Urban Area Dry Diffuse Pollutants Washoff Composition

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This chapter presents the characteristics of urban area dry pollutants buildup and subsequent washoff in stormwater in Perth, Western Australia. Accumulated dust and dirt (DD) and stormwater runoff were sampled and analyzed for associated pollutants. The study concludes that total DD and associated pollutants present significant temporal and spatial variations. Surface texture was found to be an important factor in pollutant buildup, which can affect the initial and maximum DD loadings on the surfaces. The antecedent dry period had pronounced effects on dry solids (DD and associated pollutants). Suspended solids (SS), zinc (Zn) and copper (Cu) washoff loads from impervious areas had significant variations among the test areas. Washoff concentration variations of total phosphorus (TP), nitrite and nitrate (NO₂+NO₃) were insignificant among test areas. The dissolved fraction of total phosphorus and NO₂+NO₃ was between 22 to 43% and 50 to 62%, respectively. It was observed that the initial mass of dry pollutants from impervious surfaces was much greater than the observed washoff load. Only minor portions of dry pollutants (DD and associated pollutants) were available for washoff. The available washoff load was between 0.5 to 3.5% for TP, Zn and Cu of the total dry pollutants initially accumulated on the catchments impervious areas. No correlation was found between washoff load and inter-event dry period.

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7.1 Introduction

Stormwater runoff from impervious urban areas contains diffuse pollutant loads both in dissolved and particulate forms. Diffuse source pollution may be derived from a variety of causes and land uses, including both natural and anthropogenic (human-related) sources (Morris, 1996). Some of these pollutants are results of transport and its related activities and atmospheric (wet and dry) deposition. Impervious urban areas that contribute most of urban runoff particulate are polluted by traffic related pollutants (Shaheen, 1975). These areas include parking areas, streets, driveways and sidewalks, which contribute most of the runoff to receiving waters during small rain events (Pitt, 1987). Degradation has been reported in river systems and lakes in many parts of the world, including Western Australia due to polluted stormwater.

Evaluations of urban runoff quality are a very complex procedure due to the diverse nature of pollutant sources and land uses. Simulations are therefore used to fill in missing data or information. Simulation of urban runoff quality can be inaccurate due to large uncertainties in representation of physical, chemical and biological processes.

Process-based simulations, such as pollutant buildup and washoff, are complex and require large amounts of data, but can replicate catchment pollutant characteristics and their transport through the drainage system. Buildup and washoff are the processes through which dry pollutants are deposited on impervious area and transported via runoff.

Most washoff models use initial street loadings as an important factor. This factor has been misinterpreted since it was assumed to be total street loading, but in fact it is the only the portion of the total street loadings available for washoff. Pitt (1987) found that the measured total buildup loadings were several times larger than these available washoff pollutant loadings. The street dirt and dust loadings are multiplied by an availability factor (ratio of available loading to the total loading) to match the washoff load.

Understanding of DD removals from impervious areas is therefore critical for the characterization of urban runoff quality and modeling methods of estimation. A very few investigations have been carried out to quantify and characterize the pollutants that are washed off with rain and runoff. Conder (1988) pointed out that in the Australian catchments; most water quality simulations had a major flaw. These investigations used overseas data due to the lack of available local data, especially buildup and

washoff data. Most of the models use the Sartor and Boyd (1972) data to estimate the percentage of available particulates on the street that could be removed during washoff. The data was collected in controlled dust and dirt washoff experiments at constant simulated rain intensities of about 5 to 20 mm/h. But in real conditions, the rain intensity is not constant throughout the event and hence runoff varies.

An attempt has been made to investigate West Australian urban catchment pollutant buildup and their contribution during washoff in real field conditions. The study objective was to quantify the removal of dirt and dust and other associated pollutants by rain through collecting and analyzing both accumulated sediments on the paved surfaces and stormwater runoff at the inlets to the storm sewer system. The characterization of the source area stormwater quality has many potential beneficial applications that include: the identification of hot spots; the collection of data needed to plan and design stormwater treatment and management facilities and to assess the impact of untreated stormwater to local river, lake and groundwater quality.

7.2 Sampling and Analysis

The dust and dirt (DD) loading and washoff data were collected on an urban catchment in Western Australia within Curtin University, Bentley Campus near the main entrance area (Figure 7.1). The DD samples were collected with the use of a dry vacuum over a period of six months. Buildup samples were collected in narrow strips, each 10 cm wide taken from curb to curb, on the impervious surfaces of homogenous land use test areas. The test areas, roads (smooth and rough) and parking areas were monitored. Additional monitoring and dirt buildup collection was also performed before and after cleaning and rainfall.

The sequential washoff samples were collected to quantify temporal variations at inlets before entering the drainage system over the observed storm's durations. Samples were taken at the gutter near the inlet grates. To assess information about the spatial variation, runoff samples were collected from test areas such as road surfaces (rough and smooth) and parking areas. Replicate samplings were collected at second locations at each source area for quality control. Rainfall data was obtained via a rain gauge installed close to the monitoring stations. A total of ten storm events were observed, but only eight significant storm events (Table 7.1) were included in this study.

Flow rate was measured at the sampled inlets. Stage volume curves were developed for the inlets used for washoff sampling. Vertical scales were fitted to record the stage at the inlets. The known volume was converted to flow rate by recording time and flow stages at inlets. In some areas the uneven distributions of flows across the street made it impossible to collect flow data so the only data collected was pollutant washoff concentration. The literature review revealed that a relationship could be established between rainfall total and runoff depth in the study area. Victor (1989) mentioned that the direct rainfall and runoff relationship is relatively simple and has proven its practicality in a variety of applications.

Figure 7.1 Main entrance study area in Curtin University Bentley Campus, W. Australia

Rainfall data are easy to measure and widely available as compared to runoff data. The field data showed a strong correlation ($R^2=0.85$) between parking lot runoff depth and rainfall depth (Figure 7.2). The runoff coefficient for impervious parking area was estimated to be 0.92. Fetter (1994) indicated runoff coefficient values for pavements made of asphalt or concrete surfaces are in the range of 0.7-0.95.

Buildup and washoff samples were analyzed in the laboratory for the following constituents using the method described as follows:

- Total phosphorus (TP), total Zinc (Zn) and total Copper (Cu) in dry buildup DD samples were analyzed with ICP-OES (Yvon JY-38). Samples were dried in an oven and particles sizes were determined using standard Australian methods (AS 1289).
- Total and dissolved Phosphorus, Zn and Cu were analyzed in samples with multi-parameter bench photometers (C200 series), using APHA 1992 procedures.
- Suspended solids (SS) were measured with 0.45 mm filters and vacuum filtration.

Table 7.1 Rainfall characteristics of the observed events

Storm Date	rainfall (mm)	Average intensity (mm/h)	Rain duration (hr)	Inter-event period (hr)
5 th June, 2003	9	4.5	2	25
18 th June, 2003	10	5	2	72
8 th July, 2003	11	7.5	1.5	90
18 th July, 2003	22	7.3	3	60
24 th July, 2003	8	5	1.6	75
26 th Aug, 2003	10	4.3	1.2	30
31 st Aug, 2003	8	8	1	18
14 th Sep, 2003	6	3	2	240

Figure 7.2 Rainfall and runoff relationship for the parking areas at Bentley campus

7.3 Results and Discussion

7.3.1 Dust and Dirt and Associated Pollutant Buildup

Table 7.2 shows the significant temporal and spatial variation in the accumulation of DD and associated pollutants (TP, Cu, Pb, and Zn). The DD accumulation rate was generally high in the first ten days and low afterwards.

This phenomenon was more visible for rough surfaces and parking areas. The maximum load was observed within 20 days of dry period following its cleaning. Afterwards, the daily accumulation rate was almost negligible and the load fluctuated around the peak values.

The accumulation of DD followed the sinusoidal trend (Figure 7.3); cleaning and significant rain brought the dust and dirt load to minimum values and deposition took it to the maximum. The first four months (December to April) were dry in Western Australia and the DD and its pollutants accumulated to their maximum loads before they were removed through routine street sweeping. Afterwards, both the cleaning and frequent rainfall events reduced the DD and the accumulations fluctuated mostly around the initial values. It was also apparent (Table 7.2) that the smooth roads had substantially less loadings than the rough roads during any accumulation period.

Physical characteristics of DD, such as the daily accumulation rate, were consistent with other studies (Sartor and Boyd, 1972; Pitt, 1979; Pitt and McLean, 1984; Ball *et al.*, 1998; Vaze, 2001). However, the ten day averaged dust and dirt (DD) loads on smooth roads at the Bentley campus were half of the accumulated loads reported by Sartor and Boyd (1972), but five times greater than the DD load reported by Ball *et al.* (1998).

The accumulation was concentrated in the gutter areas of the smooth roads and near the curb of the high-speed roads (blown by vehicles and wind speed). The accumulation was more evenly distributed on impervious areas in low speed zones, rough roads and in parking areas. Most of the DD accumulation was within 0.5 m of the curb (in the gutter area) and amounted to 46 % in the parking areas, 54% on the rough roads and 71% on smooth roads of the total accumulation. Sartor and Boyd (1972) indicated 90% of the street dust and dirt was distributed within 0.3 m from the curb in the no-parking zones. Grottaker (1987) reported 96% of the accumulation within 0.5 to 2.2 m of the curb.

Table 7.2 Dry Pollutant buildup load (g/curb.m).

Pollutants	Test areas	Total buildup Range	Average daily rate	
			After cleaning or rainfall	
			Within 1-10 days	Within 11-20 days
DD Solids	Parking	150-450	30	6
	Rough roads	90-310	40	3
	Smooth roads	40-110	20	2
Total phosphorus	Parking	1.3-10	0.20	0.08
	Rough roads	0.7-4.3	0.15	0.7
	Smooth roads	0.2-2.7	0.13	0.05
Total Zn	Parking	0.6-12.4	0.7	0.4
	Rough roads	2-20	0.6	0.5
	Smooth roads	3-25	0.9	0.7
Total Cu	Parking	1-9	0.3	0.1
	Rough roads	1-14	0.6	0.25
	Smooth roads	2.3-20	1	0.4
Organic matter	Parking	22-82	3	1.5
	Rough roads	6-26	0.8	0.5
	Smooth roads	3-13	0.2	0.1

Chemical potency of DD (Table 7.2) found in this study were significantly higher than that reported by other studies with similar land uses. Phosphorus accumulations were high in parking area and on rough roads, and low on smooth roads. Mean total phosphorus accumulations were in the range of 0.6 to 4 g/curb-m, with daily accumulation rates of 0.05 to 0.25 g/curb-m. Rates of phosphorus buildup on parking areas were five times higher than on the smooth road.

The daily accumulation rate for Zn, Cu and Pb was in the range of 0.25 to 0.6, 0.1 to 0.45 and 0.1 to 0.55 g/curb-m, respectively. Wanielista and Yousef (1993) reported the same limits of Zn and Pb but the accumulation of Cu was very low (0.01 g/curb-m) as compared to the present study.

7.3.2 Characteristics of Pollutant Washoff from Urban Impervious Areas

Tables 7.3 and 7.4 revealed that the concentration varies considerably among the impervious test areas with the exception of the nutrients (phosphorus, nitrite and nitrate). Maximum suspended solids concentrations were observed in parking area washoff with minimum concentrations in smooth street washoff. Mean event concentrations (EMC) and washoff loads (g/curb-m) were two times greater on rough road surfaces and three times on parking lots as compared to the smooth road surfaces.

Figure 7.3 Dust and dirt (DD) buildup (kg/curb.m) on the smooth road test area.

Total phosphorus, nitrite and nitrate washoff concentrations were similar on both types of roads (rough and smooth) but high in parking areas. The mean concentration range of phosphorus was 0.36 to 0.58 mg/L and was 2.2 to 2.7 mg/L for nitrite and nitrate. High concentrations of nutrients in parking area washoff may be due to the large number of trees and the adjacent landscaped areas present at these test sites. Wong *et al.* (2000) reported that elevated nutrients are predominantly derived from plant matter, organic waste, fertilizers, atmospheric depositions, ash from bushfires and nitrous oxide produced from vehicle exhausts. The results revealed that the concentration

of nutrients was high at Bentley campus as compared to other Australian states and overseas data.

The mean dissolved fraction of nutrients varied from 22 to 43% for phosphorous and 50 to 62% for nitrite and nitrate in the study areas. The concentration of dissolved nutrients was greater in washoff from parking lots and rough roads. Gizzard *et al.* (1976) reported that about 45% of the total phosphorus and 55% of the Total Kjeldahl Nitrogen (TKN) in urban runoff water were present in the dissolved form. The nutrients loading in the stormwater is strongly influenced by land use and other site-specific conditions. Camp (1988) found during stormwater investigations that about 90% of the phosphorous was in the particulate form. Similar results were found by Waller and Hart (1986), indicating that the particulate form of the phosphorus load was higher in magnitude than the soluble load in the surface runoff from an urban area.

Table 7.3 Characteristics of suspended solids (SS) washoff in stormwater runoff from the study areas

Suspended	Concentration Range (mean) (mg/L)	EMC mean (mg/L)	Washoff load (g/curb-m)
Parking	40-1900 (603)	400	5-18
Smooth road	10-400 (144)	126	1-6
Rough road	15-10700 (360)	319	1-12

In Western Australia, runoff from sandy catchments contains high levels of filterable reactive phosphorus and, due to its low capability to bind phosphorus, export large quantities of phosphorus to adjacent water bodies (WRC, 1998).

The concentrations of Zn and Cu in this study were in the range of 0.28 to 0.43 mg/L and 0.13 to 0.27 mg/L, respectively. Comparisons with other studies reveal that the concentration of Zn was similar to other studies, but the Cu concentrations were much higher in the present study. This elevated concentration of heavy metals is most likely attributed to heavy traffic volumes. Driscoll *et al.* (1990) found the concentrations of heavy metals, generated from the road, vary with different traffic volumes.

Table 7.4 shows that on average 30% to 50% of the zinc and copper were associated with the dissolved fraction and the remaining were with

particulate forms, similar to the finding of other studies such as Sansalone *et al.* (1997) for the same land use.

Table 7.4 Characteristics of nutrients washoff in stormwater runoff from the study areas

	Concentration mg/L		EMC mg/L	Dissolved fraction (%)		Washoff load g/curb-m
	Range	Mean	Mean	Range	Mean	Range
Total Phosphorous						
Parking	0.1-1	0.58	0.48	14-68	43	0-0.14
Smooth road	0.05-1.3	0.42	0.40	16-58	34	0-0.02
Rough road	0.02-1.2	0.46	0.36	9-38	22	0-0.02
NO ₂ +NO ₃						
Parking	1-7	2.7	2.5	16-84	58	0.004-0.13
Smooth road	0.5-3.5	2.2	2	33-90	62	0.006-0.06
Rough road	1-4	2.3	2.1	17-75	50	0-0.08
Zinc						
Parking	0.07-1.8	0.43	0.39	15-60	30	0-0.02
Smooth road	0.02-0.75	0.28	0.26	8-58	49	0-0.01
Rough road	0.06-1.15	0.38	0.33	17-61	50	0-0.01
Copper						
Parking	0.04-0.9	0.27	0.2	21-55	38	0-0.0014
Smooth road	0.03-0.6	0.14	0.12	8-50	35	0-0.008
Rough road	0.04-0.4	0.13	0.09	6-54	31	0-0.003

7.3.3 Washoff Pollutants Load and its Availability Factor

The results show that the percentage of the accumulated sediment and its associated pollutants that are available for washoff during a storm varied significantly within an event and among the events collected throughout the study areas. The results also indicated that only a minor fraction of dry pollutants accumulated on impervious surfaces could be considered available to be washed off with stormwater. The portion of the total accumulated dust and dirt (DD) load that was considered available since it

was observed as suspended solids in study's monitored storm events were 6 to 15 % in parking lot washoff, 4 to 8% in smooth road washoff and 5 to 15% on rough roads. Available phosphorus washoff load was 1 to 3% for parking lots, 1.5 to 3.5% for smooth roads, and 0.5 to 1% for rough roads. Available zinc loads were 0.5 to 2.5% for parking areas, 1.2 to 2% for smooth roads, 1.3 to 1.7% for rough roads, while available copper washoff was observed to be less than 1% of the total accumulated DD loads. Figure 7.4 presents the total phosphorus load (g/curb.m) that washoff the main entrance parking area during four events and the available dry pollutant (accumulation in percent) observed on the source areas. Pitt (1987) identified important relationships between available and total particulate loadings and found that all the pollutants present on impervious area were not available. The fraction of the total initial surface loading that was available for removal by washoff was around 3-25%, with an average of only 10% (Pitt,1987). Many modeling have typically ignored this relationship, which has a major impact on the accurate predictions of street particulate washoff.

In the present study, availability of washoff pollutants (TP, Zn, and Cu) was high on smooth roads but suspended solids had a mixed trend, high in one event but low in other events when compared to rough roads. Effects of high rainfall intensity were not clear in this study as the maximum intensity was around 7.5 mm/h which makes it difficult to compare with other studies. Previous studies found that the washoff process was more efficient for the higher rain energies and smoother pavement. Most of the previous studies used simulated rain intensities such as 5 to 20 mm/h by Sartor and Boyd (1972), and (20-60 mm/h) by Vaze (2001). The washoff for low rainfall intensity on rough streets was estimated to be only 2.8-4.5% of the total available street dust and dirt.

The inter-event dry period varied from 25 to 240 hours for observed events, but its effect on washoff loads or concentrations is not apparent in the present study. Suspended solids and NO₂ + NO₃ washoff were higher in event 1 (5th June 2002) when compared to event 2 (18th June 2002). However, the concentration of zinc was lower in event 1 when compared to event 2 and phosphorus was observed lowest in event 2. The inter-event periods for event 1 and 2 were 24 and 72 hours respectively, while rainfall intensities for both of the events were very close to each other (4.5 and 5 mm/h).

Abustan (1997) concluded that the highest event mean concentration for total phosphorous occurred when the event had the longest inter-event dry

period and the highest rainfall intensity. However for some of areas where low intensity rain is common, like Portland, Oregon, the stormwater data suggest that pollutant washoff loads may not be correlated to length of antecedent dry period (Sutherland and Jelen, 1995). Randall and Barret (1998) concluded that reliable estimates of pollutant runoff concentrations could not be made based on antecedent dry periods alone.

Figure 7.4 Total Phosphorus washoff load in main entrance parking area.

7.4 Conclusions

The accumulation of DD loads was not consistent with time. Most of the DD accumulations during the dry season reached maximum buildup within the first ten days. DD buildup on rough roads was observed to be five times greater than on smooth roads, and the maximum loads were achieved within the first 20 days after a cleaning. Most of the DD accumulation was within 0.5 m from the curb (in the gutter area) and the greatest percentage of accumulated DD load near the curb was found to be on smooth roads.

It was concluded that total DD and associated pollutants present on street surfaces have very little influence on the observed washoff load. Only a minor portion of pollutants mass observed on paved catchment surfaces were found in washoff mass and therefore considered to be available surface load.

The available surface load had significant variations within and among the events. Available washoff loads of suspended solids were between 4 and 15%, phosphorus was between 1 and 3.5 %, zinc was between 0.5 and 2.5%, and copper was less than 1%. The washoff load was not correlated to the inter-event dry period in the present study. Available surface loads of constituent pollutants (TP, Zn, and Cu) were higher on smooth roads, but suspended solids had a mixed trend, high in one event but low in others. Effects of high rainfall intensity were also not clear primarily due to limited data.

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