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Supplementary materials

Evaluation of Pollutant Removal Efficiency of a Bioretention Basin and Implications for Stormwater Management in Tropical Cities

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S-1. Site description

The field monitoring program was carried out at the Balam Estate Rain Garden (Figure S-1) in the tropical setting of Singapore. With an effective treatment area of 240 m^2, this basin receives runoff from a 16,800 m^2 residential catchment (about 88% surface imperviousness) with a time of concentration of about 10 min.[1] The basin was designed to capture 3-month ARI events following Australian guidelines.[2] The current surface storage volume (33 m^3) corresponds to a WQD of about 2 mm. More than 14 native tropical plants such as Umbrella sedge, Alligator flag, and Cattail have been planted with a planting density of more than 8 plants per square meter.[1] Plants were selected based on their extensive root systems and ability to withstand intermittent periods of flooding. Field measurement using a double-ring infiltrometer indicated an infiltration rate of 4.4 cm/hr.[3]

Catchment runoff converges at the inlet and is then distributed across two basin cells which are hydraulically interconnected by ten pipes such that the whole basin operates as a single unit (Figure S-1). Runoff spread on the basin floor infiltrates through four soil layers consisting of (from surface to bottom): a 40-cm sandy-loam filter layer; a 10-cm fine-sand transition layer; a 30-cm saturated anoxic zone of hard rocks (average size of 50 mm and 65% by volume) and wood chips (average size of 5 mm and 35% by volume); and a 15-cm drainage layer of fine gravel (average size of 2-5 mm).[1, 4] Treated runoff is collected by underdrains that drain to an outlet pipe that discharges to an adjacent drainageway (Pelton Canal). As the underdrains are at a lower elevation than the outlet, a 35-cm-deep saturated anoxic zone favoring denitrification is created. The basin also has a 1.1-m-high-by-1.2-m-wide outflow culvert with a 13.7-cm high overflow weir that limits the amount of surface ponding in the basin. Surface ponding decreases over time due to infiltration but some ponding persists for 12.5 ± 5.5 hours after a storm event. The entire soil filter media is underlain by a high-density polyethylene liner to prevent exfiltration into the surrounding soil.

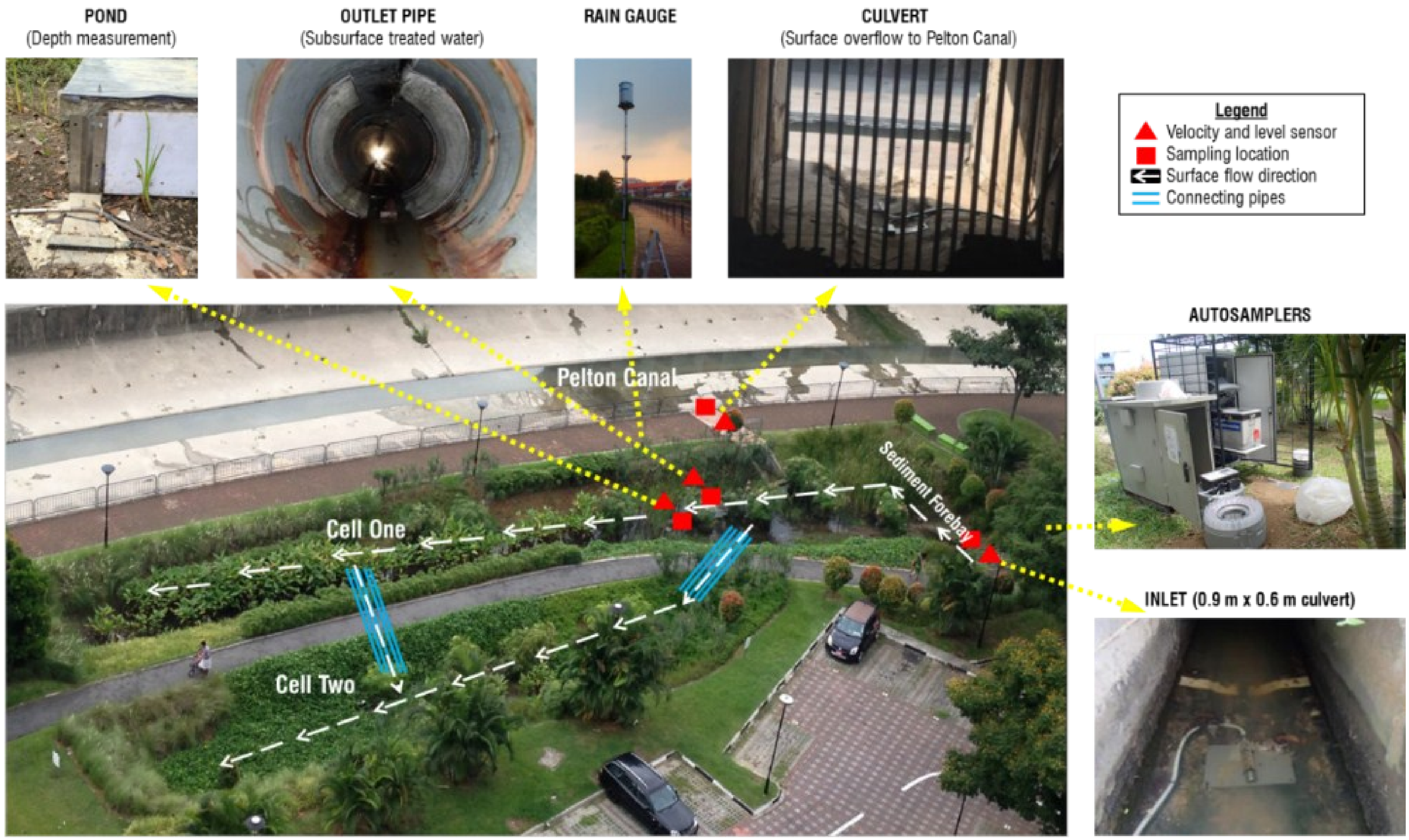


Fig. S-1 Plan view of Balam Estate Rain Garden with on-site instrumentation.

S-2. Sampling strategy

Table S-1 lists the sampling scheme adopted in this study. Table S-2 shows a comparison of different sampling strategies in the literature. Table S-3 lists the test method and detection limit of the 12 water quality parameters that were chemically analyzed. Table S-4 shows the number of water samples that were tested for the concentration of each of the 15 water quality parameters in each event at four locations (inlet, outlet, culvert, and basin floor).

Table S-1 Sampling scheme

Inlet			Outlet			Culvert			Basin		
No. of bottles	Interval	Duration	No. of bottles	Interval	Duration	No. of bottles	Interval	Duration	No. of bottles	Interval	Duration
6	2 min	12 min	8	30 min	4 hrs	4	5 min	20 min	3	5 min	15 min
12	4 min	48 min	12	60 min	12 hrs	6	10 min	60 min	3	10 min	30 min
6	10 min	60 min	4	120 min	8 hrs	4	30 min	2 hrs	8	60 min	8 hrs
24	Total	2 hrs	24	Total	24 hrs	14	Total	3h20m	14	Total	8h45m

Table S-2 Comparison of sampling strategies from literature

	n	Event-wise monitoring?	Composite sample?	Synthetic runoff?	Note
Brown & Hunt[5]	18	Yes	yes, flow-proportional		
Passeport[6]	18	Yes	yes, flow-weighted		
Passeport[6]	16	Yes	yes, flow-weighted		
Li and Davis[7]	12	Yes	yes, flow-weighted		
Li and Davis[7]	9	Yes	yes, flow-weighted		
DeBusk and Wynn[8]	28	Yes	yes, flow-weighted		single influent and effluent sample for each event. 8 months monitoring.
Trowsdale and Simcock[9]	12	Yes	no, discrete samples		culvert is not sampled and assumed to have the same water quality as inlet
Hatt et al.[10]	7	Yes	yes, composite for most events		complete pollutograph is available for 3 events (each 7-16 discrete samples for effluent). 6 months monitoring.
Hatt et al.[10]	4	yes	yes, flow-weighted	yes	
Mangangka et al.[11]	12	yes	no, discrete samples		number of samples per event and the type of sampling strategy (flow-weighted or time-based) is not reported.
Houdeshel et al.[12]	49	yes	no, discrete samples	yes	1-year monitoring
Khan et al.[13]	24	yes	yes, flow-weighted	yes	3 flow-weighted composite samples per event
Dietz and Clausen[14]	47	no	yes, weekly composite		
Dietz and Clausen[15]	72	no	yes, monthly composite		
Geheniau et al.[16]	17	no	grab samples		

Table S-3 Water quality parameters (APHA et al.[17])

Test Parameter	Standard Test Method	Detection Limit (mg/L)
Total Nitrogen, TN	4500-N (C)	0.01
Total Kjeldahl Nitrogen, TKN	4500-N_{org}	0.23
Ammonia, NH_3-N	4500- NH_3 (H)	0.003
Nitrate, NO_3-N	4500- NO_3 (I)	0.003
Nitrite, NO_2-N	4500- NO_2 (I)	0.003
Total Phosphorus, TP	4500- P (H)	0.003
Total Dissolved Phosphorus, TDP	4500- P (H)	0.003
Inorganic Phosphorus, PO_4-P	4500- P (G)	0.01
Total Organic Phosphorus, TOP	4500- P (H)	0.003
Total Dissolved Organic Phosphorus, TDOP	4500- P (H)	0.003
Total Suspended Solids, TSS	2540D	2
Chemical Oxygen Demand, COD	5220B	5

Table S-4 Number of water samples analyzed for each parameter in each event

Event		TN	TKN	NH_3-N	NO_3-N	NO_2-N	TP	TDP	PO_4-P	TOP	TDOP	TSS	COD
#3	Inlet	8	8	8	8	8	8	8	8	8	8	8	8
	Outlet	24	24	24	24	24	24	24	24	24	24	24	24
	Culvert	0	0	0	0	0	0	0	0	0	0	0	0
	Basin	1	1	1	1	1	1	1	1	1	1	1	1
#2	Inlet	24	24	24	24	24	24	24	24	24	24	24	24
	Outlet	24	24	24	24	24	24	24	24	24	24	24	24
	Culvert	12	12	12	12	12	12	12	12	12	12	12	12
	Basin	14	14	14	14	14	14	14	14	14	14	14	14
#1	Inlet	24	24	24	24	24	24	24	24	24	24	24	24
	Outlet	24	24	24	24	24	24	24	24	24	24	24	24
	Culvert	7	7	7	7	7	7	7	7	7	7	7	7
	Basin	10	10	10	10	10	10	10	10	10	10	10	10
#5	Inlet	20	20	11	20	11	11	20	20	20	20	20	20
	Outlet	24	24	24	13	13	13	13	13	13	13	13	13
	Culvert	8	8	8	8	8	14	14	14	14	8	14	14
	Basin	8	14	8	8	8	14	8	8	8	8	14	14
#6	Inlet	21	21	11	21	11	11	21	21	21	21	21	21
	Outlet	24	24	24	13	13	13	13	13	13	13	13	24
	Culvert	8	8	8	8	8	14	14	14	14	8	14	14
	Basin	8	14	8	8	8	14	8	8	8	8	14	14
#4	Inlet	24	24	24	24	24	24	24	24	24	24	24	24
	Outlet	24	24	24	24	24	24	24	24	24	24	24	24
	Culvert	13	13	13	13	13	13	13	13	13	13	13	13
	Basin	14	14	14	14	14	14	14	14	14	14	14	14
All	Inlet	121	121	102	121	102	102	121	121	121	121	121	121
	Outlet	144	144	144	122	122	122	122	122	122	122	122	133
	Culvert	48	48	48	48	48	60	60	60	60	48	60	60
	Basin	55	67	55	55	55	67	55	55	55	55	67	67

S-3. Calculation of ON, TPIP, TPOP

Three additional parameters (organic nitrogen, ON; total particulate inorganic phosphorus, TPIP; and total particulate organic phosphorus, TPOP) were derived from their relationships with the measured parameters according to

$$C_{ON} = C_{TKN} - C_{NH_3-N}$$

$$C_{TPIP} = C_{TP} - C_{TOP} - C_{PO_4-P} \qquad \text{(S-1)}$$

$$C_{TPOP} = C_{TOP} - C_{TDOP}$$

where C_{ON}, C_{TKN}, C_{NH_3-N}, C_{TPIP}, C_{TP}, C_{TOP}, C_{PO_4-P}, C_{TPOP}, and C_{TDOP} are the concentrations of organic nitrogen, total Kjeldahl nitrogen, ammonia, total particulate inorganic phosphorus, total phosphorus, total organic phosphorus, inorganic phosphate, total particulate organic phosphorus, and total dissolved organic phosphorus respectively.

S-4. Uncertainty in the removal rate calculation

Uncertainty in the removal rate determination is calculated based on propagation of the errors in quantifying loading and mass. The overall uncertainty in the removal rate arises from two sources: 1) that associated with concentration measurement using chemical analyses and 2) that associated with flow rate measurement using area-velocity sensors. Uncertainty in chemical analyses encompasses gross error and instrumental error which are reflected in the standard deviations of the duplicate recovery rate (σ_D, range 0.2 - 6.4%) and standard curve recovery rate (σ_S, range 0 - 8.5%) respectively across six sampled events. Uncertainty in flow rate measurement, σ_F, is taken as the accuracy of the instrument (ISCO-2150 Area Velocity Module), which is 2% of readings from 1.5 m/s to 6.1 m/s as provided by the manufacturer. The propagation of removal rate error for each water quality parameter is calculated using Eq. (S-2):

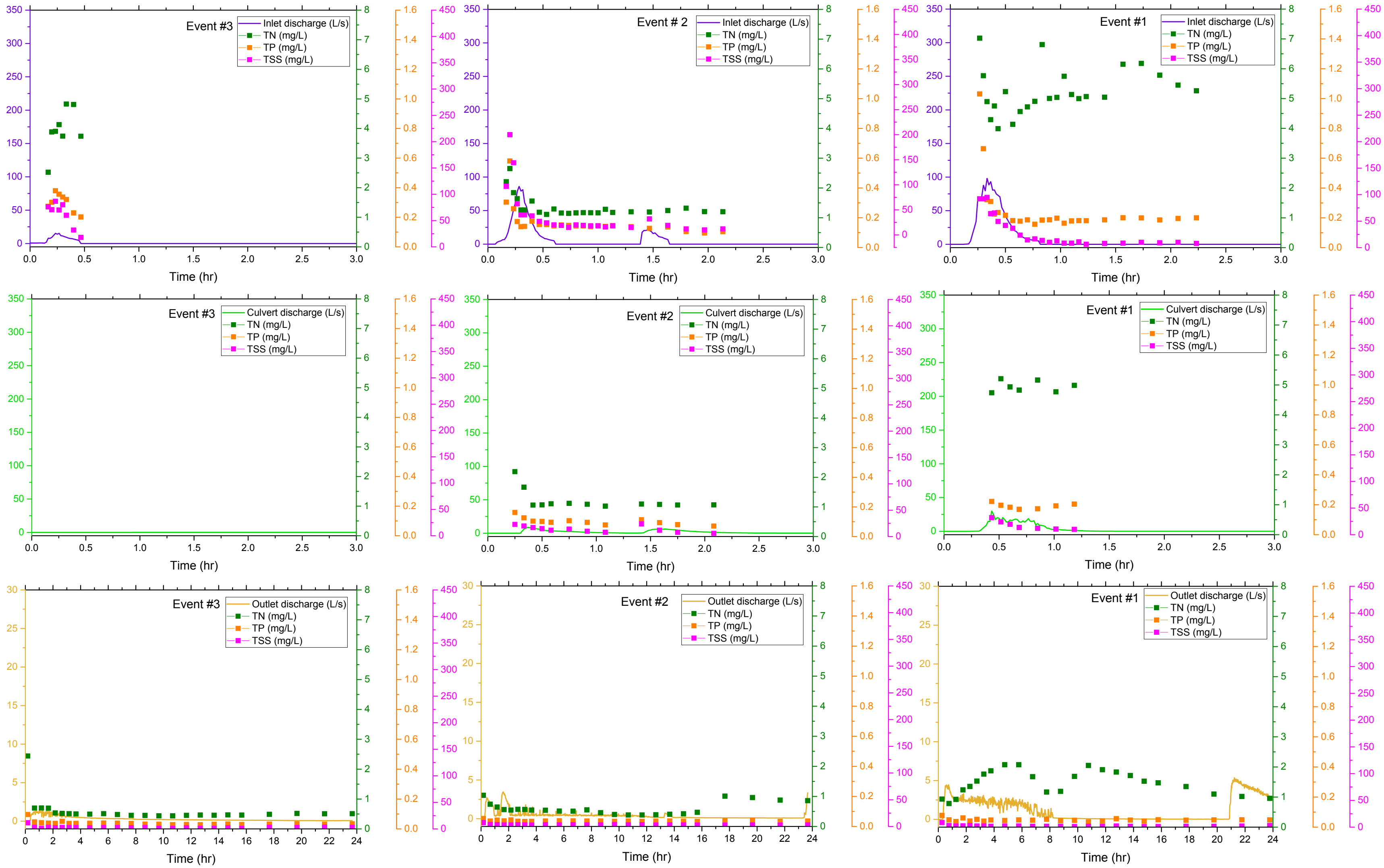
$$\sigma^2_{Removal} = \left(\frac{Q_{culvert}}{C_{inlet}Q_{inlet}}\right)^2\sigma^2_{C_{culvert}} + \left(\frac{Q_{outlet}}{C_{inlet}Q_{inlet}}\right)^2\sigma^2_{C_{outlet}} + \left(\frac{C_{culvert}Q}{\quad}\right. \ldots$$

$$\sigma^2_{Q_{culvert}} + \left(\frac{C_{culvert}Q_{culvert} + C_{outlet}Q_{outlet}}{Q_{inlet}{}^2 C_{inlet}}\right)^2\sigma^2_{Q_{inlet}} + \left(\frac{C_{ou}}{C_{inlet}}\right. \ldots$$

$$\sigma_{removal\ rate\ error} = \sqrt{\sigma^2_{Removal}} \qquad \text{(S-2)}$$

where $\sigma^2_{Removal}$ is the variance of removal rate; $Q_{culvert}$, Q_{outlet}, Q_{inlet} (L/s) are the mean flow rates, $C_{culvert}$, C_{outlet}, C_{inlet} (mg/L) are the mean parameter concentrations for each event; $\sigma^2_{C_{culvert}}$, $\sigma^2_{C_{outlet}}$, $\sigma^2_{C_{inlet}}$ (mg/L)^2 are the variances of concentration measurements; and $\sigma^2_{Q_{culvert}}$, $\sigma^2_{Q_{outlet}}$, $\sigma^2_{Q_{inlet}}$ (L/s)^2 are the variances of flow measurements for each event.

S-5. Pollutographs of TSS, TN, and TP for the six sampled events



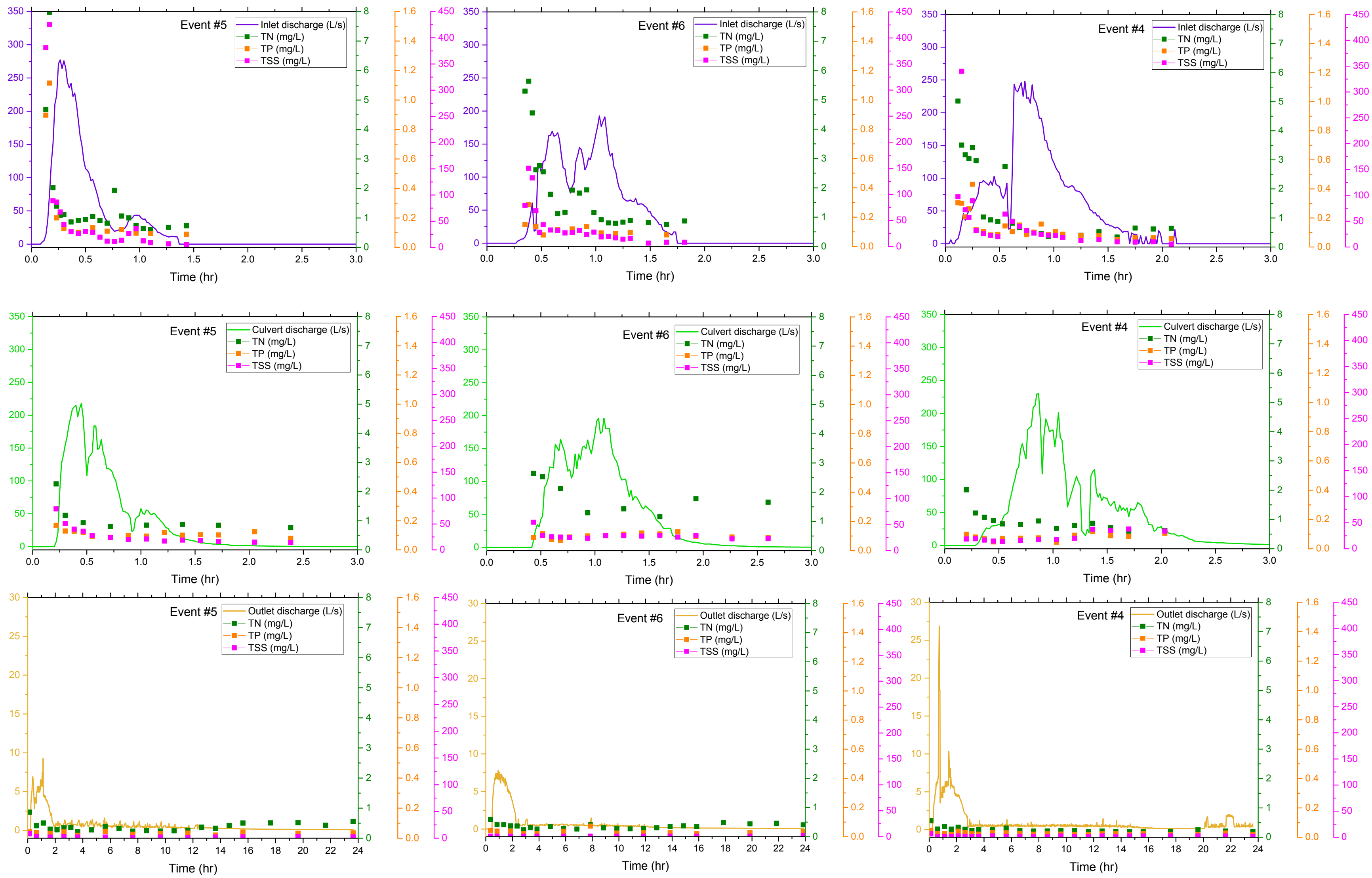


Fig. S-2 Pollutographs of TN, TP, and TSS for each of the six sampled events.

S-6. Mass load of 15 water quality parameters

Table S-5 shows the mass load of 15 water quality parameters at inlet, culvert, and outlet.

Table S-5 Mass load (g) of 15 water quality parameters at inlet, culvert, and outlet.

	Inlet							
	#3	#2	#1	#5	#6	#4	Mean	SD
TN	43.23	101.57	464.04	459.11	667.14	461.35	366.07	241.73
TKN	32.97	58.77	376.87	132.16	81.83	172.21	142.47	125.38
ON	25.89	49.17	249.94	171.94	69.63	150.61	119.53	85.94
NH_3-N	7.08	9.60	126.92	38.19	24.81	21.60	38.03	44.97
NO_3-N	4.94	29.30	49.61	286.18	470.57	177.19	169.63	181.89
NO_2-N	3.87	2.82	12.82	0.82	5.71	1.78	4.64	4.35
TP	3.35	12.64	36.20	68.93	49.31	63.43	38.98	26.73
TDP	0.86	3.62	15.03	18.03	27.95	37.82	17.22	14.12
PO_4-P	0.44	2.53	10.53	16.82	23.68	29.40	13.90	11.54
TOP	1.39	2.64	7.31	9.17	5.71	10.80	6.17	3.67
TDOP	0.25	0.79	1.72	1.67	1.79	6.15	2.06	2.09
TPIP	1.52	7.47	18.35	42.28	18.64	23.24	18.58	14.13
TPOP	1.14	1.85	5.59	7.50	3.91	4.66	4.11	2.36
TSS	701.82	3760.15	5798.28	18848.62	12242.24	17237.34	9764.74	7462.16
COD	1113.79	2721.95	7329.68	21959.25	10030.91	21393.40	10758.16	9038.26

	Culvert							
	#3	#2	#1	#5	#6	#4	Mean	SD
TN	0.00	22.01	166.52	390.91	806.86	419.17	300.91	304.78
TKN	0.00	7.68	76.21	48.23	112.20	133.40	62.95	54.40
ON	0.00	4.84	34.07	47.62	58.92	115.09	43.43	42.09
NH_3-N	0.00	2.83	42.13	0.61	53.27	18.30	19.52	23.11
NO_3-N	0.00	5.21	46.53	322.86	615.01	216.92	201.09	240.46
NO_2-N	0.00	0.81	6.29	0.61	9.46	2.07	3.21	3.81
TP	0.00	1.83	6.28	44.15	50.52	40.62	23.90	23.52
TDP	0.00	0.79	3.18	16.84	25.29	11.67	9.63	10.14
PO_4-P	0.00	0.59	2.27	14.68	21.55	6.92	7.67	8.72
TOP	0.00	0.44	1.50	9.93	6.15	9.70	4.62	4.58
TDOP	0.00	0.09	0.28	2.62	2.01	2.12	1.19	1.19
TPIP	0.00	0.81	2.50	19.54	22.81	24.00	11.61	11.63
TPOP	0.00	0.35	1.22	6.80	3.63	7.58	3.26	3.30
TSS	0.00	245.72	605.03	12879.79	13626.92	11989.16	6557.77	6895.25
COD	0.00	378.52	1015.23	15639.88	18338.23	20276.02	9274.65	9768.04

Table S-5 Continued.

	Outlet							
	#3	#2	#1	#5	#6	#4	Mean	SD
TN	13.80	20.26	133.39	21.99	22.58	24.09	39.35	46.21
TKN	9.17	13.85	70.99	7.05	7.65	18.02	21.12	24.78
ON	6.45	4.87	31.89	6.17	6.37	17.34	12.18	10.69
NH_3-N	2.73	8.99	39.10	0.89	1.28	0.68	8.94	15.10
NO_3-N	0.22	0.06	30.25	3.74	0.33	0.13	5.79	12.07
NO_2-N	0.08	0.05	21.61	2.12	3.62	0.15	4.60	8.45
TP	0.92	1.30	4.79	1.89	2.14	2.23	2.21	1.36
TDP	0.38	0.75	2.92	0.39	1.43	1.06	1.16	0.95
PO_4-P	0.15	0.58	1.94	0.40	1.19	0.43	0.78	0.67
TOP	0.36	0.26	1.17	0.45	0.40	0.89	0.59	0.36
TDOP	0.16	0.12	0.52	0.12	0.18	0.55	0.28	0.20
TPIP	0.41	0.46	1.68	1.04	0.55	0.92	0.84	0.48
TPOP	0.20	0.13	0.65	0.33	0.22	0.33	0.31	0.18
TSS	55.86	103.81	227.91	150.32	60.56	172.01	128.41	67.46
COD	501.32	699.54	2211.16	1553.36	1136.09	2807.69	1484.86	893.06

S-7. Comparison of EMC of this study to literature values

Table S-6 shows that EMC values from this study are comparable to those from another tropical study.[18] Compared to world-wide data, EMCs are generally lower in tropical Singapore catchments than in temperate catchments.[19-25]

Table S-6 Comparison of EMCs in this study to literature values

	Location	Catchment	% Imp	TN	TKN	TP	TDP	TSS	COD
Tropical climates									
This study	Singapore	High density residential	88	2.20	1.41	0.19	0.07	40	54
Chua et al.[18]	Singapore	Residential	68	1.41		0.08	0.03	66	
Temperate climates									
Duncan[19]	Worldwide	Urban		2.60		0.40		155	78
Taylor et al.[25]	Australia	Urban		2.13	1.39				
Francey et al.[20]	Australia	High density residential	74			0.35		102	
McLeod et al.[21]	Canada	Residential				0.53		190	100
Smullen et al.[22]	USA	Urban		2.51	1.67	0.34	0.10	174	66
Brezonik and Stadelmann[24]	Minnesota, USA	Urban		3.08		0.58	0.20	184	

S-8. First flush M(V) curves for TSS, TN, and TP

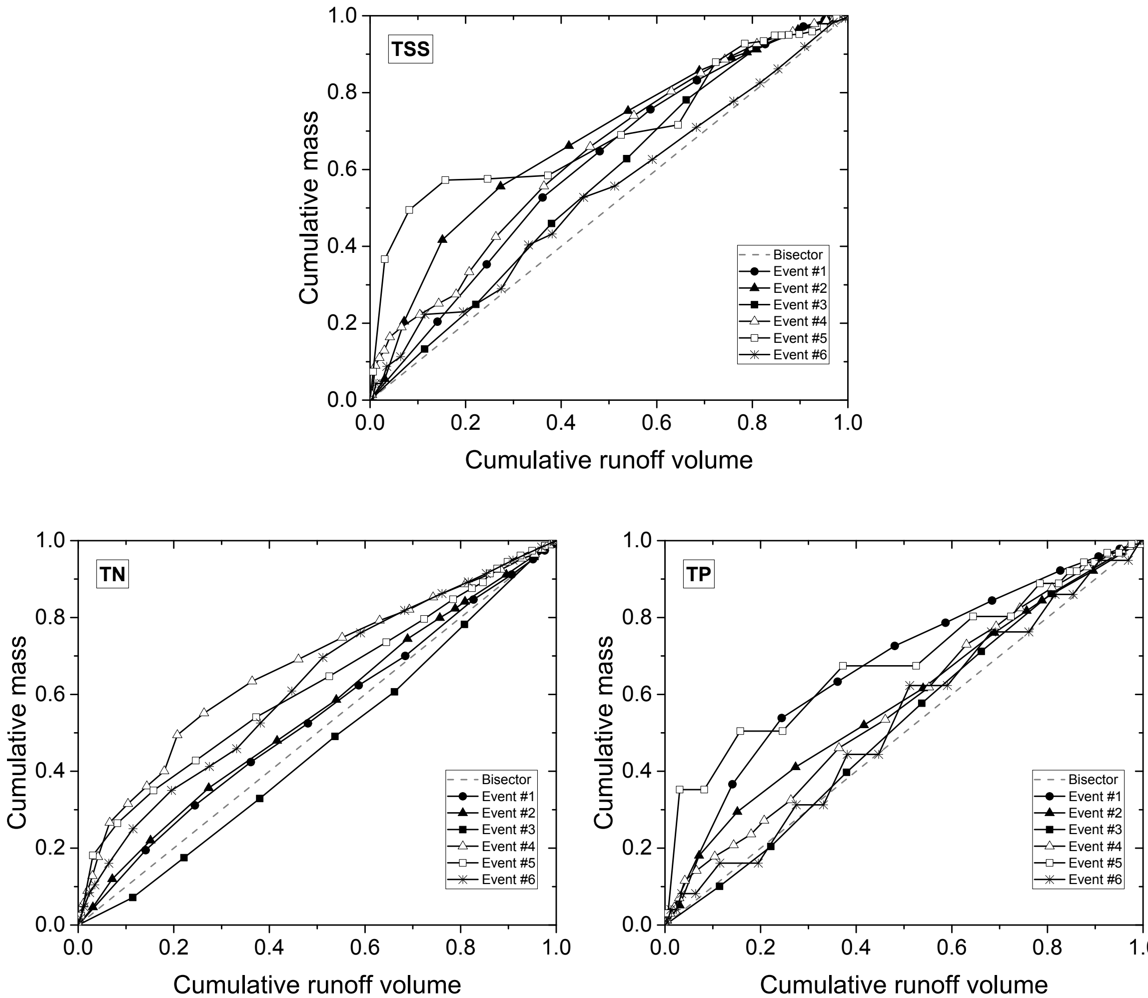


Fig. S-3 Plots of cumulative mass against cumulative runoff volume indicating the magnitude of first flush for TSS, TN, and TP.

S-9. Rainfall characterisitcs in this study

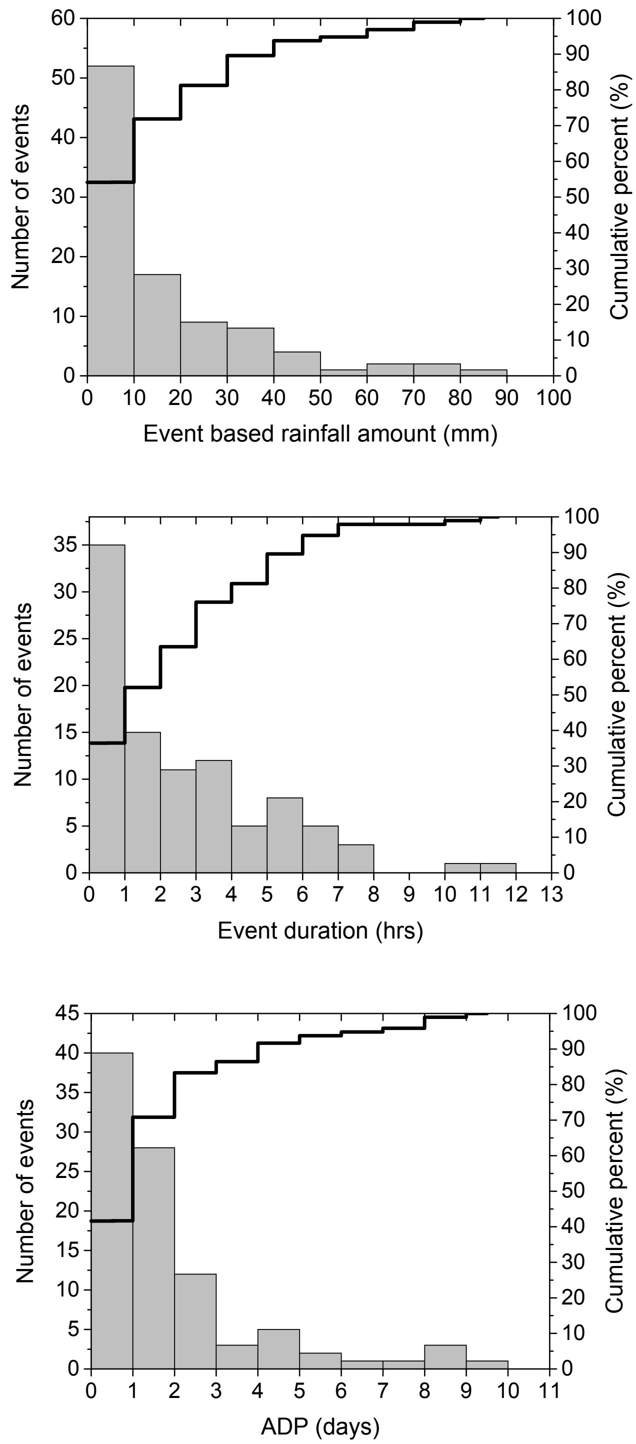


Fig. S-4 Histograms and cumulative probability curves of event-based rainfall amount (mm), event duration (hr), and ADP (days) for the 96 events observed during Apr-Nov 2013.

S-10. Frequent heavy flushing of tropical catchment

Compared to temperate climates such as the United States, the tropical climate in Singapore produces storms that are more frequent and have higher intensity and shorter duration. Table S-7 compares the mean statistics of the 96 events observed during this study to similar statistics by Driscoll et al.[26] for a selection from fifteen regions in the U.S. Table S-7 shows a wide range of rainfall patterns in the U.S., from the dry West Inland region to the wet East Gulf region. The equivalent mean rainfall intensity observed in Singapore during this study is 66% higher than that of East Gulf, the region in the U.S. identified by Driscoll et al.[26] to have the highest rainfall intensity. The mean event duration in Singapore is 56% shorter than that of East Gulf, the region in the U.S. with the shortest mean event duration. The mean time interval between event midpoints (delta) in Singapore is 61% shorter than in the Pacific Northwest, the region in the U.S. with the shortest mean delta.

Table S-7 Storm event statistics in Singapore (this study) compared to various regions in the U.S. (Driscoll et al.[26])

	Mean Event Rainfall Intensity (mm/hr)	Mean Event Duration (hr)	Mean Delta* (day)
Singapore (this study)	7.49	2.8	2.00
Mid Atlantic (U.S.)	2.34	10.1	5.96
East Gulf (U.S.)	4.52	6.4	5.42
North Central (U.S.)	2.21	9.5	6.96
West Inland (U.S.)	1.40	9.4	32.8
Pacific Northwest (U.S.)	0.89	15.9	5.13
Pacific Southwest (U.S.)	1.37	11.6	19.8

*Delta is defined as the time interval between event midpoints by Driscoll et al.[26]

Table S-8 ARI (years) if the six sampled events were to occur in Melbourne, Australia or various cities in the U.S

	08/26/13 (#3)	08/04/13 (#2)	06/25/13 (#1)	10/09/13 (#5)	10/27/13 (#6)	09/29/13 (#4)
Singapore (this study)	3-month	3-month	3-month	< 1	3-month	< 1
Melbourne	< 1	< 1	1-2	10-20	1-2	5-10
Baltimore, MD (Mid Atlantic)	< 1	< 1	< 1	1-2	< 1	< 1
Miami, FL (East Gulf)	< 1	< 1	< 1	< 1	< 1	< 1
Detroit, MI (North Central)	< 1	< 1	< 1	2-5	< 1	< 1
Reno, NV (West Inland)	< 2	1-2	5-10	> 100	10-25	50-100
Seattle, WA (Pacific Northwest)	< 0.5	0.5-2	5-10	> 100	10-20	> 100
Los Angeles, CA (Pacific Southwest)	< 1	< 1	1-2	25-50	2-5	10-25

Source of Intensity-Duration-Frequency (IDF) curves:
(PUB;[27] Pilgrim;[28] U.S. NOAA;[29] City of Seattle[30])

S-11. Rainfall intensity of events of various ARIs across the world

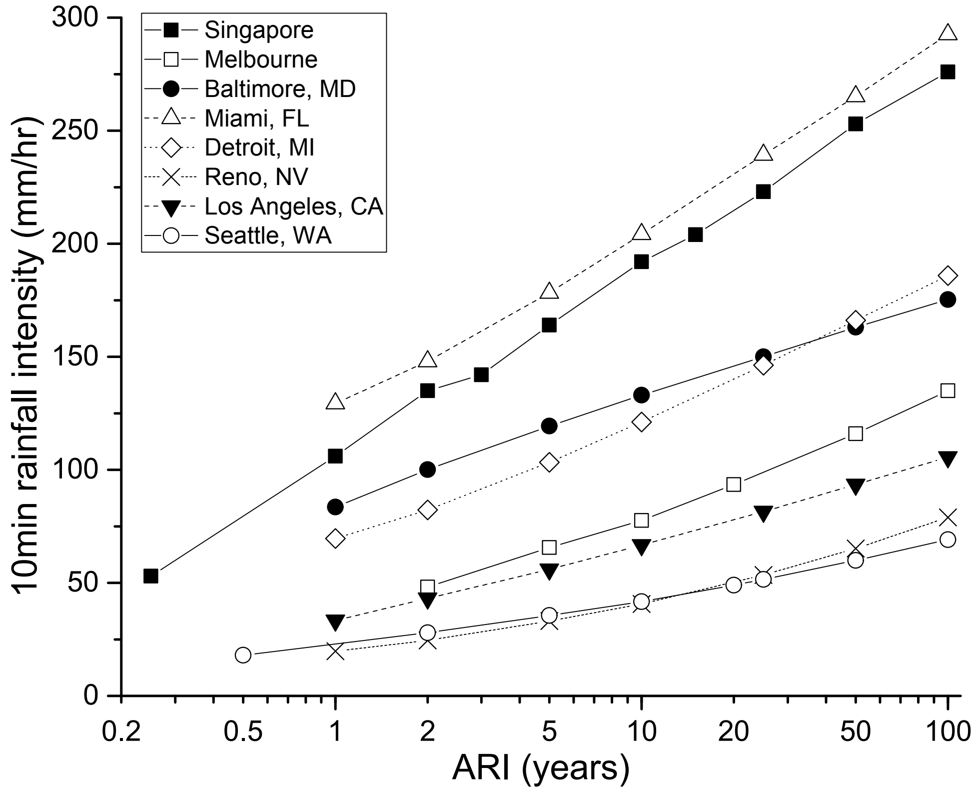


Fig. S-5 Rainfall intensity of events of various average return intervals (ARI) in Singapore, Melbourne, and selected cities in the U.S. (Sources of Intensity-Duration-Frequency (IDF) curves: PUB;[27] Pilgrim;[28] U.S. NOAA;[29] City of Seattle[30]).

S-12. References

1. J. Wang, T. H. F. Wong and G. S. Ong, presented in part at the 6th International Water Sensitive Urban Design Conference, Perth, Australia, May 5–8, 2009.
2. Facility for Advancing Water Biofiltration, *Adoption guidelines for stormwater biofiltration systems*, Facility for Advancing Water Biofiltration, Monash University, Melbourne, Australia 2009.
3. J. Wang, L. H. C. Chua and P. Shanahan, presented in part at the 3rd International Conference on Design, Construction, Maintenance, Monitoring and Control of Urban Water Systems, Urban Water 2016, San Servolo, Venice, Italy, June 27-29, 2016.
4. G. S. Ong, G. Kalyanaraman, K. L. Wong and T. Wong, presented in part at the 7th International Conference on Water Sensitive Urban Design, Melbourne Cricket Ground, Melbourne, Australia, 2012.
5. R. A. Brown and W. F. Hunt, *Journal of Irrigation and Drainage Engineering*, 2011, **137**, 132-143.
6. E. Passeport, W. F. Hunt, D. E. Line, R. A. Smith and R. A. Brown, *Journal of Irrigation and Drainage Engineering*, 2009, **135**, 505-510.
7. H. Li and A. P. Davis, *Journal of Environmental Engineering*, 2009, **135**, 567-576.
8. K. M. DeBusk and T. M. Wynn, *Journal of Environmental Engineering*, 2011, **137**, 800-808.
9. S. A. Trowsdale and R. Simcock, *J Hydrol*, 2011, **397**, 167-174.
10. B. E. Hatt, T. D. Fletcher and A. Deletic, *J Hydrol*, 2009, **365**, 310-321.
11. I. R. Mangangka, A. Liu, P. Egodawatta and A. Goonetilleke, *J Environ Manage*, 2015, **150**, 173-178.
12. C. D. Houdeshel, K. R. Hultine, N. C. Johnson and C. A. Porneroy, *Landscape Urban Plan*, 2015, **135**, 62-72.
13. U. T. Khan, C. Valeo, A. Chu and B. van Duin, *Can J Civil Eng*, 2012, **39**, 1222-1233.
14. M. E. Dietz and J. C. Clausen, *Water Air Soil Poll*, 2005, **167**, 123-138.
15. M. E. Dietz and J. C. Clausen, *Environ Sci Technol*, 2006, **40**, 1335-1340.
16. N. Géhéniau, M. Fuamba, V. Mahaut, M. R. Gendron and M. Dugué, *Journal of Irrigation and Drainage Engineering*, 2015, **141**, 04014073.
17. APHA, AWWA and WPCF, *Standard methods for the examination of water and wastewater*, American Public Health Association, Washington, D.C., USA, 21st edn., 2009.
18. L. H. C. Chua, E. Y. M. Lo, E. B. Shuy and S. B. K. Tan, *J Environ Manage*, 2009, **90**, 3635-3642.
19. H. P. Duncan, *Urban stormwater quality: A statistical overview*, Report 99/3, Cooperative Research Centre for Catchment Hydrology, Melbourne, Australia, 1999.
20. M. Francey, T. D. Fletcher, A. Deletic and H. Duncan, *Journal of Environmental Engineering*, 2010, **136**, 381-390.
21. S. M. McLeod, J. A. Kells and G. J. Putz, *Journal of Environmental Engineering*, 2006, **132**, 1470-1481.
22. J. Smullen, A. Shallcross and K. Cave, *Water Sci Technol*, 1999, **39**, 9-16.
23. U. S. EPA, *Results of the nationwide urban runoff program volume I- final report*, Report EPA-832-R-83-112, U.S. Environmental Protection Agency, Washington, D.C., USA, 1983.

24. P. L. Brezonik and T. H. Stadelmann, *Water Res*, 2002, **36**, 1743-1757.
25. G. D. Taylor, T. D. Fletcher, T. H. F. Wong, P. F. Breen and H. P. Duncan, *Water Res*, 2005, **39**, 1982-1989.
26. E. Driscoll, G. Palhegyi, E. Strecker and P. Shelley, *Analysis of storm event characteristics for selected rainfall gages throughout the United States*, Report EPA-800-D-89-001, U.S. Environmental Protection Agency, Washington, D.C., USA, 1989.
27. Public Utilities Board of Singapore, *Code of practice on surface water drainage. 6th ed. with amendments under addendum no.1.* , Public Utilities Board of Singapore, 2011.
28. D. H. Pilgrim, *Australian rainfall and runoff - A guide to flood estimation, revised edition*, Institution of Engineers, Barton, ACT, Australia 1987.
29. U. S. NOAA, Precipitation frequency data server, http://hdsc.nws.noaa.gov/hdsc/pfds, (accessed Sept 2015).
30. City of Seattle, *City of Seattle stormwater manual April 2014 review draft*, Department of Planning and Development, Seattle, Washington, USA, 2014.