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Stormwater Quality in Perth, Western Australia

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ABSTRACT This paper presents the results of an explorative study of road runoff water quality in the Perth metropolitan area, initiated and funded by Main Roads Western Australia. Road runoff samples were collected at 19 sites throughout the Perth metropolitan area during the autumn, winter, and spring months between July 1997 and August 2000. This data was analysed to determine pollutant concentration ranges and medians, and to obtain a comparison with worldwide values established in previous studies. Variation in pollutant concentration with traffic loading, total suspended solids (TSS) concentration, location and season was investigated to determine appropriate management techniques. It was found traffic volume does not significantly influence road runoff pollutant concentration. Total phosphorus (TP), total kjeldhal nitrogen (TKN), and heavy metal concentrations were found to be significantly related to TSS concentration. TP concentrations for the annual sampling period were greatest at the commencement of sampling in autumn, and decreased throughout winter and spring. It is argued that source control measures, such as suction street sweeping to remove particulates and associated pollutants, may prove to be beneficial for stormwater quality management in the Perth metropolitan area.

INTRODUCTION

Runoff from impervious road surfaces transports pollutants from roadways into waterways. Increased awareness of water quality problems, coupled with increased motor vehicle usage, has led to the need to investigate the quality of stormwater runoff in urban areas. Common road runoff pollutants, together with their corresponding sources and recorded concentration ranges, are presented in Table 1.

To date, information on stormwater quality in Western Australia is limited, however many studies have been conducted on a global basis. Makepeace et al. (1995) presented the findings of an international literature search of stormwater research from a 25 year period, including identification and quantification of contaminant parameters. Analytical data were extracted from 140 articles reporting on stormwater quality analyses, and were summarised for each parameter.

Considerable research on international urban stormwater quality has been conducted in Australia by the Cooperative Research Centre (CRC) for Catchment Hydrology. Three companion publications by Duncan were completed in 1995. The first of these (Duncan, 1995a) was a database of English language literature on urban stormwater quality, comprising over 700 titles compiled from worldwide sources. The second (Duncan, 1995b) was an annotated bibliography of Duncan (1995a). The third (Duncan, 1995c) was a review of urban stormwater processes, including pollutant buildup and washoff. More recently Duncan (1999) prepared a statistical overview of urban stormwater quality obtained by analysing the data from the literature (Duncan, 1995a,b,c). This publication describes the relationship between stormwater quality and factors such as landuse and vehicle loading.

Drapper et al. (1998, 1999, 2000a,b) reported the findings of a study of road runoff pollutants around Brisbane, southeast Queensland. Data from road runoff samples was analysed in terms of traffic volume, pavement surface type and other site characteristics. The findings of this study suggest that areas of rapid deceleration, such as traffic lights and turning lanes, result in increased concentrations of Cu, Zn and Pb, possibly due to poor fuel consumption and rapid braking. It was also found that lead concentrations have a strong positive correlation to levels of total suspended solids (Dapper et al., 1999).

Drapper et al. (2000b) and Duncan (1999) reported a significant positive linear relationship between lead and zinc concentrations and traffic volume. While these findings support Makepeace et al. (1995)'s statement that most heavy metals, including copper, show a positive correlation with vehicular traffic intensity, they also indicated that a large percentage of the variation in heavy metal concentrations is not explained by changes in traffic volume, but rather is determined by other factors such as road surface type, road design (Drapper et al., 2000b), and surrounding land use (Young et al. cited in Drapper et al., 2000b).

Other studies have reported on the relationship between pollutant concentration and inter-event dry period. Although the well known stormwater management model SWMM is based on the assumption that pollutant loading is a linear function of time since last rainfall (Duncan, 1995c), Chiew et al. (1997) reported that surface pollutant load is relatively constant at all times, and that washoff and resultant pollutant loads are strongly associated with rainfall intensity, rather than being limited by buildup time.

This paper presents the results of an explorative study of pollutant concentrations in road runoff from several sites throughout the Perth metropolitan area, initiated and funded by Main Roads Western Australia (MRWA). The study commenced in July 1997 and will continue to the end of spring 2001. Early data was analysed by Goldstone and Stubberfield (1999). In the current study, road runoff data was analysed to determine pollutant concentration ranges and medians, and to obtain a comparison with worldwide values established in previous studies. Variation in pollutant concentration with:

- traffic volume
- total suspended solids (TSS) concentration
- location, and
- season

was investigated to determine appropriate techniques for reducing the pollutant load carried to waterways in the Perth metropolitan area by stormwater. This study did not aim to gain a comparison of pollutant concentrations with standards or regulations.

Table 1: Common pollutants, sources and recorded stormwater concentration ranges (Source: LaGrega et al. (1994), Makepeace et al. (1995), Kobringer et al. (cited in Drapper et al. 1999), Duncan (1999))

Pollutant	Primary sources	Recorded concentration range (mg/L)
Aluminium	natural sources, industrial effluents, water treatment, coal combustion	0.1 – 16.0
Arsenic	industrial emissions, fossil fuel combustion, smelting, detergents, pesticides, preservatives	0.001 – 0.21
Cadmium	combustion, tyre & brake wear, lubricating oil combustion, corrosion, industrial emissions, fertilisers, insecticides	0.00005 – 13.73
Chromium	engine & brake wear, corrosion of metal plating, paints & dyes, ceramics, paper, fire sprinkler systems, pesticides	0.001 – 2.30
Copper	engine, tyre & brake wear, lubricating oil combustion, corrosion of metal plating, industrial emissions, pesticides	0.00006 – 1.41
Hydrocarbons	fuel combustion, vehicle leaks	0.64 – 19.71
Iron	vehicle body & steel highway structure corrosion, engine wear, coke & coal combustion, industrial emissions	0.08 – 440.0
Lead	gasoline combustion, gasoline additives, tyre wear,	0.00057 – 26.0
Nitrogen	fertilisers, industrial cleaning operations, animal feed and excrement, fossil fuel combustion	TKN: 0.32 – 16.0
Phosphorus	tree leaves, fertilisers, industrial wastes, detergents, lubricants	TP: 0.01 – 7.30
Oil & grease	vehicle leaks, natural compounds leached from vegetation & plant litter	0.001 – 110.0
Suspended solids	atmospheric deposition, road & vehicle wear, erosion, construction & demolition operations, vegetation	1.0 – 36,200
Zinc	tyre & brake wear, lubricating oil combustion, corrosion	0.0007 – 22.0

DATA COLLECTION

Road runoff was collected at 19 sites throughout the Perth Metropolitan Area during the winters of 1997, 1998, 1999 and 2000. The location of each site is shown on Figure 1.

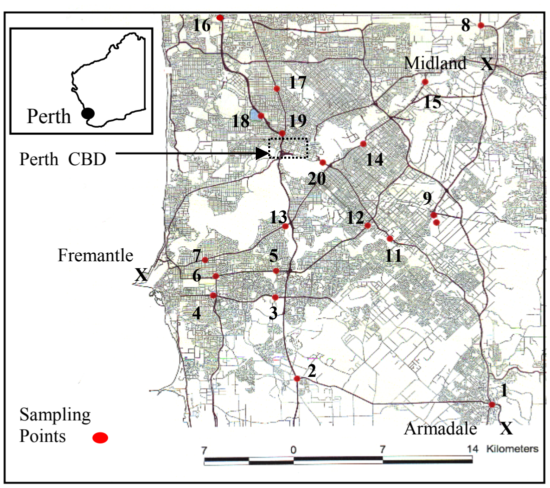

Figure 1: Sampling Locations

Samples were collected at approximately monthly intervals after rainfall events for approximately five months each year, with the first sample being collected following the first autumn rains. Samples were analysed in the laboratory to determine the level of a range of common stormwater parameters as follows:

- Biological Oxygen Demand (BOD)
- Conductivity, pH
- Total Phosphorus (TP)
- Filterable Reactive Phosphorus (FRP)
- Total Kjeldahl Nitrogen (TKN)
- Ammoniacal Nitrogen
- Nitrite
- Nitrite + Nitrate
- Total Suspended Solids (TSS)
- Metals: Chromium (Cr), Copper (Cu), Lead (Pb), Iron (Fe), Aluminium (Al), Arsenic (As), Zinc (Zn), Mercury (Hg), Cadmium (Cd)
- Oil and grease
- Hydrocarbons

Sample collection at 17 of the sampling sites was undertaken using curb water samplers, designed during the first winter of the study (Figure 2). During rainfall events, road runoff flowed through the inflow pipe into a 4 litre sample bottle. In each sampling month clean bottles were placed in the curb sampler pits when rain was forecast and were collected within two to three days of the rain event. Collected samples represent early, mid or late runoff during a storm event, depending principally on the hydraulic characteristics of the inlet pipe from the gutter to the sample bottle. The remaining 2 sites (sites 9 and 20), where the road was not curbed, were sampled manually, provided volume of runoff was sufficient at time of sampling.

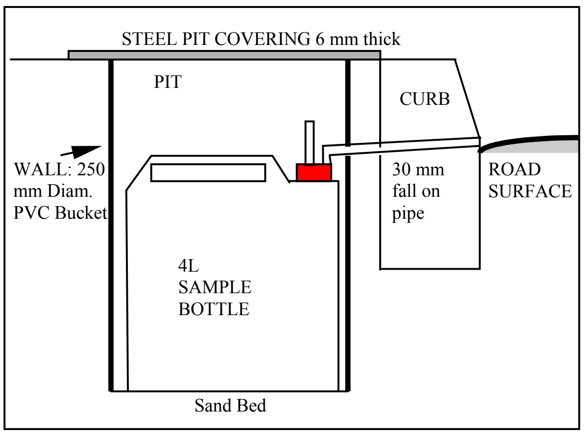

Figure 2: Curb Water Sampler Configuration

SAMPLING RESULTS

Results of sample laboratory analyses for 1997, 1998, and 1999 have been presented separately (JDA, 1997, 1998, 1999). The results from July 1997 to August 2000 are summarised in Table 2.

Table 2: Summary of Sampling Results

Pollutant	Range	Median
BOD	0.09 – 120.0	<5
Conductivity	0 – 270.0	12
pH	5.3 – 9.0	7
TP	<0.05 – 16.0	0.5
FRP	<0.005 – 8.8	<0.05
TN	0.5 – 60.0	1.75
TKN	0.06 – 70.0	1.6
TSS	<5.0 – 4800	100
Cr	<0.002 – 0.045	0.004
Cu	<0.002 – 0.66	0.04
Pb	<0.002 – 3.9	0.121
Fe	0.082 – 26.0	1.0
Al	0.015 – 13.0	0.7
Zn	<0.02 – 4.5	0.24
Hg	<0.0005 – 0.001	<0.0005
As	<0.002 – 0.013	<0.002
Cd	<0.0002 – 4.6	<0.0002
Oil & grease	<5.0 – 310.0	<5.0
Hydrocarbons	<5.0 – 170.0	<5.0

Note: Values are in mg/L except conductivity (mS/cm) & pH

FINDINGS AND DISCUSSION

Observed pollutant loads compared with reported values

Concentration ranges recorded in this study (Table 2) are generally lower than the worldwide ranges established from previous studies (Table 1). TKN, oil & grease, and hydrocarbon concentration ranges are exceptions to this, however their median concentrations are within the worldwide ranges and near the lower limit. Comparison of the results in Table 2 with those reported in Drapper et al. (2000a) indicates that stormwater quality in Western Australia is comparable to, and in most cases slightly better than, stormwater quality in south-east Queensland, which is comparable to stormwater quality reported for other Australian studies (Drapper et al., 1998).

Influence of Traffic Volume

Median concentrations of TSS, Al, Cu, Fe, Zn, Pb, TP and TKN at each site were regressed against Annual Average Weekday Traffic flow (AAWT) (expressed in terms of vehicles per day), as a measure of traffic volume. AAWT data was obtained from MRWA (1999). Site 9 was not included in the analysis because it did not have an appropriate AAWT site associated with it. AAWT values were assigned to each pollutant concentration according to the financial year of sampling.

The financial years included in the analysis were 1997/98, 1998/99 and 1999/2000. AAWT data was not available for 1999/2000 and AAWT values were not collected at some sites in certain years, therefore missing values were estimated by linear interpolation between years.

For each pollutant the yearly median concentration at each site was plotted against the corresponding AAWT. The slope and intercept of each regression line is presented in Table 3. The plot for Pb is presented in Figure 3 as an example. The slope of the regression line was positive for Pb and Cu and negative for all other pollutants, however statistical analyses revealed that the slopes were not significantly different from zero (α>0.10). Therefore, in this dataset, pollutant concentration was not related to traffic volume. This is not consistent with the statement of Makepeace et al. (1995) that most heavy metals usually show a correlation with intensity of vehicular traffic.

Table 3: Traffic Volume Regression Line Parameters

Pollutant	Slope, a	Intercept, b	Slope significance, α=0.1
TSS	-0.0044	247.71	ns
Al	$-2x10^{-5}$	1.43	ns
Cu	$9x10^{-8}$	0.05	ns
Fe	$-3x10^{-5}$	2.03	ns
Zn	$-7x10^{-6}$	0.46	ns
Pb	$6x10^{-8}$	0.24	ns
TP	$-2x10^{-5}$	1.01	ns
TKN	$-6x10^{-5}$	3.82	ns

Notes: 1. Regression line equation: $y = ax + b$, where x is traffic volume (vehicles/day), and y is pollutant concentration (mg/L)
2. ns = not significant

Figure 3 illustrates that the runoff from some sites with low traffic volume has higher lead concentrations than the runoff from sites with higher traffic volume. This was also evident for the other pollutants. The same result was observed for lead at runoff sites in south-eastern Queensland (Drapper et al., 1998). Drapper et al. (2000b) reported that approximately 70% of the variance in lead concentration was not explained by variations in traffic volume. Similarly, results from collation of international and Australian data presented in Duncan (1999) indicate that traffic density in vehicles per day explains only 22% of the variance in lead concentration in road runoff.

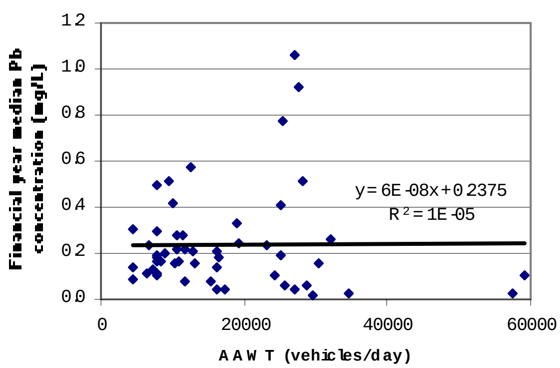

Figure 3: Financial year median lead versus AAWT for all sites

For each pollutant, concentrations were particularly low at Site 18 which collects runoff from Mitchell Freeway, where recorded AAWT's are more than double those for most other sampling sites. It is hypothesised that the amount of contaminants deposited per vehicle at site 18 was lower than at other sites due to the greater speed of traffic at this site compared to that at the remaining sites, where vehicles are more likely to be idling in congested traffic. Fuel combustion is less efficient in idling vehicles, therefore idling vehicles may emit more combustion by-products (such as Pb) than travelling vehicles. Additionally, idling and slow moving vehicles spend a greater amount of time at each location, hence it is expected that more oil and grease will be deposited on the road at locations where traffic is frequently stationary or slow moving. However, when Site 18 was excluded from the data set the slopes of the regression lines were still not significantly different from zero.

The lack of correlation between pollutant concentrations and traffic volume indicates that traffic volume is not the primary determinant of pollutant concentration in runoff from Perth roads. Pollutant loadings in runoff may be influenced by traffic speed, vehicle type, road surface type and condition, verge condition, and surrounding land uses. Higher concentrations of Cu, Pb, and Zn occuring in areas of rapid decceleration due to increased tyre and brake wear, as reported by Drapper et al. (1998, 1999, 2000a,b), would contribute to the lack of correlation.

Relationship to TSS Concentration

The relationship between TSS and Al, Cu, Fe, Zn, Pb, TP, and TKN was significant at the 0.01 significance level ($p \leq 0.01$). The most significant relationship was between Al and TSS (Figure 4) and the lowest level of significance was obtained for Pb and TSS (Figure 5). These results are consistent with previous findings. Makepeace et al. (1995) reported that Pb and Zn are associated with TSS and Duncan (1999) reported that heavy metals and phosphorus have been found to be associated with TSS. Drapper et al. (1999) found that Pb correlated strongly with TSS in southeast Queensland.

Conductivity and pH were not significantly related to TSS concentration at the 0.05 significance level ($p>0.05$).

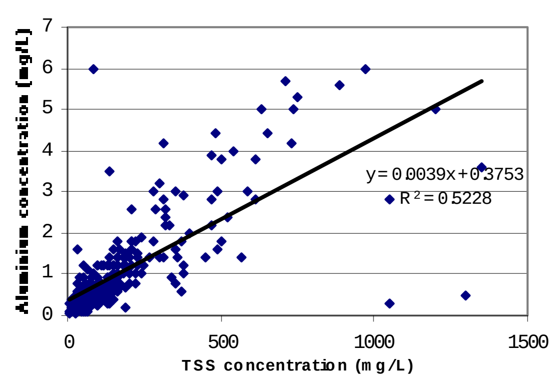

Figure 4: Aluminium concentration versus TSS concentration (all dates, all sites)

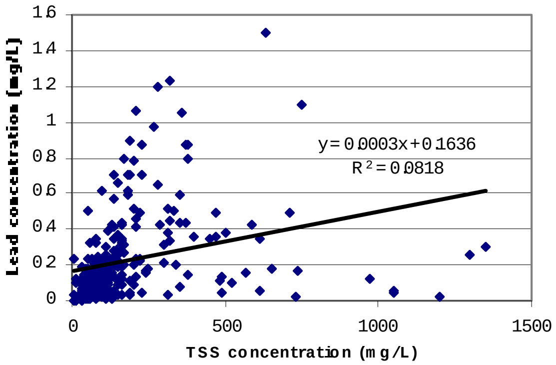

Figure 5: Lead concentration versus TSS concentration (all dates, all sites)

Variation between sampling sites

The median concentration of most pollutants was found to be highest at Site 8, on Great Northern Highway near Roe Highway intersection. Possible reasons are extensive heavy vehicle use and an unsealed sandy verge at this site. During sample collection it was frequently noted that the road pavement near Site 8 sampling port was particularly sandy. Therefore, since TSS concentration was found to be strongly correlated with the concentration of heavy metals, TP and TKN, higher pollutant concentrations at Site 8 may result from higher TSS concentrations. Higher concentrations of some pollutants, such as Cu and Zn, may be contributed to by rapid deceleration of heavy vehicles approaching the traffic lights at the Roe Highway intersection.

TP Variation between sampling dates

The median TP concentration across all sites was calculated and plotted for each sampling date (Figure 6). TP concentrations for the 1998, 1999, and 2000 annual sampling periods were greatest at the commencement of sampling in autumn (March–May), following the summer dry period, and generally decreased during the winter-spring wet period. In 1997, sampling dates were limited and sampling did not commence until after autumn. These results indicate that efficient stormwater management should include source control during the autumn months, when pollutant concentrations in this study were found to be greatest (and potentially during summer months which were not included in this study).

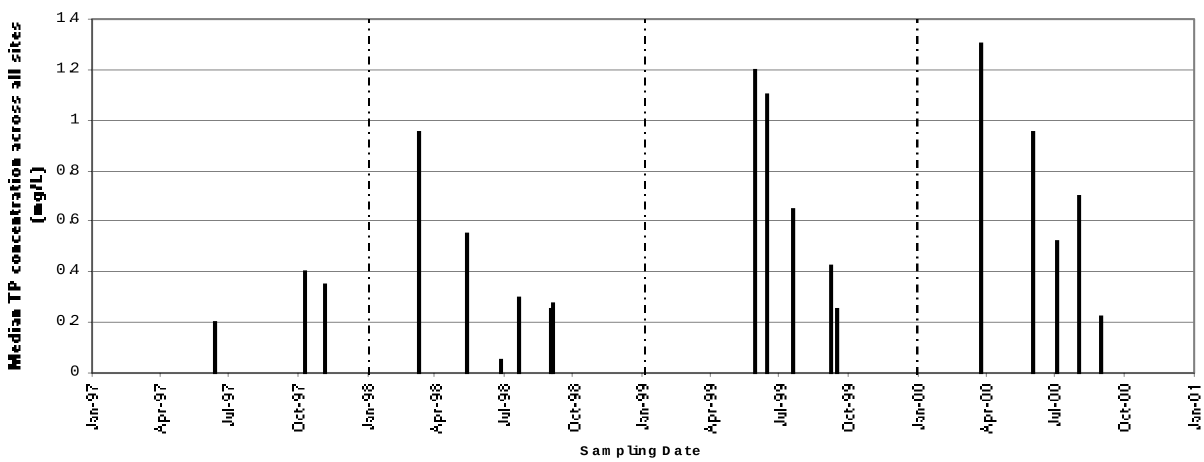

Figure 6: Variation in Median TP between Sampling Dates

CONCLUSIONS

The results of this study suggest that traffic volumes do not significantly influence the concentration of pollutants in road runoff in Perth, Western Australia. Rather, it is hypothesised that the pollutant concentration in runoff from Perth roads is significantly influenced by factors such as traffic speed, vehicle type, road surface type and condition, verge condition, and surrounding land uses.

TP, TKN and heavy metal concentrations were found to be significantly related to TSS concentration. This supports previous findings and suggests that the possible treatment of lead by treating or removing solids, as suggested by Drapper et al. (1999), may be extended to other heavy metals and nutrients also. Given that Perth road sediment particle size has previously been found to be coarser than world and Sydney stormwater suspended sediment (Pierce & Davies, 1999), suction street sweeping may be an effective management option for stormwater quality improvement in Perth. Many published papers (eg. Wong et al., 2000) ignore the potential for source control catchment management to alter the quality of stormwater, and proceed to model stormwater quality as though it is fixed by some external force. However, the above findings, coupled with previous research indicating lower cost phosphorus removal by street sweeping compared with artificial wetlands, suggest that source control measures such as this may be more appropriate for reducing pollutant loads than in-transit or end-of pipe measures, such as detention basins and artificial wetlands. Since the highest TP concentrations in this study were found to occur in the autumn months, when longer inter-event dry periods occur, effective management should include source control during the autumn months (and most probably the summer months which were not included in this study).

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