FIRST FLUSH STORMWATER POLLUTANTS FROM CARPARKS IN DIFFERENT URBAN SETTINGS

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ABSTRACT

Carparks make up a large portion of impervious urban areas. Stormwater runoff from these areas is therefore considered a significant source of pollutants to receiving urban waterways, particularly of total suspended solids (TSS) and heavy metals such as zinc (Zn), copper (Cu) and lead (Pb). Pollutant concentrations can be substantially higher during the initial period of the runoff hydrograph commonly known as first flush (FF). In Christchurch, the influence of land use around urban carparks on the water quality of the first flush is poorly understood. This research thus focuses on quantifying FF TSS and metals from carparks within different urban land use settings. To achieve this objective, grab samplers (1 L HDPE) were deployed in a hospital carpark, a university carpark, and an industrial carpark in Christchurch. Concentrations of TSS, Zn, Cu, and Pb were quantified for each of seven rain events. TSS and total metal concentrations were higher in the FF from the industrial carpark due to its unique land use activities as compared to the other two sites studied. Furthermore, dissolved Zn and Cu were found to be above recommended guidelines for all carparks. It is concluded that characterizing the FF for individual carpark types is important for the design of effective stormwater treatment systems such as filters.

Keywords: First Flush, Stormwater, Heavy Metals, TSS, Land Uses, Carparks

1 INTRODUCTION

The establishment of car parking spaces continues to grow as the number of vehicles increases together with their associated use for work and leisure activities (Revitt, et al. 2014). In New Zealand, there are 4.7 million registered vehicles (3.1 million passenger car/van) and this number continues to grow daily (NZTA, 2014). Carparks have become a key component for both transport and land use planning related to the development of commercial centers, factories, office complexes, residential housing as well as institutional complexes.

Carpark surfaces are typically impervious and, like roads, represent a major source of stormwater pollutants such as TSS, metals, anthropogenic organic compounds, nutrients and microbial contaminants (Gobel et al., 2007). Degradation of water quality in urban freshwater ecosystems typically occurs when stormwater runoff from impervious surfaces such as carparks is channeled directly into local waterways (Blakely & Harding 2005; Cochrane et al., 2010; Wicke et al., 2012). Heavy metals (importantly Zn, Cu, and Pb) and TSS are reported as the dominant pollutants in Christchurch's waterways (CCC, 2003).

Traffic related activities such as traffic volume, traffic patterns, vehicle type and maintenance, and surrounding land use have been identified as the primary contributors of the above pollutants to urban stormwater runoff (Davies et al. 2001; Goonetilleke et al. 2008; Sartor and Boyd 1972). The sources of these pollutants are therefore largely dependent upon various land uses activities, as well as atmospheric deposition (Figure 1). The main sources of Zn are combustion exhaust, galvanized parts and railing, fuel and oil, brake lining and rubber tyres (Councell et al, 2004). Cu comes off from the wear of plating, bearings, brake linings and other moving parts, whereas Pb primarily originates from the use of leaded fuel by vehicles. Besides these, materials deposited on impermeable surfaces from the air (e.g., atmospheric deposition and wind transported pollutants) can be an indirect source of these pollutants in carparks as well as contributions from connected roads and roofs. In Christchurch, the majority of the stormwater runoff from carpark surfaces is discharged, untreated, directly into urban surface waterways via underground-piped networks (CCC, 2003).

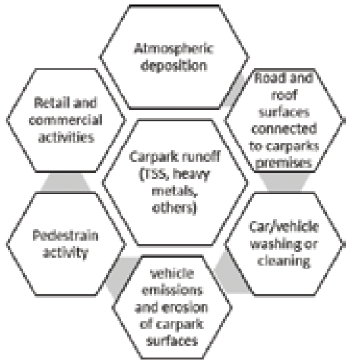

Figure 1: Sources of pollutants contributing to car parks runoff

Various monitoring studies of different impermeable surfaces have shown that pollutant concentrations are substantially higher during the initial period of the runoff hydrograph, commonly known as first flush, than in the later stage of runoff. However, the first flush process is still poorly understood and debated by researchers as several studies have observed the aforementioned phenomenon while other studies have not found discernable evidence (Han et al. 2006; Tiefenthaler et al. 2008). Therefore, understanding the first flush behavior is critical since most treatment options are designed to accommodate this initial portion of runoff events (Deng et al. 2005).

In addition, the composition and characteristics of stormwater pollutant loads vary between commercial, residential and industrial land use areas, however there is a lack of information on quantifying how land use characteristics influence pollutant loads in stormwater runoff. There is a need to better understand the relationship between land use and the corresponding stormwater quality characteristics.

In particular, there are very few studies in New Zealand that monitor pollutant loads from different land use areas during FF and thus implementing appropriate stormwater treatments for each land use area is difficult.

The objective of this study was thus to characterize stormwater pollutant loads, particularly TSS and heavy metals (dissolved and particulate), from three urban carparks representing different land use types (a hospital, a university, and industrial) during first flush conditions.

2 MATERIALS AND METHODS

2.1 SAMPLING SITES

A university carpark, a hospital carpark, and an industrial carpark in Christchurch were chosen for this study (Figure 2). These three sites represent a wide range of mixed residential, commercial, and industrial carparks in the city. The three sites have similar rainfall characteristics, which ensured that rainfall factors would not significantly contribute to any difference in observed stormwater runoff quality between sites. The university carpark (Figure 2) is located within a residential development. The site's catchment area includes a mix of roof, parking lots, trees and lawns. The site is characterized by low to medium traffic predominated by light vehicles.

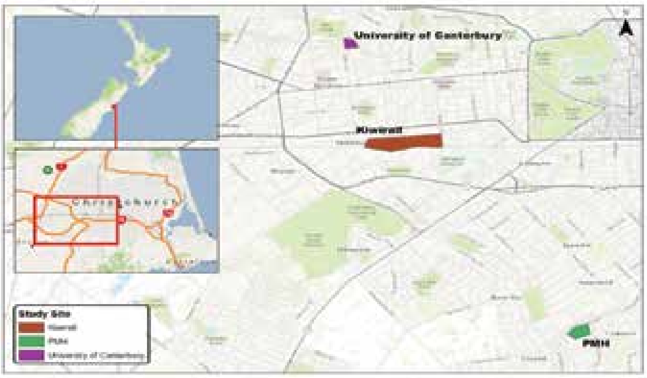

Figure 2: Three sampling sites: 1) University 2) Hospital (PMH) and 3) Industrial (Kiwirail) in Christchurch, New Zealand

The industrial (Kiwirail) carpark is located in an industrial setting. There is light industry activity in this area including rail and road freight infrastructure. The third sampling site is a hospital carpark (Princess Margaret hospital). This sampling site is located at the foot of the Port Hills within a commercial setting. The majority of the carpark is asphalt with little pervious cover.

2.2 SAMPLING METHOD

Nalgene™ Storm Water Sampler bottles (1 L HDPE) were deployed in the three urban carparks. The samplers were deployed by suspending the bottle from the sump grate with a cable tie, in the corner of the sump where the initial runoff would flow directly into the bottle (Photograph 1b). Samplers were positioned at the most appropriate place prior to a storm event, and left in place until after the storm as shown in Photograph 1b. The sampling mechanism closed after sample collection to prevent mixing and dilution with subsequent run off. After the rain started, the water simply flowed through the sampler's collection funnel, and directly in to the bottle. Once the bottle was full, a floating ball valve sealed off the sample collection port. After the sample was retrieved, the collection funnel was removed and replaced with a standard cap to prevent leaks. The use of these samplers allows the collection of first flush samples where there is only one person available to sample from many sites or when the rain starts in the evening.

Photograph 1: (a) Pathway of runoff flow (b) First flush sampler

2.3 DATA COLLECTION

Seven storm events were monitored to investigate the first flush phenomenon under various rainfall conditions from September 2015 to April 2016. After the storm event, full first flush bottles were picked up as soon as possible or early next morning if it rained in the evening. All samples were taken to the Environmental Engineering laboratory at the University of Canterbury for analysis within 24 hours of collection. The weather characteristics of each sampling event were recorded from a Campbell weather station situated at the University of Canterbury. The weather station was approximately 0.5 km from UC, 8.5 km from PMH and 3.5 km from Kiwirail. For events 1 and 2, first flush stormwater from the industrial site was not sampled due to logistical problems.

2.4 SAMPLING PROTOCOL

Before sampling, all first flush sampler bottles were thoroughly cleaned with an acid solution (10% HCl) to avoid any potential contamination. The bottles were scrubbed properly before placing them in the acid bath for a period of 48 hours. All bottles were rinsed thoroughly with deionized water and left to air dry. Following each sampling event, all the first flush samplers were replaced with fresh acid-washed first flush bottles.

2.5 SAMPLE PRESERVATION AND ANALYSIS

All samples were stored at 4^0C in a refrigerator before chemical analysis. Samples for total recoverable metal (Cu, Pb, Zn) analysis were preserved with concentrated HNO3 (70% Fisher, trace analysis grade) to a pH < 2.0 (APHA 2005). Samples for dissolved metal analysis were filtered through a 0.45 μm PVDF filter before being preserved with HNO3 to a pH < 2.0. TSS was measured in accordance to SM2540D guidelines (APHA 2005). All heavy metals were analysed by ICPMS (Agilent) according to SM3125-B (APHA 2005). The limits of detection of these methods of analysis are shown in Table 1.

Water quality Parameters	Analytical methods	Method description	Limit of Detection
TSS	APHA 2005	Filtration using pore size 0.45 μm	3g/m3
Total metals	APHA 2005 (SM 3125-B)	HNO3 digestion, ICPMS (trace level)	0.1μm/L
Dissolved metals	APHA 2005 (SM 3125-B)	Filter through 0.45 μm, ICPMS (trace level)	2.1 μm/L

Table 1: Summary of analytical methods used during the analysis

3 RESULTS AND DISCUSSION

3.1 EVENT BASED TSS LOADS FROM URBAN CARPARKS

The concentration of TSS monitored from different urban carparks varied over the seven storm events captured (Figure 3). Variation in concentration of TSS occurred within the individual storm events and between the different storm events. Rainfall event characteristics as measured at the University show a range of conditions (Table 2). Rainfall variation between sites is believed to be minimum. The significant difference in FF TSS loads between carparks suggest that carpark characteristics and surrounding land use activities may have a strong influence on TSS generation and deposition in each carpark.

Storm Events (SE)	Date of sampling	(ADD)	Rain duration (mm)	Rainfall intensity (mm/hr)	Rain depth (mm)
Storm 1	10/9/2015	4.5	3.8	2.0	8.0
Storm 2	23/9/2015	0.1	3.4	2.2	7.4
Storm 3	27/1/2016	0.2	5.2	4.4	22.7
Storm 4	17/2/2016	20.2	2.4	3.1	7.4
Storm 5	16/3/2016	5.6	2.8	2.2	3.2
Storm 6	24/3/2016	7.5	6.3	1.7	10.6
Storm 7	8/4/2016	3.6	0.9	2.4	2.0

Table 2: Summary of rainfall event characteristics

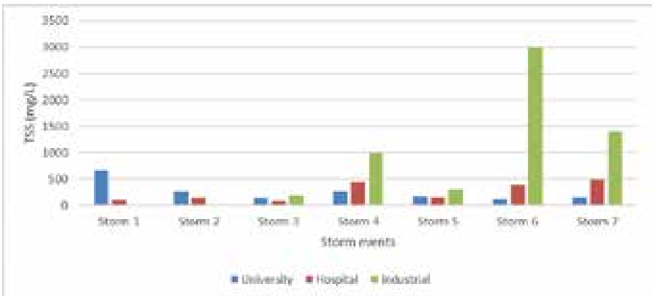

Figure 3: TSS monitored from different urban carparks for seven storm events (the industrial carpark was not monitored for storms 1 and 2)

3.2 DISTRIBUTION OF POLLUTANT LOADS BASED ON LAND USE CHARACTERISTICS

TSS concentrations were consistently higher in FF from the industrial carpark as compared to the other two carparks. The university carpark had lower TSS as compared to hospital and industrial carparks. The concentrations of TSS in the first flush from the industrial carpark were at least one order of magnitude higher than in the other two carparks (Figure 4). This was attributed to anthropogenic activities such as traffic characteristics, loading and unloading activities, the size of the vehicles involved in the industrial land use, poorer road conditions and carpark surfaces as well as less street sweeping in nearby roads as compared to residential and commercial areas. In this research, the university carpark, which was in a residential setting, exhibited the lowest first flush TSS loads (Figure 4).

The total concentration of Zn, Cu and Pb were also higher in the industrial carpark as compared to the other two carparks (Figure 5). Total Zn concentrations show a similar pattern to TSS concentration in the industrial and university carparks, suggesting that a large portion of the total Zn may come from the same source as solids in the respective carparks. Total Zn had a similar range in the university

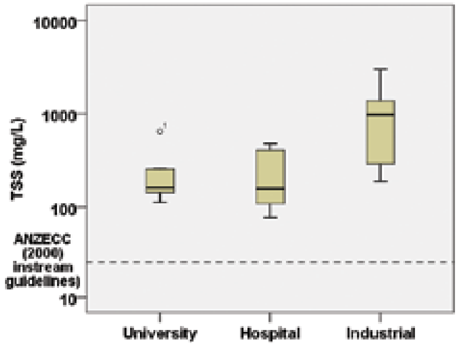

Figure 4: TSS concentrations at each sampling site (°1 denotes outliers' ± 1.5x Inter Quartile Range (IQR)

and hospital carparks whereas, lower concentration of total Cu and Pb were found in the hospital carpark. Differences of dissolved metals were observed from the different carparks. Although the loadings of dissolved metals vary widely in stormwater due to factors such as pH (Liebens, 2001; Ujevic et al., 2000), no relationship was found between dissolved metals and pH (pH ranged from 3.8 to 7.9) for any of the carparks.

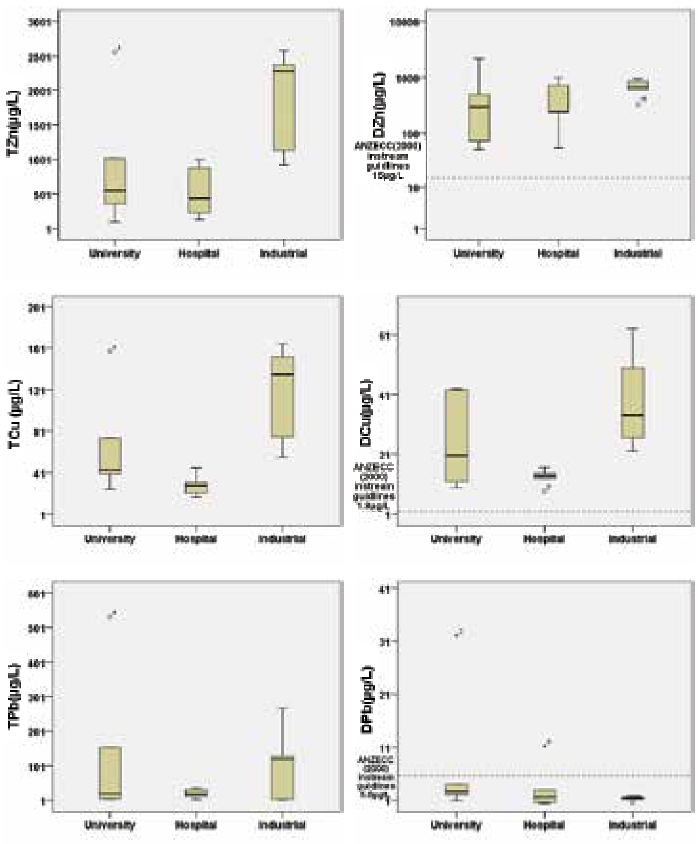

Figure 5: Comparison of total and dissolved metals concentrations in different land uses areas

3.3 HEAVY METALS PARTITIONING

The highest percentage of dissolved Zn was 68% at the university carpark, but the range did not vary widely as the industrial and hospital carparks had 62% and 65% dissolved Zn respectively (Figure 6). The dissolved Cu ranged from 45% to 49%. As expected, a smaller percentage (below 31%) of dissolved Pb was measured for all sites. The university carpark had the highest percentage of dissolved Zn, Cu and Pb as compared to the other two sites. The dissolved fraction of these heavy metals in stormmwater runoff are influence by adsorption mechanisms with solids particles (Gunawardana et al., 2015).

Zn, for example, is subject to a cation exchangable form of adsorption which has a high likelihood of being subsequently released from solid particles due to possible changes in environmental conditions.

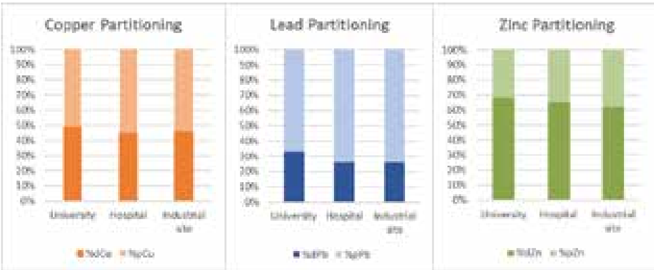

Figure 6: Average zinc, copper and lead partitioning between dissolved and particulate from each carpark

3.4 COMPARISON OF STORMWATER RUNOFF QUALITY WITH EXISTING BENCHMARKS

The observed dissolved metal concentration results were compared with the Australian and New Zealand instream guidelines for Fresh and Marine Water Quality (2000) at the 90% level of protection. For all the sites, the observed dissolved Zn and Cu values exceeded the trigger values, but dissolved lead was consistently below trigger values. TSS values were also found to be 3.7 to 120 times higher than the ANZECC (2000) instream trigger values (threshold: 25 mg/L).

Implication of dissolved metals in waterways

The presence of heavy metals (particularly in dissolved form) in urban runoff is of concern, as they are considered most toxic due to enhanced bioavailability. Dissolved heavy metals have the potential for acute and long-term toxicity for aquatic life and a greater potential of affecting groundwater (Hatje, 2003; Marsalek et al., 1999; Pitt et al., 1995). Removal of particulates can be achieved with stormwater filter systems, and this can have the potential to make a substantial improvement to instream health. The removal of dissolved metals is difficult, but if it is accomplished, it will achieve the greatest benefit in long-term improvement of waterways health.

4 CONCLUSIONS

Land use activities exhibit a strong influence on TSS and total metals loadings during the first flush. Concentrations of TSS and total metals were found to be higher in industrial carparks than in university and hospital carparks. TSS values for all sites, however, were found to be 3.7 to 120 times higher than the ANZECC (2000) instream trigger values (threshold: 25mg/L). Zn and Cu in dissolved forms were also found to be much higher than recommended ANZECC (2000) guidelines for all carparks. No relationship was found between pH and dissolved metals. High values of TSS, Zn, and Cu were attributed to anthropogenic activities within the carparks such as traffic characteristics, loading and unloading activities, the size of the vehicles involved, and the surrounding land use.

The design of stormwater filter devices to remove suspended solids and particulate heavy metals needs to be carefully formulated to suit carpark characteristics as results show that a "one size fits all" approach may not be adequate. In addition, removal of dissolved metals from runoff needs to be taken into consideration. It is recommended that additional monitoring be conducted to quantify dynamics of these pollutants over steady flow periods. Furthermore, the relationship of these pollutants with respect to different rainfall characteristics needs to be better understood.

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