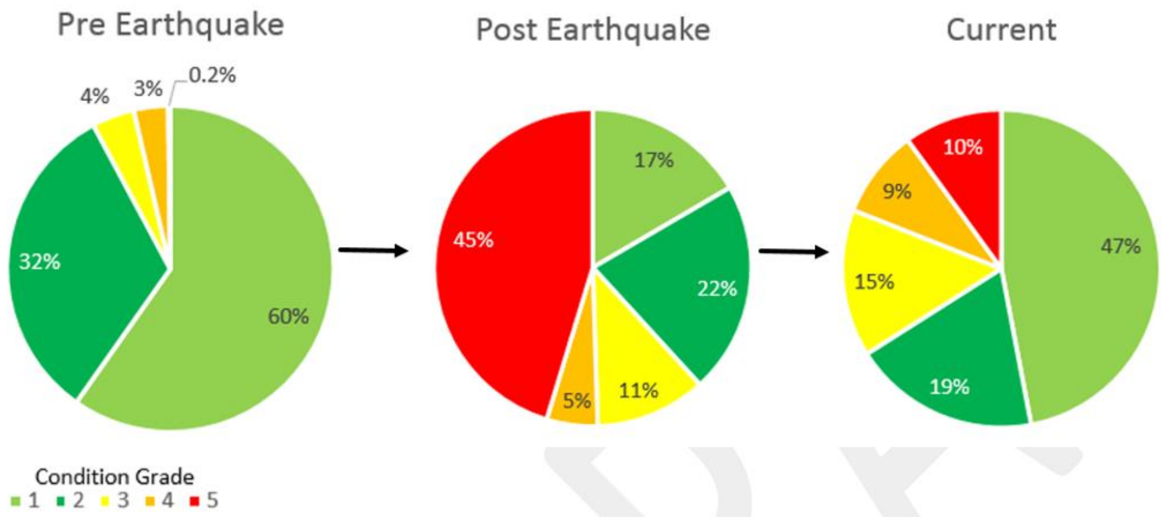
The Christchurch Overflow Compliance Assessment project was commenced and completed in 2020. The project was completed using the latest model calibration completed in 2020 and was an update to the overflow compliance assessment completed based on the model previously calibrated in 2015. The overflow consent conditions require that continuous simulation of the most recent 15-years of rainfall be completed to assess the system performance. This project included continuous simulation of the most recent 25-years of rainfall and analysis of overflow results from three different 15-year windows to investigate whether the overflow frequencies are significantly affected by the 15-year window of rainfall selected.

Overflow control measure alternatives to achieve the 2-year overflow return period target were previously assessed using a synthetic triangular rainfall pattern. To determine whether this rainfall pattern would be appropriate for future planning studies, the long-term continuous simulation results were used to predict the location of overflows occurring more frequently than once every two years and then compared to the locations predicted using the synthetic triangular rainfall pattern. This assessment demonstrated that the synthetic event did not provide a good representation of actual overflows and a new design storm was developed based on historic events.

Figure 1: Map of Christchurch City, New Zealand

Christchurch experienced a series of large earthquakes starting on September 4, 2010 (Magnitude 7.1) and culminating in the devastating February 22, 2011, Magnitude 6.3 earthquake which claimed 185 lives. The earthquakes also had a massive effect on the city's infrastructure, particularly the wastewater network. As can be seen in Figure 2, the percentage of pipes with a condition grade of 5 (very poor, expected to fail within 1-2 years) went from zero to 47% as a result of the earthquakes. As a result, inflow and infiltration into the wastewater network has increased significantly. A five-year non-enforcement agreement for the overflow consent was entered into with the regulator after the earthquakes, to allow the city time to repair its infrastructure. While NZ$2.22 billion (US$1.5 billion) was spent repairing the city's horizontal infrastructure, not all damage was repaired and 10% of wastewater pipes are still condition grade 5.

Figure 2: Assessed condition of wastewater mains (percentage by value), before and after the earthquakes, and current. Condition Grade 1 = as new, Condition Grade 5 = expected to fail within 1-2 years.



However, CCC did not expect to be able to comply with its overflow consent at the end of the five-year non-enforcement period due to the remaining damage to its infrastructure. The primary cause of capacity deficiencies within the wastewater network is high rates of inflow and infiltration (I/I), attributed to a significant portion of the network being below the groundwater table and significantly earthquake-damaged or deteriorated assets. In some parts of the catchment, rainfall dependent I/I observed between dry and wet weather flows suggest that the wastewater network provides substantial stormwater drainage capacity.

METHODOLOGY

The wet weather overflow compliance assessment was undertaken using the calibrated hydraulic model to simulate system performance based on continuous rainfall data from the period of 1995 to 2020. The assessment of overflow frequency and volume was performed for the following time periods:

1. 1995 to 2020
2. 1995 to 2010
3. 2000 to 2015
4. 2005 to 2020

The consent specifies that the most recent 15-year period (2005 to 2020) is to be used for the assessment of overflows. However, additional 15-year time windows were included in the 2020 model analysis to provide an indication of the result sensitivity to climatic variations and to ensure that climatic variations didn't significantly influence the results. This would be important when comparing 2020 model results to the previous overflow compliance assessment performed using the hydraulic model calibrated in 2015 ("2015 model"), as that was based on 2000 to 2015 rainfall data.

The wet weather overflow consent conditions require no more than two overflows per year at any one site as a short-term target. The long-term overflow control target is no more than one overflow every two years. The consent conditions also require specific overflow frequency and volume targets to be achieved for the Avon and Heathcote waterways in the City, and the Avon-Heathcote Estuary.

OVERFLOW COMPLIANCE RESULTS

The following overflow compliance assessment is based on continuous simulation of rainfall recorded between 2005 and 2020 for the recalibrated 2020 model, and rainfall recorded between 2000 and 2015 for the calibrated 2015 model. The rainfall data is spatially varied based on the available rain gauge data at 18 sites over the analysis period.

The results of the condition 5a compliance assessment are summarised in Table 1.

Table 1: Condition 5a Compliance Assessment –Annual overflow event frequency by catchment

Catchment	Average Annual CSO Frequency (spills/year/site)				
	2015 LTS Analysis	Compliance Target 2015	2020 LTS Analysis	Compliance Target 2020	Compliant?
Avon River	1.50	0.70	0.56	0.49	No
Heathcote River	2.60	0.80	1.43	0.47	No
Avon-Heathcote Estuary	1.67	0.44	1.20	0.44	No

The results indicate that the Christchurch wastewater collection system is non-compliant with respect to Condition 5a and remedial measures should be implemented to bring the system performance into compliance. However, the results also show a significant improvement in system performance and compliance when compared to the 2015 model analysis results.

The results of the condition 5b compliance assessment are summarised in Table 2 for all constructed overflows with a frequency greater than one spill in two years.

Table 2: Condition 5b Compliance Assessment - Annual overflow event frequency for individual sites listed in Schedule 1

Constructed Overflow ID	Constructed Overflow Name	Catchment	Scehdule 1 CSO (Y/N)	Target Date for < 2 Spills per Year	Average Annual Volume (m^3)	Overflow Frequency (Spills/Year)	Compliant?
WwOutfall13847	PS20/4 Fisher Ave	Heathcote	YES	30/06/2022	26,071	6.13	No
WwOutfall9578	PS1/18 67 Mandeville St	Avon	YES	Compliant 2017	659	5.73	No
WwOutfall24207	PS1/19 Picton Ave	Avon	YES	Compliant 2017	530	5.20	No
WwOutfall13982	PS21/1 Sandwich Rd/Eastern Tce	Heathcote	YES	30/06/2020	1,752	4.67	No
WwOutfall18191	PS13/1 Tilford St	Heathcote	YES	30/06/2020	1,059	4.13	No
WwOutfall24087	PS20/3 Tennyson St	Heathcote	YES	Compliant 2017	6,211	4.13	No
WwOutfall24109	PS20/2 Waltham Rd	Heathcote	NO		2,237	3.80	No
WwOutfall6846	PS42/1 Kevin St	Heathcote	NO		142	3.40	No
WwOutFall24187	PS127/2 Albert Tce	Heathcote	YES	Compliant 2017	1,776	1.73	Yes
WwOutfall24267	PS127/1 297 Centaurus Rd	Heathcote	YES	Compliant 2017	5,084	1.47	Yes
WwOutfall24249	PS117/1 15 A Coppell Place	Heathcote	YES	Compliant 2017	702	1.40	Yes
WwOutfall15484	PS20/1 Riverlaw Tce	Heathcote	NO		190	1.20	Yes
WwOutfall15445	PS20/2 Fifield Tce	Heathcote	YES	Compliant 2017	153	1.13	Yes
WwOutfall23978	PS31/1 Main Rd	Estuary	NO		1,334	1.07	Yes
WwOutfall19334	PS54/1 Belmont St	Avon	NO		74	1.00	Yes

The results shown in Table 2 show a total of eight constructed overflows that have a frequency of more than two spills per year and are non-compliant with respect to condition 5b. A further 10 constructed overflows are not achieving the long-term target of no more than one overflow every two years. Note there are significantly more overflows predicted to occur as manhole flooding that are not included in this summary and are not required to be reported as part of the compliance assessment. Manhole overflows are included in the design storm selection process and they will be addressed as part of future master planning.

The results of the condition 6 compliance assessment are summarised in Table 3 and Table 4. As currently written, evaluation of condition 6 is based on overflow volumes originating from constructed sewer overflows; and spills from manholes are presented for the 2020 Long Time Series (LTS) analysis but are not evaluated in the compliance assessment.

Table 3: Condition 6 Compliance Assessment – Annual overflow volume by catchment

Catchment	Av. Annual CSO Volume (m^3/year) from 2015 LTS		Av. Annual CSO Volume (m^3/year) from 2020 LTS	
	Schedule 1 Volume	All CSO Volume	Schedule 1 Volume	All CSO Volume
Avon River	43,684	82,475	2,888	3,249
Heathcote River	161,082	200,114	43,659	49,474
Avon-Heathcote Estuary	36	5,664	-	1,570

Table 4: Condition 6 compliance assessment – 2015 to 2020 overflow volume reduction

Catchment	Compliance Target 2020 (% volume reduction)	Schedule 1 volume % reduction	Compliant?	All CSO volume % reduction	Compliant?
Avon River	30%	93%	Yes	96%	Yes
Heathcote River	41%	73%	Yes	75%	Yes
Avon-Heathcote Estuary	0%	-	Yes	72%	Yes

The results shown in Table 4 show that predicted overflow volumes have reduced significantly from 2015 to 2020 and the overflow volume reduction in each catchment is compliant with respect to condition 6.

AFFECT OF RAINFALL ANALYSIS PERIOD

The consent conditions specify that the overflow frequency and volume assessment be completed based on the most recent 15-year rainfall data (2005 to 2020). For the evaluation of consent conditions 5 and 6, this effectively creates "moving goal posts" depending on climatic variations and cycles. To determine whether the rainfall window could have an impact on any of the consent compliance results, the assessment of overflow frequency and volume was performed for the following time periods:

1. 1995 to 2010 – Average annual rainfall of 396 mm per year

2. 2000 to 2015 – Average annual rainfall of 627 mm per year
3. 2005 to 2020 – Average annual rainfall of 629 mm per year
4. 1995 to 2020 – Average annual rainfall of 617 mm per year

The results for each time period are compared in Table 5 for overflow frequency in each catchment (condition 5a), Table 6 for overflow frequency at each site (condition 5b) and Table 7 for overflow volume in each catchment (condition 6).

Table 5: Overflow frequency in each catchment for different time periods (condition 5a)

Catchment	Average Annual Overflow Frequency (spills/year/site)			
	1995 - 2010	2000 - 2015	2005 - 2020	1995 - 2020
Avon River	0.47	0.62	0.56	0.52
Heathcote River	1.24	1.47	1.43	1.30
Avon-Heathcote Estuary	0.88	1.20	1.20	0.99

Table 6: Overflow frequency at each site for different time periods (condition 5b)

Constructed Overflow ID	Constructed Overflow Name	Catchment	Overflow Frequency (Spills/Year)			
			1995 - 2010	2000 - 2015	2005 - 2020	1995 - 2020
WwOutfall24088	PS1/12 Waltham Rd/Roger St	Heathcote	5.98	7.01	6.80	6.35
WwOutfall13847	PS20/4 Fisher Ave	Heathcote	5.34	5.96	6.13	5.47
WwOutfall9578	PS1/18 67 Mandeville St	Avon	5.09	6.09	5.73	5.33
WwOutfall24207	PS1/19 Picton Ave	Avon	4.56	5.54	5.20	4.83
WwOutfall13982	PS21/1 Sandwich Rd/Eastern Tce	Heathcote	3.91	4.36	4.67	4.25
WwOutfall18191	PS13/1 Tilford St	Heathcote	4.13	4.34	4.13	4.07
WwOutfall24087	PS20/3 Tennyson St	Heathcote	3.34	4.06	4.13	3.52
WwOutfall24109	PS20/2 Waltham Rd	Heathcote	3.04	3.55	3.80	3.19
WwOutfall6846	PS42/1 Kevin St	Heathcote	2.41	3.83	3.40	2.68
WwOutFall24187	PS127/2 Albert Tce	Heathcote	1.11	1.53	1.73	1.41
WwOutfall24267	PS127/1 297 Centaurus Rd	Heathcote	1.05	1.40	1.47	1.17
WwOutfall24249	PS117/1 15 A Coppell Place	Heathcote	1.13	1.47	1.40	1.24
WwOutfall15484	PS20/1 Riverlaw Tce	Heathcote	0.97	1.26	1.20	1.06
WwOutfall15445	PS20/2 Fifield Tce	Heathcote	0.92	1.19	1.13	1.00
WwOutfall23978	PS31/1 Main Rd	Estuary	0.80	1.07	1.07	0.88
WwOutfall19334	PS54/1 Belmont St	Avon	0.87	1.00	1.00	0.92
WwOutfall17310	PS44/1 Opawa Rd	Heathcote	1.07	1.00	0.80	0.92
WwOutfall17011	PS18/2 Mackenzie Ave	Heathcote	0.93	0.80	0.60	0.76
WwOutFall24182	PS43/2 107 Ashgrove Tce	Heathcote	0.47	0.73	0.60	0.52

Table 7: Overflow volume in each catchment for different time periods (condition 6)

Catchment	Average Annual Overflow Volume (m^3/year)			
	1995 - 2010	2000 - 2015	2005 - 2020	1995 - 2020
Avon River	1,408	3,400	3,246	2,553
Heathcote River	34,710	54,084	49,474	42,178
Avon-Heathcote Estuary	785	1,920	1,570	1,323

The results of the 2005 to 2020 time period can be up to 10% different (less conservative) when compared to the results from 2000 to 2015 time period. Conversely, comparing results of the 2005 to 2020 time period with the much longer 1995 to 2020, 25-year time period can be up to 30% different (more conservative). Surprisingly, the results indicate no change in the outcome of compliance with respect to condition 5a, condition 5b or condition 6.

To avoid having a moving target for compliance (since the existing condition requires the most recent 15-years of rainfall to be used each time the compliance assessment is updated), CCC recommended to ECAN that either a fixed window of time be used for all future compliance assessments or that a design storm that is suitably representative of the target return period be used to assess compliance.

DESIGN STORM SELECTION

The objective of the design storm review was to ensure the design storm used for wastewater infrastructure planning is representative of a 2-year return period based on the 25-year continuous simulation results. The assessment was based on overflow volume, peak and spatial distribution.

The 25-year continuous simulation results were reviewed to identify historical events that corresponded to an overflow return period of approximately 2 years. The initial review was completed by ranking the total system-wide overflow volume and overflow peak discharge to find events corresponding approximately to a 2-year ARI. Due to a high degree of rainfall spatial variance in the historical events that were close to a 2-year return period, it was decided to repeat the overflow statistical analysis by receiving environment rather than system-wide.

The most distinct trend in rainfall spatial variance was that higher-than-average rainfall occurs over southern catchments incorporating the Heathcote river, Avon-Heathcote Estuary and adjacent catchments of Halswell and Ocean. Conversely, lower than average rainfall occurs over northern catchments incorporating the Avon river and adjacent catchment of Styx river. Therefore, the overflow statistical analysis was performed separately for overflows occurring in each of those two groups.

The overflow statistical analysis results for the northern catchments are shown in Table 8 and for the southern catchments in Table 9.

The spatial distribution of overflows (including both constructed overflows and manhole overflows) are compared to the preferred 2-year design storm performance in Figure 3.

The following 2-year design storm alternatives were short listed for consideration:

1. 3-year, 24-hour synthetic rainfall event (previously found to give close to a 2-year return period response).
2. 3-year, 24-hour synthetic rainfall event modified to provide an improved representation of 2-year return period overflow results.
3. August 5, 1995 and May 26, 2010 composite event
4. August 5, 1995 and April 17, 2014 composite event
5. August 5, 1995 and April 17, 2014 composite event with dates aligned to coincide with weekday dry weather flow.

The results from each scenario compared in Table 10 show that Scenario 5 above achieves the SSO volume and peak discharge that is most consistent with a 2-year return period from the 25-year continuous simulation of rainfall data.

The preferred 2-year design storm, presented in Figure 3, was the August 5, 1995 and April 17, 2014 composite event. This event provided the best representation of 2-year ARI overflow volumes, peaks and spatial distribution and comprised events of sufficiently short duration to be convenient for planning.

The selected 2-year design storm will be verified by completing a 15-year continuous simulation of the optimized master plan to check that the overflow frequency is within the acceptable target level of service. Having an accurate 2-year design enables the engineering team to efficiently evaluate capital improvement planning alternatives that will meet the ECAN compliance objectives.

Table 8: Northern catchments overflow statistical analysis results

Overflow Event	Max Total Rainfall (mm)			Constructed Overflows		Mahhole Flooding		Total CSO and MH		Event ARI (Yrs)				
	6 hrs	24 hrs	Event	Total Volume (m^3)	Total Peak (L/s)	Total Volume (m^3)	Total Peak (L/s)	Total Volume (m^3)	Total Peak (L/s)	6h Rainfall	24h Rainfall	Total Volume	Total Peak	Avg. Vol/Peak ARI
Outfall Discharge Events														
Mar 4, 2014	33	110	128	9596	327	37650	1258	47246	1585	7.1	50.0	**7.1**	**50.0**	28.6
Jun 20, 2013	12	41	87	5350	61	82604	409	87955	469	0.2	0.8	**50.0**	**1.3**	25.6
Jun 16, 2013	25	67	98	8531	219	72616	824	81147	1043	1.5	5.6	**16.7**	**7.1**	11.9
May 7, 2003	29	33	33	390	86	6279	1250	6669	1336	3.3	0.4	**0.9**	**16.7**	8.8
Apr 28, 2014	24	56	67	8878	150	71594	705	80472	855	1.2	2.6	**10.0**	**3.8**	6.9
Apr 17, 2014	28	67	73	2201	89	32497	844	34698	933	2.4	7.1	**4.5**	**5.6**	5.1
Jul 30, 2008	20	41	62	461	17	37688	607	38150	624	0.6	0.8	**5.6**	**2.9**	4.2
Jul 15, 1996	19	44	89	1377	94	20285	827	21661	921	0.5	1.1	**2.9**	**4.5**	3.7
Jul 17, 1999	30	69	91	4223	107	28669	690	32892	797	4.5	10.0	**3.8**	**3.3**	3.6
Aug 5, 1995	23	47	62	1365	68	14297	530	15662	598	0.9	1.4	**2.4**	**2.4**	2.4
Aug 12, 2012	25	59	97	1508	30	20487	437	21994	466	1.4	3.3	**3.3**	**1.2**	2.2
Jul 21, 2017	24	37	73	1133	26	18493	520	19626	547	1.1	0.6	**2.6**	**1.7**	2.2
Oct 12, 2000	34	74	82	1739	102	11041	490	12780	593	50.0	16.7	**1.9**	**2.2**	2.0
Jun 1, 2019	24	59	82	366	24	7809	594	8175	618	1.2	3.8	**1.1**	**2.6**	1.9
Aug 6, 2004	25	58	72	1010	24	13881	323	14891	347	1.6	2.9	**2.2**	**0.9**	1.5
Nov 16, 2002	25	46	88	896	41	8600	475	9496	516	1.9	1.3	**1.4**	**1.5**	1.5
Aug 16, 2011	22	31	62	237	14	7418	541	7655	554	0.9	0.4	**1.0**	**1.9**	1.4
Apr 14, 2017	25	39	61	435	31	8078	513	8513	544	1.7	0.7	**1.2**	**1.6**	1.4
Jun 9, 2014	14	38	56	112	8	14539	270	14651	278	0.2	0.6	**2.0**	**0.7**	1.4
Jul 27, 1999	19	44	72	468	17	9345	449	9813	467	0.5	1.2	**1.5**	**1.2**	1.4
Apr 29, 2002	29	43	45	932	70	7627	430	8559	499	3.8	0.9	**1.3**	**1.4**	1.3
May 12, 2006	30	46	46	618	34	7578	469	8196	503	5.6	1.4	**1.2**	**1.4**	1.3
May 26, 2010	20	49	128	538	26	10450	287	10987	313	0.6	1.7	**1.6**	**0.8**	1.2
Jun 28, 2008	20	42	52	629	26	8666	383	9295	409	0.6	0.9	**1.4**	**1.0**	1.2
Dec 22, 2018	16	18	23	103	35	1632	536	1735	571	0.3	0.1	**0.2**	**2.0**	1.1
Oct 19, 2011	28	45	45	414	21	7385	427	7799	448	2.2	1.2	**1.1**	**1.1**	1.1
May 3, 2008	21	52	62	834	51	5882	396	6716	446	0.8	1.9	**0.9**	**1.1**	1.0

Table 9: Southern catchments overflow statistical analysis results

Overflow Event	Max Total Rainfall (mm)			Constructed Overflows		Mahhole Flooding		Total CSO and MH		Event ARI (Yrs)				
	6 hrs	24 hrs	Event	Total Volume (m^3)	Total Peak (L/s)	Total Volume (m^3)	Total Peak (L/s)	Total Volume (m^3)	Total Peak (L/s)	6h Rainfall	24h Rainfall	Total Volume	Total Peak	Avg. Vol/Peak ARI
Outfall Discharge Events														
Mar 4, 2014	33	110	128	53709	721	204912	2194	258621	2915	7.1	50.0	**50.0**	**16.7**	33.3
Oct 12, 2000	34	74	82	60619	965	185746	2008	246365	2973	50.0	16.7	**10.0**	**50.0**	30.0
Aug 12, 2012	25	59	97	53802	382	197058	819	250860	1201	1.4	3.3	**16.7**	**3.3**	10.0
Nov 16, 2002	25	46	88	19697	557	104531	1451	124229	2008	1.9	1.3	**3.3**	**10.0**	6.7
Aug 7, 2006	12	38	64	32384	288	162110	1097	194494	1385	0.2	0.6	**7.1**	**4.5**	5.8
Apr 28, 2014	24	56	67	41376	417	136648	1047	178024	1465	1.2	2.6	**4.5**	**5.6**	5.1
May 12, 2006	30	46	46	12766	414	36443	1140	49210	1554	5.6	1.4	**1.7**	**7.1**	4.4
Jul 21, 2017	24	37	73	31473	333	143698	1034	175172	1367	1.1	0.6	**3.8**	**3.8**	3.8
Jun 16, 2013	25	67	98	19697	281	163147	607	182844	888	1.5	5.6	**5.6**	**1.7**	3.6
Apr 17, 2014	28	67	73	17449	383	64188	771	81637	1153	2.4	7.1	**2.4**	**2.9**	2.7
Jul 27, 1999	19	44	72	24021	293	98054	547	122075	839	0.5	1.2	**2.9**	**1.4**	2.2
May 26, 2010	20	49	128	18548	315	41395	684	59944	999	0.6	1.7	**2.0**	**2.2**	2.1
Jun 20, 2013	12	41	87	48890	242	37184	368	86074	610	0.2	0.8	**2.6**	**0.9**	1.8
Oct 19, 2011	28	45	45	5594	309	17178	747	22771	1056	2.2	1.2	**0.8**	**2.6**	1.7
Jul 17, 1999	30	69	91	16316	353	25185	558	41501	910	4.5	10.0	**1.5**	**1.9**	1.7
May 19, 2009	14	29	79	9730	312	59520	382	69250	694	0.2	0.3	**2.2**	**0.9**	1.6
Dec 20, 2006	33	52	70	7974	289	32296	556	40270	845	16.7	2.0	**1.4**	**1.5**	1.4
Apr 29, 2002	29	43	45	6318	293	16643	703	22962	996	3.8	0.9	**0.8**	**2.0**	1.4
Jun 28, 2008	20	42	52	6742	238	29987	538	36729	776	0.6	0.9	**1.2**	**1.3**	1.2
Sep 10, 2000	20	33	38	6296	290	31028	484	37324	774	0.5	0.5	**1.2**	**1.2**	1.2
Jul 30, 2008	20	41	62	8943	147	43187	296	52130	443	0.6	0.8	**1.9**	**0.6**	1.2
Jul 15, 1996	19	44	89	5797	285	32049	445	37846	730	0.5	1.1	**1.3**	**1.1**	1.2
Jul 5, 2008	20	36	45	7081	214	34244	351	41324	565	0.7	0.5	**1.4**	**0.8**	1.1
Jul 24, 2008	13	26	37	1896	147	42434	288	44330	436	0.2	0.2	**1.6**	**0.5**	1.1
May 3, 2008	21	52	62	6494	261	15354	563	21847	824	0.8	1.9	**0.8**	**1.4**	1.1
Oct 10, 1995	18	30	31	4723	246	24492	462	29215	708	0.4	0.4	**1.1**	**1.0**	1.0

Table 10: Comparison of design storm alternatives

Design Event Trial Scenario	Northern Catchment Event Rainfall (mm)	SSO Peak (L/s)	SSO Volume (ML)	Peak ARI (years)	Volume ARI (years)	Southern Catchment Event Rainfall (mm)	SSO Peak (L/s)	SSO Volume (ML)	Peak ARI (years)	Volume ARI (years)
3-Year 24-Hour Synthetic	58	245	6.4	**0.7**	**0.9**	58	675	14.1	**0.6**	**0.5**
3-Year 24-Hour Modified	58	546	17.6	**1.7**	**2.5**	79	1,265	46.6	**3.5**	**1.7**
Composite North - Aug 5, 1995 South - May 26, 2010	54	592	15.6	**2.2**	**2.4**	51	906	69.5	**1.9**	**2.2**
Composite North - Aug 5, 1995 South - Apr 17, 2014	54	606	16.0	**2.5**	**2.4**	66	978	45.9	**1.7**	**2.0**
Composite/Weekday-Aligned North - Aug 5, 1995 South - Apr 17, 2014	54	570	14.4	**2.0**	**2.0**	66	1,045	49.1	**2.5**	**1.6**

Figure 3: Selected 2-year ARI design storm - August 5, 1995 and April 17, 2014 composite event