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Characterising stormwater gross pollutants captured in catch basin inserts

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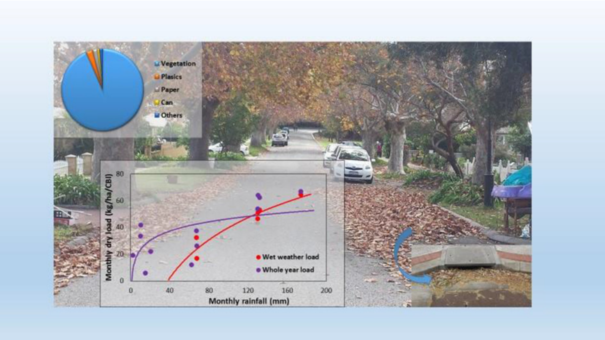
HIGHLIGHTS

- Catch basin insert is a promising technology to capture stormwater gross pollutant (GP) at source.
- A new type of catch basin insert was evaluated which has the capacity of capturing pollutants down to 150 μm.
- Effects of catchment characteristics on GP, moisture content, particle size distribution and GP composition were studied.
- Loading rate coefficient of pollutants was determined which mainly contributed from vegetation.

GRAPHICAL ABSTRACT



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ABSTRACT

The accumulation of wash-off solid waste, termed gross pollutants (GPs), in drainage systems has become a major constraint for best management practices (BMPs) of stormwater. GPs should be captured at source before the material clogs the drainage network, seals the infiltration capacity of side entry pits or affects the aquatic life in receiving waters. BMPs intended to reduce stormwater pollutants include oil and grit separators, grassed swales, vegetated filter strips, retention ponds, and catch basin inserts (CBIs) are used to remove GP at the source and have no extra land use requirement because they are typically mounted within a catch basin (e.g. side entry pits; grate or gully pits). In this study, a new type of CBI, recently developed by Urban Stormwater Technologies (UST) was studied for its performance at a site in Gosnells, Western Australia. This new type of CBI can capture pollutants down to particle sizes of 150 μm while retaining its shape and pollutant capturing capacity for at least 1 year. Data on GP and associated water samples were collected during monthly servicing of CBIs for one year. The main component of GPs was found to be vegetation (93%): its accumulation showed a strong relationship ($r^2 = 0.9$) with rainfall especially during the wet season. The average accumulation of total GP load for each CBI was 384 kg/ha/yr (dry mass) with the GP moisture content ranging from 24 to 52.5%. Analysis of grain sizes of GPs captured in each CBI showed similar distributions in the different CBIs. The loading rate coefficient (K) calculated from runoff and GP load showed higher K-values for CBI located near trees. The UST developed CBI in this study showed higher potential to capture GPs down to 150 μm in diameter than similar CBI devices described in previous studies.

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1. Introduction

In urban areas, natural vegetation has been replaced by paved surfaces, resulting in soil compaction, which renders the surfaces impervious and prevents the natural infiltration of rainwater, increasing surface runoff. This rapid urbanization with the construction of new urban assembly may drastically change the hydrologic, hydraulic and environmental characteristics of rural catchments (Sidek et al., 2016). Urbanization not only causes flooding as a physical impact but also increases pollution problems in urban rivers and other receiving waters (Wong et al., 2002). Stormwater pollutants may cause physical, chemical and/or biological damage to the environment.

Stormwater pollutants may be broadly classified into two categories: (i) gross pollutants (GP) such as vegetation (plant-based debris), litter (paper, plastic, cans and others) and sediments of different sizes and (ii) dissolved pollutants including nutrients, heavy metals, and hydrocarbons. The dissolved pollutants result mainly from automobile emissions, fluid leaks from vehicles, residential use fertilizers and pesticides, refuse, and animal faces (Harmayani and Anwar, 2016). The pollutants such as trash, litter and vegetation with diameters larger than 5 mm are usually considered as GPs (ASCE, 2007). In this study, pollutants down to 150 μm diameter captured in catch basin inserts (CBI) were considered as GPs. These finer particles are classified as suspended solid (SS) in stormwater runoff and remain suspended in flowing waters which can carry harmful pollutants (Zhao and Li, 2013; Zhao et al., 2010).

The concentration of nutrients such as total phosphorous (TP) or total nitrogen (TN) may increase in urban waterways because of decomposition of vegetation. These pollutants are particularly problematic because they contribute to eutrophication in receiving water bodies (Meng Nan et al., 2011; Sansalone and Buchberger, 1997; Taylor et al., 2005; Seitzinger et al., 2002) hypoxia, and loss of biodiversity. While some data exists for TN and TP contribution to waterbodies from vegetation or leaf litter captured in continuous deflective systems (CDSs) and side entry pit traps (SEPTs) (Allison et al., 1998b) there is no data available for CBIs.

A critical review on urban catchments showed that a significant amount of street waste enters stormwater drainage systems due to rain and wind (Madhani et al., 2009) and that this waste also has important effects on the dissolved and total nutrient content being discharged to the environment by stormwater. Selbig (2016) studied the reduction of nutrient concentrations in road runoff by implementing municipal leaf collection and street cleaning programs. It was shown that the total and dissolved phosphorus could be reduced by 84 and 83% and total and dissolved nitrogen by 74 and 71%, respectively, by implementing these programs. However, the current Australian street sweeping practices are not effective for removing the growing street wastes (Walker and Wong, 1999). Similar findings were also found elsewhere in the USA (Lippner et al., 2000). This led to the development of stormwater quality improvement devices at the point of waste generation such as a drain basket/SEPT in order to protect the urban waterways from street borne pollution (Allison et al., 1998a). The other type of device used for the removal of GP is the GP Trap (GPT) but this is difficult to clean periodically and is not effective for removal of pollutants <5 mm. The GPT is not effective in treating stormwater at the source because it is placed at outlets of piped drainage system and mainly captures litter and debris (Ghani et al., 2011; Allison et al., 1998a; Madhani et al., 2009; Madhani and Brown, 2011; Madhani and Brown, 2015; Saberi et al., 2008).

A few studies have focused on capturing pollutants using drain baskets (also termed as catch basin insert-CBI) in side entry pits before they enter the drainage system (CIWMB, 2005; GeoSyntec and UCLA, 2005; Kostarelos and Khan, 2007; MacLure, 2009; Kostarelos et al., 2011). Kostarelos and Khan (2007) and Kostarelos et al. (2011) evaluated pollutant removal efficiency of six CBIs under laboratory and field conditions. They studied the removal of five water quality parameters (TSS, TN, TP, TPH and BOD_5) at three different flow rates (50, 150 and 300 L/min) with three contaminant concentrations (low, medium, high). The study also focused on the installation characteristics, durability and maintenance of CBIs, as well as whether the inserts can be conveniently, safely, and economically installed and maintained. A similar study was performed by GeoSyntec and UCLA (2005) to remove oil and grease in four CBIs. Chrispijn (2004) did a field survey for three different ASPT namely Enviropod Filter, Ecosol RSF 100 and SEPTs (designed by Hobart City Council). A small number of traps from each type were installed in comparable locations in and around Sullivans Cove, Hobart, Tasmania, Australia to monitor the retention of pollutant materials (e.g., GP) including heavy metals for 6 months 22 days. Lau et al. (2001) performed field and laboratory tests on CBI in the City of Santa Monica, USA, collecting the GP from CBI twice during their testing period to determine the pollutant size distribution. Although different types of trapping devices are now available, there is a dearth of information on pollutant characteristics captured in CBIs. The characteristics of pollutants captured in CBIs has not been fully tested in practical field conditions under the influence of seasonal variations for a Mediterranean climate such as occurs in Perth, Western Australia where high rainfall intensity in short duration prevails.

A new form of CBIs has recently been introduced by Urban Stormwater Technologies Pty Ltd (UST; previously known as Templug) to remove stormwater pollutants at source in the drainage systems and installed by a few city councils in Western Australia (Rothleitner, 2011). In this study, gross pollutants (GPs) and water quality data were collected from the new UST CBIs during their monthly servicing over one year. The data are presented to understand the types, quantities, physical and chemical properties of urban stormwater pollutants captured at source in the CBIs and the contribution of nutrients from these pollutants to the aquatic environment.

2. Study area, materials and methods

2.1. Study site

The study site was Federation Parade (City of Gosnells, Western Australia) (Fig. 1), which is located in the vicinity of a market and library and surrounded by trees, primarily *Eucalyptus salubris*. The catchment contributing the road runoff has an area of 2.83 ha. Only the runoff from this catchment, as shown by the boundary lines in Fig. 1 enters the pits. The site is classified as a commercial land use type. The city of Gosnells is within the Perth metropolitan area (32.0481°S 115.9844°E) located 20 km southeast of Perth CBD and is 10 m above average mean sea level. The city maintains an extensive drainage network designed to prevent flooding of roads and properties. As part of this maintenance, sweeping of roads and cleaning of gullies is undertaken on a regular basis to reduce build-up of leaf litter and other detritus in drains. Although a considerable level of effort is undertaken, leaves and debris washed from private property can still block the drainage network. Due to the high-water table and the nature of the soil types across the city, on-site stormwater disposal for new real estate developments is becoming increasingly complex.

2.2. The UST catch basin insert (CBI)

The CBIs used in this study were designed and developed by UST (formerly Templug) which can capture pollutants down to 150 μm. None of the previously discussed CBIs can capture pollutants down to these small particle sizes. The UST CBI has a bypass flow section for high flows of heavy rain to avoid flooding; a diffuser (a small perforated section) into the basket to dissipate the energy of incoming water flow; a special type of geotextile which is reusable (>12 times) that does not deform with time and heavy load (Fig. 2). CBIs reported in the literature comprise either only framed structures or only geotextile bags or both, without the above features (Kostarelos et al., 2011; MacLure, 2009;

Fig. 1. The study site showing Federation Parade, City of Gosnells, Western Australia.

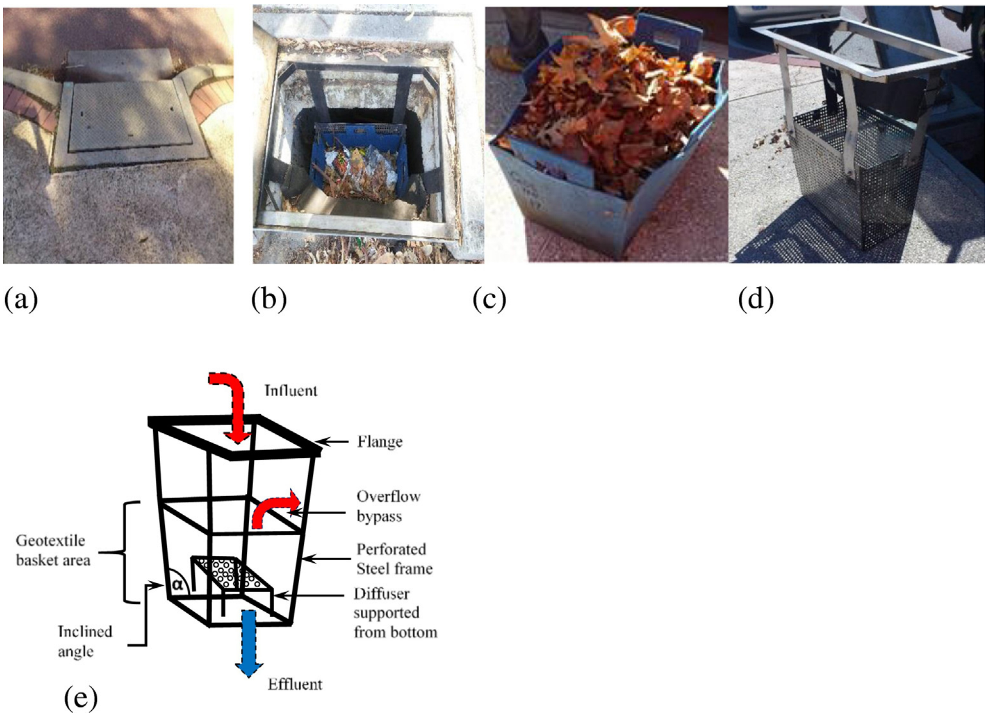

Fig. 2. The UST CBI used at the study site a) external view of a side-entry pit; (b) UST CBI showing the blue geotextile basket; (c) geotextile basket filled with typical plant detritus during our servicing; (d) perforated steel frame to support the geotextile with bypass section (e) schematic diagram of UST CBI (green colour indicates filtered water). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

GeoSyntec and UCLA, 2005; CIWMB, 2005; Chrispijn, 2004; Lau et al., 2001). The UST device is designed to insert into each individual side-entry pit, which can be easily retrofitted to existing drainage infrastructure. The geotextile drain basket material is a special type of synthetic non-woven needle punched polypropylene geotextile, which can be re-used, and is cleanable by reverse flushing. UST was the first to integrate this material into a CBI for the purposes of stormwater management with the aim of capturing GP at the source. After significant research, the material originally designed for marine purposes, has been further developed to produce a highly effective filter system. The shape of the basket supports the glue holding the material sections together, forming a frame. The basket is angled (α) specifically to allow optimal water flow through the material. If the inserts fill up and water passes over the sides, the water will flow down the side of the basket and into a tray under the basket (not shown in Fig. 2) which can contain adsorbents (e.g. Mycelex) to remove hydrocarbons and other dissolved pollutants.

The UST CBIs were installed into 17 side entry pits within the stormwater drainage system in Federation Parade and the site has been maintained by monthly servicing since 2013. Out of these 17 CBIs, four were selected for this study (CBIs 6, 7, 8 and 13). CBIs 6–8 were selected based on their location and slopes considering the maximum runoff and vegetative waste entering the CBIs. CBI 13 was selected because it is on the other side of the road and is also located near a car park so it is more likely to collect contaminants derived from motor vehicles. The stormwater runoff that passes through the CBIs enters the drainage system and ultimately drains into the Canning River.

2.3. Sampling and methodology

In order to collect samples from the selected CBIs, twelve site visits were made during the monthly servicing of CBIs between May 2015–April 2016. The monthly servicing intervals varied from 14 to 38 days depending on the availability of industry personnel and weather conditions.

The monthly load captured in each CBI was manually collected and stored in a plastic bag for further analysis. Each bag was weighed immediately upon return to the lab for gross wet mass. The samples were then oven dried at 60 °C for at least 48 h. Higher temperature tended to melt or burn litter items and therefore a cooler, longer drying cycle was used compared to typical laboratory drying procedures at 105 °C (Allison et al., 1998a). The gross pollutant materials were then manually sorted and weighed. Different types of materials were sorted including vegetation (leaves and twigs), plastics (food and drink containers, sheeting), papers (newspapers, cardboard, food and drink packet), cans (cans and jars) and others (glass, clinical waste, clothes and miscellaneous items). A similar classification was also used by Allison et al. (1998a).

The pit water quality was measured in water samples collected below the CBI. The water samples were collected following standard procedures (DoW, 2009) and different water quality parameters such as, total suspended solids (TSS), orthophosphate (PO_4^{3-}), ammonia-nitrogen (NH_3-N), nitrite- nitrogen (NO_2^-N), and nitrate- nitrogen (NO_3^-N) were measured. The TSS concentrations were measured by Standard Method 2540B (Eaton et al., 1995) using membrane filtration apparatus. The concentrations of PO_4^{3-}, NH_3N, NO_2^-N, and NO_3^-N were measured following standard methods given in APHA (1998) using an AQUAKEM 200 water analyzer (Labmedics Analytical Solutions; detection limit of 0.002 mg/L with a 1.5% measurement error at 95% confidence level). Two milliliters of each sample was filtered through 0.45 mm membrane filter (GE Water and Process Technologies) prior to nutrient measurement. In this study, PO_4^{3-} was considered as total phosphate (TP) and total nitrogen (TN) was calculated as the summation of NH_3-N, NO_2-N and NO_3-N respectively (Chunyan et al., 2015).

Analyses for moisture content, pollutant size distribution and composition of solid samples were carried out using methods described previously (ASTM, 2014; ASCE, 2007; Allison et al., 1998a). The moisture content (% mass) was measured gravimetrically for each solid sample (Allison et al., 1998a). The pollutant size distribution was carried out using sieve analysis (ASTM Standard, 2014). Solid samples (100–500 g) from each CBI were taken for sieve analysis using ISO 3310: BS 410-1:2000 sieve sizes 0.075, 0.15, 0.3, 0.425, 0.6, 1.18, 2.36 and 4.75 mm.

The runoff for each CBI inlet (assuming the inlet runoff catchment area same for each inlet) was calculated using the rational formula (Subramanya, 2013; Standards Australia, 2003): $Q = CIA$, where, Q is the flow rate (m^3/s), C is the runoff coefficient, I is the rainfall intensity (mm/h) and A is the catchment area (m^2). The rational formula is commonly used to determine the peak flows and unit hydrographs or kinetic wave approaches are used for runoff generation. The rational formula was used in this study because of the maximum accumulation of GPs occurring during the peak flow. Allison et al. (1998a) also showed that GP loads increased with increasing flow, reaching their maximum at peak flow. The runoff coefficient was taken as 0.9 for an unroofed impervious area (Standards Australia, 2003). The rainfall intensity was calculated from 1-minute rainfall duration depth data collected from the Bureau of Meteorology, Western Australia.

3. Results and discussion

3.1. The effect of catchment characteristics on the extent of capture of gross pollutants

The amounts of gross pollutants observed in areas with different urban intensities of residential, commercial and industrial activities is related to climatic conditions such as wind, the volume of traffic, topography, population density and most importantly hydrological parameters. The hydrological parameters are energy factors that govern the mechanism of mobilisation and transportation of gross pollutants from the streets or pathways into stormwater systems. These factors relate to the number of stormwater drains in a given urban or catchment area, the fraction of imperviousness, the topography and the profile of the roadside gutter. In dry conditions, wind and traffic movement are likely to convey material into the drains while during rainfall events, it has been previously observed that approximately 77% of street litter enters the drains and as little as 2.6 mm of rainfall is adequate to provide the transport mechanism (Madhani et al., 2009).

In our study, the CBIs were found to effectively capture gross pollutants at the source during each servicing event. Gross pollutants including sediments >150 μm diameter can be captured in the CBIs, as shown in a separate filtration experiment (see Supplementary Information) for the UST CBI geotextile material. As the site did not have coarser sediments, the main gross pollutants collected from the CBIs comprised vegetation and litter. The monthly servicing data are presented in Table 1, along with meteorological data and the calculated average dry load (kg/ha/CBI).

The mass of captured pollutants (average dry load) was plotted against rainfall for both the whole year data and for the period of wet weather months (April–October) (Fig. 3). This showed that there was a strong relationship between the GP load and the rainfall in the latter (wet weather) period ($r^2 = 0.90$). This is consistent with a study by Allison et al. (1998a) who also found a similar relationship between event load and rainfall volume ($r^2 = 0.78$) in a stormwater drain during wet weather (May–August). However, for the whole year data in our study, this relationship did not hold, as shown by the lower r^2 value of 0.41 (Fig. 3). This indicates that GP load is affected by other factors such as wind. In wet weather, high runoff is the main driver for accumulation of GP into CBIs while strong wind (with low rainfall) appears to be the main mechanism to transport the material into the side entry pits during dry periods. The wind speed is not uniform over the month and that is why a low regression value ($r^2 = 0.10$) was obtained in a separate plot (not shown) for wind speed versus GP load. The variation of GP captured in each CBI was tested by ANOVA (at 5%

Table 1
Average monthly servicing data of four CBIs.

[a]Servicing dates	[b]Total rainfall (mm)	[c]Last rain from servicing dates	[d]Total no. of rainfall events	[e]Servicing interval	[f]Max. wind speed (km/h)	[g]Avg. dry load (±SD) (kg/ha/CBI)
13/05/15	130.6	8	7	28	37	51(±20)
20/06/15	174	0	10	38	33	64(±21)
25/07/15	132	2	13	35	28	53(±10)
29/08/15	130	3	20	34	11	46(±9)
26/09/15	68	11	8	27	37	17(±8)
27/10/15	20.8	7	5	30	22	20(±4)
29/11/15	62.3	1	8	31	33	13(±4)
22/12/15	15.4	15	4	23	48	10(±4)
05/01/16	0	–	0	14	28	26(±13)
09/02/16	10.6	16	2	34	56	38(±4)
16/03/16	2.6	14	2	37	52	21(±5)
22/04/16	67.4	5	7	36	56	25(±10)

[a] The date at which the servicing was done.
[b] Sum of rainfall between the interval of two consecutive servicing dates.
[c] Number of days form last rainfall prior to servicing date.
[d] Number of rainfall events between the two consecutive servicing dates.
[e] Number of days between two consecutive servicing.
[f] Maximum wind speed recorded between the two consecutive servicing dates (BoM, 2016).
[g] The average dry load found in the CBIs.

significance level). There was no significant difference ($p > 0.05$) between yearly pollutant loads captured in each of the different CBIs. When the data for each individual CBI was analysed, there was no significant difference in GP load within the wet months (April–September; $p > 0.05$) and again, no significant difference within the dry months (October–March). However, there was a significant difference between the dry period load and the wet period load ($p < 0.05$).

3.2. Total gross pollutants captured at source: comparison of devices

Total gross pollutants captured at source can be collected using a variety of devices such as, catch basin inserts (CBI), continuous deflective system (CDS), inline netting system (NET), gross pollutant trap (GPT), at source pit traps (ASPT) and side entry pit trap (SEPT) (Allison et al., 1998a; Lewis, 2002; Chrispijn, 2004; Kostarelos and Khan, 2007). The amount of gross pollutant (mass basis) captured in different devices are shown in Table 2. To compare the total GP capture with other devices, only May–November data is presented. For the UST CBI tested in this study, the average accumulation of total GP load for each CBI were calculated as 384 kg/ha/yr (dry mass) and 919 kg/ha/yr (wet mass). These results are 13 times and 1.5 times higher than the similar study conducted in Melbourne and Sydney respectively (Allison et al., 1998a). The main difference between these studies is that Allison et al. (1998a) used SEPT and a CDS system which could not capture particles <5 mm, while the UST CBI captured particles down to 150 μm. In another study, Chrispijn (2004) found a GP load of 2250 kg (wet mass) for a 7-month survey, which is equivalent to 4000 kg/yr for 63 devices in Hobart, Tasmania. In their study, significantly higher captured wet loads were found for Enviropod and Ecosols (1711 kg/ha/yr and 1427 kg/ha/yr respectively) compared to SEPTs (878 kg/ha/yr). The Enviropod showed a higher capture load as it could capture pollutants down to 200 μm while the screen sizes of the other two devices were 3 mm (Ecosol) and 33 mm (Council's SEPT). The pollutant load also depends on catchment characteristics, seasonal and climatic variations and causes for outliers such as land uses, illegal discharges, and pollutant hotspots.

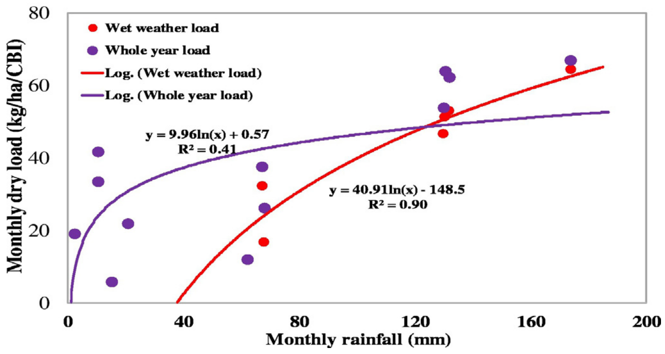

Fig. 3. Rainfall volume against dry load for wet weather and whole year.

The annual load in the devices (Table 2) may be affected by other parameters such as device dimensions, density of vegetation in the catchment and peak flows at the CBI inlets and hence the comparison of results should be normalized for these factors also. However, in this study, the captured load is normalized by their respective catchment areas per devices (last two columns of Table 2) because of the unavailability of other parameters. The results revealed that the UST CBI shows higher capture capacity (kg/ha) than the other devices throughout the year. However, the monthly dry load (kg) of the CDS system reported by Allison et al. (1998a) also shows a higher value because it was used at the outfall of a large catchment. The physical dimension of the CDS (usually 35 m^2) is much greater than that of the CBI (<0.5 m^2), although this depends on multiple factors such as catchment area, site location, target pollutants and land use, expected pollution loads and storage volume to minimise lifecycle costs (ROCLA, 2016). A detailed description of the CDS system can be found in Allison et al. (1998a) and Birch and Matthai (2009). The smaller catchment area in our study gave a proportionally greater GP load than the other larger catchments, i.e. Table 2 also indicates that although Enviropod and UST CBI have nearly equal opening sizes but the UST CBI shows 8.25 times higher captured load (kg/ha) for 28 times smaller catchment area (2.83 ha versus 80 ha). These results suggest that the incoming flow in larger catchments is higher, possibly resulting in pollutants bypassing the devices and/or remobilisation of captured loads. A survey by Allison et al. (1998a) revealed that a combination of a CDS and 192 SEPT captured 225% higher GP load than a single CDS system for the same catchment area. These results confirm other reports (e.g. Chrispijn, 2004) that for optimal performance, the GP capture devices should be installed in relatively high density throughout the catchment. One advantage of the UST CBI is that since it is specifically designed to use existing drainage infrastructure it can be easily retrofitted in most locations: comparable devices either need the infrastructure or drain to be replaced or have limited capture ability when fitted to existing infrastructure.

Table 2
Total gross pollutants captured in different devices.

Reference	Survey year	Location	Catchment characteristics	Devices ([a])	Screening size	Device dimensions (m^3)	[b]Peak flows per inlet (m/s)	Collection months	Days between cleans	Weight (kg)		Weight (kg/ha/device)		Weight (kg/ha/yr/device)	
										Wet	Dry	Wet	Dry	Wet	Dry
This study	2015–16	Gosnells Perth	Commercial area (2.83 ha)	UST catch basin insert (CBI) (4)	150 μm (geotextile)	<0.5	0.035	May	28	53	19	18.7	6.7	3676	1536
								Jun	38	83	24	29.3	8.5		
								July	35	55	20	19.4	7.1		
								Aug	34	51	18	18.0	6.2		
								Sep	27	13	6	4.7	2.2		
								Oct	30	17	8	5.9	2.7		
								Nov	31	6	5	2.3	1.8		
Chrispijn (2004)	2002	Hobart Tasmania	Commercial area and majority of the stormwater system being tidally influenced (80 ha)	Enviropod Side Entry Pit Trap (SEPT) (20)	200 μm (filter bag)	<0.5	n.a.	May	27	147	n. a.	1.8	n. a.	1711	n. a.
								Jun	32	340	n. a.	4.3	n. a.		
								July	33	167	n. a.	2.1	n. a.		
				Ecosol SEPT (11)	3 mm (Steel mesh)			May	27	25	n. a.	0.3	n. a.	1427	n. a.
								Jun	32	113	n. a.	1.4	n. a.		
								July	33	38	n. a.	0.5	n. a.		
				Council's SEPT (32)	33 mm (Steel mesh)	n.a.		May	27	81	n. a.	1.0	n. a.	878	n. a.
								Jun	32	225	n. a.	2.8	n. a.		
								July	33	96	n. a.	1.2	n. a.		
Allison et al. (1998a)	1996	Coburg Central Melbourne	35% commercial and 65% residential land use with 192 road entrances to the drainage system (50 ha)	Continuous Deflective System (CDS) (1)	5 mm	144 (6X6X4)	0.1	May	19	252	72	5.0	1.4	n. a.	n.a.
								Jun	34	348	111	7.0	2.2		
								July	27	422	122	8.4	2.4		
				CDS (1) + SEPT (192)	5 mm	n.a.	n.a.	Aug	27	n. a.	111	n. a.	2.2		
								Sep	32	n. a.	366	n. a.	7.3		
								Oct	15	n. a.	206	n. a.	4.1		
								Nov	31	n. a.	285	n. a.	5.7		

[a] Number of devices tested.
[b] Normalized to the catchment area.

3.3. Impact of moisture content of gross pollutants

Moisture content in the GPs can play a role in the rate of decomposition of vegetation and the release of nutrients to the environment. The moisture content was determined in each CBI and results are shown in Fig. 4. The mean moisture content (%) with their standard deviation found in CBIs varied between 24.05 (±12.63) to 52.49 (±13.85) for the whole year period. As expected, within the whole year period, the moisture content was higher during the wet season than during the dry period. A one-way ANOVA test (5% significance level) confirmed significant variation ($p < 0.05$) in moisture content in CBIs located on different sides of the road but no significant difference ($p > 0.05$) was observed among CBIs located on the same side of the road (e.g., CBI 6–8). The moisture content has an influence on the decomposition of materials captured within the CBI and hence their size distribution (see Section 3.4). As discussed, the presence of moisture content within the CBIs has implications on the decomposition of organic GP (such as leaves) that can increase dissolved nutrients to the runoff water coming in the next rain event (Selbig, 2016). As the CBI geotextile is not capable of removing any dissolved pollutants, it is necessary to service the CBIs well before the accumulated GPs are significantly decomposed.

3.4. Size distribution of captured gross pollutants

The size distribution of on-site GP captured depends on the land-use type, location and seasonal climate variability. The degree of variability describes the overall pollutant size distribution in each CBI. According to Selbig et al. (2016), the Shapiro-Wilk test (Helsel and Hirsch, 2002) for normality revealed that most of the individual particle size fractions, across a number of samples, did not show normal or log-normal distribution for skewness. Because of this degree of variability and the lack of normality in the data, the median distribution was chosen as the most appropriate representation of particle size distribution in each CBI. Usually, in highly skewed datasets, the median is a better representation of the population centre than the mean (Selbig et al., 2016). Hence, the median distribution (with standard deviation) for each sieve size was calculated for the yearly GP captured in each CBI.

The results revealed that the percentage of GP retained on 4.75 mm sieve for CBIs 6, 7 and 8 varied from 58.03–68.24, indicating that 60–70% GP captured within these CBIs were larger than 4.75 mm. However, for CBI 13 the percentage was higher (>80%). The main reason for the difference was likely to be the moisture content and location of CBIs. Due to the low moisture content in CBI 13, the percentage of the breakdown of vegetation (mainly leaves) was lower. Since CBI 13 was located on the other side of the road as shown in Fig. 1, the larger size pollutants did not enter this CBI during periods of low rainfall. However, during the wetter months between May–August (>150 mm), larger pieces of vegetation were more commonly found in this CBI because the heavier rainfall was able to transport these materials effectively (Fig. 5). The results indicate that the maximum percentage fines throughout the year in CBI 13 were <30%. From the median distribution, the pollutant sizes were arranged from higher to lower order as CBI 13 > 7 ≈ 8 > 6, i.e. the pollutants inside CBI 6 generally had a lower proportion of larger sizes (>4.75 mm) compared to other drains.

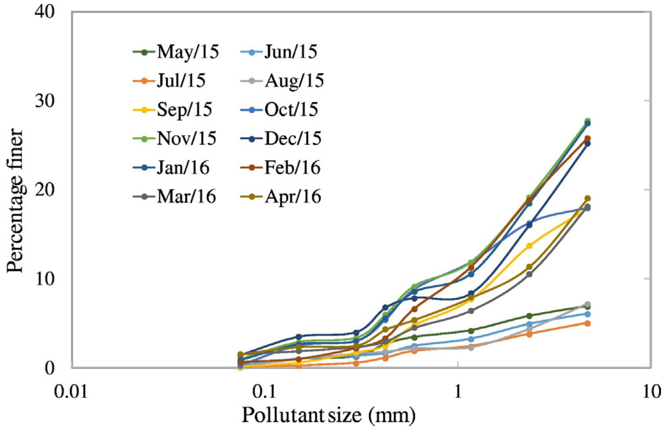

Fig. 5. Size distribution of gross pollutants captured in CBI 13.

An ANOVA test confirmed that there was a significant difference (at 5% significance level) in yearly pollutant size distribution among four CBIs ($p < 0.05$) but there was no significant difference in pollutant sizes in different months of the year within the same CBI. This is because of the topographical location of each CBI. Similar sizes of monthly vegetative loads were accumulated in the same CBIs. The results clearly revealed that the pollutant size distribution varied from one CBI to another for different months but did not vary in the GP captured in each individual CBI. Again there was a significant difference ($p < 0.05$) of pollutant size distribution in wet weather with respect to the dry period. This is because the size distribution may be affected in wet weather due to the higher moisture content enhancing the decomposition of vegetation.

The loading rate coefficients (K) for different pollutant sizes captured in different CBIs are shown in Table 3. The K-value for each pollutant size indicates their relative accumulation in CBIs. The coefficients (K) were calculated with runoff and pollutant load data. These coefficients are similar to event mean concentration (EMC), which is a flow-weighted average of constituent concentration (Lee and Bang, 2000). The EMC for an individual storm event can also be defined as

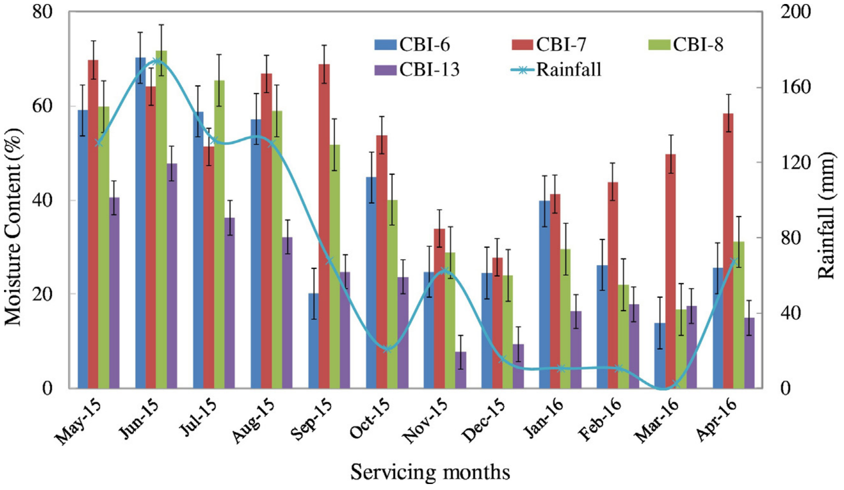

Fig. 4. Mean moisture content showing maxima and minima with corresponding monthly rainfall data in the different CBIs.

Table 3
Loading rate coefficients *(K)* of collected sample (kg/m^3 of runoff).

Particle sizes (μm)	CBI number			
	CBI 6	CBI 7	CBI 8	CBI 13
>4750	1.03	1.25	0.99	1.03
1180–4750	0.28	0.29	0.19	0.12
300–1180	0.18	0.17	0.12	0.06
<300	0.06	0.06	0.05	0.03
Total (K)	1.55	1.77	1.34	1.24

the total pollutant load divided by total runoff volume which is known as loading rate coefficient (Lee and Bang, 2000; Lau et al., 2001). These loading rate coefficients have two systematic errors. The coefficients will be lower than the actual load as the CBI has a provision of bypass flow during heavy rainfall period. In contrast, it will be higher than the actual load if other controlling factors such as wind velocity and car speeds are considered for pollutant movement. These coefficients can be used as a first-order approximation of the GP load to be expected from the commercial sites in urban areas in a climate similar to Perth, Western Australia. The results in Table 3 revealed that CBI 7 has the highest K-value (1.77) indicating higher relative accumulation of GP. This was because CBI 7 was closer to the pollutant source (trees, vegetation), which contributed to higher accumulation of GP in this CBI. These results are also compareable with those of Lau et al. (2001) who found the same range of coefficients for a commercial area. However, Lau et al. (2001) calculated the coefficients from one sampling data while yearly averaged (12 months' data) data were used in this study, which provides better representation of the field situation.

3.5. Gross pollutant compositions

The GP accumulated in CBIs usually comprises a mixture of vegetation (leaves, clippings, and branches) and litter (plastic, paper, cans and other miscellaneous matter). The percentages of different types of GP in these categories revealed that the vegetation contribution was mostly above 90% of the total GP and that this composition remained reasonably consistent throughout the year. The amount of vegetation captured in CBIs depends on the surrounding environment, which in this case includes large eucalypt trees that shed copious quantities of leaves, branches, nuts and bark that enter the drainage systems through stormwater run-off and/or wind. In addition, a large proportion of trimmings from maintenance of grass verges enters the stormwater drains. During wet weather, the roadside gutter contains abundant organic matter especially grass clippings preventing a continuous flow of stormwater into the drains and causing blockages. The decomposing mass may contribute to the nutrients that enter the waterways, creating oxygen-depleting substances that are unfavourable to the aquatic environment.

Sustainable and green cities are the main foci of current urban planning. The city planners and designers are promoting the concepts of green (or 'living') walls and roofs in urban centres (Callaghan, 2008; Madhani et al., 2009). However, as these plans are implemented, the generation of green litter will proportionally increase and buildings covered with vegetation will further add to the nutrient load in our waterways (Madhani et al., 2009). Additional elements including plastic, paper, cans and "others" made up the remainder of the GPs collected in the CBIs. "Others" mainly consisted of cigarette butts, glass, syringes, etc. which were primarily contributed by human activities. The current study site is a commercial land-use type surrounded by a shopping centre, a health centre, and a library, which are patronised heavily daily. Although CBI 13 is located on the other side of the road it showed a similar composition of pollutants to that in the other CBIs. The results revealed that a high percentage of vegetation may be found in stormwater systems, even for mixed activity urban areas.

Comparison of the UST CBI with previously described devices that capture GPs (e.g. GPT, CDS, SEPT, ASPT) showed that while the compositions of captured GPs were similar for all devices (Table 4), the major differences in the devices were in their screening sizes and operation and maintenance procedures. The GPT device has several disadvantages such as high construction costs, large visual impact usually on a recreational area and their frequency of trash rack blocking and subsequent overflowing including high maintenance program costs (Allison et al., 1998a). Maintenance of some GPTs may require large vertical clearances. Hence before construction of GPTs, it needs to be ensured that appropriate clearance zones (e.g. to trees, overhead power lines, awnings) are available for cleaning. The time to clean a single GPT unit is approximately 4 h (including transportation and cleaning) and servicing occurs annually, depending on site characteristics. CDS and Vortex are also associated with high construction cost and require separate land area. SEPTs are baskets fitted below the entrance to drains from road gutters. When stormwater passes through the baskets to the drain, material larger than the basket mesh size (5–33 mm) is retained. This material remains in the basket until it is removed by a maintenance crew, typically every four to six weeks (Allison et al., 1998a). ASPT's units can be cleaned either manually or by an eductor truck. The total time taken for the clean, including travelling time and disposal for four ASPT units is 4 h (Watson, 2005). The UST CBI is usually serviced 10 times/year in the following manner: (a) truck pulls up next to the side entry pit and the drain lid or grate is removed or opened; (b) the CBI unit is lifted out of the drain by the Hiab crane or manually by two crews; (c) the geotextile basket with pollutant material is removed from the unit and a new one is installed on-site; the device is then reinstalled into the drain and the drain lid or grate is reinstalled or closed (Fig. 2). The whole process is carried out in this manner to keep traffic disruption to a minimum. The average time for a service is approximately 10 min. The collected geotextile bags with pollutant materials from the field are serviced/cleaned by reverse fluid flush back at the base where wastes are sorted for reuse or possible recycling which also takes roughly 10 min for each unit. The special type of geotextile used in the UST CBI is a key to its ease of use. The performance of the geotextile material is restored to near new condition by removing the captured sediment and vegetation with a high-pressure fluid flow (400 kPa) without destroying its original basket shape. It was found that newly developed urban areas generate significant quantities of silt and sediment run-off, which can fill up the swale pit even prior to the completion of the development. Trapping these pollutants into CBI units at-source will significantly reduce the sedimentation build-up in these pits and also on-going maintenance costs in downstream pipelines. The ability to fit CBI units to existing systems means that drainage lines serving pollutant-generating catchments such as schools, shopping precincts and central business districts, can be targeted for effective treatment of stormwater at significantly reduced cost. Each unit may be manufactured to suit the configuration of each individual pit. This is an important feature as there are a wide range of pit dimensions and depths across the different localities. There is a concern about stormwater treatment at source that the installation of devices may cause blockages resulting in localised flooding. However, the CBI unit has its unique design with a by-pass (Fig. 2) ensuring inflows passing continuously through the pit even when its collection unit is full.

3.6. Gross and aqueous phase pollutants in dry and wet seasons

The impact of CBIs on water quality was largely related to the retention of moisture within decaying vegetation which has been reported as promoting the release of nutrients. The accumulation of gross pollutants in dry and wet seasons and the subsequent aqueous phase contamination, total pollutant load and concentrations of nutrients and suspended solids are shown in Table 5. The pollutant load in the wet weather period was found to be higher because of the rainfall-runoff carrying these loads (Table 5). However, the vegetation in CBI 13 was lower because

Table 4
Composition of gross pollutants captured in different traps.

Ref.	Survey year	Site description	Device types	Screening size	Vegetation/sediments	Litter	Method
					(%)		
This study	2015–16	Perth, Western Australia	CBI 6	150 μm (geotextile)	93	8	mass
		Federation parade, Gosnells	CBI 7		97	3	
		(Commercial area)	CBI 8		92	8	
			CBI 13		91	9	
Chrispijn (2004)	2002	Hobert, Tasmania, Australia	Enviropod	200 μm (filter bag)	98	2	mass
		Sullivan's Cove	EcoSol	3 mm (Steel mesh)	97	3	
		(Commercial, light Industrial, trafficked areas)	Council's SEPT	33 mm (Steel mesh)	94	6	
Allison et al. (1998a)	1996	Melbourne, Australia	CDS	5 mm	80	20	mass
		Coburg					
Great lake councils (2002)	2001–02	Sydney, New South Wales, Australia	ASPT	200 μm (mesh)			mass
		Stroud			97	3	
		Bulahdelah			70	8	
		Nabiac			29	71	
		Forster			71	29	
		Tuncurry			97	3	
		Tea Gardens			96	4	
		Hawks Nest			97	3	
Lewis (2002)	2001	Melbourne, Victoria, Australia					mass
		Melbourne City	NET[a]	n.a.	83	17	
		Melbourne City	SEPT	3 mm	91	9	
		St Kilda (Residential area)			94	6	
		Frankston (Commercial/shopping precinct)			76	24	
Greenway et al. (2002)	1999–03	Brisbane, Queensland, Australia	CDS	5 mm	97	3	mass
		Brisbane (Residential area)	vortex	5 mm	99	1	
Watson (2005)	2004	Tauranga, New Zealand	ASPT	200 μm (mesh)	82	18	mass
Lippner et al. (2000)	2000	Los Angeles, USA	drains	n.a.	60–80	–	mass
Kim et al. (2006)	2000–02	Southern California, USA	drains	n.a.	90	10	volume
Marais et al. (2004)	2000–01	Cape Town, South Africa					mass
		(All residential area)					
		Imizamo Yethu	SEPT & GPT	n.a.	21	79	
		Ocean site			60	40	
		Summer Greens			64	36	
		Fresnaye	GPT		100	0	
		Welgemoed			100	0	
		Cape Town CBD	SEPT & GPT		65	35	
		Montague Gardens			38	62	

[a] Inline netting system.

of its location, which is on the other side of the road further from the trees.

The pit water quality in terms of nutrient concentrations (TSS, TP and TN), averaged for dry (November–March) and wet (April–October) seasons (Table 5), is within the large range of values reported in the literature for fully developed urban areas in Australia (Wong, 2006). During the dry period TSS was higher than during the wet season because there appeared to be greater transport of fine particles in the dry period. TP and TN were higher in wet season possibly because the water-soluble components of nutrients are transported more readily by the road runoff from nearby market areas and parking lots. In addition, the moist vegetation accumulated in the CBIs may add to the nutrient load through decomposition. Ball and Ara (2010) and Allison et al. (1998b) confirmed the release of TP and TN from moist vegetation. Ball and Ara (2010) reported that >50% of phosphorous in leaves is released within 22 days of submergence. Allison et al. (1998b) indicated that 5–20% of nutrients can leach from vegetation under moist conditions. The decomposition of plant material may follow a first order exponential decay model (Olson, 1963; Ball and Ara, 2010): $P_t = P_0 e^{-kt}$ where P_0 is the initial nutrient content in vegetation, P_t is the amount of nutrient remaining after the time t, and t is the time in days. This indicates that there would be more release of nutrients into water if conditions inside the CBIs remain moist for the longer term, which will enrich the nutrient concentrations in the receiving water bodies. In this study, higher TP concentrations in the wet season (>the trigger value in ANZECC, 2000) may have resulted from stagnation of water in the pit and the accumulation of GPs within CBIs in moist conditions for up to a month. Allison et al. (1998b) and Birch and Matthai (2009) found higher TP (0.14–0.6 mg/L) and TN (1.5–4 mg/L) concentrations in CDS effluent. The CDS are usually serviced annually and the GPs remain under water for longer term in this device. However, the concentrations of TP and TN in CBI effluents were found to be lower in this study when compared to other literature (Allison et al., 1998b; Birch and Matthai, 2009). This was because the CBI is serviced monthly and GPs are accumulated within the basket.

Table 5
Total pollutant load and water quality parameters in dry and wet seasons.

Parameter	Season	CBI-6	CBI-7	CBI-8	CBI-13
		Pollutant load (kg/ha) Mean (±std. dev)			
Vegetation	Dry	21(±10)	24(±14)	23 (±10)	17(±11)
	Wet	45(±23)	48(±0.5)	36(±23)	23(±13)
Litter	Dry	1.4(±0.8)	1(±0.9)	0.7(±0.4)	1.5(±0.6)
	Wet	4.5(±0.8)	0.7(±0.5)	3.7(±2.4)	3.5(±6.3)
		Concentration in pit water (mg/L)			
TSS	Dry	368(±352)	476(±347)	–	135(±75)
	Wet	309(±238)	387(±358)	–	101(±118)
TP	Dry	0.02(±0.02)	0.06(±0.05)	–	0.02(±0.02)
	Wet	0.07(±0.08)	0.17(±0.14)	–	0.04(±0.06)
TN	Dry	0.32(±0.29)	0.27(±0.13)	–	0.56(±0.41)
	Wet	0.84(±1.2)	0.37(±0.49)	–	0.26(±0.43)

The configuration of the side entry pit has a significant influence on stormwater infiltration and hence overall stormwater management. The side entry pit is primarily thought to function as a soak well but often the bottom of the pit becomes effectively sealed to water due to stormwater contaminants and accumulation of GPs. Hence it is necessary to capture the contaminants at source and then service the CBI on a regular basis. In this case, CBIs can be used since they provide easy access for cleaning both the CBI (e.g., servicing) and the pit. However, several operational parameters still require further research, such as the optimum frequency of servicing, which is dependent on the infiltration/retention capacity of CBI materials and site-specific conditions. Regular servicing of the CBI and maintenance of the side entry pit will allow the release of relatively clean water to aquifers and receiving water bodies and will also keep the storm drainage network free from blockages and ensure that it operates effectively.

4. Conclusion

This paper has demonstrated the nature, type and size of gross pollutants captured at source in a catch basin insert. A new type of CBI, developed by UST, was trialled in an urban area in the City of Gosnells, Western Australia. Gross pollutants were collected from the CBI and water samples were collected from the side entry pit under each CBI during monthly servicing over the course of one year. The GP load was affected by seasonal conditions, being highest during the winter (wet) months due to mobilisation of pollutants by rainfall and storm events. In the dry months, the greatest factor in terms of GPs loading was thought to be median wind speed although sufficiently detailed wind speed data was not available. The prevailing wind patterns during the dry months are generally regular easterly in the morning with south-westerly sea breezes in the afternoon, whereas during the wet months most days are calm, but maximum wind speeds can be high during sporadic storm events. The GP compositions were evaluated and vegetative waste was found to be the greatest contributor of all the GP types (93%) in all 4 CBIs. This reflected the nature of the site, which was an urban commercial area near parkland with numerous trees, and indicated the site specificity for GP characteristics. The moisture content of the GPs varied between 24 and 52.5%. The sizes of captured GP were found to be of similar distribution in all CBIs for the sizes varying between 0.075 and 4.75 mm. The sieve size of 0.075 mm showed <1% of solids accumulation, indicating the CBI is suitable for capturing GPs above 150 μm. The loading rate coefficient (K), showing relative accumulation of GPs, was found to be higher in the CBIs located near trees. The GP capture capacity of different types of devices was reviewed and it was found that the UST CBI has higher potential to capture GP per unit area above 150 μm. Comparison of this study with previous studies confirmed the importance of the density of capture devices in terms of their effectiveness. Large catchments with high flow and a low density of capture devices can result in a significant portion of the GP load by-passing the devices and/or remobilisation of the captured loads. Higher densities of smaller devices, as was the case in this study, may be more effective in capturing GPs than larger devices spread further apart. However, this study was carried out at one site only and further investigation is required for site specific information on the performance of the CBI, e.g. in a range of brownfield and/or greenfield sites.

List of abbreviations

ANOVA	analysis of variance
ASPT	at source pit traps
ASTM	American Society for Testing and Materials
BMP	best management practices
BS	British Standard
BOD	biochemical oxygen demand
CBD	central business district
CBI	catch basin insert
CDS	continuous deflective system
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EMC	event mean concentration
GP	gross pollutant
GPT	gross pollutant trap
ISO	The International Organization for Standardization
NET	inline netting system
NSW	New South Wales
SEPT	side entry pit trap
SS	suspended solids
TN	total nitrogen
TPH	total petroleum hydrocarbon
TP	total phosphorous
TSS	total suspended solids
UST	Urban Stormwater Technologies Pty Ltd.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2017.01.210.

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