Kingett
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ASSESSMENT OF URBAN STORMWATER QUALITY IN THE GREATER WELLINGTON REGION

OCTOBER 2005

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on behalf of

Greater Wellington Regional Council

prepared by

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Executive Summary

Greater Wellington Regional Council have previously described the nature and effects associated with the discharge of urban stormwater to freshwater and marine receiving environments in the region. This report presents and discusses the results of stormwater sampling undertaken between June 2002 and September 2004 by Greater Wellington Regional Council to provide further characterisation of the nature of urban stormwater generated in the Wellington Region. A total of 11 different sampling sites were used to collect stormwater from a range of different catchments in the region. The catchments ranged from newer residential (Browns Bay Stream catchment, Pauatahanui Inlet) through to catchments with well established industrial land (e.g., Parkside Rd in Gracefield Lower Hutt). Stormwater sampling was commenced within the first hour of the rainfall event and continued at hourly intervals until six samples had been collected and combined.

General stormwater quality

The samples collected were examined for a range of general constituents including phosphorous and nitrogen. The pH measured in the Wellington samples was found to be similar to the pH measured in stormwater in other New Zealand studies. The suspended solids concentrations measured was similar to concentrations recorded in other studies in New Zealand. The land use difference observed in suspended solids concentration between residential and industrial catchments appears to reflect the general difference observed in other studies. Examination of the size of particles present showed that Wellington data is representative of other data reported in the international and New Zealand literature. That is, about 70% of the suspended particles are <59 µm in size. Dissolved organic carbon and total organic carbon concentrations observed in the stormwater samples collected appear similar to concentrations recorded in other studies.

Metals

A range of trace elements (metals and metalloids) were measured in the dissolved and particulate fractions of the stormwater samples collected. The concentrations of the elements arsenic, barium, chromium, nickel, strontium and tin appear low when compared to what would be expected naturally. Concentrations of cadmium, cobalt, manganese, mercury, selenium, silver and vanadium were indeterminate when compared to natural concentrations due mainly to a lack of information as to the natural concentrations of some elements in New Zealand freshwaters.

In the samples collected from residential catchments, concentrations of aluminium antimony and lead were considered to be moderate compared to natural concentrations. Concentrations of copper and zinc were considered to be high compared to what would be expected naturally. The concentration of dissolved antimony, chromium, cobalt and zinc was found to be higher in the samples from commercial/industrial compared to residential catchments. The concentrations of dissolved arsenic, antimony, cadmium, chromium, lead, manganese, mercury, nickel, selenium and probably silver and vanadium were present at concentrations that were lower than the ANZECC (2000) trigger values. Several trace elements were measured at concentrations higher than ANZECC (2000) trigger values.

Although the concentrations of cobalt are higher than the triggers identified by ANZECC (2000) for the protection of freshwater aquatic life, it is likely that toxicity is limited through a variety of water chemistry mechanisms.

The concentrations of dissolved copper are higher than the freshwater and marine triggers identified by ANZECC (2000). The lowest concentration recorded in the Wellington samples collected was 0.0025 g/m^3.

The dissolved lead concentrations from the residential catchments are low compared to concentrations in many published New Zealand studies. If those studies that pre-date the removal of lead from petrol are excluded then there are a few studies which have reported low lead concentrations but not as low as this study. The median concentrations from the Wellington industrial/commercial catchments are also low by comparison with other New Zealand data. With the Parkside Rd industrial catchment data excluded, the concentrations fall below the ANZECC (2000) trigger for 95% protection.

All samples collected from the residential catchments had concentrations of dissolved nickel that were below the ANZECC and USEPA ‘chronic’ values. The concentrations measured in stormwater from several of the industrial catchments were above the ANZECC (2000) trigger value.

Dissolved zinc concentrations in Wellington stormwater are elevated compared to natural concentrations. Concentrations were markedly elevated in two samples from industrial catchments. Concentrations were typically higher than ANZECC trigger values but when compared to USEPA (2002) criteria for the protection of aquatic life, most of the samples collected from residential catchments were below the guideline. In industrial catchments most of the samples were above the criteria concentration.

Concentrations of a number of elements were found to be present in suspended particulates in stormwater at elevated concentrations. Of these a number were present at concentrations higher than the ANZECC (2000) trigger values.

In the samples from the residential catchments, eight of 10 particulate samples (two fractions, five samples) had concentrations of copper that were over the ISQG-Low trigger value. In the samples from industrial catchments all samples had concentrations over the ISQG-Low trigger. In the residential catchment samples, two of 12 samples were higher than the ISQG-High trigger and five of 11 samples from the industrial catchments had concentrations that were higher than the ISQG-High trigger.

For lead, nine of 10 samples had concentrations over the ISQG-Low and six over the ISQG-High. In the samples from industrial catchments all samples had concentrations over the ISQG-Low and the High trigger value. 16 of 20 samples collected were over the upper trigger value. This would indicate that the particulate materials have the potential to increase the concentration of lead in receiving environment sediments.

All samples examined with the exception of one sample (Browns Stream) had concentrations of zinc that were higher than the ANZECC (2000) ISQG-High trigger value. As a result of the elevated concentrations present in the suspended particulate material, deposition of the particles will have the potential to increase the concentration of zinc in sediments.

In depositional environments, the elements chromium, copper, nickel, lead, and zinc are the elements most likely to result in an increase in sediment concentration as a consequence of elevated concentrations in urban stormwater particulate material. Based upon the available data, it is evident that urban stormwater will contribute to sediment contamination through the deposition of suspended solids in stormwater.

Organic Compounds

Key organic compound groups examined included the polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides (including dieldrin and the DDT group) and chlorophenols. The dissolved concentrations of the organic compounds were compared with the ANZECC (2000) and USEPA (2002) water quality guidelines/criteria. The concentrations of compounds in the suspended particulate fractions was compared to any ANZECC (2000) sediment quality guidelines.

PAHs were detected in eight of the 11 stormwater samples collected. The three samples that did not contain any measurable PAHs were from residential catchments. No relationship were identified between the land-use of the catchment and the concentration or type of PAH compounds detected. The PAHs most often detected across all sites were pyrene and chrysene, both 4-ringed PAHs. Two of the residential catchment sites had similar PAH profiles, dominated by high molecular weight PAHs. The third residential catchment site had a completely different profile, being dominated by low molecular weight PAHs, particularly naphthalene. The highest concentrations of PAH were detected in an industrial stormwater sample, from Hutt Park Road (total PAH 2,110 µg/m^3). The only PAH ANZECC (2000) identifies a trigger value for is naphthalene for which the trigger value for the protection of 95% of freshwater organisms is 160 µg/m^3. Concentrations measured were lower than the ANZECC (2000) trigger value.

Particulate concentrations of PAHs were high with the concentration generally reflecting the concentration measured in the dissolved fraction.

The profile identified appeared to reflect the emission of PAHs from motor vehicles.

Polychlorinated biphenyls (PCBs) were found in the ‘dissolved’ fraction in seven out of 11 samples with the highest concentrations in an industrial sample (Hutt Park Road). Total PCB concentrations were 52.7 µg/m^3 at this site and 37 out of the 45 PCB congeners analysed were detected in this sample, more than all other samples. Stormwater from residential land-uses contained lower concentrations of PCBs (0 – 0.826 µg/m^3) with only three of six samples from residential land-use having PCBs above the limit of detection. Stormwater samples that did not contain detectable PCBs were from streams and creeks rather than stormwater pipes. The PCB congener profile suggests that the PCBs are from a similar source and possibly a diffuse source such as atmospheric deposition.

The examination of suspended particulates filtered from stormwater showed that in the 0.7–59 µm fraction at least one PCB congener was detected in each of the samples collected. In the >59 µm fraction PCBs were detected in eight out of 11 samples. Four samples (one from an old residential catchment, one commercial and two industrial) contained over 100 µg/kg of PCBs in both the 0.7–59 µm fraction and the >59 µm fraction. Higher concentrations were generally found in the finer 0.7–59 µm fraction compared to the coarse fraction. The highest total concentrations in the particulate fractions were in the sample collected from the commercial catchment in Waring Taylor Street. The PCB profiles in the samples was very similar indicating that the PCBs in stormwater samples are potentially from the same source. Although PCBs have not been used in New Zealand since the 1980s, sources still remain in the environment (e.g., soils containing residuals of historic contamination).

The median concentrations of total PCBs measured in the Wellington stormwater suspended solids is similar to the ANZECC (2000) trigger value of 23 µg/kg. The maximum concentrations are similar and typically five times the ANZECC (2000) threshold. The presence of measurable concentrations of PCBs in Wellington stormwater indicates that the stormwater provides a load of PCB to the receiving environment. The concentrations measured relative to ANZECC (2000) trigger values indicate that the suspended particulates may contribute to poor sediment quality when deposited.

Organochlorine pesticides were detected in all of the stormwater samples, in either the ‘dissolved’ or particulate fractions. More were detected in samples from sites with industrial or commercial land-use than the residential land-use sites. Dieldrin, p,p’-DDT and p,p’-DDE (a metabolite of p,p’-DDT) were detected the most frequently. This is a common pattern of detectability in New Zealand. As was found for PCBs, the data shows that although DDT has not been used in New Zealand since the 1980s, sources still remain within the environment.

Examination of samples for chlorophenols showed that higher concentrations were generally present in samples collected industrial and commercial land-use compared to residential land-use.

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Document Quality Assurance

This report has been prepared in accordance with Kingett Mitchell quality assurance procedures. All relevant quality control information in relation to biological and/or environmental data is identified within the document. The report has been reviewed and is approved for release as set out below.

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1. Introduction

Clean and healthy rivers, streams and coasts are an objective of Greater Wellington's strategic plan. One target for that objective is that by 2013 there will be no significant deterioration of water quality in key streams and rivers. Stormwater discharges may represent a major impediment to the achievement of this objective. Work on stormwater undertaken by Greater Wellington has a number of objectives. These objectives are:

- To identify the contaminants of concern and the sources of these contaminants.
- To determine whether stormwater discharges are causing environmental effects and, if so, how much of an effect and where.

Previous review work on the nature and effects associated with urban stormwater has been undertaken by Greater Wellington (refer Williamson et al. 2001). The present report presents and discusses the results of work undertaken by Greater Wellington Regional Council to provide further characterisation of the nature of stormwater generated in the Wellington Region.

2. Sample Sites and Methods

2.1 Sample Sites

A total of 11 different sampling sites were used to collect stormwater from a range of different catchments in the Greater Wellington region. Table 2.1 identifies the sites. The locations of the sites are shown in Fig. 2.1. Dates when samples were collected are provided in Table 2.1.

2.2 Landuse

The 11 catchments ranged from newer residential through to catchments with well established industrial land. Table 2.1 summarises the land use for each of the sites based upon the general characteristics of the catchments upstream of the sampling sites.

In this evaluation, a number of sites had single dominant land-uses. However, some had mixed land-uses or contributions from rural/bush land-uses. To facilitate comparison between samples sites, all sites were categorised as either residential or commercial/industrial. With this division four sites fell into the commercial/industrial land use category and six into the residential land use category. The mixed land-use site – Semple St was placed into the commercial/industrial landuse category.

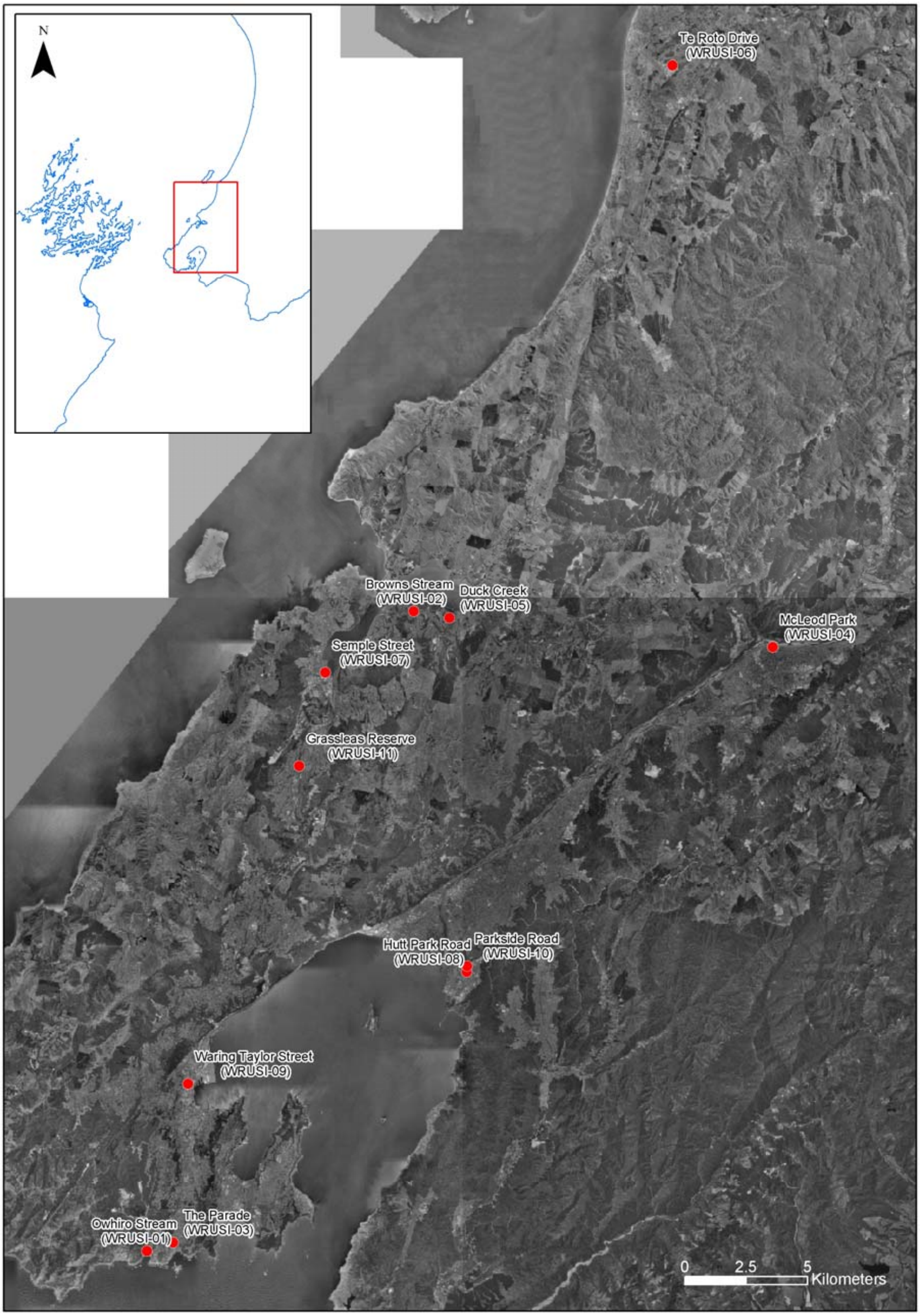

Fig. 1.1: Location of stormwater sampling sites.

Table 2.1: Sampling site information.

Sample Number	Site	Landuse	Sampled from Open Channel or Pipe	Rainfall during sampling (mm)	Sampling date	Catchment area (ha)
WRUSI-01	Owhiro Stream stormwater	Residential	Open Channel	NA	9/6/02	-
WRUSI-02	Browns Stream stormwater	Residential - New	Open Channel	NA	17/6/02	123
WRUSI-03	The Parade stormwater	Residential	Pipe	12.0	24/8/02	467
WRUSI-04	McLeod Park stormwater	Residential - Old	Pipe	13.5	2/5/03	35
WRUSI-05	Duck Creek stormwater	Residential - New	Open Channel	16.0	2/5/03	869
WRUSI-06	Te Roto Drive stormwater	Industrial	Pipe	5.0	9/6/03	
WRUSI-07	Semple Street stormwater	Mixed Industrial/Residential/ Commercial	Pipe	8.5	3/10/03	995
WRUSI-08	Hutt Park Road stormwater	Industrial	Pipe	2.0	4/9/03	323
WRUSI-09	Waring Taylor Street stormwater	Commercial	Pipe	9.9	12/5/03	52
WRUSI-10	Parkside Road stormwater	Industrial	Pipe	3.5	18/6/04	
WRUSI-11	Grassleas Reserve stormwater	Residential	Pipe	NA	27/9/04	210

2.3 Sampling and Sample Processing

Sampling was commenced within the first hour of the rainfall event and continued at hourly intervals until six samples had been collected and combined. Water depth was measured continuously using a pressure transducer mounted in a perforated steel pipe standing on the culvert or stream bed. Two or three gaugings were carried out at open channel sites during the rainfall event. Table 2.1 summarises the sampling dates that sampling was carried out on.

Sampling for Metal Analysis

Two 1 L samples were taken using a LDPE-lined container. The sample was immediately passed through 2,000 µm (micron) and 250 µm polyester screens and drained into a polyethylene basin. The basin was sub-sampled using a plastic syringe, transferring about 160 mL into an acid-washed 1 L polyethylene container, 16 mL into a nitric acid washed unpreserved 100 mL polyethylene container, and 16 mL into a sulphuric/dichromate preserved 100 mL glass container. During the sampling procedure the sample was stirred with a plastic spatula with back and forward strokes to maintain homogeneity. The balance of the liquid was discarded when sub-sampling was complete.

When all six samples had been collected the screens were dried and the > 2000 µm and 250-2000 µm fractions each removed, weighed, and transferred to plastic or glass vials.

The vials and 1 L polyethylene container were provided to IGNS for analysis by PIXE (Particle Induced X-Ray Emission). The dry solids were pelletised. The liquid was filtered using pre-weighed 60 µm nylon net and

0.45 µm nucleopore filters. Pellets and filters were analysed for metals using PIXE.

Sampling TSS/pH/Nutrients Analysis

A 2 L sample was taken using a stainless steel container and transferred to a stainless steel basin. The basin was sub-sampled using a syringe, transferring about 160 mL to a 1 L unpreserved polyethylene container, 40 mL to a 250 mL sulphuric-preserved polyethylene container, and about 16 ml to a 100 mL unpreserved glass container. During the sampling procedure the sample was stirred with a stainless steel spatula with back and forward strokes to maintain homogeneity. The remaining liquid was discarded when sub-sampling was complete.

The samples were sent to R J Hill Laboratories and analysed for pH, TSS, TP, DRP-P, NO_x-N, TKN, TOC/DOC. TN was calculated by addition of TKN and NO_x-N.

Sampling for Organic Compound Analysis

A 2 L sample was taken using a stainless steel container and transferred directly to a pre-cleaned 4 L glass container using a glass funnel. The glass containers were sent Agriquality for the analysis of organic compounds. All six samples were passed through pre-weighed 60 µm and 0.7 µm filters. Retained material on each filter was weighed and analysed for PAHs, OCs, PCBs, and CPs. Filtrate was analysed for PAHs, OCs, PCBs, and CPs.

2.4 Analytical methods

Nutrients/ TSS

The, pH, TSS, and the nutrients: TKN, TON, Nitrate-N, Nitrite-N, DRP, TP, DOC and TOC were analysed at Hill Laboratories. The analytical results are summarised in Appendix 1.

Metals

Dissolved metals were analysed at Hill Laboratories by ICP-MS according to APHA 3125B. The full analytical results are contained in Appendix 1.

Particulate metals were analysed by PIXE at IGNS. The analytical results are presented in Appendix 1.

Organics

Analysis for PAHs, OCs, PCBs, and CPs was carried out at Agriquality by Isotope Dilution. The full analytical results are presented in Appendix 2.

Data

As the data used in this report comprises a relatively limited set of sample from different land-uses, only limited statistical analysis has been undertaken. Where comparisons are made, comparisons of small populations of raw data were made using T- test with non-significant comparisons being considered to have p values of >0.05.

3. General Water Quality

3.1 pH

The pH of the stormwater samples collected in this study ranged from 6.6 to 7.3 with a median of 6.9. There were no differences between the pH of those samples from residential catchments versus those with predominance of industry.

The pH of urban stormwater runoff is typically around 7.0. Variation is dependent upon the chemistry of contributing land use adjacent to the road, the road surface and the pH of rainfall during the rainfall event. Typically rainfall in New Zealand is acidic (pH <6.0). pH during stormwater runoff events can vary depending upon the volume of accumulated water in catchpits as the pH of catchpit waters differ to that of stormwater runoff. Macaskill et al. (2003) reported a number of pH results for stormwater in Rotorua which were typically about 6.8.

Data for roof runoff (which is an important component of stormwater) in New Zealand (ARC 2004) indicates that the pH of roof runoff is typically more alkaline than rainwater. Roofs with surfaces made of materials such as concrete have the potential to raise the pH of roof runoff. This arises as rainwater flows over the surface of material containing $CaCO_3$ which is dissolved in the water. The pH change depends on circumstances, and ranges from about 0.4 units on average up to about 2 pH units (ARC 2004). Similar pH changes would occur as rainwater flows over other concrete surfaces.

Overall, the pH measured in the Wellington stormwater samples is similar to the pH measured in stormwater in other studies carried out in New Zealand.

3.2 Total Suspended Solids

The median total suspended solids (TSS) concentration in the Wellington samples was 76 g/m^3. The median concentration in the residential catchments (n=5) was 59 g/m^3 and in the industrial catchments 90 g/m^3. Although the industrial catchment stormwater had higher TSS, the difference between the residential and industrial catchments was not statistically significant (p=0.053).

Suspended solids in urban runoff has been reviewed by Williamson (1993) and also by Kennedy (2003a). Table 3.1 provides a summary of New Zealand stormwater suspended solids data. The residential median and industrial median concentrations shown in the Table are similar to the median data reported from the samples collected in this study. This similarity reflects the general difference in the amount of suspended particulate matter contributed within these different land uses to stormwater.

The variability amongst the urban runoff data is not surprising given the large number of factors that influence particle sources and contributions of particles to the road surface and other surfaces.

Table 3.1: Suspended solids in urban runoff (all data g/m^3).

Location/Study	Site/Landuse	Concentration	Reference
Urban Runoff			
Review - 10%ile		50	Williamson (1993)
50%ile		170	Williamson (1993)
90%ile		470	Williamson (1993)
Residential Wellington			
Pakuranga, Auckland	R	16.7	ARC (1992)
Pakuranga (median EMC)	R	41.4	ARC (1994)
Glendowie, Auckland	R	151	Worley (2000)
St Heliers, Auckland	R	55.1	Worley (2000)
Rotorua City	R	33	Macaskill et al. (2003)
Kaikorai Valley Dunedin	Residential with some industrial	86.9	Mosley & Peake (2001)
Rotorua City	C	20	Macaskill et al. (2003)
Takapuna	C/R	16	Meritec (2000b)
Mt Roskill, Auckland	R/I	97.3	Worley (2000)
Median		**41.4**	
Industrial/Ind-Commercial			
Wairau Creek	C/I	79.2	Meritec (2000a)
Waitakere (testing station)	C/I	10	WCC (1997)
Halswell, Christchurch	C/I	102	Elliot (1996)
Southdown, Auckland	I	52.0	ARC (1992)
Tamaki, Auckland	I	253	Worley (2000)
Rotorua City	I	78	Macaskill et al. (2003)
Median		**78.6**	

Notes: R = residential; C = commercial; I = industrial.

Overall, the TSS concentrations observed in the stormwater samples collected in the Wellington region appear similar to concentrations recorded in other studies in New Zealand. The land use difference observed between residential and industrial catchments appears to reflect the general difference observed in other studies.

3.3 Total and Dissolved Organic Carbon

Both total and dissolved organic carbon were measured in the samples collected from the 11 sites. The median total organic carbon (TOC) was 7.5 g/m^3 with a range of 4.2-14.6 g/m^3. There was no difference in the TOC concentration between the residential and industrial sites in the study. The median dissolved organic carbon (DOC) concentration was 3.3 g/m^3 (range 1.2-5.7 g/m^3), which represented about 44% of the TOC. Concentrations in residential samples were similar to those from industrial catchments.

Concentrations of DOC in urban streams have been reported in the range 1.8-8.2 g/m^3 (Timperley & Kuschel 2000). DOC measured in runoff from artificial roofs by ARC (2004) showed that DOC concentrations were <1 g/m^3 but with the presence of sources of terrestrial plant organic matter such as pollen and leaves this could rise to more than 50 g/m^3. Mosley & Peake (2001) who studied stormwater quality draining the Kaikorai Valley in Dunedin reported a median DOC concentration of 9.7 g/m^3 and concluded that the majority of the DOC present in the stormwater arose from decaying plant material and soil particles. DOC plays an important role in stormwater (and stream water) chemistry as it complexes a number of key stormwater contaminants.

TOC in suspended matter showed that TOC ranged from 2.44 to 13.97% with an outlier of 30%. The median concentration was 10.24%. There is little comparative TOC data for stormwater or stormwater particulates in New Zealand.

ARC (1992) reported information for TOC in dusts in streets of Pakuranga and Southdown in Auckland and in suspended sediments in stormwater from Pakuranga. Sediments in Pakuranga contained concentrations of TOC ranging from 3.58-8.04% in the 47 µm fraction to 1.46-24.1% in the 1-2 mm fraction. In stormwater, the concentrations tended to increase with increasing particle size (11.6% in 0.02 mm particles to 22.6% in >0.25 mm particles indicating that in that case, the organic matter was probably present in particulate form.

Overall, the DOC and TOC concentrations observed in the stormwater samples collected in the Wellington region appear similar to concentrations recorded in other studies.

4. Nutrients

4.1 Nitrogen

Total nitrogen

Total nitrogen (TN) concentrations in Wellington stormwater ranged from 0.8 to 2.9 g/m^3 with a median of 1.6 g/m^3. The stormwater from the residential samples contained a higher median concentration than the samples from the industrial catchments (1.9 compared to 1.4 g/m^3). This difference may be attributable to the greater amount of organic matter available in residential suburbs than in industrial catchments (e.g., from lawn mowing and greater density of trees etc.). Total Kjeldahl nitrogen (TKN) concentrations were lower (based on the medians TKN was 62.5% of TN). TKN analysis does not include total oxidised nitrogen (TON).

Nitrate-N

Table 4.1 summarises data for nitrate-N concentrations in Wellington stormwater and elsewhere in New Zealand. The available data in Table 4.1 indicates that the concentration of nitrate-N in New Zealand urban runoff can be high. In the Wellington samples, nitrate-N was notably elevated in three residential suburbs (1, 2 and 3) where the concentrations ranged from 1.03-1.26 g/m^3.

Table 4.1: Nitrogen in urban stormwater in the Wellington region (all data g/m^3).

Study	Location	Landuse	TN	TKN	NO_3-N	NH_4-N
This study	Wellington	All (n=11)	1.6	1.0	0.30	-
		Residential (n=6)	1.9	0.7	0.665	-
		Industrial (n=3)	1.4	1.0	0.31	-
ARC (1992**)**	Pakuranga	Residential	-	-	0.606	0.024
ARC (1994)	Pakuranga	Residential			0.626	0.043
ARC ((1992)	Southdown	Industrial			0.981	0.038
Mosley & Peake (2001)	Kaikorai	Residential with some industrial	-	-	0.833	-
Macaskill et al. (2003)	Rotorua	Residential	-	-	0.0595	0.057
	Rotorua	Commercial	-	-	0.042	0.062
	Rotorua	Industrial	-	-	0.034	0.019
Williamson (1993)	10%ile		-	-	0.375	0.025
	50%ile				0.800	0.100
	90%ile				1.50	0.25

Notes: TN – Total nitrogen; TKN – Total Kjeldahl nitrogen; NO_3 – Nitrate; NH4-N – Ammoniacal nitrogen.

The available New Zealand urban stormwater data indicates that there are significant differences between catchments in relation to the nitrate-N concentrations. The cause of the differences is not known but it is evident that the Rotorua urban data (Macaskill et al. 2003) is lower than other stormwater data collected from urban areas. The differences may be related to local landuse practices and historical additions of nitrate-N to groundwater within the catchment.

Ammoniacal-N

Although no ammoniacal-N data was collected in this study, data for other New Zealand urban stormwater data indicates that ammoniacal nitrogen concentrations would typically be 0.05 g/m^3 or less in the absence of significant reduced dissolved inorganic nitrogen (DIN) (Refer Table 4.1). Reduced DIN could be derived in some situations from sewage/putrescible waste in the stormwater or from catchpits where anaerobic conditions can result in a greater proportion of the DIN being present as ammonia.

4.2 Phosphorus

Total phosphorus

Total phosphorus (TP, strong acid extractable) concentrations ranged from 0.025-0.071 g/m^3. Table 4.2 summarises a range of New Zealand data. Fig. 4.1 shows that the relationship between TP and suspended solids. TP concentration appears closely related to the suspended solids concentration measured in the same samples. When all samples are considered the relationship is apparent but not statistically significant ($p>0.05$). When the two just residential sites (Sites 3 and 4) are not included, the relationship is statistically significant ($R^2 = 0.795$, $p<0.05$).

Table 4.2: Phosphorus in urban stormwater in the Wellington region (all data g/m^3).

Study	Location	Landuse	Dissolved reactive phosphorus	Total phosphorus
This study	Wellington	All (n=11)*	0.036	0.192
		Residential (n=6)	0.037	0.215
		Industrial (n=3)	0.028	0.251
ARC (1992)	Pakuranga	Residential	0.019	0.098
ARC (1994)	Pakuranga	Residential	0.014	0.101
ARC ((1992)	Southdown	Industrial	0.723	0.192
Mosley & Peake (2001)	Kaikorai	Residential with some industrial	0.038	0.118
Macaskill et al. (2003)	Rotorua	Residential	0.036	0.118
		Commercial	0.032	0.109
		Industrial	0.01	0.179
Williamson (1993)	10%ile	-	0.013	0.2
	50%ile		0.040	0.42
	90%ile		0.070	1.12

Notes: * - two other catchments (mixed land use; commercial).

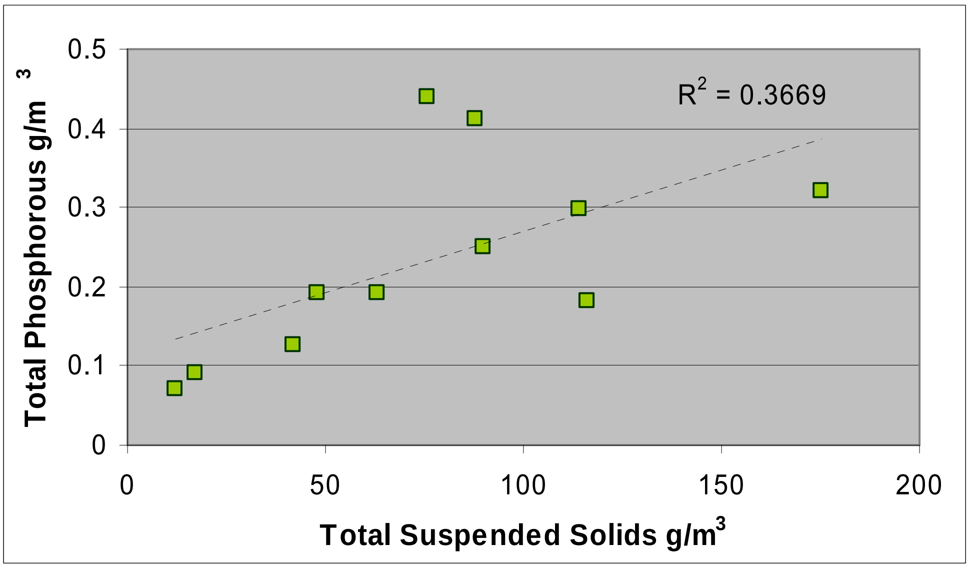

Fig. 4.1: Relationship between suspended solids and total phosphorus.

Dissolved reactive phosphorus

The median dissolved reactive phosphorus (DRP) concentration from the Wellington data is very similar to the median data from other locations in urban Dunedin and Rotorua and also to the 50%-ile data identified by Williamson (1993) (Table 4.1).

5. Metals in stormwater

5.1 Introduction

The work undertaken on stormwater quality in this study was carried out using dissolved trace element concentrations (for convenience referred to as metals in this report). This provides information on the transport of metals that may be bioavailable and potentially toxic but does not provide information on the load of contaminant transported (e.g., associated with particulate matter in the stormwater). It should be noted that dissolved refers to the concentration of metal obtained following filtration of the sample through a 0.45 µm filter. This is the generally accepted definition of dissolved fraction. However, even below this filter cut off, there are some substances that can be considered as not truly dissolved. If we examine the sizes of materials at this end of the particle size spectrum, coarse colloidal comprises materials in the range 0.45-0.1 µm, colloidal material is in the range 0.1 µm-1,000 D (daltons) and truly dissolved material is considered to be less than 1,000 D in size. Colloidal materials are single molecules or aggregates of molecules that remain in suspension and do not settle.

In this section, although dissolved concentrations were measured, comparison of metal concentrations with total suspended solids (TSS) concentrations is made to provide a graphical visualisation of the concentration data obtained.

In the following sections, comparison is made with ANZECC (2000) and USEPA (2002) water quality guidelines/criteria. For those trace elements for which toxicity and hence guideline/criteria concentrations vary with water hardness (e.g., cadmium, chromium^{3+}, copper, lead, nickel and zinc), the guideline values used in this assessment have been calculated using the default hardness of 30 g/m^3 $CaCO_3$. Hardness calculated from dissolved calcium and magnesium data showed average hardness of about 24 g/m^3 (as $CaCO_3$) for sites from the residential catchments (range 9.05-61.5 g/m^3) and industrial/commercial catchments (range 16.75-37.2 g/m^3) (data is presented in Appendix 1). There was no statistical difference between the land-use types. In the respective sections that follow the default values have been presented and hardness is not specifically discussed in those sections. Further comment is provided on the comparison of dissolved metal concentration data as obtained in this study with the ANZECC (2000) triggers in Section eight of this report.

5.2 Aluminium

Aluminium (Al) is a key structural element in soils and sediments. As noted above dissolved fractions obtained using 0.45 µm filters includes some colloidal material that can pass the pores in the filter. This results in the dissolved data including both dissolved and colloidal Al in the analytical result. In many waters, the true dissolved Al concentration is a reflection of the equilibrium between compounds such as Al hydroxides and the pH of the waters. Overall, ionic strength is important for the Al-toxicity in organisms such as fish as the interaction between aqueous aluminium and the fish gills is important and a range of common ionic constituents can lessen the effects of toxicity. Fig. 5.1 shows that the dissolved Al concentrations for the sites sampled fell within a relatively narrow range.

The data collected suggests a weak but possible relationship between suspended solids and dissolved Al (not statistically significant, R^2=0.0921, $p>0.05$). This relationship doesn't appear to reflect land use factors and may relate to the colloidal Al concentration reflecting the suspended solids concentration. There appears to be no published dissolved Al data for urban stormwater.

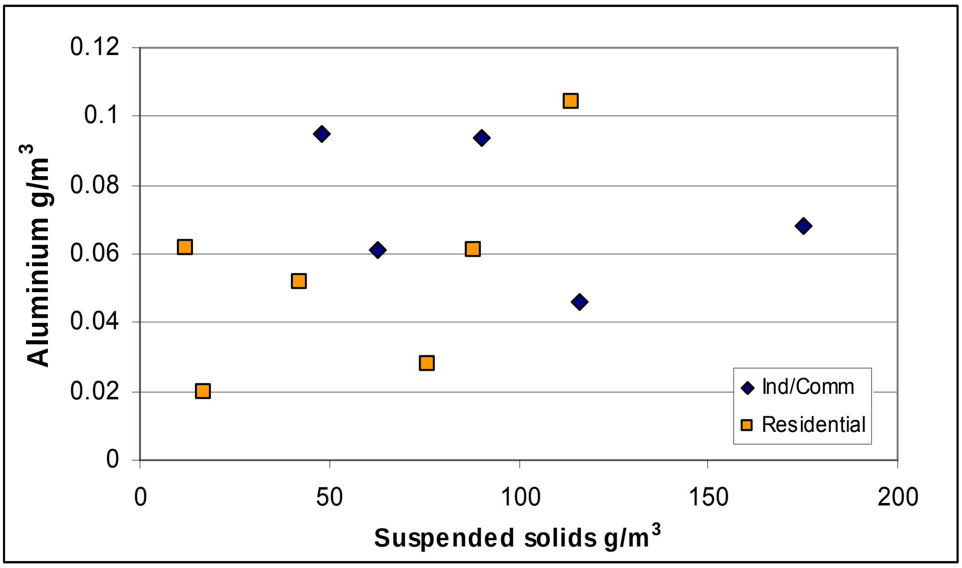

Fig. 5.1: Dissolved aluminium in Wellington stormwater.

ANZECC (2000) identifies a moderate reliability trigger value (95% protection) of 0.055 g/m^3 for freshwaters (at pH values >6.5). USEPA (2002) identifies a chronic criterion (CCC) of 0.087 g/m^3 (this figure is based upon total recoverable metal) for the protection of freshwater aquatic life. Comparison of the data in Fig. 5.1 would suggest that concentrations of dissolved Al are elevated when compared to this trigger value (about half the Wellington data is higher than the ANZECC trigger). Given the complexity of Al chemistry in freshwaters, any direct comparison of the stormwater data with the ANZECC (2000) trigger should be made with caution.

5.3 Antimony

An overview of antimony (Sb) in the urban environment was provided in Kennedy (2003). Antimony is present in urban dusts and street dusts with concentrations in the Wellington region of the order of 9 mg/kg (compared to a crystal abundance of about 0.3 mg/kg) (Wedepohl 1995). The elevated concentration of Sb in urban dusts should result in some elevation in the concentration of Sb in urban stormwater.

Comparison of the residential and industrial/commercial land-use data showed that the Sb concentrations were significantly higher in the industrial catchment samples (0.2 compared to 0.7 mg/m^3, log transformed, p=0.019).

Fig. 5.2, illustrates the range in the concentration of Sb in Wellington urban stormwater. In the absence of any unusual local contamination by Sb urban dusts would be expected to contribute about 0.0001 g/m^3 (0.1 mg/m^3) of dissolved and particulate Sb per 100 g/m^3 of suspended solids.

Based upon the data shown in Fig. 5.2, the Hutt Park and Parkside Road samples stand out above the other samples. The concentrations at a number of the other sites are not inconsistent with what might be expected in uncontaminated storm flows.

Kennedy (2003) suggested that motor vehicles might be the most significant source of Sb in street dusts (and hence stormwater).

In the absence of antimony mineralisation (e.g., stibnite deposits) the natural concentration of Sb in freshwater is typically <0.001 g/m^3 and may be much lower. Filella et al. (2002) provides more information on the variability in Sb concentrations in freshwater.

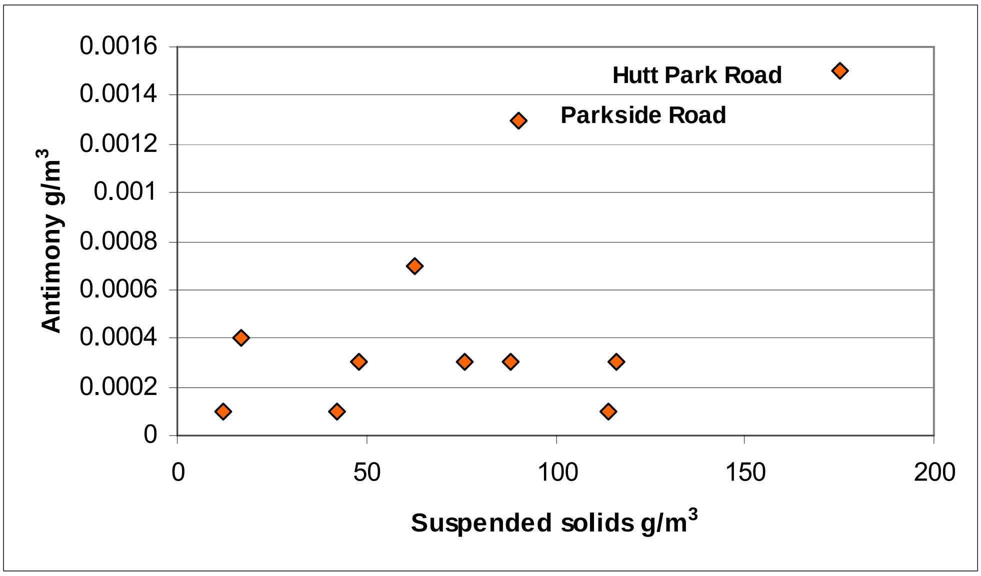

Fig. 5.2: **Dissolved antimony in Wellington stormwater.**

ANZECC (2000) identify a freshwater low reliability trigger value of 0.009 g/m^3 (antimony III) using an AF (acute factor) of 1000. As noted by ANZECC this is only an “indicative interim working level”. The corresponding marine trigger is 0.270 g/m^3 but this has lower reliability than the freshwater trigger value (ANZECC 2000). Concentrations of dissolved Sb in Wellington stormwater are lower than the ANZECC (2000) trigger value.

5.4 Arsenic

Arsenic (As) concentrations in the Wellington stormwater samples ranged from <0.001 to 0.002 g/m^3 with the exception of a single site with 0.004 g/m^3 (Browns Stream stormwater). There were no differences between the land-uses. Kennedy (2003b) provides an overview of the As in soils and sediments and available information on concentrations in stormwater. The data in Kennedy (2003b) suggests that urban street dusts in the Wellington area might contain about 6 mg/kg As.

Dissolved concentrations of arsenic in fresh water in New Zealand are strongly influenced by the proximity of geothermal activity. The geochemistry of As in natural waters is described by Smedley & Kinniburgh (2002). Typical concentrations in freshwater are less than 0.01 g/m^3 and frequently less than 0.001 g/m^3.

ANZECC (2000) has a high reliability freshwater trigger value of 0.024 g/m^3 for the protection of aquatic life (95% level of protection). For coastal waters, the trigger value has low reliability but has been identified as 0.0023 g/m^3 was derived for As (III) in marine waters. Concentrations of As in Wellington stormwater are lower than the ANZECC (2000) trigger value.

5.5 Barium

Fig. 5.3 presents the data obtained from the stormwater samples collected in this study. The median Ba concentration for all samples was 0.009 g/m^3. There were no significant differences between sites and land uses ($p>0.05$) and no relationship between dissolved barium concentration and suspended solids concentration ($R^2=0.0106$, $p>0.05$). Concentrations of Ba in freshwaters appear highly variable with concentrations of the order of 0.01-0.1 g/m^3 not uncommon.

Fig.5.3: **Dissolved barium in Wellington stormwater.**

The nature of Ba in urban street particulate matter will influence the solubility. Although Ba is a relatively abundant element in soils and sediments (In Wellington concentrations are typically about 500 mg/kg – refer Kennedy 2003b), the concentrations are higher in urban street dusts with some sites having concentrations over 1,000 mg/kg. It is likely that a portion of the additional Ba present on road surfaces is derived from the wear of brake pads in motor vehicles where the Ba is likely to be present as baryte. In addition any Ba derived from paint sources is likely to be present as baryte. Although there is added Ba in stormwater, it is not possible to say what proportion of the Ba in the Wellington stormwater samples is derived from contamination by man-made sources such as motor vehicles and where the dissolved Ba is derived from.

There are no triggers identified by ANZECC (2000) or USEPA (2002) for the protection of aquatic life.

5.6 Cadmium

Dissolved cadmium (Cd) was measured at concentrations at or below detection limit (<0.00005 g/m^3) in all samples collected from sites other than those categorised as industrial (i.e., at sites 1, 2 and 3). At these sites the average dissolved cadmium concentration was 0.00011 g/m^3 (0.11 mg/m^3). Table 5.1 provides a summary of New Zealand stormwater data for Cd in stormwater.

Table 5.1 Median dissolved cadmium concentrations in New Zealand urban stormwater (all units g/m^3).

Site	Land-use	Median	Range	Reference
Residential				
Wellington	R	<0.00005	<0.00005-0.00005	This study
Kaikorai valley, Dunedin	R**	-	-	Mosley & Peake (2001)
Pakuranga, Manukau City	R	0.000018	-	ARC (1992)
Rotorua City	R	<0.00005	-	Macaskill et al. (2003)
Commercial Industrial				
Wellington	C/I	0.0001	0.00007-0.00015	This study
Rotorua City	C	0.00013	-	Macaskill et al. (2003)
Portobello Rd Dunedin	M	-	-	Brown & Peake (2001)
Halswell Junction, Christchurch	C/I	-	-	Elliot (1996)
Rotorua City	I	0.000014	-	Macaskill et al. (2003)
Natural baseline				
Waitekauri River	RUR/B	0.000007 ± 0.000004*+	-	Kingett & Associates (1987)
Coromandel Streams	B	-	<0.00005-0.019*	Livingston (1987)
Upper Manuherikia River		-	0.005-0.020**	Ahlers & Hunter (1984)

Note: + = average and one standard deviation; * = unfiltered acid extractable concentrations. R = residential; C = commercial; I = industrial; RUR = rural; B = bush; ** - with some industrial.

The data in Table 5.1 shows that in residential areas, concentrations are typically <0.00005 g/m^3. The natural concentration of Cd in freshwaters in New Zealand, in the absence of high particulate concentrations and mineralisation containing Cd is, very low. Published concentration data reflects this with data including an average concentration of 0.000007 ± 0.000004 g/m^3 (acid soluble Cd) for low flows (TSS concentration of 11 g/m^3) in the Waitekauri River catchment in the Coromandel (Kingett & Associates 1987) and, a range of 0.000005-0.00002 g/m^3 for the Manuherikia River in Otago (Ahlers & Hunter 1984). The concentrations measured in the three samples from industrial catchments in Wellington are similar to concentrations recently measured in other industrial catchments in locations such as Rotorua (Table 5.1).

ANZECC (2000) has identified a high reliability freshwater trigger value of 0.0002 g/m^3 for the 95% level of protection. This figure applies to a low hardness of 30 g/m^3 as $CaCO_3$. The corresponding 95% protection level trigger for coastal waters is 0.00055 g/m^3. The data obtained in the current study indicates that dissolved Cd concentrations are lower than the ANZECC (2000) trigger value. In industrial catchments, the median or average Cd concentrations approach the trigger value but are still lower.

5.7 Chromium

Dissolved chromium (Cr) was detected in all stormwater samples collected (median 0.00175 g/m^3, range 0.0006-0.0069 g/m^3). Table 5.2 provides a summary of published data for Cr in freshwaters in New Zealand. When the data in Fig. 5.4 is examined, this would suggest that the samples collected may contain typical concentrations of Cr apart from the two samples with concentrations above 0.005 g/m^3 from industrial catchments (Semple St is a mixed catchment and Waring Taylor St. is a commercial catchment).

Table 5.2 Median dissolved chromium concentrations in New Zealand urban stormwater (all units g/m^3).

Site	Land-use	Median	Range	Reference
Residential				
Wellington	R	0.001	0.0006-0.002	This study
Commercial Industrial				
Wellington	C/I	0.0031 (0.001-0.0069)	0.0081 (0.0063-0.0225)	This study
Natural baseline				
Waitekauri River	R/B	0.00021 ± 0.00015*	-	Kingett & Associates

Notes * - unfiltered acid extractable concentrations, average and one standard deviation.
R = residential; C = commercial; I = industrial; RUR = rural;
B = bush.

Comparison of the residential Cr data (mean 0.0012 g/m^3, n=6) and the industrial/commercial data (mean 0.0036 g/m^3, n=5) showed that the residential sites had statistically lower Cr concentrations than those from the industrial/commercial sites (log transformed p=0.032).

ANZECC (2000) has not identified any Cr (III) trigger values for freshwater environments. For marine waters, ANZECC (2000) identifies a 99% protection trigger value of 0.0077 g/m^3 and a high reliability freshwater trigger value of 0.0002 g/m^3 for the 95% level of protection. The concentrations of dissolved Cr in Wellington stormwater were low with the higher concentrations measured in the industrial catchment stormwater approaching the ANZECC (marine) trigger value.

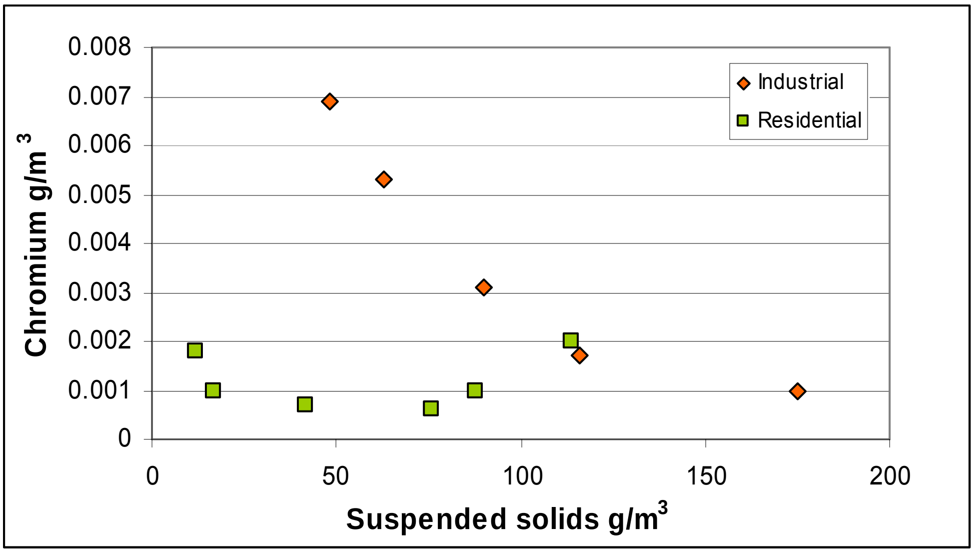

Fig. 5.4: Chromium in Wellington stormwater.

5.8 Cobalt

The median cobalt (Co) concentration in Wellington stormwater was 0.003 g/m^3 (range 0.001-0.005 g/m^3) with a significant difference between the samples collected from residential catchments (median 0.001 g/m^3) and industrial/commercial catchments (0.003 g/m^3) (p=0.01).

There appears to be no published comparative data for Co in urban stormwater in New Zealand. Kennedy (2003b) provides an overview of Co in the urban environment, with urban street dusts having a concentration of typically about 10 mg/kg. That review reported higher concentrations in samples that were collected by Kennedy & Gadd (2003). In that case the higher concentration may be attributable to elevated Co in volcanic scoria used for roading.

The dissolved cobalt concentrations in ambient, uncontaminated environments are generally low (0.0001-<0.005 g/m^3) (Nagpal 2004). Durum et al. (1971) reported the results of a sampling program for minor elements including cobalt, in surface water in the United States and

Puerto Rico. Cobalt concentrations exceeded the detection limit of 1 mg/m^3 in only 37% of samples. Smith & Carson (1981) compiled literature values for cobalt in water in the United States finding that the Co concentrations were below the detection limit of 0.001 g/m^3 in most freshwaters in the United States.

ANZECC (2000) has identified a trigger value of 1 mg/m^3 for Co in freshwater environments (for 95% protection). For 90% protection, the trigger rises to 0.014 g/m^3.

Overall, the dissolved Co concentration in Wellington stormwater is similar to dissolved Co measured in freshwaters. The concentrations of Co are slightly higher in stormwater from industrial catchments suggesting some elevation of concentration. Although the concentrations of Co are higher than the triggers identified by ANZECC (2000) for the protection of freshwater aquatic life, it is likely that toxicity is limited through a variety of water chemistry mechanisms.

5.9 Copper

The median dissolved copper (Cu) concentration in the Wellington stormwater samples was 0.0069 g/m^3. There was no statistical difference in the concentrations measured in the residential catchments (0.0055 g/m^3) and the industrial/commercial catchments (median 0.0081 g/m^3). Table 5.3 provides a comparative summary of the Cu concentrations in stormwater from the Wellington residential catchments with other residential data collected elsewhere in New Zealand.

Concentrations appear to be in the lower range of the concentrations recorded in stormwater from other residential catchments in New Zealand. The median concentration from the industrial/commercial catchments is similar to that reported for stormwater from a commercial catchment in Rotorua City.

Fig. 5.5 shows the concentration of Cu compared to the amount of suspended solids in the sample. The majority of the samples show a generally uniform concentration of about 0.005 g/m^3 Cu. The Waring Taylor St stormwater however shows evidence of increases in dissolved Cu concentration compared to other sites. It may be that some buildings in the Waring Taylor St. catchment have copper facades, gutters or down-pipes.

Kennedy (2003) provided an overview of Cu concentrations in urban dust/road surface particulates. The data indicates that virtually all particulates in the urban environment are contaminated with Cu. Fig. 5.6 illustrates the variation in dissolved Cu concentration between catchment land use (in this case the commercial stormwater catchments have been separated from the industrial land use catchments). For comparison, Table 5.3 also identifies some New Zealand data for natural concentrations of Cu. That data indicates that concentrations in waters with low suspended solids are about 0.0002 g/m^3.

Table 5.3: Median dissolved copper concentrations in New Zealand urban stormwater and natural waters (all units g/m^3).

Site	Land-use	Median	Range	Reference
Residential				
Wellington	R	0.00545	0.0025-0.010	This study
Kaikorai valley, Dunedin	R**	0.0097	-	Mosley & Peake (2001)
Pakuranga, Manukau City	R	0.0032	-	ARC (1992)
Rotorua City	R	0.0041	-	Macaskill et al. (2003)
Commercial Industrial				
Wellington	C/I	0.0081	0.0063-0.0225	This study
Rotorua City	C	0.005	-	Macaskill et al. (2003)
Portobello Rd Dunedin	M	0.009	-	Brown & Peake (2001)
Halswell Junction, Christchurch	C/I	0.009	-	Elliot (1996)
Rotorua City	I	0.0102	-	Macaskill et al. (2003)
Natural baseline				
Waitekauri River	R/B	0.00019 ± 0.00008^{*+}	-	Kingett & Associates (1987)
Manuherikia River	R	-	0.000012-0.00042*	Ahlers & Hunter (1984)
Coromandel Streams	R/B	-	<0.00005-0.00033*	Beaumont et al. (1987)

Notes * - unfiltered acid extractable concentrations. + , average and one standard deviation. R = residential; C = commercial; I = industrial; M = mixed; RUR = rural; B = bush; ** - with some industrial.

Fig. 5.5: Copper and suspended solids in Wellington stormwater.

Concentrations of Cu in Wellington stormwater are higher than would be expected in the absence of contamination. This is not unexpected given the common use of copper in the urban environment (refer Kennedy 2003).

ANZECC (2000) identifies a 90% trigger value for the protection of freshwater organisms in slightly-moderately disturbed ecosystems of 0.0014 g/m^3. The corresponding trigger for marine environments is 0.0013 g/m^3. The concentrations of dissolved Cu in Wellington stormwater are higher than the freshwater and marine triggers identified by ANZECC (2000). The lowest concentration recorded in the Wellington samples collected was 0.0025 g/m^3.

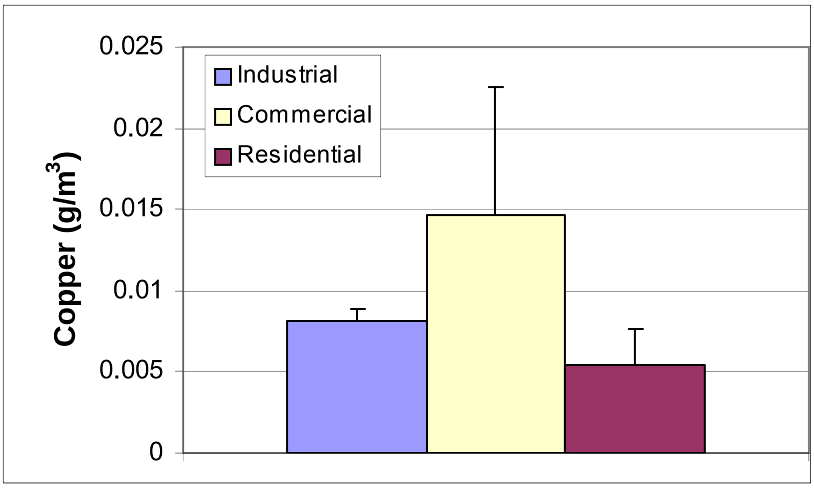

Fig. 5.6: Copper (median and standard error) and land-use in Wellington stormwater.

5.10 Iron

Concentrations of dissolved iron (Fe) in the stormwater samples from the sites in the Wellington region were variable. Iron is a key structural element in geological materials and is a common contaminant in urban environments (e.g., due to the occurrence of rust, refer Kennedy 2003). The median concentration amongst all 11 samples collected was 0.08 g/m^3 (range <0.02-0.24 g/m^3) and there were no statistical differences between land-use types. The concentrations of dissolved iron will be affected by the redox environment within the stormwater system and in particular the state of the water in the catchpits at the time of rainfall. Catchpits represent a potential storage volume within the stormwater network for anaerobic waters. Anaerobic waters will increase the production of dissolved Fe and also dissolved manganese in the catchpit waters. This increase in concentration may be evident as a first flush.

ANZECC (2000) does not identify any triggers for the protection of aquatic life from elevated concentrations of Fe in water. USEPA (2002) identifies a chronic criteria (CCC) of 1.0 g/m^3 for the protection of aquatic life from the effects of iron (which it identifies as a non-priority pollutant). The concentration of Fe in Wellington stormwater was lower than the USEPA criteria. Excess dissolved iron in stormwater may lead to flocculation of iron oxides in some situations where stormwater (especially baseflow) is discharged from stormwater pipes where the water is derived from groundwater drainage into the pipes.

5.11 Lead

The lead (Pb) concentration in Wellington stormwater had a median of 0.0008 g/m^3 with a range of 0.0003-0.0115 g/m^3 (Table 5.4). Concentrations were lower in the samples from residential catchments (median 0.0008 g/m^3) compared to the residential/industrial catchments (2.5 mg/m^3) however the difference was not statistically significant (p=0.11).

Table 5.4 Median dissolved lead concentrations in New Zealand urban stormwater and natural waters (all units g/m^3).

Site	Land-use	Median	Range	Reference
Residential				
Wellington	R	0.0008	0.0003-0.0035	This study
Kaikorai valley, Dunedin	R	0.0029	-	Mosley & Peake (2001)
Pakuranga, Manukau City	R	0.00021	-	ARC (1992)
Rotorua City	R	0.0033	-	Macaskill et al. (2003)
Pakuranga	R	0.00021	0.00010-0.00041	ARC (1992)
Commercial Industrial				
Wellington	C/I	0.0025	0.0006-0.0115	This study
Rotorua City	C	0.0013	-	Macaskill et al. (2003)
Portobello Rd Dunedin	M	0.0012	-	Brown & Peake (2001)
Halswell Junction, Christchurch	C/I	<0.001	-	Elliot (1996)
Rotorua City	I	0.0014		Macaskill et al. (2003)
Natural baseline				
Waitekauri River	R/B	<0.00007 ± 0.00004*$^+$	-	Kingett & Associates (1987)
Manuherikia River	R	-	0.00005-0.00030*	Ahlers & Hunter (1984)
Coromandel Streams	R/B	-	<0.00005-0.00016*	Beaumont et al. (1987)

Notes * - unfiltered acid extractable concentrations. + = average and one standard deviation. R = residential; C = commercial; I = industrial; M = mixed; RUR = rural; B = bush.

Fig. 5.7 shows the relationship between suspended solids and Pb concentration in stormwater. As can be seen from the figure, relatively low concentrations of Pb were measured in most of the samples. An elevated concentration was identified at one site, Parkside Road in Gracefield. This area has been subject to significant industrial lead contamination in the past (a lead battery factory).

Natural concentrations of Pb are very low in the absence of contamination. Historically most natural waters have been contaminated due to the global distribution of Pb (from smelting, lead in petrol etc.). The New Zealand data in Table 5.4 provides an indication of how low the concentrations can be with three studies reporting concentrations down to 0.00005 g/m^3.

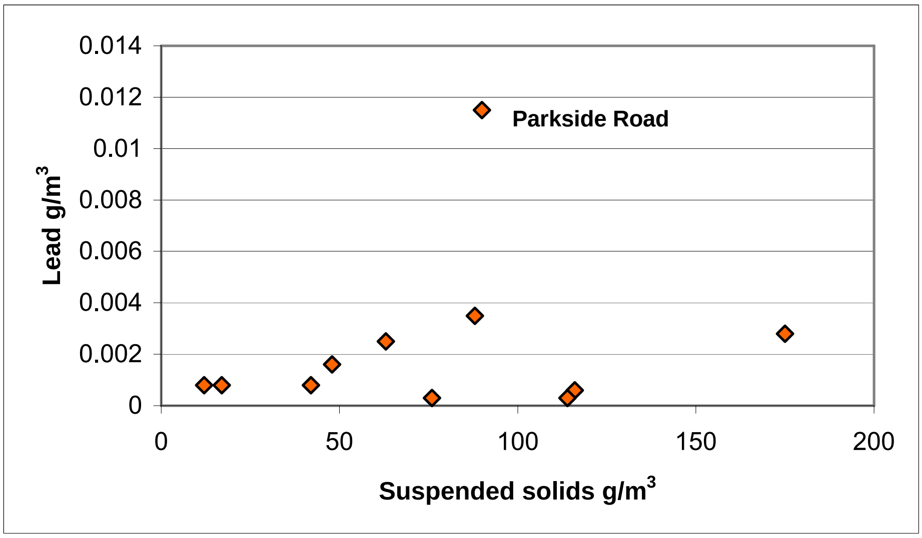

Fig. 5.7: Lead in Wellington stormwater.

The dissolved Pb concentrations from the residential catchments are low compared to many of the published New Zealand studies (Table 5.4). If those studies that pre-date the removal of Pb from petrol are excluded then there are a few studies which have reported low Pb concentrations but not as low as this study. The median concentrations from the Wellington industrial/commercial catchments is also low by comparison with other studies (e.g., median of 0.0025 g/m^3 compared with 0.0139 g/m^3 from the Rotorua City study).

Comparison of dissolved Pb concentrations is also complicated by the difficulty of measuring low concentrations of Pb. ARC (1992) reported a median of 0.00021 g/m^3 in sampling carried out using clean techniques in 1992.

ANZECC (2000) identifies a 95% trigger for the protection of aquatic life from elevated concentrations of Pb in freshwaters of 0.0035 g/m^3. USEPA (2002) identifies a chronic criteria (CCC) of 0.0025 g/m^3 for the protection of aquatic life from the effects of Pb. The concentrations of Pb in Wellington stormwater are predominantly lower than the USEPA criteria. With the Parkside Rd samples excluded, the concentrations fall below the ANZECC (2000) trigger for 95% protection.

5.12 Manganese

Manganese (Mn) is not typically included in environmental studies as Mn is not regarded as an environmentally significant element. Manganese is an interesting element in that it undergoes significant changes in chemistry due to changes in redox conditions. As indicated earlier, redox changes occur with stormwater when water is stored in catchpits and pipes. These changes in environmental conditions may explain some of the variability in the stormwater samples collected in this study.

Information on Mn in the urban environment and concentrations in soils, sediments and urban dusts is overviewed by Kennedy (2003). Concentrations of Mn vary considerably between soils depending upon geological conditions. The median Mn concentration in all samples was 0.016 g/m^3 with the median concentrations in the residential and industrial catchments being 0.0115 and 0.022 g/m^3 respectively. No statistical differences between land-use was identified. Fig. 5.8 shows that of the samples collected, the concentrations were notably elevated in two samples; one from the residential catchment of Grassleas Reserve and one from the industrial catchment of Parkside Road.

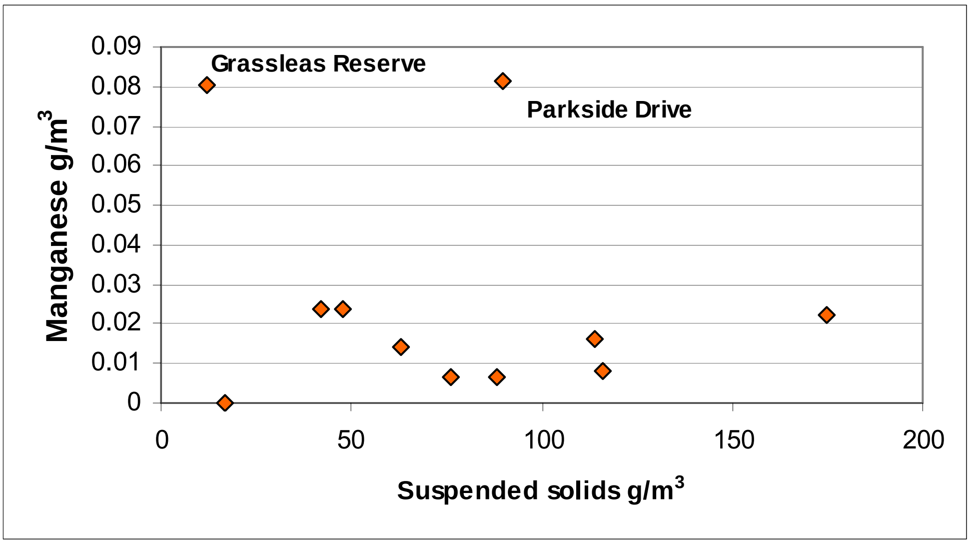

Fig. 5.8: Manganese in Wellington stormwater.

ANZECC (2000) identifies a 95% trigger for the protection of aquatic life from elevated concentrations of Mn in freshwaters of 1.9 g/m^3. USEPA (2002) does not identify any criteria for the protection of aquatic life from the effects of Mn. The concentrations of dissolved Mn in Wellington stormwater are all much lower than the ANZECC trigger.

5.13 Mercury

Mercury (Hg) was not detected in any of the stormwater samples collected at a detection limit of <0.00008 g/m^3. There appears to be no readily available published data for Hg in urban stormwater in New Zealand or overseas.

Kennedy (2003b) reviewed the available information on Hg in urban gutter and road dusts in New Zealand. It was noted that gutter/road dusts contain Hg and that elevated concentrations had been reported in road environments in Wellington in the late 1970s. Based on the natural concentration of Hg in sediments in the Wellington region (which will reflect soil concentrations to some extent), natural soils might be expected to contribute of the order of 0.00001-0.00002 g/m^3 Hg (based on total Hg) in the absence of contamination (hence the lack of detection in the stormwater samples collected in this study).

Natural concentrations of Hg have been measured in some New Zealand rivers. Kingett & Associates (1987) reported concentrations of Hg in a range of streams in the Waitekauri area of the Coromandel as below 0.00001 g/m^3 (<0.01 mg/m^3).

ANZECC (2000) identify a trigger value of 0.0006 and 0.0004 g/m^3 for a 95% level of protection in freshwater and marine environments respectively. The USEPA (2002) chronic criteria for protection of aquatic life is 0.00077 g/m^3. The non detected concentration measured in all samples was lower than the respective trigger and criteria.

5.14 Nickel

Although the median nickel (Ni) concentrations in Wellington stormwater were 0.000375 g/m^3 in the residential catchments and 0.0009 g/m^3 in the industrial/commercial catchments, the differences were not significantly different ($p>0.05$). Comparison with natural concentrations of Ni in New Zealand freshwaters (in waters with low TSS) in Table 5.5 shows that the dissolved Ni concentrations in Wellington stormwater are relatively low.

Looking further at the spread in concentrations measured, Fig. 5.9 shows the difference between the industrial versus residential sites noted earlier.

As shown in Table 5.5, natural concentrations of Ni in New Zealand freshwaters appear to be about 0.0002 g/m^3 (0.2 mg/m^3). The median concentration obtained for the residential catchments is slightly higher than the available data for natural concentrations. It should be noted that the natural concentrations are acid soluble Ni rather than dissolved and as such as the dissolved concentrations would be expected to be slightly lower than that identified.

Table 5.5: Dissolved nickel concentrations in New Zealand urban stormwater and natural waters (all units mg/m^3).

Site	Land-use	Median	Range	Reference
Residential				
Wellington	R	0.000375	<0.0005-0.0008	This study
Commercial Industrial				
Wellington	C/I	0.0009	<0.0005-0.0017	This study
Natural baseline				
Waitekauri River	R/B	0.0002 ± 0.00012*	-	Kingett & Associates (1987)
Otago – Waters of Leith	Mixed	0.00022	-	Dickson & Hunter (1981)

Notes * - unfiltered acid extractable concentrations, mean and one standard deviation; R = residential; C/I = commercial/industrial; R/B = rural/bush.

Fig. 5.9: **Nickel in Wellington stormwater.**

ANZECC (2000) identify a trigger value of 0.011 and 0.07 g/m^3 for a 95% level of protection in freshwater and marine environments respectively. The USEPA (2002) chronic criteria for protection of aquatic life in freshwaters and marine waters are 0.052 and 0.0082 g/m^3. All samples collected from the residential catchments were below the ANZECC and USEPA 'chronic' values. The concentrations measured in stormwater from several of the industrial catchments were above the ANZECC (2000) trigger value.

5.15 Selenium

Selenium (Se) concentrations in all of the stormwater samples collected were <0.001 g/m^3. There is very little data for Se in urban stormwater and no published data for Se in urban stormwater in New Zealand. Concentrations in fresh waters are typically low unless catchment geology provides a source of selenium. Kingett & Associates (1987) reported that most samples of water collected from the Waitekauri catchment in the Coromandel had concentrations of Se <0.0005 g/m^3.

Based upon the limited Se information there is no evidence that Se concentrations are elevated in urban stormwater in Wellington. ANZECC (2000) identify a trigger value of 0.011 g/m^3 (as total Se) for a 95% level of protection in freshwater environments. The USEPA have recently revised their approach to the Se criteria and the criteria is not solely based on concentration in freshwaters (refer USEPA 2004). The acute criteria is based on in-water concentration (the 24-hour average concentration of total recoverable selenium in water seldom (e.g., not more than once in three years) exceeds 0.258 g/m^3 for selenite and the chronic criteria is based on Se concentration in fish tissue (refer USEPA 2004 for more information).

Overall, based upon a comparison with the ANZECC (2000) trigger value, the concentrations in Wellington urban stormwater are lower than the trigger value.

5.16 Silver

Silver (Ag) concentrations in the stormwater samples collected were <0.0001 g/m^3 in all samples but the Waring Taylor St site in central Wellington (commercial) where the concentration measured was just above detection at 0.0002 g/m^3.

Kennedy (2003b) provided an overview of Ag in the urban road environment as it related to the presence of Ag in urban street dusts. Low concentrations of Ag (e.g., <1 mg/kg) present in road surface particulate materials would not be detected in stormwater at the detection limits used (even with total acid digestion). Kennedy (2003b) reported elevated concentrations of Ag in street dusts in the Wellington region (refer Section 6.16).

ANZECC (2000) identify a trigger value of 0.05 mg/m^3 in freshwater and 0.0014 g/m^3 in marine waters for a 95% level of protection. USEPA (2002) has acute criteria for Ag in freshwater and marine waters of 0.0032 and 0.00019 g/m^3 (there are no chronic criteria). Based upon the non-detection of dissolved Ag in Wellington stormwater (at a LLD of 0.0001 g/m^3), dissolved Ag concentrations are lower than the ANZECC freshwater trigger value.

5.17 Strontium

Strontium (Sr) concentrations were measured in Wellington stormwater samples even though Sr is not normally considered to be of environmental significance. Strontium is a relatively common element in geological materials and is present in urban road surface materials at about 250 mg/kg (refer review by Kennedy 2003b). Strontium has moderate solubility in freshwaters. Concentrations in all stormwater samples ranged from 0.016 to 0.11 g/m^3 with a median concentration of 0.039 g/m^3. The Sr concentrations in stormwater from the residential and industrial/commercial catchments were 0.026 and 0.040 g/m^3 respectively (the difference was not statistically significant, p=0.44)

Fig. 5.10 shows that dissolved Sr concentrations in the stormwater samples collected in the region were similar and unrelated to TSS concentrations. One site appeared to have higher Sr concentration compared to other sites and it is possible that the different concentration observed in the Owhiro Stream reflects local catchment geology.

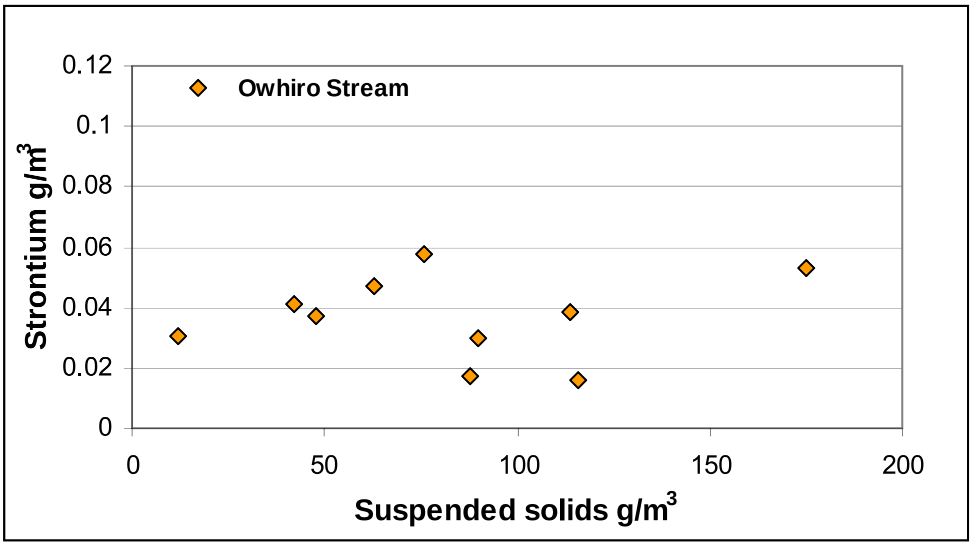

Fig. 5.10: Strontium in Wellington stormwater.

ANZECC (2000) and USEPA (2002) do not identify and triggers or criteria for the protection of fresh or marine biota.

5.18 Tin

Dissolved tin (Sn) was not detected in Wellington stormwater samples at a detection limit of 0.0005 g/m^3. There appears to be no published data for dissolved Sn or acid extractable Sn in urban stormwater.

There is limited data on the presence of Sn in urban road dusts and sediments (refer review of Kennedy 2003 and Section 6.16). Based upon data from Waitakere City (median concentration of 11.5 mg/kg acid extractable Sn in road surface particulates), a concentration of 11.5 mg/kg Sn in suspended particulates would provide a concentration of about 0.0011 g/m^3 of Sn in stormwater when suspended solids are at a concentration of 100 g/m^3 (based upon full extraction of the Sn present in the particulate matter). The low concentration in Wellington stormwater suggests that the availability, solubility or extractability of Sn in the sediments is likely to be low.

Neither ANZECC (2000) nor USEPA (2002) identify trigger values or criteria for the protection of aquatic life from exposure to Sn.

5.19 Vanadium

Dissolved vanadium (V) was not detected in any samples at a limit of detection of 0.001 g/m^3. No information has been sighted on V in urban stormwater. The concentration of V in freshwater is dependent on local geology and can range from 0.0002 to more than 0.1 g/m^3 (WHO 1988). Minelli et al. (2000) reported vanadium concentrations in surface waters and groundwater in selected sites in Italy ranging from 0.001 to 0.140 g/m^3.

Vanadium is a common element in soils and urban dusts etc., with concentrations around 75 mg/kg in sediment on Wellington roads (Kennedy 2003) (refer Section 6.13). If the total V concentration was measured, then the concentration during storm events would be expected to be about 0.005-0.010 g/m^3. It is likely that the non-detected concentrations reflect a low solubility and limited contamination of catchment environments.

ANZECC (2000) identify a trigger value of 0.1 g/m^3 for the protection of marine biota at a 95% level of protection. USEPA (2002) does not identify any criteria for the protection of aquatic biota. Although the detection limit used to measure V in this study was higher than the ANZECC (2000) guideline there is a high probability that the actual concentration is lower than the trigger value.

5.20 Zinc

Zinc (Zn) is a very common trace metal in the urban environment and urban stormwater can contain moderate to high concentrations of dissolved and total zinc. Table 5.6 which summarises the Wellington data for dissolved zinc and provides comparative New Zealand data from urban catchments, shows that the concentration in the residential catchments is significantly lower than the industrial/commercial catchments (p=0.036). This data is also shown in Fig. 5.11 where the commercial sites were separated from the industrial to highlight the difference between the industrial and residential catchments further.

Comparison of the median Zn concentrations in Wellington stormwater with other urban catchments shows that the concentrations are very similar to the Zn concentrations reported by Macaskill et al. (2003) for Rotorua City (Table 5.11). Examination of the Wellington data further as shown in Fig. 5.12 shows that the Te Roto Drive (Paraparaumu Industrial area) and the Parkside Drive (Gracefield Industrial area) stand out as having higher concentrations of Zn than would be expected irrespective of their suspended solids concentration.

Table 5.6: Median dissolved zinc concentrations in New Zealand urban stormwater and natural waters (all units g/m^3).

Site	Land-use	Median	Range	Reference
Residential				
Wellington	R	0.077	0.022-0.132	This study
Kaikorai Valley, Dunedin	R**	0.107	-	Mosley & Peake (2001)
Pakuranga, Manukau City	R	0.170,	-	ARC (1992)
Rotorua City	R	0.033	-	Macaskill et al. (2003)
Commercial Industrial				
Wellington	C/I	0.266	0.108-1.050	This study
Rotorua City	C	0.096	-	Macaskill et al. (2003)
Portobello Rd Dunedin	M	0.682	-	Brown & Peake (2001)
Halswell Junction,	C/I	0.435	-	Elliot (1996)
Rotorua City	I	0.172	-	Macaskill et al. (2003)
Natural baseline				
Manuherikia River	R	-	0.00007-0.0005	Ahlers & Hunter (1984)
Waitekauri River	R/B	0.00082 ± 0.00077*$^+$	-	Kingett & Associates (1987)
Ohinemuri River	M	-	0.0004-0.00084*	DSIR (1985)
Coromandel Streams	R/B	-	<0.0002-0.0008*	Beaumont et al. (1987)

Notes * - unfiltered acid extractable concentrations. + = average and one standard deviation. R = residential; C = commercial; I = industrial; M = mixed; R/B = rural and bush; ** with some industrial.

As identified in Table 5.6, concentrations of Zn in freshwaters in the absence of contamination are low, typically around 0.5 mg/m^3. With the suspended solids present in the samples collected, concentrations might naturally be of the order of 0.005 g/m^3 depending upon the extractability of the Zn in the suspended sediments.

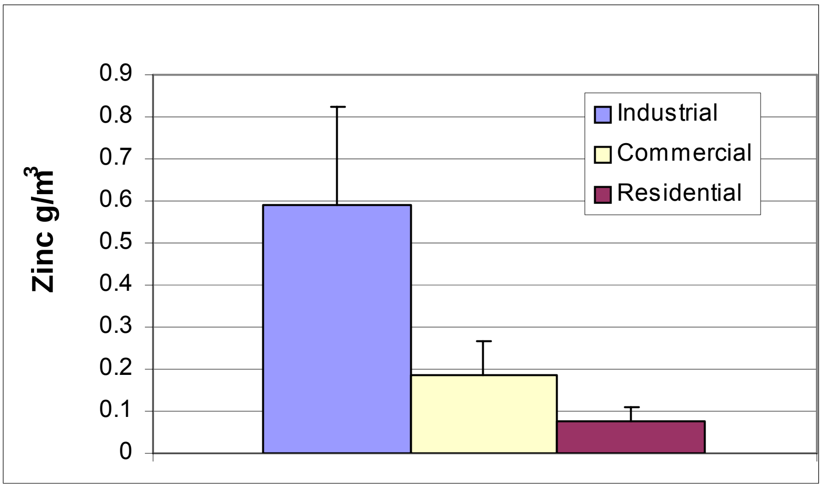

Fig. 5.11: **Dissolved zinc (median and standard error) concentrations in stormwater and landuse.**

ANZECC (2000) identify trigger values of 0.008 and 0.015 g/m^3 for a 95% level of protection in freshwater and marine environments respectively. The USEPA (2002) chronic criteria for protection of aquatic life in freshwaters and marine waters are 0.12 and 0.081 g/m^3. All samples collected were above the ANZECC (2000) triggers. When compared to the USEPA (2002) criteria, 1 of 6 samples from the residential catchments exceeded the chronic criteria and 4 of 5 samples from the industrial/commercial catchments exceeded the chronic and acute criteria (as the concentrations are the same for freshwater and similar for marine waters).

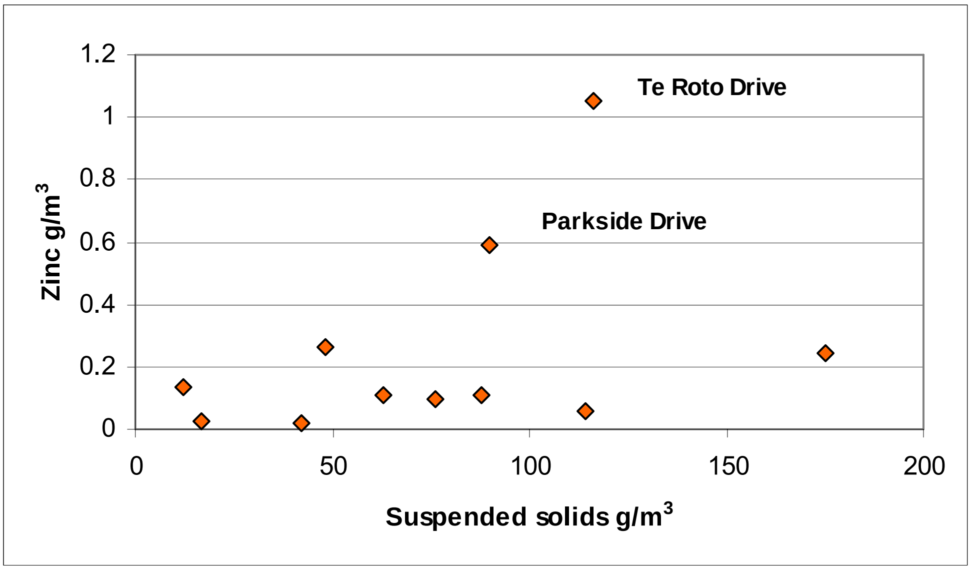

Fig. 5.12: **Zinc in Wellington stormwater.**

Overall, Zn concentrations in urban stormwater are elevated compared to natural concentrations. Concentrations were markedly elevated in two samples from industrial catchments (Refer to Fig. 5.12). Concentrations were typically higher than ANZECC trigger values but when compared to USEPA (2002) criteria for the protection of aquatic life, most of the samples collected from residential catchments were below the guideline. In industrial catchments most of the samples were above the criteria concentration.

5.21 Other elements

Analytical data was collected for a number of other dissolved elements during the ICMPS analysis of the stormwater samples. This data is summarised in Appendix 1.

Bismuth was not detected at <0.0001 g/m^3; thallium was not detected at <0.00005 g/m^3 in any sample; lanthanum was not detected at <0.0001 g/m^3 in most samples but was detected in six samples in the range 0.0001-0.0016 g/m^3. Caesium was not detected in most samples at a detection limit of <0.0001 g/m^3 with a detection at 0.0004 g/m^3 in 1 of 3 samples collected at industrial/commercial site 9.

Rubidium was detected at low concentrations in all samples within the range 0.0004-0.0039 g/m^3. Boron was detected in all samples within the narrow range 0.018-0.054 g/m^3 (refer Appendix 1 for individual site data). None of these elements were present at environmentally significant concentrations.

6. Metals in particulate material

6.1 Introduction

A range of metals were examined in two fractions of suspended particulates in stormwater using PIXE. The first fraction comprised the filterable solids above 0.45 µm and below 59 µm in size. For the purpose of this study and comparison with other information 59 µm has been assumed to be equivalent to the silt – fine sand boundary in the MIT (Massachusetts Institute of Technology) grain size classification system (refer Means & Parcher 1966). The second grain size fraction included materials within the size interval 60-249 µm. This corresponded to fine-medium sand boundary in the US bureau of soils classification (200 µm is the boundary separating fine and medium sand in the MIT and International classifications).

Within this section, information on particle size of suspended material in stormwater samples and the results of PIXE analysis of the particulate materials is presented. The PIXE analysis was undertaken on very small amounts of material. The weight of materials on the filter papers ranged from 9–28.8 mg (median 29.8 mg) for the 0.4-59 µm particles and

0.5-35.7 mg for the 60-249 µm particulate material (median 8.8 mg). It is likely that in the PIXE analysis, the mass on the filter paper influences the analytical signal interpreted as concentration of a particular element. Typically a minimum mass of material is required to obtain a suitable signal to interpret. Figs. 6.1 and 6.2 shows that at lower mass higher concentrations are found for some elements (e.g., silver). In both figures note that both the x-axis and the y-axis scale are log scales.

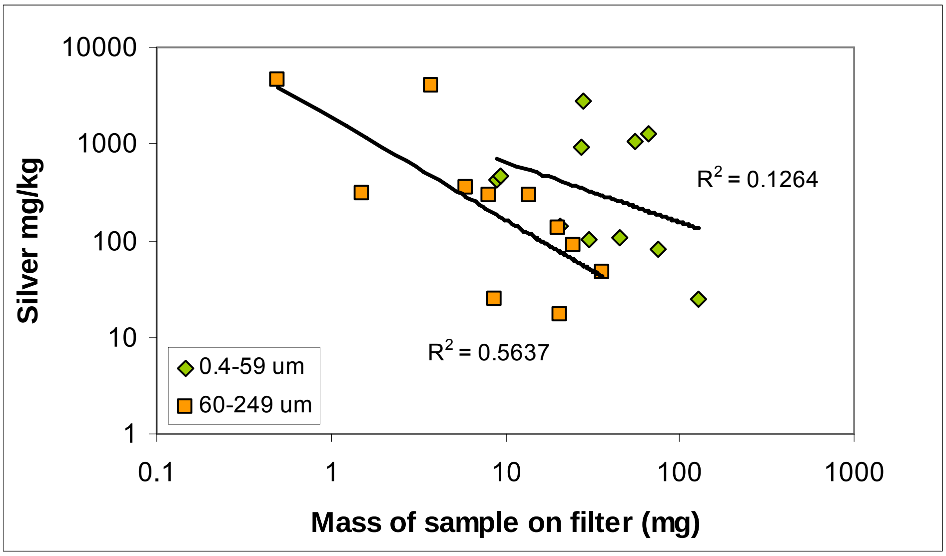

Fig. 6.1: **Silver concentration data obtained using PIXE and sample mass for two particle size classes obtained from Wellington stormwater.**

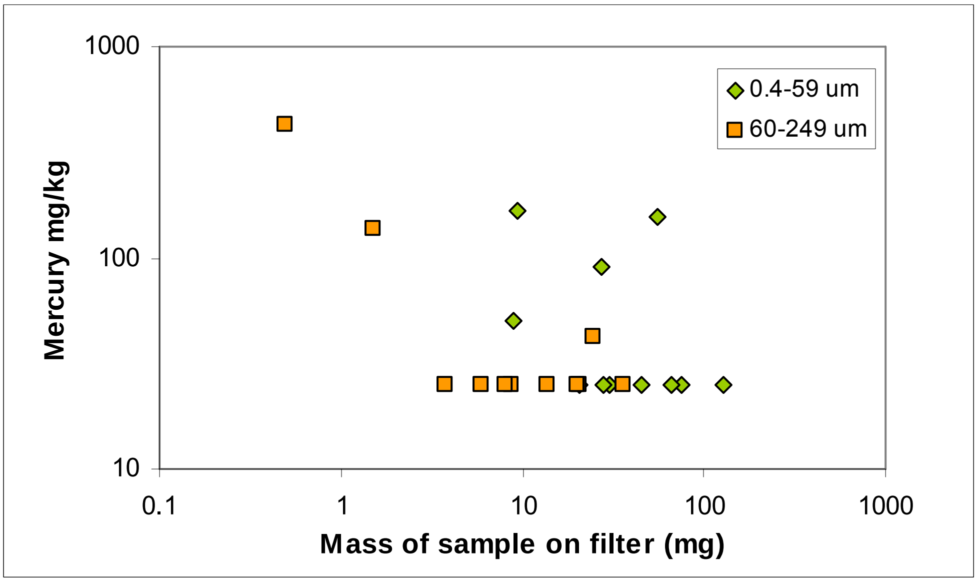

Fig. 6.2: **Mercury concentration data obtained using PIXE and sample mass for two particle size classes obtained from Wellington stormwater.**

On the basis of the possible influence of low sample mass on PIXE results, the data for two samples was excluded from the assessment. The two samples were 1 (Owhiro Stream site) and 11 (Grasslea Reserve site) for the 60-249 µm suspended solids fraction. A further sample which had slightly higher (but still low) sample mass (sample 6 - Te Roto drive) was included in the assessment.

In the following sections, the data for each of the metals determined using PIXE are discussed. Some comparative data is provided including some road surface particulate concentration data from Kennedy (2003). That publication contains a summary of much of the New Zealand data in this area. In addition where data is available, comparative information on natural concentrations of the elements (e.g., unpublished concentration data for stream sediments from Pauatahanui Inlet) and any published information on the concentrations of metals in suspended sediments in stormwater is presented. For each element, information on the concentrations relative to any ANZECC (2000) sediment quality guidelines is also given.

6.2 Particle size

Proportions of suspended particulate material retained on filter papers during the analysis of metals were determined by drying and weighing filter papers before and after filtration. Table 6.1 summarises the information obtained during the analysis of metals in particulate matter. The data provides a broad indication that much of the suspended particulate matter included in the samples collected was <59 µm in size (i.e., less than silt size).

Table 6.1: Particle size distribution in suspended sediment samples (all units % by weight).

	Median	Minimum	Maximum
<59 µm			
Residential	67.49	36.79	85.71
Commercial/Industrial	82.09	46.61	92.73
>60 - <249 µm			
Residential	25.46	3.7	44.07
Commercial/Industrial	8.96	5	33.9
>249 µm			
Residential	11.64	0	25.93
Commercial/Industrial	8.96	1.44	19.49

Kennedy (2003b) reviewed New Zealand information on particulate matter in stormwater in New Zealand. ARC (1992) reported particle size distribution information in residential and industrial stormwater in the Auckland area. The work showed that <63 µm sized particles dominated samples examined accounting for 51.1-87.75% of the particle mass.

Examination of particles in large bulk samples indicated a lower proportion in the <63 μm fraction (37.5%) with a greater proportion in the >249 μm fraction (12.3%). In earlier work in North Shore City, Williamson (1985) found that 50% of particulates were <26 μm in size.

A variety of overseas work has shown that stormwater particles are dominated by fine sediment. Roger et al. (1998) found that suspended sediments were dominated by particles less than 50 μm in size (86%). When the mass of the sediment transported in the runoff in suspension and that carried as bed load were considered, Roger et al. (1998) determined that 77.8% of all of the material transported was <50 μm in size.

Overall, the Wellington stormwater particle data is representative of data reported in the international and New Zealand literature. That is, about 70% of the suspended particles are <59 μm in size.

6.3 Aluminium and Rubidium

Aluminium (Al) is a key structural element in silicate minerals in soils and sediments. Rubidium (Rb) is a relatively common element that tends to mimic the distribution of many common elements in silicate matrices (e.g., potassium etc.). Rubidium is generally closely related to Al concentration in soils and sediments of the Wellington region. The relationship is dependent upon the sample extraction used for the analysis. Table 6.2 summarises the Al concentration and Table 6.3 the Rb data for the two grain size fractions.

Fig. 6.3 shows the broad relationship between Al and Rb in the stormwater particulate samples collected. Variations in the concentration of either element are generally not considered to have any environmental significance. Both Rb and Al are elements where the natural global flux is much greater than the anthropogenic contribution. Klee & Graedel (2004) estimated the anthropogenic mobilisation of these elements to be 25% and 26% respectively.

Table 6.2: Aluminium in Wellington stormwater suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	maximum
<0.4-59 μm			
Residential	27,830	15,513	60,445
Commercial/Industrial	33,178	18,313	62,463
>60-<249 μm			
Residential	17,475	10,353	18,116
Commercial/Industrial	30,805	16,604	63,382

Table 6.3: Rubidium in Wellington stormwater suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	maximum
<0.4-59 µm			
Residential	91	70	147
Commercial/Industrial	226	108	250
>60-<249 µm			
Residential	71	47	182
Commercial/Industrial	80	80	165

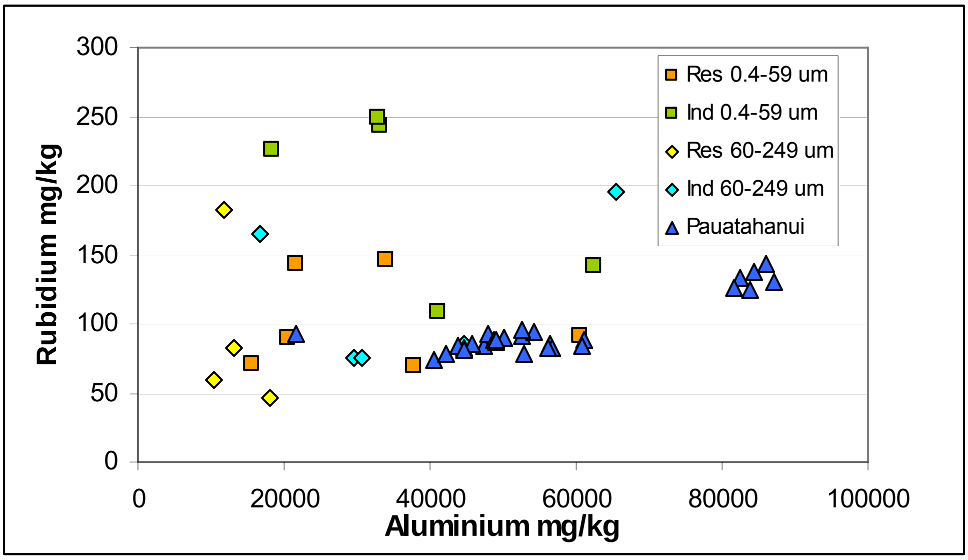

Fig. 6.3: Aluminium and rubidium in particulate matter in Wellington stormwater.

There is a broad scatter in some of the stormwater data which is assumed to be a reflection of contributions to the stormwater system rather than analytical variation. Of interest is the higher concentration of Rb in the finer particles of suspended solids from the commercial/industrial catchments.

There are no sediment quality guidelines for Al or Rb in ANZECC (2000).

In the following sections, the Al data that is available for all samples is used as a comparative ‘benchmark’ to identify how much sediment may be present in the sample. As shown in Fig. 6.3, there tends to be a natural relationship between natural concentration of Al and many elements (in that case Rb) as most elements are associated with the particulate minerals through sorption or being present within the mineral matrix.

6.4 Arsenic

For arsenic (As) a significant number of analytical results (14 of 20) were measured as less than the detection limit (20 mg/kg). With the two particulate fraction samples of low sample mass excluded, the range of detected concentrations were 35-81 mg/kg in the samples of 60-249 µm material and 31-51 mg/kg in the samples of 0.4-59 µm material (three samples in each case). Natural concentrations of arsenic are variable (Kennedy 2003b) with soils in the region typically having concentrations ranging up to 10 mg/kg.

Data for sediments from Pauatahanui Stream (Kennedy unpublished) ranged from non detectable (<1 mg/kg) in sand fractions with fine sediments (<35 µm) containing up to 10.8 mg/kg. Particulate matter from Waitakere City roads contained up to 14 mg/kg of arsenic (Kennedy & Gadd 2003) and particulate matter from Auckland City roads contained up to 6 mg/kg (Ng et al. 2003). Examination of a range of gutter dust samples from Wellington and Lower Hutt identified an upper concentration of 11.2 mg/kg (n=63) (Kennedy 2003b). That sampling included some locations within catchments encompassed by the current study. As such it is likely that the As data derived through PIXE analysis in this study overestimated the As present in those samples that it was detected.

ARC (1992) reported low concentrations of As in suspended solids from stormwater from the Pakuranga catchment in Auckland. The concentrations ranged from 8.1 in >250 µm particles to 18 mg/kg in 120-250 µm particles with the <20 µm particles containing 11 mg/kg (the weighted whole sample average was 13 mg/kg). It is not possible to determine at this stage whether the detected As concentrations in the Wellington stormwater samples is identified elevated concentrations of As or not.

ANZECC (2000) does not have a sediment quality trigger for As.

6.5 Barium

Barium (Ba) concentrations in stormwater particulate matter ranged from <50 mg/kg up to 1,366 mg/kg (two data points of ~1,500 mg/kg were excluded due to low sample mass). Data is summarised in Table 6.4. When the samples from the two land-uses were combined, the Ba concentration was higher in the finer fraction (<59 µm) compared to the coarser particulate material (p=0.019).

Table 6.4 Barium in Wellington stormwater suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	maximum
<59 µm			
Residential	339	<50	1,302
Commercial/Industrial	468	364	1,366
>60-<249 µm			
Residential	153	<50	288
Commercial/Industrial	<50	<50	579
Road surface particulates			
Waitakere City <63 µm [1]	147.5	82.4	333
Gracefield – Ind <2 mm [2]	515	505	614
Petone – Res <2 mm [2]	523	416	575

Notes: [1] – From Kennedy & Gadd (2003); [2] – From Kennedy (2003b).

Fig. 6.4 shows Ba data for both particulate size fractions obtained from Wellington stormwater. A number of predominantly coarser particle size samples were found to contain low concentrations of Ba (<50 mg/kg). The concentrations of Ba were too low given the moderate to high natural concentration of Ba in sediments in the Wellington region. It is possible that these data are an artefact of the analytical method used to determine Ba.

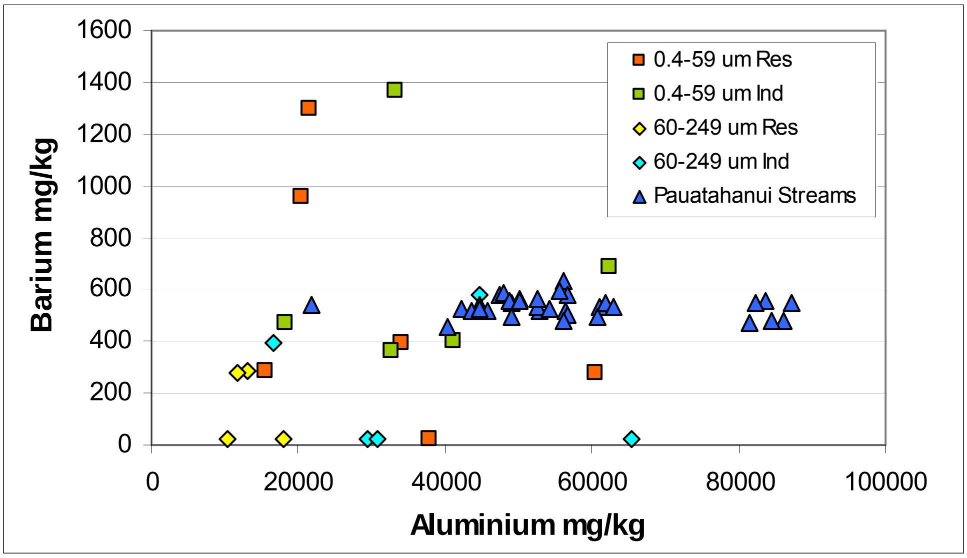

Fig. 6.4: Barium in particulate matter in Wellington stormwater.

The cause of the low concentrations was not identified as low or alternatively very high concentrations of other elements were not reported in these samples. The majority of the concentration data was similar to that measured in sediments from Pauatahanui Stream (refer Fig. 6.4).

Kennedy (2003b) provides a brief overview of Ba soil concentrations. Concentrations of Ba in road gutter dusts in the Wellington and Lower Hutt area had medians ranging from 515 to 877 mg/kg, similar to those measured in this study.

Klee & Graedel (2004) estimated the global anthropogenic mobilisation of Ba to be 80%. Ba is a common constituent in the emissions from motor vehicles as Ba is a common constituent of the material in brake pads (Kennedy 2003b).

ANZECC (2000) has not identified a sediment quality guideline for Ba.

Overall, Ba concentrations in stormwater particulate material are similar to those present in Wellington stream sediments. Several samples collected from both residential and industrial/commercial catchments contained high concentrations. Elevated concentrations of Ba have been reported in urban road-surface particulate material in the Wellington region and elsewhere in New Zealand.

6.6 Cobalt

Cobalt concentrations in soils vary depending upon the geological material the soils were derived from. As an example, ARC (2001) reported median Co concentrations in most soils in the Auckland area as having medians below 10 mg/kg. One group of soils derived from volcanic materials had a mean slightly over 40 mg/kg with a maximum concentration of above 160 mg/kg. Kennedy & Gadd (2003) reported a median strong acid extractable Co concentration for road surface materials in Waitakere City of 21 mg/kg (range 11-32 mg/kg, n=34) and Fergusson & Ryan (1984) reported a median Co concentration on Christchurch roads of 10 mg/kg (range 9.3-36 mg/kg). A range of overseas studies have reported Co concentrations in materials on road surfaces (refer Kennedy 2003b) with medians ranging from 3 to 19 and a highest reported concentration of 17 mg/kg (in the cases where data was reported).

Examination of the PIXE data for both grain size fractions in the suspended solids showed that there was considerable variation in the concentrations measured.

The concentrations in the 0.4-59 µm fraction from residential catchments had a median of 19 mg/kg (range 5-49 mg/kg). A higher median was identified for the 60-249 µm fraction samples taken from the residential catchments (69 mg/kg, 25-104 mg/kg). The analytical data indicates that the samples from industrial catchments might have higher Co concentrations. In both fractions, the range in concentration is large with the 0.4-59 µm samples ranging from a low similar to the residential samples (12 mg/kg) up to 1,100 mg/kg. Likewise for the coarser fraction the results ranged from 14-457 mg/kg. The elevated concentrations in both fractions occurred in three geographically separated catchments (Nos. 6 – Te Roto Drive; 7 – Semple Street; 8 – Hutt Park Road

Table 2.1). The cause of this unusual elevation in these three samples (analytical or environmental contamination) has not been identified.

Klee & Graedel (2004) estimated the anthropogenic mobilisation of Co to be small at 6%. Cobalt is not a significant contaminant on road surfaces and vehicle contributions appear small (Kennedy 2003b). ANZECC (2000) has not identified a sediment quality guideline for Co.

6.7 Cadmium

Cadmium (Cd) was detected in one of eleven 0.4-59 µm fraction samples and four of nine samples of 60-249 µm particulate material. The detected concentrations ranged from 27-219 mg/kg. The natural concentration of Cd in soils is generally low (Kennedy 2003b). Kennedy (2003b) summarised Cd concentrations from a number of studies which had maximum concentrations ranging up to 21 mg/kg. Given that the LLD for the PIXE analysis in this study (20 mg/kg) is well above the normal gutter/road dust Cd concentration of <10 mg/kg, it is likely that the analytical detection limit and method is not sufficiently accurate and precise to detect (with confidence) elevated concentrations of Cd in the Wellington stormwater suspended sediment samples.

The natural concentration of Cd in sediments in the Wellington region is <0.1-1 mg/kg in fine sediments and can be very low in sandy sediments (<0.01 mg/kg).

ARC (1992) reported moderate concentrations of Cd in suspended solids from stormwater from the Pakuranga catchment in Auckland. The concentrations ranged from 0.44 in 20-47 µm particles to 1.7 mg/kg in 120-250 µm particles with the <20 µm particles containing 0.83 mg/kg (the weighted whole sample average was 0.89 mg/kg).

Klee & Graedel (2004) estimated the global anthropogenic mobilisation of Cd to be significant at 17% and Kennedy (2003b) provided a rough order estimate of the contribution of motor vehicles to road surface particulate Cd concentrations of about 15%.

ANZECC (2000) has sediment quality trigger concentrations of 1.5 and 10 mg/kg corresponding to the ISQG-Low and ISQG-High respectively. As the analytical detection limit for Cd in this study is well above the ANZECC (2000) sediment quality guidelines it is not possible to provide any conclusive indication as to the relative quality of the stormwater suspended particulate material. It is likely based on other New Zealand data that the concentrations are not significantly elevated compared to the ANZECC (2000) guideline values.

6.8 Chromium

Chromium concentrations in stormwater suspended particulates collected in this study are summarised in Table 6.5. The data indicated that concentrations were lower in the samples from residential catchments compared to the samples from industrial/commercial catchments. The difference was not statistically significant in the finer fraction but was statistically different within the coarser fraction (p=0.053 untransformed, p=0.028 log-transformed). Variability was high in all groups of samples except for the coarser samples from residential catchments.

Table 6.5 Chromium in Wellington stormwater suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	maximum
<59 µm			
Residential	53	16	106
Commercial/Industrial	67	5	178
>60-<249 µm			
Residential	32.5	25	43
Commercial/Industrial	132	34	220
Road surface particulates			
Waitakere City <63 µm [1]	86.5	39	178
Gracefield – Ind <2 mm [2]	62	53	76
Petone – Res <2 mm [2]	49	35	110

Note [1] – From Kennedy & Gadd (2003); [2] – From Kennedy (2003b).

Comparison of the median concentrations with data for uncontaminated sediments in the Wellington region and data available for road surface and road gutter particulates shows that the coarser particulates from the residential catchments contain low concentrations of Cr and generally similar to what would be expected in stream and coastal sediments and soils in the region (i.e., about 40-60 mg/kg) (Kennedy 2003b).

The remaining samples contain Cr at concentrations ranging from low to higher than would be expected compared to background soils and sediments. Comparison with data for road surface particulates indicates that the concentrations measured are similar to those measured in a number of studies of Cr in road surface particulates (refer examples in Table 6.2). ARC (1992) undertook Cr analysis of suspended particulates collected from stormwater from the residential catchment of Pakuranga with the concentrations ranging from 29 mg/kg in 20-47 µm particles up to 126 mg/kg in 150-250 µm particles with 50 mg/kg in the <20 µm particles (the weighted sample average was 61 mg/kg). The Wellington and Pakuranga Cr concentrations are similar.

Klee & Graedel (2004) estimated the global anthropogenic mobilisation of Cr to be significant at 99%. Although Cr is a relatively common element in the New Zealand environment the relative degree of mobilisation is likely to be smaller. Kennedy (2003b) provided a rough order estimate of the contribution of motor vehicles to road surface particulate Cr concentrations of 40-50%.

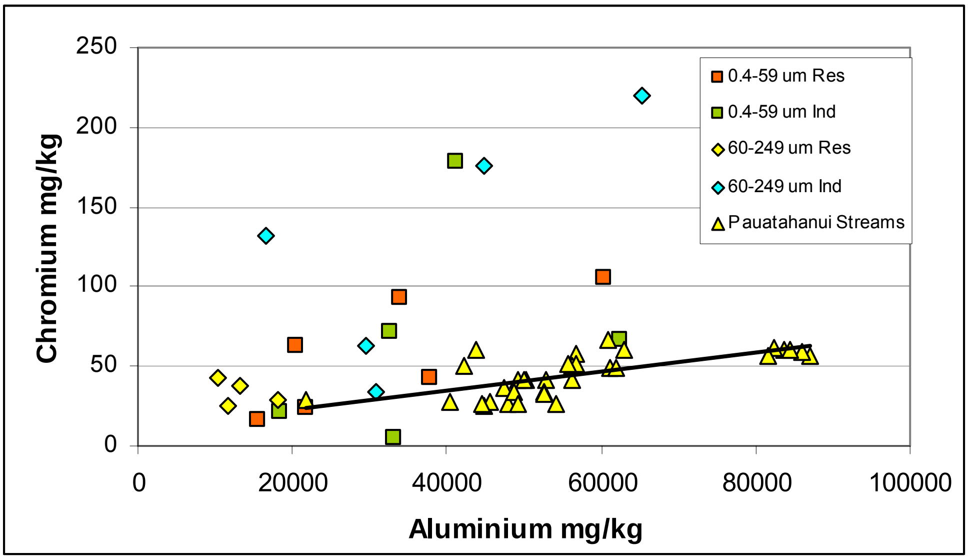

Fig. 6.5: Chromium in particulate matter in Wellington stormwater.

ANZECC (2000) have identified sediment quality guidelines for Cr with the ANZECC (2000) ISQG-Low and ISQG-High being 80 and 370 mg/kg respectively. In the samples of particulates from the residential catchments, two of ten samples (combining the samples from the two fractions as if they were different samples) had concentrations over the ISQG-Low. In the samples from industrial catchments the corresponding number was four of ten samples over the ISQG-Low guideline. In those catchments where the concentrations are higher than the ISQG-Low guideline, the particulate material will have some potential to increase local sediment Cr concentrations depending upon the local sediment contributions (as concentration is influenced by the deposition of contaminated versus uncontaminated sediments).

6.9 Copper

Table 6.5 summarises copper (Cu) data in suspended particulates from stormwater collected in this study. Copper concentrations in most soils, stream and other sediments in the Wellington region are low (refer Kennedy 2003b). As with Co, Cu concentrations can be elevated in some soils, especially if influenced by volcanic parent materials. When compared to the concentration of Cu measured in road surface particulate materials, the concentrations in either the residential or industrial land use categories were similar to other published data (refer Table 6.6).

The Cu concentration was higher in the coarse particulates from commercial catchments compared to the finer particles. For a given particulate fraction, the average Cu concentration is higher in the samples from industrial/commercial catchments compared to residential catchments. In the case of the coarser suspended particles although this was a factor of at least two times, the difference was not statistically significant (i.e., p>0.05, data log transformed).

Table 6.6: Copper in Wellington stormwater suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	Maximum
<59 µm			
Residential	166.5	10	405
Commercial/Industrial	227	161	21,682
>60-<249 µm			
Residential	135.5	21	296
Commercial/Industrial	374	130	633
Road surface particulates			
Waitakere City <63 µm [1]	297	142	539
Gracefield – Ind <2 mm [2]	129	67	294
Petone – Res <2 mm [2]	93	32	153

Note: [1] – From Kennedy & Gadd (2003); [2] – From Kennedy (2003b).

ARC (1992) undertook Cu analysis of suspended particulates collected from stormwater from the residential catchment of Pakuranga. Concentrations ranged from 123 mg/kg in <20 µm particles up to 187 mg/kg in 150-250 µm particles (the weighted sample average was 153 mg/kg). Comparison of the Pakuranga data with the Wellington data in Table 6.6 indicates that the concentrations are similar.

Comparison of the Cu data with stream sediment data collected in the region shows that the suspended solids collected from the stormwater carries a relatively high Cu concentration with few samples having concentrations that would be considered uncontaminated. Only one sample of stormwater suspended sediment collected in this study which contained 10 mg/kg Cu was close to what would be considered a background concentration (Fig. 6.6). Glasby et al. reported a concentration of 20 mg/kg for <20 µm particulates in sediments in Pauatahanui Inlet.

ANZECC (2000) have identified sediment quality guidelines for Cu with the ANZECC (2000) ISQG-Low and ISQG-high being 65 and 270 mg/kg respectively. In the samples of particulates from the residential catchments, eight of 10 samples (treating the two particle size fractions as different samples) had concentrations over the ISQG-Low. In the samples from industrial catchments all samples had concentrations over the ISQG-Low trigger. In the residential catchment samples, two of 12 samples were higher than the ISQG-High trigger and five of 11 samples from the industrial catchments had concentrations that were higher than the ISQG-High trigger.

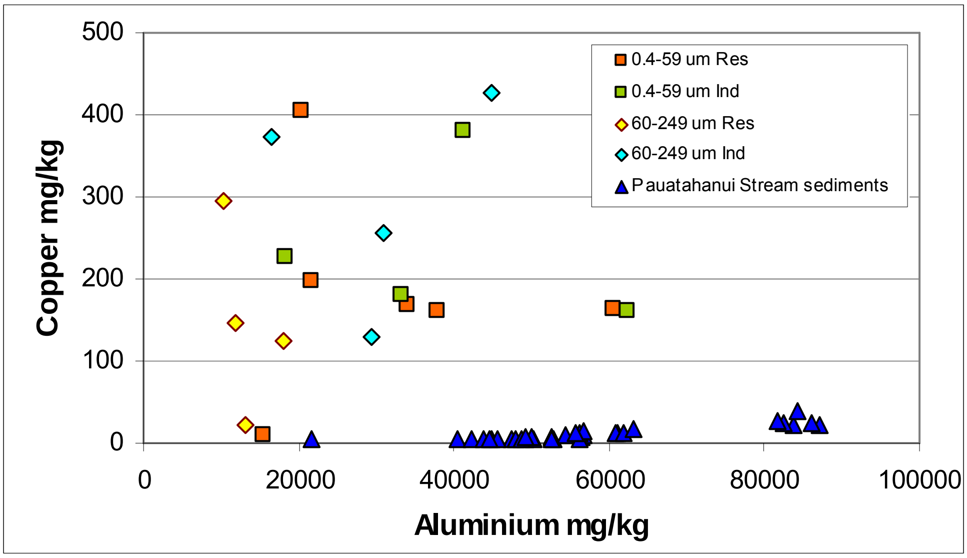

Fig. 6.6: Copper in particulate matter in Wellington stormwater.

Overall, the Cu data shows a significant enrichment of Cu in stormwater suspended particulates. Although, the degree of enrichment is generally greater in industrial/commercial catchments compared to residential catchments, the difference in this study was not statistically significant. Klee & Graedel (2004) estimated the global anthropogenic mobilisation of Cu to be significant at 85% and Kennedy (2003b) provided a rough order estimate of the contribution of motor vehicles to road surface particulate Cu concentrations at 40-50%.

6.10 Lead

Table 6.7 summarises the concentration of lead (Pb) in suspended solids in Wellington urban stormwater. Table 6.7 shows that the median concentration of Pb in the fine particulate suspended particulate material in Wellington stormwater was similar. The concentrations in the coarser fraction displayed a higher concentration in the commercial compared to residential catchments difference between the two particle sizes and land-uses. This difference was not significantly different due to the variability in the concentrations within each land-use ($p>0.05$, log-transformed).

Upper concentrations of Pb were about 1,000 mg/kg with the exception of the sample from the Parkside Rd site in Lower Hutt. In that catchment, there is a history of industrial Pb use (e.g., battery factory). The high concentrations noted in Table 6.7 for Pb in road surface particulates in Gracefield are derived from lead in petrol and from industrial source using Pb.

Table 6.7: Lead in Wellington stormwater suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	maximum
<59 µm			
Residential	302.5	78	1,076
Commercial/Industrial	298	248	896
>60-<249 µm			
Residential	232	34	685
Commercial/Industrial	405	232	3,391
Road surface particulates			
Waitakere City <63 µm [1]	276	151	559
Gracefield – Ind <2 mm [2]	923	639	3,495
Petone – Res <2 mm [2]	888	207	1,999

Note [1] – From Kennedy & Gadd (2003); [2] – From Kennedy (2003b).

Concentrations of Pb in soils and sediments that have not been subject to contamination are typically low, at around 10 mg/kg with fine silts and clays containing concentrations of up to 25 mg/kg. The steam sediments from Pauatahanui Inlet shown in Fig. 6.7 (P Kennedy unpublished) have a median concentration of 17 mg/kg and a range of 9-34 mg/kg (this is similar to the concentrations of 27 mg/kg for <20 µm particulates reported by Glasby et al. (1990) for sediments from Pauatahanui Inlet). The lowest Pb concentrations measured and summarised in Table 6.7 is 34 mg/kg in one of the residential catchments. The next closest concentration was 72 mg/kg indicating that most if not all of the suspended particulates collected were significantly contaminated by Pb.

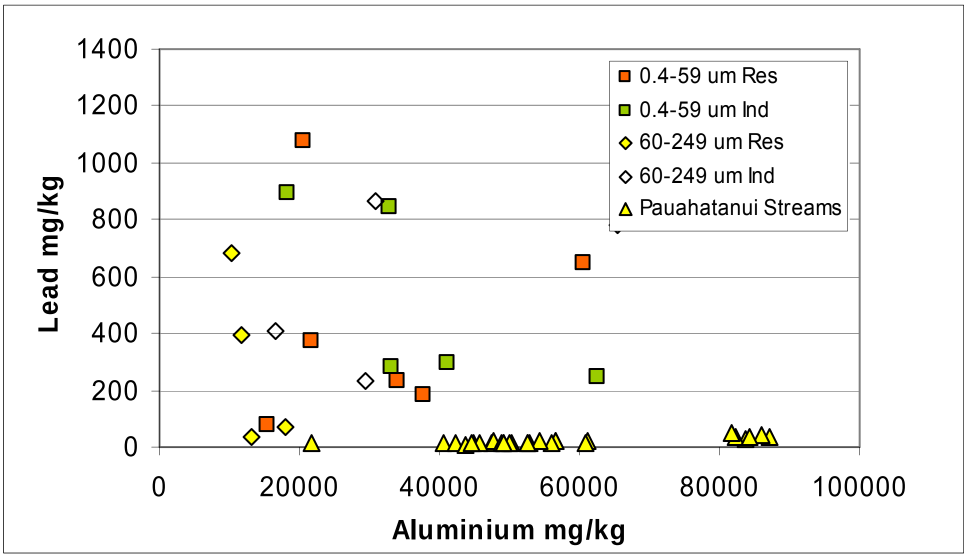

Fig. 6.7: Lead in particulate matter in Wellington stormwater.

ARC (1992) undertook Pb analysis of suspended particulates collected from stormwater from the residential catchment of Pakuranga with the concentrations for the different particle size fractions ranging from 392 to 939 mg/kg. Although the Pakuranga concentration data was collected prior to the removal of Pb from petrol, the concentrations are similar to the upper concentrations measured in the Wellington stormwater samples.

Klee & Graedel (2004) estimated the anthropogenic mobilisation of Pb to be significant at 84% and Kennedy (2003b) provided a rough order estimate of the contribution of motor vehicles to road surface particulate Pb concentrations of 50-60%. Historically Pb has been mobilised on a global scale with significant Pb contamination through most urban environments. There is information in New Zealand suggesting that since Pb was removed from petrol the flux of Pb to the New Zealand coastal environment and contamination of sediments has reduced and or declined (refer ARC regional sediment monitoring programme, Reed & Webster 2004).

ANZECC (2000) have identified sediment quality guidelines for Pb with the ISQG-Low and ISQG-high being 50 and 220 mg/kg respectively. In the samples of particulates from the residential catchments, nine of 10 samples (combining the data from both particle size fractions) had concentrations over the ISQG-Low. In the samples from industrial catchments all samples had concentrations over the ISQG-Low trigger. When the data is compared to the ISQG-High trigger, six of 10 residential samples were over the high trigger and all samples from industrial/commercial catchments. In all, 16 of 20 samples were over the upper trigger value. This would indicate that the particulate materials have the potential to increase the concentration of Pb in receiving environment sediments.

Overall, the concentration of Pb in all samples of stormwater suspended particulate examined from the Wellington region showed evidence of significant contamination and most samples had concentrations that were higher than the ANZECC (2000) ISQG-High trigger value.

6.11 Nickel

Table 6.8 presents a summary of the nickel (Ni) concentrations measured in suspended sediment samples collected from Wellington stormwater. The concentrations are similar to those measured in road surface/gutter sediment data from the Wellington region (e.g., refer Kennedy 2003b). ARC (1992) reported Ni concentrations in stormwater particulates collected from Pakuranga in Auckland ranging from 12–54 mg/kg with a weighted whole sample average of 25 mg/kg. Examination of the data in Table 6.8 shows that the median Ni concentration in samples from commercial/industrial catchments is higher that that from residential catchments. The difference is however not significant (p.0.05).

Table 6.8 Nickel in suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	Maximum
<59 µm			
Residential	17.5	<10	29
Commercial/Industrial	15	<10	40
>60-<249 µm			
Residential	12.5	<10	25
Commercial/Industrial	31	<10	106
Road surface particulates			
Gracefield industrial <2 mm[1]	19	17	20
Karori residential <2 mm[1]	21	13	25

Note [1] – From Kennedy (2003b).

Fig. 6.8 illustrates the relationship between Al and Ni in stormwater particulates and comparative Wellington stream sediments. The Wellington stream sediment particle Ni data indicates that there is a relationship between the Ni concentration and Al which is a reflection of decreasing particle size (the finer clays etc., having higher Ni concentrations). Overall, the data in Fig. 6.8 indicates that some of the suspended sediment samples collected from Wellington stormwater have Ni concentrations similar to those measured in the Pauatahanui Stream sediments.

Klee & Graedel (2004) estimated the global anthropogenic mobilisation of Ni to be significant at 69% and Kennedy (2003b) provided a rough order estimate of the contribution of motor vehicles to road surface particulate Ni concentrations of about 45%.

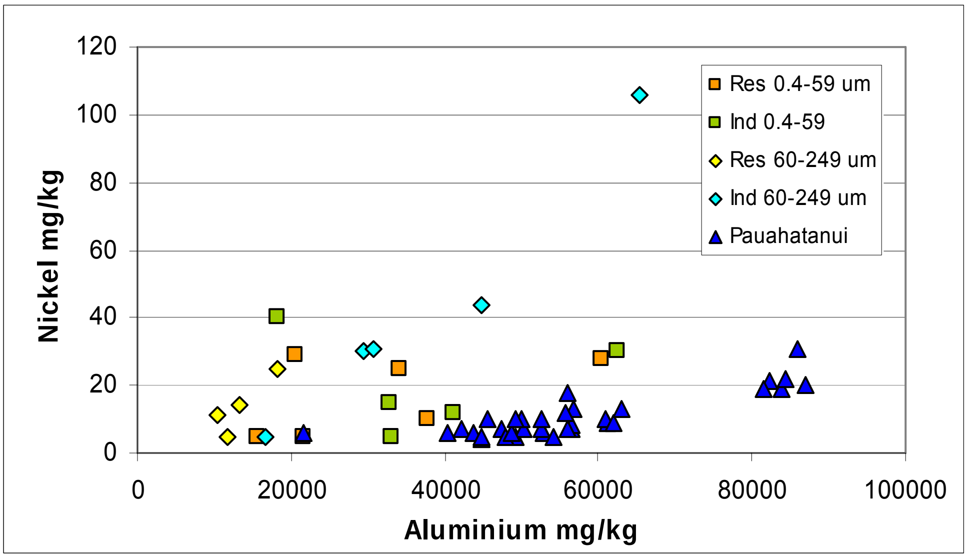

Fig. 6.8: Aluminium and nickel in particulate matter in Wellington stormwater.

ANZECC (2000) have identified sediment quality guidelines for Ni with the ISQG-Low and ISQG-High being 21 and 52 mg/kg respectively. Four of 10 residential and six of 10 industrial catchment samples had concentrations higher than the ISQG-Low (10 of 20 samples). Only one sample (from Te-Roto Drive, an industrial catchment) had a Ni concentration higher than the ANZECC ISQG-High.

Overall, the examination of Ni in stormwater particulates collected in the Wellington region indicates limited contamination. About 50% of suspended particulate samples had concentrations over the ISQG-Low but it should be noted that the ISQG-Low trigger is only slightly higher than what might be considered a local median sediment concentration and is lower than the concentration of Ni naturally present in fine stream sediments in some parts of the Wellington region.

6.12 Strontium

Table 6.9 presents a summary of the strontium (Sr) concentrations measured in suspended sediment samples collected from Wellington stormwater. The concentration data obtained indicates that the median Sr concentration for samples collected from residential catchments (for both particle size fractions) is lower than that in the suspended sediments from the industrial catchments. The differences observed were not statistically significant in either case ($p>0.05$). The median concentrations appear on first comparison to be lower than those concentrations measured previously in whole (<2 mm) road gutter sediments collected in the Wellington region (refer Kennedy 2003b).

Table 6.9: Strontium in suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	Maximum	N
<59 µm				
Residential	88.5	58	565	6
Commercial/Industrial	118	57	140	5
>60-<249 µm				
Residential	127	68	140	4
Commercial/Industrial	153	105	440	5
Road surface particulates				
Seaview industrial <2 mm[1]	217	163	281	12
Karori residential <2 mm[1]	246	213	362	12

Note [1] – From Kennedy (2003b).

Fig. 6.9 illustrates the relationship between aluminium and Sr in stormwater particulates. The stream sediment particle Sr data indicates that there is a relationship between the Sr concentration and aluminium which is a reflection of decreasing particle size (the finer clays etc having higher Sr concentrations). Data in Kennedy (2003b) indicated that the Sr/Al relationship may be unclear but that fine sediment particles may have concentrations higher than some coarse particles but similar to very coarse particles) (>0.5 mm) where clays make up part of the material in lithic (rock) fragments.

Strontium is not an environmentally significant element and ANZECC (2000) has not identified any sediment quality trigger values for Sr.

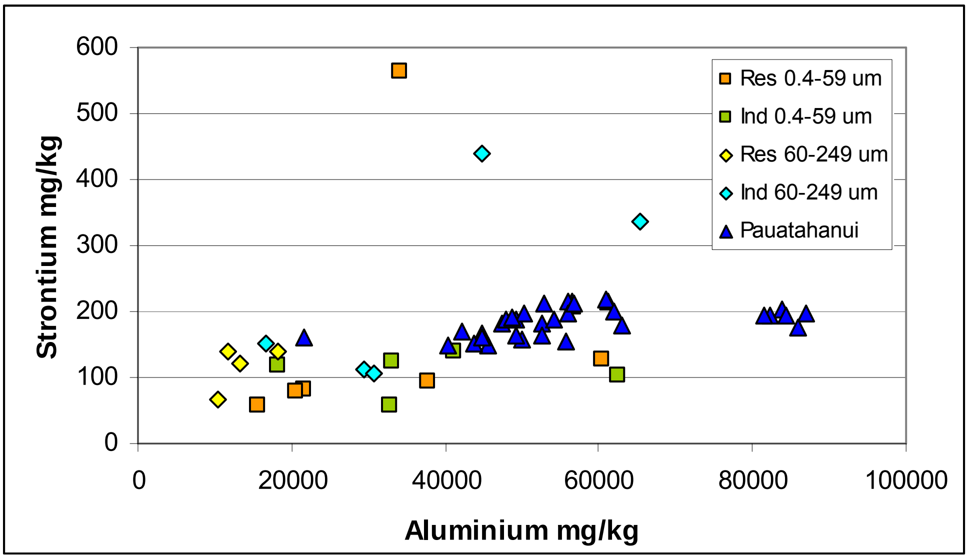

Fig. 6.9: Aluminium and strontium in particulate matter in Wellington stormwater.

Overall, the data in Fig. 6.9 indicates that most of the suspended sediment samples examined have Sr concentrations similar to those measured in the Pauatahanui Stream sediments. Several samples however had concentrations significantly higher than the main body of data (2 industrial samples (60-249 µm) and one residential sample (0.4-59 µm).

6.13 Vanadium

Table 6.10 presents a summary of the vanadium (V) concentration data for the suspended sediment samples collected in this study. The concentration of V in the fine particulate fraction (<59 µm) samples from industrial/commercial catchments is higher than that from residential catchments ($p=0.037$). Although the concentration in the coarser suspended particulate material (59-249 µm) from the industrial/commercial catchments was higher than that from the residential catchments, the difference was not statistically different ($p=0.06$ log transformed). The higher concentration in the industrial/commercial land-use was attributable to the vanadium concentrations is three samples (412-757 mg/kg) from geographically separate catchments in the region (sites 6, 7 and 8).

Table 6.10 Vanadium in suspended sediment samples (all units mg/kg by weight).

	Median	Minimum	Maximum	N
<59 µm				
Residential	72	41	105	6
Commercial/Industrial	412	54	757	5
>60-<249 µm				
Residential	82.5	40	130	4
Commercial/Industrial	135	96	211	5
Road surface particulates				
Waitakere City street surface <63 µm[1]	117	<100	417	34
Seaview industrial <2 mm[2]	75	37	92	12
Karori residential <2 mm[2]	69	66	74	12

Note [1] – From Kennedy & Gadd (2003); [2] – From Kennedy (2003b).

When the residential and commercial particle fractions are combined there is a significant difference between the concentration of particles from residential compared to industrial/commercial catchments (p=0.021). It is likely that the significance is strongly influenced by the three outliers from the industrial catchments.

The data obtained indicates that the median V concentration for samples collected from residential catchments (for both particle size fractions) is similar to concentrations of V measured previously in particulate matter collected from street gutter surfaces in the Wellington region (Data from Kennedy 2003b).

Other data such as that from Waitakere City indicates that concentrations of V may be higher, however, in that case, the elevated concentrations (determined using strong acid extraction) may be related to the particular geochemistry of volcanic materials used in road surfaces. Data collected by Fergusson & Ryan (1984) from Christchurch in the 1980s had low concentrations of V (median 48, range 41-68 mg/kg) similar to those measured in Wellington street gutter materials (Kennedy 2003b).

Fig. 6.8 illustrates the relationship between Aluminium and V in the stormwater particulates. The comparative stream sediment data indicates that there is a relationship between V concentration and aluminium which is a reflection of decreasing particle size (the finer clays etc having higher V concentrations). Kennedy (2003b) identified a similar relationship with V concentrations increasing from 2-40 mg/kg in coarser sediments to over 80 mg/kg in fine sediments. The majority of the Wellington stormwater samples are generally within the range expected. A group of industrial samples in both particle size groups have higher concentrations. Given that the mass of material used in the PIXE analysis in those samples is moderate the analysis may not be influenced by sample mass effects.

Klee & Graedel (2004) estimated the global anthropogenic mobilisation of V to be significant at 72% (with most from the use of fossil fuels).

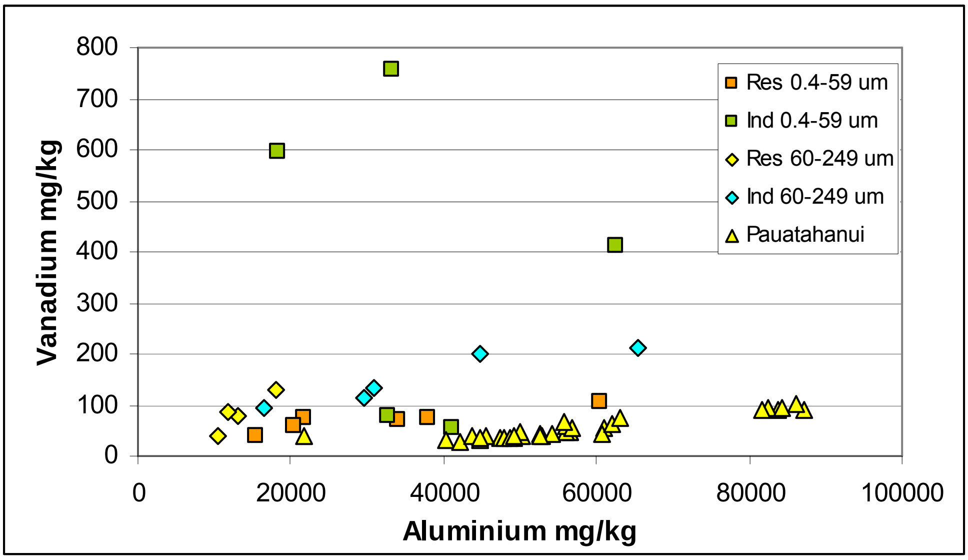

Fig. 6.10: Aluminium and vanadium in particulate matter in Wellington stormwater.

ANZECC (2000) or USEPA do not have any sediment quality triggers/guidelines for V. Overall the concentrations of V measured in a number of the Wellington stormwater particles are similar to those measured in uncontaminated sediments (e.g., those with concentrations around 100 mg/kg). Higher concentrations of V were measured in several samples from industrial/commercial catchments. The cause of the elevated concentration in each case was not identified.

6.14 Zinc

Table 6.10 and Fig. 6.11 summarises the zinc (Zn) concentrations present in two particulate fractions in the suspended solids present in Wellington stormwater. The median concentrations in both land uses were higher in the <59 µm samples compared to the 60-249 µm fraction samples.

There were no significant differences between samples from different land-uses for either particle size fraction ($p>0.05$).

The concentrations measured appear generally similar to those measured historically in particulate matter on road surfaces in Wellington. ARC (1992) examined Zn in a number of fractions of suspended particulate matter collected from stormwater in the catchment of Pakuranga. The Zn concentrations ranged from a low of 2,030 mg/kg in 47-180 µm particles to 2,480 mg/kg in coarser particles >250 µm in size.

Table 6.11 Zinc concentration in suspended sediment samples from Wellington stormwater (all units mg/kg, dry weight).

	Median	Minimum	Maximum	N
<59 µm				
Residential	1,753	201	8,896	6
Commercial/Industrial	2,620	1,117	4,069	5
>60-<249 µm				
Residential	814.5	422	5,546	4
Commercial/Industrial	1,639	1,032	9,307	5
Road surface particulates				
Waitakere City street surface <63 µm [1]	723	267	2,690	34
Seaview industrial <63 µm [2]	1,043	395	2,304	12
Karori residential <63 µm [2]	1,316	432	4,246	12

Note [1] – From Kennedy & Gadd (2003); [2] – From Kennedy (2003b).

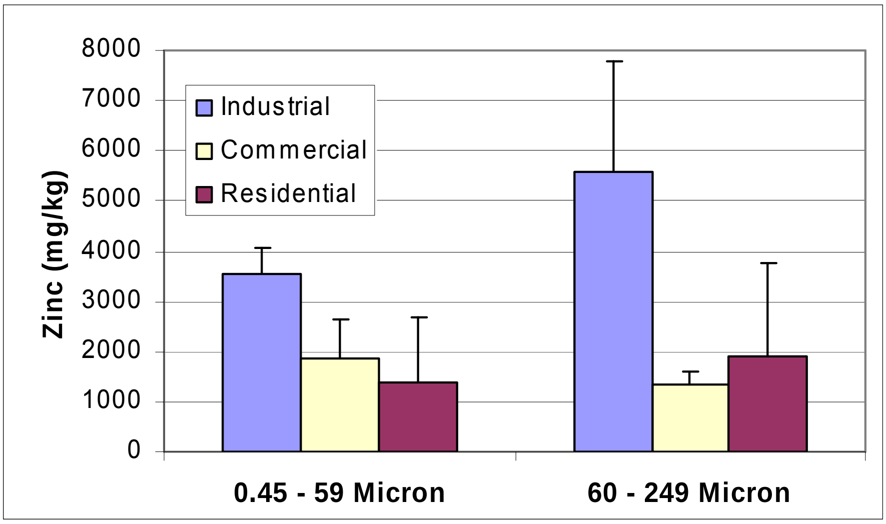

Fig. 6.11: Zinc in Wellington stormwater particulate matter.

Kennedy (2003b) provides information on typical concentrations of Zn in New Zealand road surface particulates and in soils and sediments. Fig. 6.12 includes data from stream sediments in Pauatahanui Inlet. That set of data indicates that background concentrations are typically about 50 mg/kg with concentrations increasing as the grain size becomes smaller. The data in Fig. 6.11 shows a set of <35 µm stream sediment particles with a median Zn concentration of 103 mg/kg (this is similar to the concentrations of 97 mg/kg for <20 µm particulates reported by Glasby et al. (1990) for sediments from Pauatahanui Inlet). In finer sediments, the Zn concentration may be higher. Kennedy (unpublished) analysed total Zn in <2 µm particles taken from Pauatahanui Stream sediments and historical sediments in cores in Wellington Harbour. The means of the various samples ranged from 145-192 mg/kg.

The comparison of data illustrates clearly that the stormwater suspended particles are clearly enriched in zinc. No statistically significant differences could be detected between land-uses in this study.

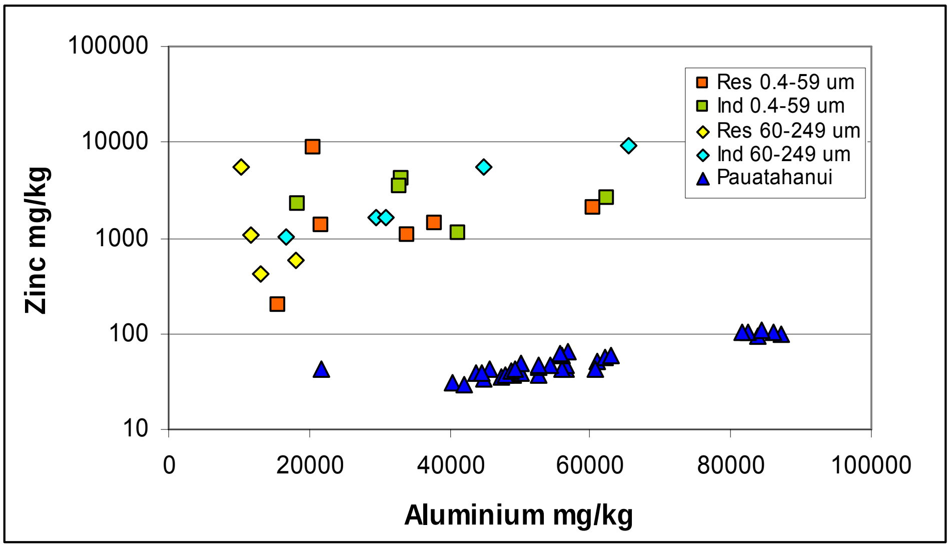

Fig. 6.12: Aluminium and zinc in Wellington stormwater particulate matter.

Klee & Graedel (2004) estimated the global anthropogenic mobilisation of Zn to be moderate at 47% with most derived from mining. Kennedy (2003b) provided a rough order estimate of the contribution of motor vehicles to road surface particulate Zn concentrations of about 40%.

ANZECC (2000) have identified sediment quality guidelines for Zn with the ISQG-Low and ISQG-High being 200 and 410 mg/kg respectively. All samples collected with the exception of one sample (Browns Stream) had concentrations that were higher than the ANZECC (2000) ISQG-High. The concentrations are considerably higher than what would be considered a background concentration. As a consequence, the particulate materials have the potential to increase the concentration of Zn when deposited in receiving environment sediments.

Overall, the concentration of Zn in all samples of stormwater suspended particulate examined from the Wellington region showed evidence of significant contamination and all but one sample had concentrations that were higher than the ANZECC (2000) ISQG-High trigger value.

6.15 Mercury, Antimony and Silver

For mercury (Hg), detection limit data (LLD 50 mg/kg) was reported for 8/12 samples in the 0.4-59 µm fraction (three samples reported as containing 90-167 mg/kg Hg) and 8/9 samples in the 60-249 µm fraction (2 low mass samples deleted). The analytical LLD was elevated compared to natural soil (~0.1 mg/kg) or even typical road particulate concentrations of Hg.

Kennedy (2003b) reported median values for road surface samples collected in the Wellington area ranging from 0.067 to 1.0 mg/kg (six locations, 35 samples). It should be noted that corresponding samples of material contained in three catchpit sumps had a median Hg concentration of 6.1 mg/kg (range 0.5-40 mg/kg). ARC (1992) examined the concentration of Hg in particulate material taken from bulk stormwater samples collected in Pakuranga. The Hg concentrations ranged from a low of 0.95 mg/kg in 20-47 µm particles to 1.7 mg/kg for particles >250 µm in size (the weighted sample average concentration was 1.3 mg/kg)

The ANZECC (2000) ISQG-Low and High sediment quality trigger values are 0.15 and 1.0 mg/kg respectively. Due to 'analytical' uncertainties it is not considered appropriate to compare the results obtained in this study with the ANZECC (2000) trigger values. There is insufficient data to identify whether Hg in stormwater will contribute to increases in sediment concentrations in receiving environments. There is historical evidence from past studies of elevated concentrations of Hg on road surfaces and in stormwater.

Antimony (Sb) was only quantified in three samples at a detection limit of 100 mg/kg. Sb was reported as not detected in those samples of material in the 60-259 µm size range. In the 0.4-59 µm fraction samples, one sample was reported as containing no detectable Sb but two samples were reported as containing 110 (industrial catchment) and 170 (residential catchment) mg/kg Sb. Given the natural concentration of Sb and the available data on Sb in road surface particulate matter, the concentrations would expect to be elevated. In known industrial situations where elevated lead occurs, Sb may be present as a contaminant (at a ratio of the order of 50:1). In the stormwater samples which contained elevated concentrations of Sb, the lead concentration would indicate potentially a low concentration of Sb. However, the Sb concentrations produced by the PIXE analysis in this study are identified as having a low level of confidence.

The ANZECC (2000) ISQG-Low and High sediment quality trigger values are 2 and 25 mg/kg respectively. Due to 'analytical' uncertainties noted above and the high detection limit, it is not considered appropriate to compare the detected results obtained in this study with the ANZECC (2000) trigger values.

Analysis using PIXE detected very high concentrations of silver (Ag). The results ranged from 17-3,965 mg/kg (excluding the two low mass samples). However, the very high concentrations are not considered to be likely as other data (e.g., refer Kennedy 2003b) would indicate that concentrations are much lower and also the concentrations suggested by the data would be commercially valuable. Fig. 6.13 shows the apparent relationship between Al and Ag concentrations. It is probable that this relationship reflects a matrix or other factor influencing the Ag concentration determined by the PIXE.

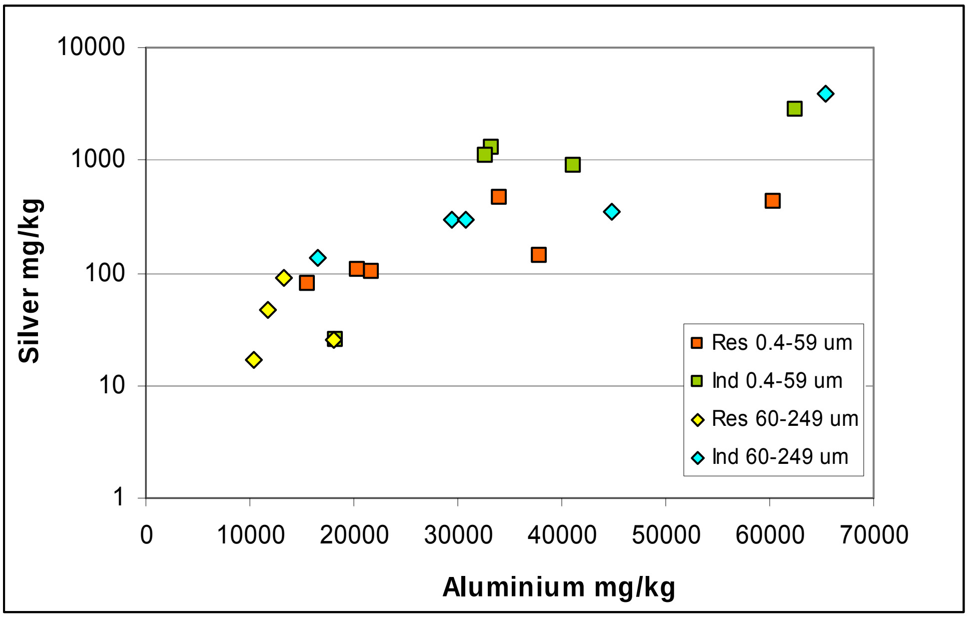

Fig. 6.13: Aluminium and silver in Wellington stormwater particulate matter.

Overall, although analysis were carried out for Sb, Hg and Ag in this study, the results are considered to have too low a level of confidence to enable them to be used to assess the degree of contamination by these elements that may be present.

7. Organic Compounds

7.1 Introduction

This section examines the data obtained for key groups of organic compounds in stormwater and particulate material in stormwater. Information is provided for both dissolved and particulate fractions.

The dissolved concentrations are compared with the ANZECC (2000) and USEPA (2002) water quality guidelines/criteria. For each element, information on the concentrations of compounds in suspended particulate fractions of the samples relative to any ANZECC (2000) sediment quality guidelines is also given.

In this section of the report, as the concentrations of many of the organic compounds present in stormwater are very low the units used are µg/m^3 (i.e., 10^{-6} of a g/m^3). In the data table that follow information on non-detect concentrations are not presented as the detection limits varied considerably for samples. This information is presented in Appendix 2.

7.2 PAHs

Dissolved Fraction

PAHs were detected in eight of the 11 stormwater samples collected. The three samples that did not contain any measurable PAHs were from residential catchments. Table 7.1 provides a comparative summary of the PAH data obtained.

There was no apparent relationship between the land-use of the catchment and the concentration or type of PAH compounds detected. The PAHs most often detected across all sites were pyrene and chrysene, both 4-ringed PAHs. Two of the residential catchment sites had similar PAH profiles, also being dominated by high molecular weight PAHs. The third residential catchment site had a completely different profile, being dominated by low molecular weight PAHs, particularly naphthalene (210 µg/m^3).

The highest concentrations of PAH were detected in an industrial stormwater sample, from Hutt Park Road, with total concentrations of 2,110 µg/m^3 (sum of detected PAHs). This was made up of high molecular weight PAHs (more than 3 rings), with the addition of acenaphthene.

The sample from Parkside Road (near the Hutt Park Rd catchment in Lower Hutt) also contained elevated PAHs, with a sum of 420 µg/m^3. This included several low molecular weight compounds, but was dominated by high molecular weight compounds. The commercial site sample was dominated by low molecular weight PAHs, including naphthalene and phenanthrene.

Brown et al. (2003) reported on PAH concentrations in stormwater in Dunedin. They examined dissolved, colloidal and particulate PAHs and identified that in stormwater from Portobello Road, 33% of the PAHs were dissolved during baseflow and 63% during stormflow. They attributed the change to the increase in the amount of PAH rich particles in the stormwater. Brown et al. (2003) also showed that separation of the dissolved phase into truly dissolved and colloidal PAH showed that apart from naphthalene, only minor amounts of the PAHs were present in colloidal PAH. Examination of the ratio of dissolved to particulate fractions in that study showed that the proportion of dissolved decreased from >80% for fluorine and acenaphthene to less than 10% for the individual PAHs with molecular weights greater than that of benzo(b)fluoranthene.

Table 7.1 Comparison of PAHs in stormwater samples from Wellington and other sites (all data $\mu g/m^3$).

Polycyclic aromatic hydrocarbon	Residential dissolved (This Study)[1]	Ind/Comm. dissolved (This Study)[1]	Porirua Motorway (Sheriff 1995)[2]	NZ Highways (O'Riley et al. 2002) (EMCs, 6 events) [1]	Canadian Highway (Marsalek et al. 1997)[3]	Japanese Highway (Shinya et al. 2000) (EMCs 4 events) [1]
Naphthalene	ND (5)- 210	ND (3) - 78 – 94	-	-	-	-
Acenaphthylene	ND (5)- 8.5	ND (3) - 8.3 – 15	<4 (<3 – 7)	-	14.7	-
Acenaphthene	ND (5) - 14	ND (3) - 3.9 – 20	<5 (<3 - <10)	-	24.8	-
Fluorine	ND (5) - 12	ND (2) - 11 – 29	<10 (<5 - <10)	-	56.2	-
Phenanthrene	ND (5) - 18	ND (3) - 21 – 110	<10 (<10 - 55)	90 - 376	397	120 - 465
Anthracene	ND (5) - 2.1	ND (4) - 6.6	<2 (<2 – 8.3)	-	-	17 - 33
Fluoranthene	ND (3) - 4.1 – 18	ND (2) - 17 – 310	14 (<5 – 75100)	104 - 665	504	86 - 419
Pyrene	ND (3) - 7.4 – 20	ND (1) - 32 – 400	16.3 (<5 – 86.6)	185 - 1490	454	90- 363
Benz(a)anthracene	ND (4) - 2.1 – 6.2	ND (2) - 1.8 – 140	<5 (2 – 29.1)	-	-	16 - 81
Chrysene	ND (3) - 1.3 – 12	ND (1) - 3.7 – 240	14 (<3 – 74)	-	-	60 - 175
Benzo(b)fluoranthene	ND (3) - 1.2 – 5.7	ND (2) - 2.9 – 230	<10 (<5 – 34.9)	-	23.9	43 - 154
Benzo(k)fluoranthene	ND (3) - 0.86 – 5.2	ND (3) - 37 – 190	<10 (<3 – 37700)	-	135	20 - 96
Benzo(a)pyrene	ND (4) - 3.4 – 5.0	ND (2) - 0.95 – 180	<10 (<3 – 24.7)	-	186	26 - 99
Indeno(1,2,3-c,d) pyrene	ND (3) - 3.4 – 6.6	ND (3) - 39 – 190	5 (<2 – 30.2)	-	143	36 - 115
Dibenz(a,h)anthracene	ND	ND (3) -7.2 – 40	<2 (<1 - <10)	-	-	14 – 30
Benzo(g,h,i)perylene	ND (4) - 3.7 – 8.7	ND (2) - 3.4 - 170	16 (<5 – 65.7)	-	222	72 – 190
Total detected PAH	**33 – 278**	**4.35 – 2,110**	**57 (15.6 – 30.8)**	**-**	**2,291**	**676 – 2,351**

Notes: [1] Data presented as range where ND = non-detect (number of non-detects) and then the range of the detected concentrations. [2] Data presented as median (range). [3] Mean of all data, n=29.

The only PAH for which ANZECC (2000) identifies a trigger value for the protection of aquatic life is naphthalene for which the trigger value for the protection of 95% of freshwater organisms is 160 µg/m^3 (0.16 mg/m^3). Concentrations measured were lower than the ANZECC (2000) trigger value.

Particulate Fraction

PAHs in stormwater partition into suspended or bottom sediment as they are heavy lipophilic compounds. PAHs were detected in all samples in the 0.7 to 59 µm fraction of suspended particulate matter and in 9 out of 11 samples in the >59 µm fraction. The highest concentrations were found in those samples that also had the highest aqueous concentrations (samples from industrial catchments). The compound detected at highest concentration was naphthalene, at 9,200 µg/kg in the 0.7–59 µm fraction of a single sample from one of the residential catchments. There was no apparent relationship between the land-use and the PAH concentrations (Table 7.2) as with the aqueous samples.

Low molecular weight PAHs such as naphthalene, acenaphthene and fluorine were rarely detected (four to six of 11 samples, Figs. 7.1 and 7.2), but dominated two samples from industrial catchments. PAHs with five rings or more were only detected in those samples that had high total PAH concentrations. This was also apparent for the dissolved samples. The lower contribution of the heavy molecular weight PAHs may be related to the aqueous nature of the samples. These PAHs may have been bound to larger sediment particles that were not included in the stormwater sampled.

For most samples, the highest concentrations of PAHs were measured in the > 59 µm fraction. Fluoranthene, pyrene and chrysene appeared to be more associated with the larger particulates (> 59 µm fraction) than the smaller-sized particulates. PAHs are strongly bound to soot particles in stormwater samples and it may be that soot particles are larger particles, found in the > 59 µm fraction.

Concentrations of individual PAH compounds were similar in particulate matter from this study and in overseas studies, particularly where fine particulate material was measured. PAH concentrations in the stormwater suspended particulate material were higher than those measured in particulate material collected from gutters and roads in Waitakere City (Kennedy & Gadd 2003) (Table 7.3). This is likely to be due to the coarser size of the particulate material collected in that study.

Street dusts from Waitakere City had consistent profiles for all samples and were dominated by phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene and benzo[g,h,i]perylene (Kennedy & Gadd 2003). The PAH profiles of the Wellington particulate material were generally more variable (Figs. 7.1 and 7.2) but did demonstrate a similar dominance of phenanthrene, fluoranthene and pyrene suggesting vehicle related sources of PAHs.

Table 7.2 Summary of PAH concentrations in particulate material from stormwater samples (all data µg/kg, dry weight).

Land use	**ANZECC (2000) trigger values**		**Residential[1]**		**Industrial / Commercial[1]**	
Size Fraction (mm)	**ISQG-L**	**ISQG-H**	**0.7 – 59 µm**	**>59 µm**	**0.7 – 59 µm**	**>59 µm**
Naphthalene (NAP)	160	2,100	ND (5) - 9,200	ND(4) - 5,000 – 5,300	ND (3) - 420 – 950	ND(3) - 1200 – 1,400
Acenaphthylene (ACY)	44	640	ND (3) - 130 – 360	ND(4) - 230 – 710	ND (1) - 32 – 800	ND(3) - 170 – 740
Acenaphthene (ACE)	16	500	ND (4) - 40 - 620	ND(4) - 100 – 410	ND (2) - 47 – 70	ND(4) - 58
Fluorine (FLU)	19	540	ND (4) - 91 - 500	ND(5) - 350	ND (2) - 85 – 150	ND(3) - 190 – 240
Phenanthrene (PHE)	240	1,500	ND (3) - 650 – 100	ND(3) - 780 – 1,300	ND (2) - 600 – 1,400	ND(3) - 870 – 2,000
Anthracene (ANT)	85	1,100	ND (3) 130 - 280	ND(3) - 80 – 320	ND(1) - 49 – 270	ND(2) - 170 – 280
Fluoranthene (FLT)	600	5,100	110 – 2,300	ND(1) - 440 – 3,300	100 – 2,500	ND(1) - 100 – 9,600
Pyrene (PYE)	665	2,600	110 – 2,400	ND(1) - 450 – 2,900	220 – 3,400	ND(1) - 1900 – 11,000
Benz(a)anthracene (BAA)	261	1,600	37 – 1,300	ND(1) - 120 – 1,500	26 – 2,500	ND(1) - 400 – 4,200
Chrysene (CRY)	384	2,800	75 – 1,800	ND(1) - 290 – 2,400	75 – 3,600	ND(1) - 790 – 5,800
Benzo(b)fluoranthene (BBF)	-	-	29 – 1,500	ND(2) - 210 – 1,500	43- 3,400	ND(1) - 480- 4,200
Benzo(k)fluoranthene (BKF)	-	-	40 – 1,700	ND(2) - 200 – 1,600	37 – 3,400	ND(1) - 410 – 3,900
Benzo(a)pyrene (BAP)	430	1,600	57 – 1,500	ND(2) - 170 – 1,600	270 – 2,700	ND(1) - 340 – 3,300
Indeno(1,2,3-c,d) pyrene (IND)	-	-	ND(5) - 2,100	ND(4) - 200 – 1,700	ND (1) - 320 – 2,700	ND(1) - 390 – 3,400
Dibenz(a,h)anthracene (DBA)	63	260	ND(5) - 350	ND(5) - 300	ND(2) - 53 – 620	ND(2) - 64 – 740
Benzo(g,h,i)perylene (BGP)	-	-	ND(3) - 130 - 2500	ND(4) - 290 - 2200	110 – 2,500	ND(1) - 570 – 3,500
Total PAH	**552 – 1,700***	**3,160 - 9,600***	**411 – 19,200**	**3,480 – 26,800**	**609 – 25,000**	**6,500 – 49,900**

Notes: [1] Data presented as range where ND = non-detect (number of non-detects) and then the range of the detected concentrations.

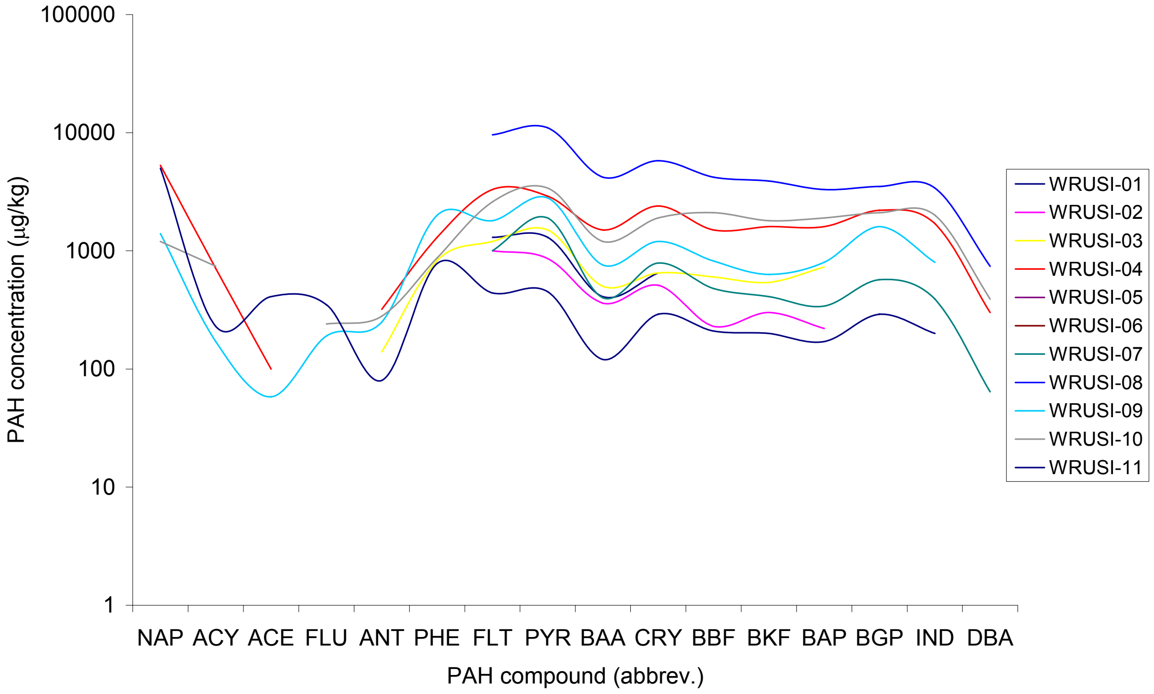

Fig. 7.1: **PAH concentrations in the >59 µm fraction of suspended particulate material (refer Table 7.2 for abbreviations).**

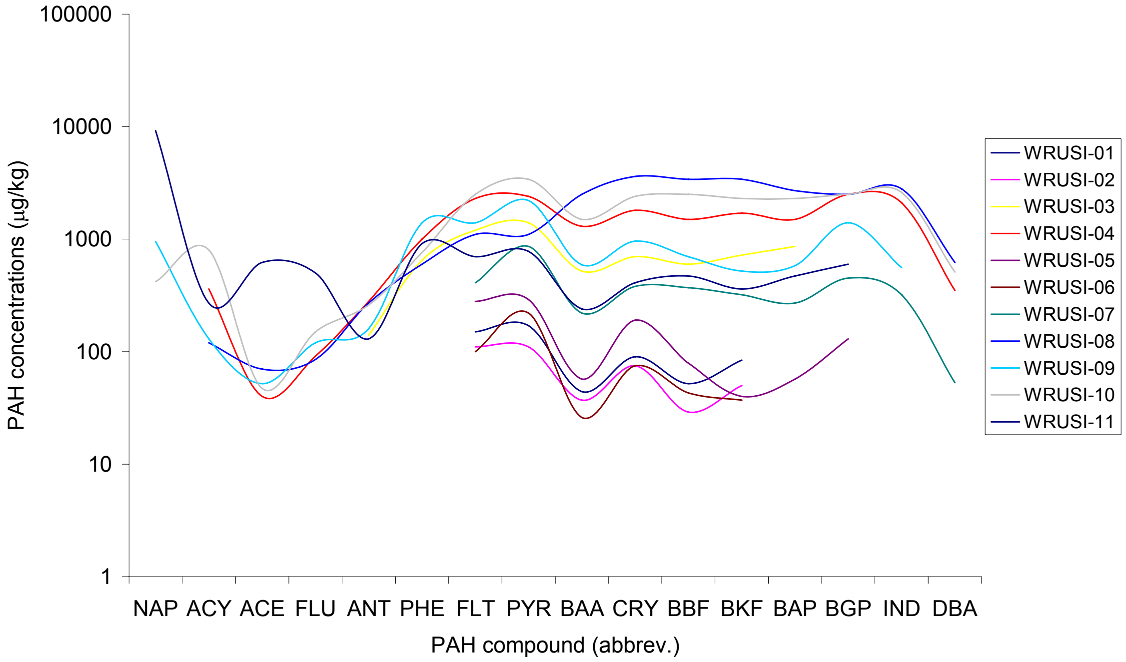

Fig. 7.2: **PAH concentrations in the 0.7-59 µm fraction of suspended particulate material (refer Table 7.2 for abbreviations).**

Table 7.3 Comparison of PAH concentrations in particulate material with Waitakere City road surface samples, Auckland gutter dust samples and Brisbane roadside soil (all data µg/kg, dry weight).

Location	**Wellington**		**Waitakere City**[5]	**Pakuranga**[1]		**Southdown**[1]		**Brisbane Roadside soil**[2]	**Santa Monica roads**[3]		**Olwiger Bach Germany**[4]
Size Fraction (µm)	**0.7 – 59 (median)**[7]	**> 59 (median)**[7]	**<2000 (median)**	**<47**	**47-120**	**<47**	**47-120**		**<43**	**43-100**	**<2 to 63-200**
Naphthalene	950	3200	<200								
Acenaphthylene	130	470	<40								
Acenaphthene	52	100	175								
Fluorine	120	240	<40								
Phenanthrene	835	870	120	-	-	-	-	715	515	215	183-1,022
Anthracene	160	210	<40	20	22	10	10	27.8	23	169	24 – 147
Fluoranthene	700	1300	209	545	335	230	210	174	846	224	350 – 1,958
Pyrene	860	1900	275	560	315	240	220	214	816	444	-
Benz(a)anthracene	240	500							198	162	-
Chrysene	410	790	102	445	290	120	110	572	653[5]	263	-
Benzo(b)fluoranthene	470	710	135	270	180	10	90	-	-	-	-
Benzo(k)fluoranthene	360	585	<50	105	70	40	35	201	-	-	-
Benzo(a)pyrene	720	765	70	210	155	85	75	363	229	541	-
Indeno(1,2,3-c,d) pyrene	2100	1250	<30	55	40	20	20	-	-	-	76-402
Dibenz(a,h)anthracene	430	345	58	-	-	-	-	584	-	-	11-83
Benzo(g,h,i)perylene	1000	1850	170	280	260	230	170	598	-	-	217-710

Notes: [1] ARC (1992); [2] Yang et al. (1991). [3] Lau & Stenstrom 2001. [4] Krein & Schorer (2000); [5] Kennedy & Gadd (2003); [6] chrysene/triphenylene; [7] median of samples with detectable levels.

PAH concentrations in suspended solids from all landuses exceed the ANZECC (2000) trigger values in a number of samples for most PAHs. The ISQG-High is exceeded by the maximum concentration measured for a number of PAHs.

7.3 Polychlorinated Biphenyls

Dissolved Fraction

PCBs were found in the 'dissolved' fraction in seven out of 11 stormwater samples. This is somewhat surprising as PCBs are hydrophobic (log K_{ow} 4.0–6.9, EPA/USACE, 1998). The solubility of PCBs can be increased through the presence of dissolved organic matter (DOM) such as humic and fulvic acids (Uhle et al. 1999). PCBs bound to DOM would be included in this 'dissolved' fraction (Brown & Peake 2003).

PCBs were found at highest concentrations in an industrial stormwater sample (Hutt Park Road). Total PCB concentrations were 52.7 µg/m^3 at this site and 37 out of the 45 PCB congeners analysed were detected in this sample, more than all other samples. Other stormwater samples from industrial and commercial land-uses contained 0–6.82 µg/m^3. Stormwater from residential land-uses contained lower concentrations of PCBs at 0–0.826 µg/m^3, with only three out of six samples from residential land-use measuring PCBs above the detection limit. Those stormwater samples that did not contain detectable PCBs were from streams and creeks.

PCBs have previously been measured in stormwater at 14–8,900 µg/m^3 (Williamson 1993), however these samples would have contained particulate material and were collected from the 1980s, when PCBs may still have been in use in many parts of the world. In more recent stormwater sampling from 1994 to 2000, PCBs were not detected in 242 samples from a range of different land-uses, including residential, transportation and light industrial (LA County 2000).

The profile of PCB concentrations was very similar for those samples containing more than three PCB congeners. This suggests that the PCBs are from a similar source and possibly a diffuse source such as atmospheric deposition. The presence of 8, 9 and 10-chlorine substituted PCBs in the samples (congeners #194 to #209) suggests that the PCBs came from Arochlor 1260 (EPA 2003).

The highest TEQ (toxic equivalence) was found in an industrial sample (Hutt Park Road), at 2.7 fg/m^3 (femto – 10^{-6} ug/m^3) much higher than the TEQ for all other 'dissolved' samples, which ranged from 0.00351 to 0.868 fg/m^3. This difference was due to the presence of congener #126 (3,3',4,4',5-penta-) in this sample at 0.021 pg/m^3. This congener has a TEF (toxic equivalency factor) of 0.1, resulting in a TEQ based on this congener only, of 2.1 fg/m^3. No other samples contained this particular congener. The TEFs for all other PCB congeners range from 0.00001 to 0.01.

Particulate PCBs

At least one PCB congener was detected in each of the samples collected when the 0.7–59 µm fraction was analysed. PCBs were detected in eight out of 11 samples when the >59 µm fraction was analysed. Four samples (one from an old residential catchment, one commercial and two industrial) contained over 100 µg/kg of PCBs in both the 0.7–59 µm fraction and the > 59 µm fraction. Higher concentrations were generally found in the 0.7–59 µm fraction, possibly due to the greater surface area that is available for binding on the smaller sized particulates. For each stormwater sample, there were additional congeners detected in the 0.7–59 µm fraction that were not present in the > 59 µm fraction. Despite this there was no evidence of a relationship between the size of particulates and the particular congeners detected.

The highest total concentrations in the particulate fractions were in the commercial catchment sample (Waring Taylor Street), measuring 677 µg/kg in the 0.7–59 µm fraction (38 out of 45 congeners present) and 678 µg/kg in the > 59 µm fraction (39 out of 45 congeners present).

This sample had a total TEQ of 81.9 pg/g for the 0.7–59 µm fraction. The industrial sample from Hutt Park Road had a similar concentration of 648 µg/kg in the 0.7–59 µm fraction, but a much lower TEQ, at 30.4 pg/g. This difference is mainly due to the higher concentration in the Waring Taylor Street sample of PCB #126 (3,3',4,4',5-penta-, 0.64 µg/kg) which has a TEF of 0.1. In comparison, the Hutt Park Road sample contained 0.23 µg/kg of PCB #126. This PCB congener has a much higher TEF than all other congeners (0.1 compared to 0.00001–0.01).

The PCB profiles were very similar for each of the samples (Fig. 7.3) and between the two sizes of particulates. This provides further evidence that the PCBs in stormwater samples are from the same source.

There is little comparative concentration data for PCBs in urban stormwater suspended solids or in street surface particulates. ARC (1992) presented data for particle size fractions from gutter dusts in an industrial and residential catchment in Auckland. The ARC data ranged from 15.8-27.2 µg/kg for material from Pakuranga (residential–23 congeners) and 28.6-199 µg/kg in material from Southdown (Industrial). This data is summarised in Table 7.4. The Wellington data indicates although the median concentrations are lower, the older Southdown data is at the upper end of the range measured in the Wellington samples. This shows that although PCBs have not been used in New Zealand since the 1980s, sources still remain in the environment (e.g., soils containing residuals of historic contamination). The flux of PCBs to the New Zealand environment has not yet declined and particulate material can transport PCBs resulting in contamination of receiving environment sediments.

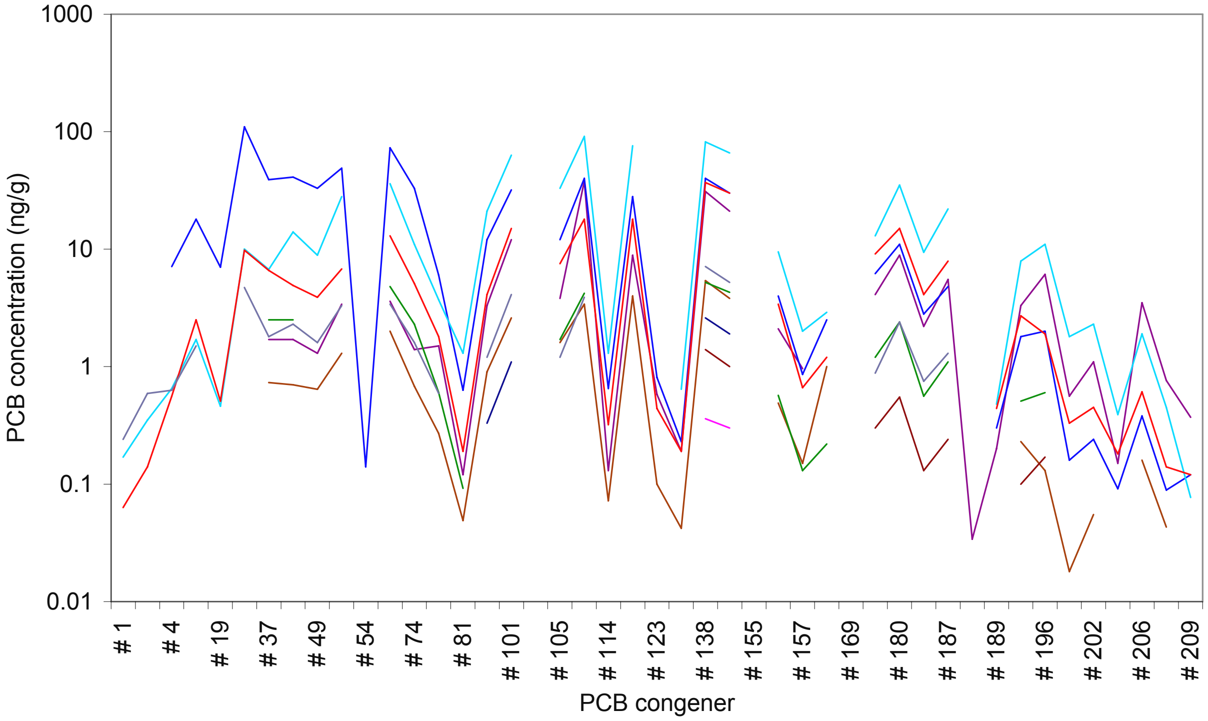

Fig. 7.3: PCB concentrations in the 0.7-59 μm fraction of stormwater suspended particulate material.

Table 7.4 Summary of PCB congener concentrations in Wellington stormwater particulates and comparative data (all results μg/kg dry wt).

Location/landuse	Sample	Median	Range	Reference
Wellington, residential	0.7-59 μm	23.6	ND-164	This study
	>59-249 μm	26.5	0.165-173	This study
Pakuranga, residential	<47 μm	20.6[1]	-	ARC (1992)
	47-120 μm	16.8[1]	-	ARC (1992)
Wellington, industrial	0.7-59 μm	23.6	ND-164	This study
	>59-249 μm	26.5	0.165-173	This study
Southdown, industrial	<47 μm	199[1]	-	ARC (1992)
	47-120 μm	102[1]	-	ARC (1992)

Notes: [1] – single data point for each particle size fraction.

The median concentrations of total PCBs measured in the Wellington stormwater suspended solids is similar to the ANZECC (2000) trigger value of 23 μg/kg. The maximum concentrations are similar and typically five times the ANZECC (2000) threshold. The presence of measurable concentrations of PCBs in Wellington stormwater indicates that the stormwater contributes a load of PCB to the receiving environment. The concentrations measured relative to ANZECC (2000) trigger values indicate that the suspended particulates may contribute to poor sediment quality when deposited.

7.4 Organochlorine Pesticides

Organochlorine pesticides (OCPs) were detected in all stormwater samples, in either the ‘dissolved’ or particulate fractions. More OCPs were detected in samples from sites with industrial or commercial land-use than the residential land-use sites. All the OCPs analysed, with the exception of heptachlor epoxide, were detected in at least one sample, in either the ‘dissolved’ or one of the particulate fractions.

Dieldrin, p,p’-DDT and p,p’-DDE (a metabolite of p,p’-DDT) were detected the most frequently. This extent of detection agrees with the Ministry for the Environments (MfE 1998) organochlorines programme, which also found that dieldrin and DDT (and metabolites) were the most commonly detected organochlorine pesticides. Highest DDT concentrations were measured from the industrial sample from Hutt Park Road. There was no apparent difference between the DDT concentrations from residential and industrial catchments (Fig. 7.4).

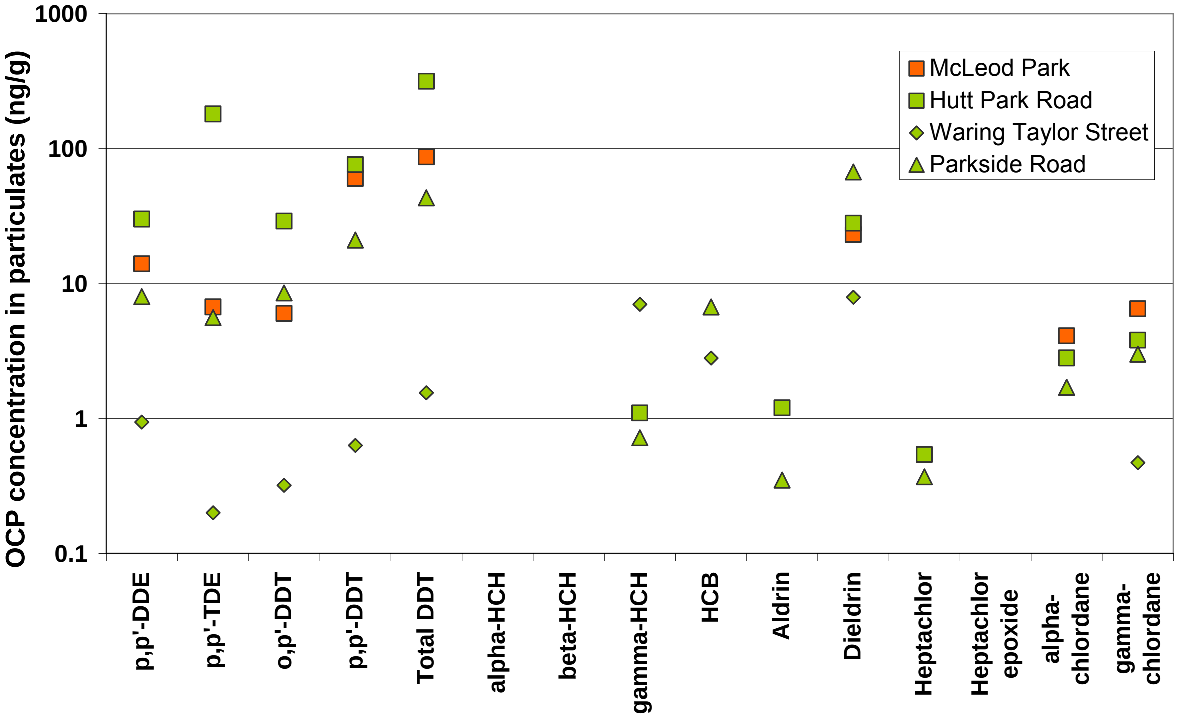

Fig. 7.4: OCP concentrations in 0.7–59 µm particulate material.

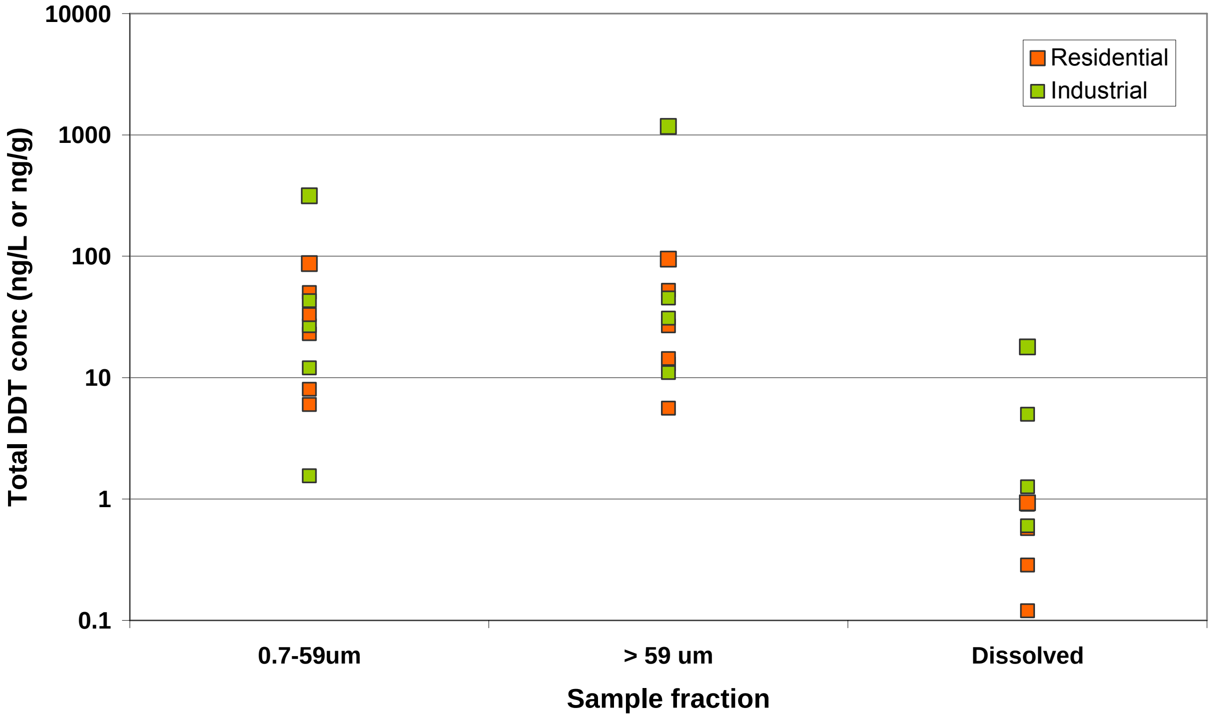

Fig. 7.5: **DDT concentrations in particulate material and dissolved samples.**

There is some comparative concentration data for DDT in stormwater suspended solids or in street surface particulates from ARC (1992). Gutter dusts from Pakuranga, a residential catchment in Auckland, contained similar concentrations of DDT to the Wellington residential catchments. Data for Southdown, an industrial catchment, contained similar concentrations to the median measured in particulates from industrial stormwater in Wellington, however the maximum found in Wellington was higher. As for PCBs, the data shows that although DDT has not been used in New Zealand since the 1980s, sources still remain in the urban environment. In some locations, the DDT may have been derived from previous agricultural land.

7.5 Chlorophenols

Dissolved

Of the range of chlorophenol congeners measured (mono. di, tetra and penta-chlorophenols), pentachlorophenol (PCP) was the most common chlorophenol present in detectable concentrations (3.9–52 pg/m^3). This was detected in all but one sample (Grasslea Reserve residential catchment in Tawa). Comparison of the concentrations measured or non-detected is made difficult by the differing limits of detection for different stormwater samples.

Table 7.5 Summary of DDT concentrations in Wellington stormwater particulates and comparative data (all results µg/kg dry wt).

Location/landuse	Sample	Median	Range	Reference
Wellington, residential	0.7-59 µm	28	6-86.7	This study
	>59-249 µm	20.5	5.6-94.5	This study
Pakuranga, residential	<47 µm	16.7[1]	-	ARC (1992)
	47-120 µm	14.9[1]	-	ARC (1992)
Wellington, industrial	0.7-59 µm	26.8	1.55-315	This study
	>59-249 µm	30.9	ND-1,170	This study
Southdown, industrial	<47 µm	35.98[1]	-	ARC (1992)
	47-120 µm	24.73[1]	-	ARC (1992)

Notes: [1] – single data point for each particle size fraction.

Irrespective of the differences in detection limits between samples, the samples from the residential catchments contained lower concentrations of PCP (<6, 4-15 pg/m^3) than the samples from the industrial/commercial/mixed catchments (17-52 pg/m^3). The congeners 4-MCP, 2,4/2,5 DCP, 2,6-DCP, 2,4,5 and 2,4,6-TCP, 2,3,4,6-TeCP were detected in the samples from the industrial/commercial catchments. Of these congeners, 2,6 DCP was detected in two samples from residential catchments. One residential catchment (Grasslea Reserve) had detectable concentrations of some of the other congeners detected in the samples from industrial catchments.

Particulate

A generally similar pattern was seen in the chlorophenol concentrations in the particulate fractions to that in the 'dissolved' fraction, with higher concentrations in the samples from industrial and commercial land-use. Total concentrations and the number of non-detects was dependent on the detection limit for the particulate sample.

In the finer particulate fraction (0.7-59 µm) a range of congeners were detected at low concentrations. Two samples contained elevated concentrations of measurable congeners. The sample from Duck Creek contained 330 µg/kg 4-MCP. In the coarser particulate material (the >59 µm fraction), the sample from Hutt Park Road catchment had the highest concentration of chlorophenols, with a PCP concentration of 310 µg/kg. No other chlorophenols were detected in this sample, presumably due to high detection limits for other congeners (7–40,000 µg/kg). This PCP concentration was substantially higher than all other samples (5.4–25 µg/kg) and suggests there may be a historic or current source (e.g., timber treatment site) in the catchment.

8. Overview and Summary

8.1 Introduction

Williamson et al. (2001) reviewed the effects of urban stormwater in the Wellington region. The review provided an overview of the effects of urban stormwater discharges to freshwater and to marine waters. Subsequent to that review Kennedy (2003a) has also reviewed the effects of stormwater discharges from roads on freshwater and marine environments. The key points arising from the review by Williamson et al. (2001) relevant to this study included:

- Occasional exceedences of water quality guidelines for Cu and Zn.
- High concentrations of Cu, Pb and Zn are present in stream sediments.
- Evidence of elevated concentrations of trace elements near stormwater outfalls such as the Semple St. drain in Porirua and drains around the Wellington City drainage catchment.

8.2 General stormwater quality

Overall, the pH measured in the Wellington stormwater samples is similar to the pH measured in stormwater in other studies carried out in New Zealand.

The median total suspended solids (TSS) concentration in the Wellington stormwater samples was 76 g/m^3. The median concentration in the residential catchments was lower than in the industrial catchments (59 g/m^3 and 90 g/m^3 respectively). Although the industrial catchment stormwater had a higher TSS concentration, the difference between the residential and industrial catchments was not statistically significant ($p=0.053$).

The DOC and TOC concentrations observed in the stormwater samples collected in the Wellington region were similar to concentrations recorded in other studies. Total nitrogen concentrations were elevated (median of 1.6 g/m^3) with samples from the residential catchments having a higher median concentration than the samples from the industrial catchments. The median DRP concentration (0.04 g/m^3) was relatively low and similar to data from other locations in New Zealand such as urban Dunedin and Rotorua.

8.3 Dissolved elements in stormwater

This study measured the concentration of a range of elements in urban stormwater from residential and industrial/commercial catchments. Table 8.1 summarises the results in relation to the degree of increase in concentration over natural concentrations and identifies whether the concentrations measured exceed the ANZECC (2000) 95% protection trigger for freshwater biota.

When comparing metal concentrations in urban stormwater with the ANZECC trigger values, comparisons are typically made using total recoverable (TR - strong acid extractable) metals. A comparison of data obtained using TR extraction will provide an over-estimation of the amount of that element that is bioavailable (as the acid extracts from inert materials in the water). As the main proportion of toxic effect in water comes from dissolved materials, ANZECC (2000) consider that it is appropriate to filter the samples collected (e.g., as carried out in this study to 0.45 µm for metals). The dissolved concentration data can then be compared to the trigger values in a more direct comparison.

If TR extraction was used and the result exceeded the ANZECC (2000) trigger, ANZECC then recommend that the sample be filtered and re-analysed. This step was circumvented in this study. If the dissolved concentration exceeds the trigger values then further evaluation such as direct toxicity assessment is recommended (ANZECC 2000).

The data summary in Table 8.1 indicates that exceedences of the ANZECC trigger values occurs for Cu, Co, Ni and Zn. In this study concentrations of Pb did not exceed the ANZECC (2000) trigger values. Co and Ni are additional elements to those identified by Williamson et al. (2001) as exceeding trigger values. The lower concentrations of Pb relative to the trigger value may be the result of declining lead concentrations over time since Pb was removed from petrol in New Zealand.

It should also be noted that dissolved Pb concentrations are typically low and although the actual data has not been evaluated some older data may be artificially elevated due to laboratory and sampling errors. As noted above, comparison with the ANZECC (2000) and identification of exceedence of the trigger values does not constitute a de-facto identification of waterborne toxicity. Toxicity is affected by a number of aspects of water chemistry. These need to be evaluated prior to any affirmation of potential toxicity issues.

In addition, the trigger values are based upon a particular ANZECC (2000) data set. The trigger values are subject to change and new data. As such although ANZECC (2000) indicate that exceedence of the trigger values should result in further evaluation of potential toxicity, the trigger values themselves may require further evaluation.

It should also be noted that in terms of any assessment of effects, the comparison of concentrations in stormwater and the ANZECC (2000) trigger values does not account for any dilution arising from reasonable mixing. When considering reasonable mixing, it is likely that during the winter when stormwater provides on-going contributions to freshwater streams, it is possible that freshwater biota may be exposed to the concentrations of the key elements identified in Table 8.1 for extended periods of time. It is unlikely that stormwater discharge to coastal environments where reasonable dilution would be expected will result in any waterborne adverse effects as minimal dilution is required for all of the key elements identified in Table 8.1 to bring concentrations below the ANZECC (2000) trigger values.

Table 8.1: Dissolved trace elements in urban stormwater in the Wellington region.

Elements	Residential catchments		Industrial catchments	
	Concentration[1]	Exceed ANZECC (2000) trigger	Concentration[1]	Exceed ANZECC (2000) trigger
Aluminium	M	Yes[2]	M	Yes[2]
Antimony	M	No	M	No
Arsenic	L	No	L	No
Barium	L?	NT	L?	NT
Cadmium	?	No	?	No
Chromium	L	No	L	No
Cobalt	L?	Yes	M?	Yes
Copper	H	Yes	H	Yes
Iron	?	NT	?	NT
Lead	M	No	H	No[3]
Manganese	?	No	?	No
Mercury	?	No	?	No
Nickel	L	No	M	Yes
Selenium	?	No	?	No
Strontium	L	NT	L	NT
Silver	L?	No?	L?	No?
Tin	L	NT	L	NT
Vanadium	L?	No?	L?	No?
Zinc	H	Yes	H	Yes

Note: [1] – Relative increase in concentrations compared to natural concentration – L – low; M – medium; H – High. NT = No trigger value. [2] – Yes – higher than ANZECC (2000) trigger, [3] – No – Lower than ANZECC (2000) trigger, NT – No trigger value.

Of all of the elements, the Zn concentrations measured in Wellington urban stormwater are elevated compared to natural concentrations and concentrations were markedly elevated in two samples from industrial catchments (Refer Fig. 5.12). Concentrations were typically higher than ANZECC trigger values but when compared to USEPA (2002) criteria for the protection of aquatic life, most of the samples collected from residential catchments were below the guideline. In industrial catchments most of the samples were above the criteria concentration.

8.4 Particulates in stormwater

This study measured the concentration of a range of elements in the particulate material in suspension in urban stormwater from residential and industrial/commercial catchments in the Wellington region. Table 8.2 provides a summary of the results obtained in relation how the concentration compares to natural sediment concentrations and whether the concentrations measured exceed the ANZECC (2000) ISQG-Low and High for the protection of sediment dwelling biota.

The summary indicates that in depositional environments, the elements Cr, Cu, Ni, Pb, and Zn are the elements most likely to result in an increase in sediment concentration as a consequence of elevated concentrations in urban stormwater particulate material. Based upon the available data, it is evident that urban stormwater will contribute to sediment contamination through the deposition of suspended solids in stormwater. Contributions will also be made by larger particles and by dissolved elements (that are taken out of solution through sorption and removal processes when stormwater enters saline water). Williamson et al. (2001) and Kennedy (2003a) discuss sediment quality and effects on benthic biota, the former study summarising examples of elevated concentrations of key elements adjacent to stormwater outfalls in the Wellington region

Table 8.2: Trace elements in urban stormwater particulates in the Wellington region.

Elements	Residential catchments		Industrial catchments	
	Concentration[1]	ANZECC (2000)	Concentration[1]	ANZECC (2000)
Aluminium	NA	NT	NA	NT
Antimony	?	No?	?	No?
Arsenic	L	NT	L	NT
Barium	M	NT	M	NT
Cadmium	?	?	?	?
Chromium	M	Some Yes	M	Some Yes
Cobalt	L	NT	M-H?	NT
Copper	M-H	Most Yes	H	YES
Iron		NT		NT
Lead	H	Yes	H	YES
Manganese	?	NT	?	NT
Mercury	M-H	No	M-H	No
Nickel	M	Some Yes	M	Some Yes
Selenium	?	NT	?	NT
Strontium	L	NT	L	NT
Silver	?	No	?	No
Tin	?	NT	?	NT
Vanadium	?	NT	?	NT
Zinc	H	Yes	H	Yes

Note: [1] – Relative increase in concentrations compared to natural concentration – L – low; M – medium; H – High. NT = No Trigger.

8.5 Organic compounds

This study has provided information on the concentration of a number of key groups of organic compounds in dissolved and particulate phases in Wellington urban stormwater.

Dissolved PAH concentrations were low to non-detectable in residential stormwater from newer catchments that drained to Pauatahanui Inlet and the Owhiro Stream. As expected, PAH concentrations were highest in the stormwater collected from the Hutt Park Rd industrial catchment. In most samples the PAH profile was dominated by heavier PAHs which reflected weathering of the PAH assemblage. In some samples, lighter or more volatile PAHs were identified.

Particulate concentrations of PAHs were high with the concentration generally reflecting the concentration measured in the dissolved fraction. The profile identified appeared to reflect the emission of PAHs from motor vehicles.

The examination of stormwater samples for organochlorine compounds detected a range of compounds and the PCB congeners present in each sample were similar. PCB concentrations were highest in the samples collected from the industrial Hutt Park stormwater catchment. The concentrations in the stormwater particulates with up to 678 µg/kg total PCB measured. The concentrations are high compared to available data for stormwater and road surface particulates.

The evaluation of organochlorine pesticide concentrations showed that compounds such as DDT were present at moderate concentrations with up to 315 µg/kg total DDT present in samples from industrial catchments.

Examination of samples for chlorophenol compounds (historically used in timber preservation) showed that samples from the industrial catchments tended to have more chlorophenols than those from residential catchments. The tendency for the industrial catchment samples having higher concentrations compared to residential catchments is likely to be a reflection of the historically higher use of such compounds in those catchments.

The stormwater from the industrial Hutt Park stormwater catchment had elevated concentrations of metals, PAHs, PCBs, OCPs and chlorophenols. The elevation in this catchment compared to other catchments is likely to reflect historical use and contamination of soils (or local fill, landfills) and groundwater within the catchment. Given that many of the OCP compounds involved have been withdrawn from use in New Zealand or are not permitted to be used it is unlikely that the cause is current use or land use in the catchment.

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Appendices

Appendix 1

Summary of analytical results – general water quality and metals.

Table A1-1: General water quality of Wellington stormwater samples (all data g/m^3 except pH).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**
pH	7.7	7.7	6.9	6.7	6.8	6.9	6.6	7.3	7.3	6.8	7.2
Total Suspended Solids	17	114	76	88	42	12	116	48	175	63	90
Nitrate-Nitrogen	1.03	1.12	1.22	0.002	0.235	0.306	0.301	0.164	0.171	0.383	0.164
Nitrite-Nitrogen	0.004	0.005	0.034	< 0.002	0.005	0.005	0.006	0.006	0.010	0.022	0.018
Total Oxidised Nitrogen	1.03	1.12	1.26	0.002	0.240	0.311	0.308	0.171	0.181	0.405	0.182
Total Kjeldahl Nitrogen	0.5	1.2	1.7	1.4	0.7	0.4	0.6	1.0	1.0	1.2	1.7
Total Nitrogen	1.6	2.3	2.9	1.4	0.9	0.8	0.9	1.2	1.2	1.6	1.9
Dissolved Reactive Phosphorus	0.038	0.055	0.036	0.065	0.033	0.016	0.025	0.049	0.028	0.029	0.043
Total Phosphorus	0.091	0.299	0.439	0.411	0.126	0.071	0.181	0.191	0.32	0.192	0.251
Dissolved Organic Carbon	3.3	5.7	4.1	2.6	2.6	1.2	2.5	2.1	1.7	1.4	2.0
Total Organic Carbon	5.2	9.4	13.4	14.6	6.9	4.8	7.5	5.6	11.7	10.2	4.2
Derived values											
Particulate Organic Carbon	1.9	3.7	9.3	12	4.3	3.6	5	3.5	10	8.8	2.2
% Organic Carbon in TSS	11.18	3.25	12.24	13.64	10.24	30.00	4.31	7.29	5.71	13.97	2.44

Notes: Landuse – r = residential; i = industrial/commercial.

Table A1-2: Dissolved elements in Wellington stormwater samples (all data g/m^3).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-06	WRUSI-11	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**
Aluminium	0.020	0.104	0.028	0.061	0.052	0.046	0.062	0.095	0.068	0.061	0.094
Antimony	0.0004	< 0.0002	0.0003	0.0003	< 0.0002	0.0003	< 0.0002	0.0003	0.0015	0.0007	0.0013
Arsenic	0.001	0.004	< 0.001	< 0.001	0.001	< 0.001	0.002	0.002	0.001	0.002	0.002
Barium	0.0083	0.0090	0.0126	0.0081	0.0060	0.0053	0.0116	0.0062	0.0113	0.0107	0.0105
Cadmium	< 0.00005	< 0.00005	< 0.00005	0.00005	< 0.00005	0.00011	< 0.00005	< 0.00005	0.00007	< 0.00005	0.00015
Chromium	0.0010	0.0020	0.0006	0.0010	0.0007	0.0017	0.0018	0.0069	0.0010	0.0053	0.0031
Cobalt	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0003	0.0004	0.0003	0.0005	0.0003	0.0005
Copper	0.0040	0.0036	0.0069	0.0100	0.0025	0.0063	0.0070	0.0067	0.0090	0.0225	0.0081
Iron	< 0.02	0.12	0.04	0.06	0.12	0.04	0.24	0.10	0.06	0.08	0.11
Lead	0.0008	0.0003	0.0003	0.0035	0.0008	0.0006	0.0008	0.0016	0.0028	0.0025	0.0115
Manganese	< 0.0005	0.0163	0.0064	0.0064	0.0239	0.0081	0.0803	0.0238	0.0220	0.0142	0.0816
Mercury	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008
Nickel	< 0.0005	0.0007	< 0.0005	0.0005	< 0.0005	< 0.0005	0.0008	< 0.0005	0.0017	0.0009	0.0011
Rubidium	0.0012	0.0009	0.0010	0.0031	0.0016	0.0004	0.0008	0.0007	0.0009	0.0016	0.0009
Selenium	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Silver	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0002	< 0.0001
Strontium	0.113	0.0387	0.0579	0.0172	0.0414	0.0158	0.0306	0.0370	0.0531	0.0471	0.0301
Tin	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Vanadium	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001
Zinc	0.024	0.056	0.097	0.108	0.022	1.05	0.132	0.266	0.247	0.108	0.589

Notes: Landuse – r = residential; i = industrial/commercial.

Table A1-3: Other dissolved elements in Wellington stormwater samples (all data g/m^3).

	WRUSI-01	**WRUSI-02**	**WRUSI-03**	**WRUSI-04**	**WRUSI-05**	**WRUSI-06**	**WRUSI-11**	**WRUSI-07**	**WRUSI-08**	**WRUSI-09**	**WRUSI-10**
Landuse	**r**	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**
Calcium	16.1	4.67	7.32	3.87	3.83	2.97	4.06	5.08	8.16	7.1	5.95
Magnesium	5.19	2.21	2.77	0.55	1.74	0.0003	1.61	1.92	1.96	3.51	1.34
Hardness (as $CaCO_3$)	61.5	20.7	29.7	11.9	16.7	9.05	16.75	17.6	28.4	37.2	19.24
Boron	0.046	0.004	< 0.001	0.018	0.028	0.023	0.027	0.035	0.032	0.028	0.054
Lithium	3.7	1.1	1.6	0.7	1.2	0.8	1.1	1.1	3.8	2.2	2.1
Bismuth	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cesium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1-0.4	< 0.1
Lanthanum	< 0.1	0.7	< 0.1	< 0.1	0.2	< 0.1	0.2	0.2	< 0.1	0.6	0.1
Thallium	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005

Notes: Landuse – r = residential; i = industrial/commercial.

Table A1-4: Trace elements in 0.7-59 µm particulate fraction from Wellington stormwater (all data mg/kg).

	Detection Limit	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse		r	r	r	r	r	r	i	i	i	i	i
Aluminium	10	60445	15513	21645	20477	37833	34015	33178	62463	18313	41162	32741
Antimony	100	NQ	NQ	NQ	NQ	NQ	170	NQ	NQ	NQ	<100	110
Arsenic	20	<20	<20	<20	32	<20	<20	<20	<20	<20	51	31
Barium	50	278	286	1302	957	25	364	392	1366	690	468	403
Cadmium	20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	77
Chromium	10	106	16	24	63	43	93	<10	67	21	178	71
Cobalt	10	24	13	14	49	36	5	852	597	1100	12	89
Copper	20	164	<20	197	405	161	169	180	161	227	381	21682
Iron	10	37075	15183	29719	20629	24010	40292	31993	37380	36117	30614	27864
Lead	50	644	78	373	1076	186	232	282	248	896	298	844
Manganese	10	1198	372	514	393	639	1647	509	604	505	653	412
Mercury	50	<50	<50	<50	<50	<50	167	<50	<50	<50	90	157
Nickel	10	28	<10	<10	29	10	25	<10	30	40	12	15
Rubidium	20	92	71	144	90	70	147	243	142	226	108	250
Selenium	20	<20	<20	<20	<20	44	38	<20	<20	<20	<20	51
Silver	50	426	80	102	105	139	471	1273	2766	<50	907	1079
Strontium	20	128	58	83	78	94	565	124	103	118	140	57
Tin	50	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Vanadium	20	105	41	76	58	74	70	757	412	595	54	77
Zinc	20	2101	201	1352	8896	1404	1055	4069	2620	2263	1117	3532

Notes: Landuse – r = residential; i = industrial/commercial.

Table A1-5: Trace elements in 60-249 µm particulate fraction from Wellington stormwater (all data mg/kg).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10	WRUSI-11
Landuse	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**	**r**
Aluminium	43150	13190	11759	10353	18116	65382	29486	30805	16604	44752	149056
Antimony	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	<100	<100	<100
Arsenic	163	<20	<20	44	35	<20	<20	<20	<20	81	363
Barium	1517	288	281	25	25	25	25	25	392	579	1519
Cadmium	<20	<20	27	36	219	<20	<20	<20	<20	178	<20
Chromium	112	38	25	43	29	220	63	34	132	176	880
Cobalt	117	42	25	96	104	457	157	142	14	36	1145
Copper	277	21	146	296	125	633	130	255	374	428	1145
Iron	58027	24782	38835	17146	25928	70498	25666	36982	23597	53568	502910
Lead	1047	34	392	685	72	778	232	864	405	3391	268
Manganese	4425	1801	1047	450	1931	1775	1301	1095	659	2123	69999
Mercury	138	42	<50	<50	<50	<50	<50	<50	<50	<50	428
Nickel	140	14	<10	11	25	106	30	31	<10	44	186
Rubidium	227	82	182	60	47	195	75	76	165	85	1920
Selenium	<10	21	17	17	<10	16	<10	<10	<10	76	1261
Silver	314	90	46	17	<50	3965	293	299	137	355	4688
Strontium	313	120	138	68	140	335	111	105	153	440	1986
Tin	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Vanadium	295	77	88	40	130	211	112	135	96	200	2064
Zinc	2717	422	1057	5546	572	9307	1613	1639	1032	5591	12178

Notes: Landuse – r = residential; i = industrial/commercial.

Appendix 2

Summary of analytical results – organic compounds

Table A2-1: Dissolved polyaromatic hydrocarbon compounds in Wellington stormwater samples (all data mg/m^3).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**
Naphthalene	<0.7	<0.5	<0.02	<0.4	<0.4	0.21	<0.4	<0.08	<0.2	0.094	0.078
Acenaphthylene	<0.02	<0.02	<0.003	<0.02	<0.01	0.0085	<0.02	<0.004	<0.02	0.0083	0.015
Acenaphthene	<0.005	<0.005	<0.001	<0.01	<0.008	0.014	<0.01	<0.01	0.02	0.0039	<0.0.005
Fluorene	<0.005	<0.005	<0.001	<0.01	<0.008	0.012	<0.04	0.029	<0.0.04	0.012	0.011
Phenanthrene	<0.02	<0.01	<0.006	<0.05	<0.03	0.018	<0.08	<0.04	<0.1	0.11	0.021
Anthracene	<0.003	<0.005	<0.002	<0.005	<0.003	0.0021	<0.01	<0.008	<0.04	0.0066	<0.006
Fluoranthene	<0.01	<0.005	0.0041	0.018	<0.008	0.0049	<0.04	<0.03	0.31	0.022	0.017
Pyrene	<0.005	<0.01	0.01	0.02	<0.009	0.0074	<0.05	0.04	0.4	0.032	0.047
Benz(a)anthracene	<0.003	<0.003	0.0021	0.0062	<0.001	<0.0005	<0.003	<0.002	0.14	0.0018	0.0095
Chrysene	<0.003	<0.003	0.003	0.012	<0.0009	0.0013	<0.01	0.0037	0.24	0.0055	0.026
Benzo(b)fluoranthene	<0.003	<0.003	<0.36	0.0057	<0.002	0.0012	<0.006	<0.003	0.23	0.0029	0.043
Benzo(k)fluoranthene	<0.003	<0.003	0.0033	0.0052	<0.0004	0.00086	<0.002	<0.0.002	0.19	<0.003	0.037
Benzo(a)pyrene	<0.003	<0.003	0.0034	0.0055	<0.0006	<0.001	0.00095	<0.001	0.18	<0.004	0.033
Indeno(1,2,3-c,d)pyrene	<0.003	<0.003	0.0034	0.0066	<0.002	<0.003	<0.002	<0.002	0.19	<0.02	0.039
Dibenz(a,h)anthracene	<0.003	<0.003	<0.001	<0.002	<0.002	<0.003	<0.0008	<0.0007	0.04	<0.02	0.0072
Benzo(g,h,i)perylene	<0.003	<0.003	0.0037	0.0087	<0.001	<0.003	0.0034	<0.002	0.17	0.01	0.0.038

Notes: Landuse – r = residential; i = industrial/commercial.

Table A2-2: Polyaromatic hydrocarbon compounds in 0.7-59 µm fraction of suspended solids from Wellington stormwater samples (all data µg/kg).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**
Naphthalene	<2000	<900	NQ	<900	<3000	9200	<300	<400	<400	950	420
Acenaphthylene	<200	<40	130	360	<200	270	<40	32	120	130	800
Acenaphthene	<40	<10	<200	40	<90	620	<10	<30	70	52	47
Fluorene	<40	<50	<600	91	<200	500	<40	<70	85	120	150
Phenanthrene	<200	<100	650	1000	<900	910	<200	<400	600	1400	760
Anthracene	<40	<30	140	280	<100	130	<40	49	270	160	260
Fluoranthene	150	110	1200	2300	280	700	100	410	1100	1400	2500
Pyrene	170	110	1400	2400	290	780	220	860	1100	2200	3400
Benz(a)anthracene	44	37	520	1300	57	240	26	220	2500	590	1500
Chrysene	90	75	700	1800	190	14	75	380	3600	960	2400
Benzo(b)fluoranthene	52	29	600	1500	79	470	43	370	3400	700	2500
Benzo(k)fluoranthene	84	50	720	1700	40	360	37	320	3400	520	2300
Benzo(a)pyrene	<60	<30	860	1500	57	470	<80	270	2700	580	2300
Indeno(1,2,3-c,d)pyrene	<10	<6	<4	2100	<80	<400	<70	320	2800	560	2600
Dibenz(a,h)anthracene	<10	<6	<3	350	<70	<300	<20	53	620	<300	510
Benzo(g,h,i)perylene	<20	<6	<3	2500	130	600	110	450	2500	1400	2500

Notes: Landuse – r = residential; i = industrial/commercial.

Table A2-3: Polyaromatic hydrocarbon compounds in 60-249 µm fraction of suspended solids from Wellington stormwater samples (all data µg/kg).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**
Naphthalene	<30000	<7000	<4000	5300	<1000	5000	<20000	<2000	<30000	1400	1200
Acenaphthylene	<2000	<200	<300	710	<100	230	<2000	<100	2000	170	740
Acenaphthene	<200	<100	<400	100	<50	410	<500	<90	1000	58	<70
Fluorene	<200	<200	<1000	<200	<80	350	<2000	<200	3000	190	240
Phenanthrene	<1000	<700	830	1300	<400	780	<5000	<1000	<10000	2000	870
Anthracene	<200	200	140	320	<200	80	<800	170	<3000	250	280
Fluoranthene	1300	1000	1200	3300	<200	440	<2000	1000	9600	1800	2600
Pyrene	1300	860	1500	2900	<300	450	<3000	1900	11000	2800	3400
Benz(a)anthracene	410	360	500	1500	<50	120	<300	400	4200	760	1200
Chrysene	650	510	650	2400	<100	290	<1000	790	5800	1200	1900
Benzo(b)fluoranthene	<400	230	600	1500	<80	210	<600	480	4200	820	2100
Benzo(k)fluoranthene	<400	300	540	1600	<40	200	<400	410	3900	630	1800
Benzo(a)pyrene	<400	220	730	1600	<300	170	<500	340	3300	800	1900
Indeno(1,2,3-c,d)pyrene	<100	<30	<40	1700	<60	200	<500	390	3400	800	2000
Dibenz(a,h)anthracene	<100	<30	<60	300	<40	<200	<500	64	740	<400	390
Benzo(g,h,i)perylene	<100	<60	<40	2200	<100	290	<1000	570	3500	1600	2100

Notes: Landuse – r = residential; i = industrial/commercial.

Table A2-4: Dissolved organochlorine compounds in Wellington stormwater samples (all data mg/m^3).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**
alpha-HCH	<0.08	<0.06	0.030	<0.3	<0.4	0.075	<0.6	<0.2	<0.4	0.065	<0.09
beta-HCH	<0.09	<0.07	<0.03	<0.4	<0.5	<0.1	<0.7	<0.1	<0.3	<0.08	0.32
gamma-HCH	<0.3	<0.9	0.58	<0.8	<0.4	0.29	<0.9	<0.4	1.9	1.3	0.61
HCB	<0.3	<0.2	<0.009	<1	<0.8	<0.4	<0.8	<0.2	<0.3	0.35	0.40
Aldrin	<0.08	<0.06	0.010	<0.2	<0.3	0.14	<0.4	<0.08	<0.2	<0.06	0.11
Dieldrin	<0.8	2.2	1.3	<2	<0.6	0.31	<0.9	<0.9	4.4	4.2	2.9
Heptachlor	0.072	0.076	<0.08	<0.1	<0.07	<0.2	<0.6	<0.1	<0.1	<0.1	0.17
Heptachlor epoxide	<0.07	<0.05	<0.05	<0.7	<0.9	<0.1	<0.2	<0.1	<0.06	<0.3	<0.3
alpha-chlordane	<0.2	<0.1	0.085	<0.2	<0.3	<0.09	<0.4	<0.2	0.25	0.28	0.21
gamma-chlordane	<0.2	<0.2	<0.2	<0.5	<0.2	<0.08	<0.4	<0.2	<0.6	0.28	0.24
p,p'-DDE	0.57	0.12	0.36	<0.2	<0.3	0.17	<0.9	<1	1.8	1.6	0.38
p,p'-TDE	<0.1	<0.09	0.065	<0.3	<0.4	0.040	0.37	<0.1	10	0.27	<0.2
o,p'-DDT	<0.01	<0.008	0.11	0.25	<0.7	0.075	<0.1	<0.08	1.3	0.51	0.27
p,p'-DDT	<0.3	<0.3	0.37	0.68	<0.6	<0.2	0.23	<0.2	4.8	2.6	0.61

Notes: Landuse – r = residential; i = industrial/commercial.

Table A2-5: Organochlorine compounds in 0.7-59 µm fraction of suspended solids from Wellington stormwater samples (all data mg/kg).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**
alpha-HCH	<0.2	<0.2	<0.3	<0.2	<1	<2	<0.9	<0.1	<0.2	<0.4	<0.3
beta-HCH	<0.2	<0.2	<0.5	<1	<4	<3	<0.9	<0.1	<0.4	<0.6	<0.5
gamma-HCH	<1	<0.6	<3	<3	<6	<3	<1	<0.6	1.1	7.0	0.72
HCB	<1	<1	<2	<5	<9	<8	<3	<1	<1	2.8	6.7
Aldrin	<0.2	<0.2	<0.4	<0.3	<1	<1	<0.6	<0.3	1.2	<0.2	0.35
Dieldrin	<10	<2	22	23	<10	6.8	<9	10	28	7.9	67
Heptachlor	0.37	<0.3	<0.7	<1	<3	<1	<2	<0.2	0.54	<0.3	0.37
Heptachlor epoxide	<0.1	<0.2	<0.8	<0.6	<3	<4	<2	<0.5	<0.2	<1	<2
alpha-chlordane	<2	<0.8	<3	4.1	<8	<8	<1	<1	2.8	<0.4	1.7
gamma-chlordane	<2	<1	<4	6.5	<8	<10	<2	<2	3.8	0.47	3.0
p,p'-DDE	1.5	14	18	14	23	22	12	14	30	0.94	8.0
p,p'-TDE	1.1	1.6	2.8	6.7	<20	1.5	<10	1.9	180	0.20	5.6
o,p'-DDT	<0.05	<0.03	4.8	6.0	<8	9.5	<4	2.1	29	0.32	8.5
p,p'-DDT	3.4	5.0	25	60	<20	<50	<10	8.8	76	0.63	21
Total DDT	6	8	50.2	86.7	23	33	12	26.8	315	1.55	43.1

Notes: Landuse – r = residential; i = industrial/commercial.

Table A2-6: Organochlorine compounds in 60-249 µm fraction of suspended solids from Wellington stormwater samples (all data mg/kg).

	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10	WRUSI-11
Landuse	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**	**r**
alpha-HCH	<4	<2	<2	1.2	<2	<30	<0.7	<30	0.56	<2	<2
beta-HCH	<6	<3	<4	<4	<3	<40	<0.9	<10	<0.6	<3	<3
gamma-HCH	<6	<3	<3	<4	<2	<40	<2	<40	22	<3	<3
HCB	<10	<4	<4	<10	<5	<100	<3	<60	3.1	7.1	<7
Aldrin	<5	<2	<3	<2	<0.9	<20	<1	<10	<0.4	<2	<0.9
Dieldrin	<80	<9	29	25	<9	<500	<20	<800	32	59	4.8
Heptachlor	<8	<4	<5	<2	<0.6	<30	<0.4	<30	<0.5	<0.9	<1
Heptachlor epoxide	<9	<3	<4	<6	<3	<90	<2	<10	<2	<7	<3
alpha-chlordane	<7	<3	<9	<7	<3	<30	<0.9	<60	1.9	<1	<2
gamma-chlordane	<8	2.4	<10	<8	<4	<40	<2	<60	1.9	3.1	<9
p,p'-DDE	5.6	13	17	19	20	<100	<40	110	11	12	9.8
p,p'-TDE	<2	<4	3.9	26	<20	<60	<5	910	1.9	5.7	0.96
o,p'-DDT	<3	<1	5.4	8.5	<3	<40	<6	50	4.0	8.6	3.6
p,p'-DDT	<10	<10	27	41	6.7	<40	11	100	14	19	<10
Total DDT	5.6	13	52.4	94.5	26.7	<100	11	1170	30.9	45.3	14.36

Notes: Landuse – r = residential; i = industrial/commercial.

Table A2.7: Dissolved chlorophenol compounds in Wellington stormwater samples (all data mg/m^3).

Congener	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**	**r**
2-MCP	<30	<30	<3	<100	<100	<0.2	<100	<100	<100	0.90	0.22
3-MCP	<0.6	<0.4	<3	<0.05	<0.05	<0.04	<3	<0.1	<0.1		0.16
4-MCP	<0.5	<0.3	<3	<2	<2	0.23	<4	<0.4	<0.5	0.37	4.3
2,3-DCP	<1.0	<2	<20	<0.05	<0.1	<0.05	<2	<0.1	<0.1	<0.2	<0.4
2,4/2,5-DCP	<2	<4	<10	<5	<2	3.5	<6	2.4	4.5	1.7	3.4
2,6-DCP	<2	<4	<10	0.80	0.55	1.0	<3	1.1	<1	0.91	1.4
3,4-DCP	<0.3	<0.2	<10	<0.05	<0.1	<0.04	<2	<0.1	<0.2	<0.2	<0.3
3,5-DCP	<0.8	<2	<20	<0.1	<0.1	<0.05	<2	<0.1	<0.1	<0.2	<0.4
2,3,4-TCP	<0.3	<0.2	<3	<0.2	<0.05	<0.07	<0.7	<0.04	<0.1	<0.2	<0.1
2,3,5-TCP	<0.4	<0.3	<3	<0.3	<0.05	<0.09	<0.8	<0.05	0.10	<0.2	
2,3,6-TCP	<0.4	<0.1	<3	<0.1	<0.05	<0.09	<0.8	<0.05	0.05	<0.2	<0.1
2,4,5-TCP	<0.4	<2	<2	<0.4	<0.2	<0.07	<1	0.25	0.7	<0.2	0.59
2,4,6-TCP	<2.0		<4	<3	<2	2.1	<3	2.8	1.6	2.4	6.2
3,4,5-TCP	<0.4	<0.3	<3	<0.1	<0.05	<0.07	<0.7	<0.2	<0.2	<0.2	<0.1
2,3,4,5-TeCP	<0.2	<0.2	<2	<0.2	<0.1	<0.057	<0.5	<0.4	<0.4	<0.2	<0.3
2,3,4,6-TeCP	<1.0	<2	<2	<0.9	<0.5	0.24	<20	0.55	1.2	0.9	3.0
2,3,5,6-TeCP	<0.5	<0.8	<3	<0.05	<0.05	<0.05	<0.5	<0.1	<0.3	<1	
2,3,4,5,6-PCP	13.0	15.0	9.4	6.0	3.9	<6	17.0	7.0	25.0	23.0	52
Sum	ND	15.0	9.4	6.8	4.45	7.07	17.0	14.1	33.15	30.18	71.27

Notes: Landuse – r = residential; i = industrial/commercial. ND – Not determined.

Table A2.8: Chlorophenol compounds in 0.7-59 µm fraction of suspended solids from Wellington stormwater samples (all data mg/kg).

Congener	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**	**r**
2-MCP	<8	<30	22	<200	<1000	15	<60	<400	<100	2.3	1.5
3-MCP	<0.7	<0.4	<8	1.2	<4	1.5	<0.8	<0.1	<0.2	<0.5	0.30
4-MCP	10	4.7	<7	27	160	18	<0.7	<2	<1	3.6	1.2
2,3-DCP	<8	<2	<20	<1	<4	<2	<0.4	<0.09	<0.06	<0.8	<1
2,4/2,5-DCP	<10	<10	<20	14	59	29	<2	<7	<4	6.0	2.5
2,6-DCP	<7	<2	<20	0.44	<2	<2	<0.9	<0.4	<0.2	<0.7	<1
3,4-DCP	<0.6	<0.3	<20	0.88	<2	<2	<0.2	<0.4	<0.4	<0.7	<1
3,5-DCP	<6	<1	<30	<0.6	<0.6	<2	<0.08	<0.2	<0.1	<0.8	<1
2,3,4-TCP	<0.6	<0.3	<7	<0.3	<0.6	<2	<0.04	<0.09	<0.06	<0.8	<0.5
2,3,5-TCP	<0.7	<0.4	<9	<0.3	<0.6	<3	<0.04	<0.1	<0.06	<1	<0.6
2,3,6-TCP	<1	<0.4	<9	<0.3	<0.6	<3	<1	<0.1	<0.06	<1	<0.6
2,4,5-TCP	<40	<20	<7	3.2	<10	<2	<0.2	<1	1.1	<0.8	0.64
2,4,6-TCP	<4	<4	<8	5.3	30	3.5	<6	<1	<0.8	1.1	1.2
3,4,5-TCP	<0.7	<0.4	<9	0.44	<0.6	<2	<0.04	<0.1	0.12	<0.9	<0.5
2,3,4,5-TeCP	<0.6	<0.3	<6	<1	<1	1.6	<0.08	<0.7	<0.5	<0.4	<1
2,3,4,6-TeCP	<4	<2	<20	2.6	<7	1.3	<2	<1	0.48	0.40	0.71
2,3,5,6-TeCP	<6	<0.7	<10	0.29	<0.6	<2	<4	<0.1	<0.1	<0.6	0.47
2,3,4,5,6-PCP	<40	<10	<200	29	<40	14	<4	6.7	9.5	10	31
Sum	10	4.7	22	85.4	246	84.0	ND	6.68	11.2	23.3	39.5

Notes: Landuse – r = residential; i = industrial/commercial. ND Not determined.

Table A2.9: Chlorophenol compounds in 60-249 µm fraction of suspended solids from Wellington stormwater samples (all data mg/kg).

Congener	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-11	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10
Landuse	**r**	**r**	**r**	**r**	**r**	**i**	**i**	**i**	**i**	**i**	**r**
2-MCP	<50	<100	<60	<500	<700	16	<5000	<1000	<40000	2.2	2.9
3-MCP	<60	<10	<70	<1	<0.5	1.2	<2	<1	<40	0.39	0.95
4-MCP	<50	<10	<60	25	330	16	<40	<10	<300	6.9	3.9
2,3-DCP	<200	<30	<200	<1	<0.5	<1	<2	<0.7	<10	<1	<4
2,4/2,5-DCP	<100	<30	<200	<10	130	19	<70	<30	<200	6.8	8.8
2,6-DCP	<200	<30	<200	<1	<2	1.5	<2	<1	<7	<1	<4
3,4-DCP	<200	<30	<200	<2	<0.5	<1	<2	<0.6	<7	<1	<4
3,5-DCP	<200	<40	<200	<0.3	<0.5	<1	<2	<0.8	<7	<1	<4
2,3,4-TCP	<60	<10	<40	<0.3	<0.5	<2	<2	<0.5	<7	<1	<2
2,3,5-TCP	<70	<10	<50	<0.7	<0.5	<2	<2	<0.7	<7	<1	<2
2,3,6-TCP	<70	<10	<50	<0.7	<0.5	<2	<2	<0.6	<7	<1	<2
2,4,5-TCP	<60	<10	<40	<4	<3	<2	<2	<3	<10	<1	<2
2,4,6-TCP	<60	<10	<40	<5	100	2.5	<300	<7	<60	1.6	2.0
3,4,5-TCP	<70	<10	<50	0.69	<0.5	<2	<2	<0.6	<7	<1	<2
2,3,4,5-TeCP	<40	<8	<30	<1	<1	1.1	<4	<3	<10	0.52	<2
2,3,4,6-TeCP	<50	<8	<30	<3	<3	0.76	<60	<1	<10	0.69	0.76
2,3,5,6-TeCP	<80	<10	<50	<0.3	<0.5	<1	<200	<0.6	<106	<0.6	<0.7
2,3,4,5,6-PCP	<100	<30	<200	20	<10	5.4	<40	<20	310	16	25
Sum	0	0	0	45.2	564	62.3	ND	ND	307	34.7	44.3

Notes: Landuse – r = residential; i = industrial/commercial. ND – Not determined.

Table A2-10: Dissolved PCB congeners in Wellington stormwater (all data mg/m^3).

Congener	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10	WRUSI-11
# 1	<0.08	<0.07	<0.08	<0.05	<0.004	<0.06	<0.05	<0.04	<0.02	0.017	0.0061
# 3	<0.07	<0.05	<0.03	<0.02	<0.05	<0.05	<0.09	<0.05	0.044	0.025	0.014
# 4	<0.03	<0.02	<0.3	<0.10	<0.10	<0.20	<0.20	2.4	0.11	0.088	0.025
# 15	<0.10	<0.10	<0.10	<0.10	<0.10	<0.20	<0.30	1.9	0.11	0.15	0.044
# 19	<0.10	<0.06	<0.04	<0.04	<0.04	<0.04	<0.07	1.1	0.042	0.042	<0.03
# 28	<0.10	<0.10	<0.3	<0.40	<0.40	<0.40	<1.0	8.9	0.52	0.57	0.15
# 37	<0.08	<0.08	<0.05	<0.09	<0.08	<0.05	<0.50	3.4	0.15	0.22	0.057
# 44	<0.02	<0.03	<0.05	<0.09	<0.08	<0.06	<0.50	3.0	0.46	0.18	0.063
# 49	<0.02	<0.02	<0.05	<0.09	<0.09	<0.06	<0.40	2.4	0.38	0.18	0.044
# 52	<0.04	<0.05	<0.09	<0.20	<0.10	<0.10	<0.60	3.6	0.71	0.25	0.081
# 54	<0.06	<0.04	<0.006	<0.02	<0.01	<0.07	<0.02	0.017	<0.02	<0.05	<0.01
# 70	<0.06	<0.06	<0.10	<0.10	<0.10	<0.20	<0.90	5.8	0.65	0.35	0.076
# 74	<0.03	<0.03	<0.05	<0.06	<0.06	<0.04	<0.40	2.7	0.28	0.16	0.032
# 77	<0.03	<0.03	<0.02	<0.02	<0.02	<0.04	<0.07	0.49	0.034	0.048	0.011
# 81	<0.03	<0.02	<0.005	<0.009	<0.007	<0.04	<0.02	0.054	<0.02	<0.02	<0.01
# 99	<0.008	<0.02	<0.02	<0.05	<0.03	<0.04	<0.20	0.78	0.17	0.086	0.018
# 101	<0.03	<0.05	<0.08	<0.10	<0.07	<0.10	<0.50	2.3	0.58	0.35	0.051
# 104	<0.05	<0.03	<0.004	<0.004	<0.002	<0.02	<0.01	<0.006	<0.005	<0.01	<0.005
# 105	<0.03	<0.04	<0.05	<0.04	<0.02	<0.05	<0.20	0.95	0.15	0.16	0.012
# 110	<0.03	<0.07	<0.08	0.20	<0.07	0.058	<0.40	2.9	0.64	0.36	0.042
# 114	<0.02	<0.01	<0.006	<0.01	<0.004	<0.02	<0.02	0.054	<0.01	<0.02	<0.008
# 118	<0.06	<0.07	<0.09	<0.10	<0.04	0.060	<0.40	2.1	0.38	0.38	0.031
# 123	<0.03	<0.02	<0.006	<0.01	<0.004	<0.02	<0.02	0.069	0.020	<0.02	<0.008
# 126	<0.02	<0.01	<0.007	<0.01	<0.004	<0.03	<0.02	0.021	<0.01	<0.02	<0.01
# 138	<0.04	<0.08	<0.10	0.15	<0.04	<0.20	<0.50	2.9	0.44	0.64	0.030
# 153	<0.03	<0.06	<0.09	0.11	<0.05	<0.10	<0.50	2.1	0.41	0.51	0.021
# 155	<0.03	<0.03	<0.002	<0.004	<0.003	<0.01	<0.01	<0.005	<0.003	<0.01	<0.004
# 156	<0.02	<0.02	0.0067	<0.01	<0.009	<0.04	<0.02	0.30	0.043	0.056	<0.008
# 157	<0.02	<0.01	<0.003	<0.01	<0.009	<0.04	<0.02	0.068	<0.01	<0.03	<0.008
# 167	<0.03	<0.03	0.016	<0.05	<0.009	<0.04	<0.02	0.24	0.013	<0.03	<0.008
# 169	<0.02	<0.006	<0.004	<0.02	<0.01	<0.05	<0.02	<0.008	<0.02	<0.03	<0.01
# 170	<0.02	<0.03	0.015	<0.03	<0.009	<0.04	<0.03	0.43	0.057	0.14	<0.01
# 180	<0.02	<0.03	<0.008	0.042	<0.007	<0.04	<0.20	0.77	0.16	0.28	0.018
# 183	<0.02	<0.03	<0.008	<0.01	<0.007	<0.04	<0.05	0.20	0.053	0.069	<0.01
# 187	<0.02	<0.03	<0.02	0.027	<0.007	<0.04	<0.20	0.34	0.11	0.13	<0.01
# 188	<0.02	<0.02	<0.005	<0.01	<0.006	<0.04	<0.02	<0.006	<0.01	<0.03	<0.009
# 189	<0.02	<0.02	<0.007	<0.01	<0.009	<0.04	<0.03	0.025	<0.02	<0.03	<0.01
# 194	<0.006	<0.005	<0.004	0.015	<0.005	<0.02	<0.02	0.13	0.027	0.044	<0.007
# 196	<0.006	<0.004	<0.002	0.031	<0.006	<0.02	<0.02	0.13	0.053	0.033	<0.007
# 199	<0.006	<0.004	<0.002	<0.007	<0.004	<0.01	<0.02	0.011	0.0058	<0.02	<0.004
# 202	<0.02	<0.01	<0.005	<0.02	<0.004	<0.01	<0.02	0.018	0.0083	<0.03	<0.005
# 205	<0.02	<0.01	<0.004	<0.01	<0.005	<0.02	<0.02	0.0081	<0.005	<0.01	<0.006
# 206	<0.02	<0.007	<0.005	<0.03	<0.004	<0.02	<0.05	0.029	0.0086	0.012	<0.002
# 208	<0.02	<0.01	<0.004	<0.009	<0.003	<0.01	<0.01	<0.02	<0.003	<0.004	<0.002
# 209	<0.02	<0.009	<0.006	<0.008	<0.003	<0.03	<0.05	<0.02	<0.002	<0.004	<0.003
Sum	0	<0.08	0.0377	0.578	0	0.118	0	52.7	6.82	5.53	0.826

Table A2-11: PCB congeners in 0.7-59 µm particulate fraction (all data ng/g).

congener	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10	WRUSI-11
# 1	<0.30	<0.20	<0.30	<0.30	<0.70	<0.05	<0.20	<0.10	0.17	0.063	0.24
# 3	<0.30	<0.10	<0.20	<0.50	<1.0	<0.10	<0.50	<0.10	0.35	0.14	0.59
# 4	<2.0	<1.0	<2.0	<0.90	<2.0	<0.20	<0.90	7.1	0.65	0.56	0.63
# 15	<0.90	<0.40	<1.0	<3.0	<5.0	<0.50	<3.0	18	1.7	2.5	1.5
# 19	<0.50	<0.20	<0.30	<0.50	<1.0	<0.08	<0.40	7.0	0.46	0.51	<0.90
# 28	<2.0	<1.0	<3.0	<10.0	<20.0	<3.0	<10.0	110	10	9.8	4.7
# 37	<1.0	<0.40	0.73	1.7	<6.0	<2.0	2.5	39	6.7	6.6	1.8
# 44	<0.30	<0.20	0.70	1.7	<4.0	<1.0	2.5	41	14	4.9	2.3
# 49	<0.30	<0.10	0.64	1.3	<4.0	<0.90	<3.0	33	8.9	3.9	1.6
# 52	<0.60	<0.20	1.3	3.4	<6.0	<1.0	<5.0	49	28	6.8	3.3
# 54	<0.20	<0.10	<0.02	<0.04	<0.08	<0.01	<0.10	0.14	<0.09	<0.02	<0.40
# 70	<1.0	<0.50	2.0	3.6	<9.0	<3.0	4.8	73	36	13	3.4
# 74	<0.60	<0.20	0.68	1.4	<4.0	<2.0	2.3	33	11	5.1	1.6
# 77	<0.40	<0.20	0.27	1.5	<1.0	<0.40	0.60	6.0	3.7	1.8	0.59
# 81	<0.10	<0.06	0.049	0.12	<0.20	<0.02	0.092	0.63	1.3	0.19	<0.30
# 99	0.33	<0.09	0.90	3.3	<2.0	<2.0	<3.0	12	21	4.1	1.2
# 101	1.1	<0.30	2.6	12	<5.0	<1.0	3.1	32	63	15	4.1
# 104	<0.10	<0.07	<0.01	<0.03	<0.03	<0.005	<0.05	<0.01	<0.04	<0.02	<0.20
# 105	<1.0	<0.30	1.6	3.8	<2.0	<1.0	1.7	12	33	7.5	1.2
# 110	1.9	<0.30	3.4	38	<5.0	<2.0	4.2	40	91	18	3.9
# 114	<0.10	<0.05	0.072	0.13	<0.10	<0.03	<0.09	0.65	1.3	0.32	<0.20
# 118	<2.0	<0.40	4.0	8.9	<4.0	1.1	3.7	28	76	18	3.1
# 123	<0.20	<0.06	0.10	0.58	<0.10	<0.03	<0.30	0.81	<5.0	0.44	<0.20
# 126	<0.10	<0.04	0.042	0.19	<0.10	<0.03	<0.09	0.23	0.64	0.19	<0.20
# 138	2.6	0.36	5.4	31	<3.0	1.4	5.2	40	82	37	7.1
# 153	1.9	0.30	3.8	21	<3.0	1.00	4.3	30	66	30	5.2
# 155	<0.08	<0.05	<0.02	<0.02	<0.03	<0.007	<0.06	<0.008	<0.05	<0.03	<0.09
# 156	<0.40	<0.08	0.49	2.1	0.16	0.16	0.57	4.0	9.5	3.4	0.53
# 157	<0.20	<0.05	0.15	0.96	<0.10	<0.05	0.13	0.86	2.0	0.66	<0.40
# 167	<0.90	<0.10	1.0	<5.0	<0.10	<0.20	0.22	2.5	2.9	1.2	<0.40
# 169	<0.08	<0.03	<0.05	<0.09	<0.10	<0.06	<0.10	<0.04	<0.20	<0.08	<0.80
# 170	0.33	0.067	0.80	4.1	<0.40	0.30	*1.2*	6.2	13	9.1	0.88
# 180	<0.08	<0.03	<0.05	8.9	<0.70	0.55	2.4	11	35	15	2.4
# 183	<0.08	<0.06	<0.05	2.2	<0.40	0.13	0.56	2.8	9.4	4.1	0.75
# 187	0.37	0.082	0.94	5.5	<0.50	0.24	1.1	4.8	22	7.9	1.3
# 188	<0.06	<0.04	<0.03	0.034	<0.09	<0.006	<0.20	<0.02	<0.20	<0.05	<0.40
# 189	<0.06	<0.04	<0.04	0.20	<0.10	<0.09	<0.20	0.30	0.48	0.44	<0.50
# 194	0.13	0.029	0.23	3.3	<0.10	0.10	0.51	1.8	7.9	2.7	<0.50
# 196	<0.02	<0.008	0.13	6.1	<0.10	0.17	0.60	2.0	11	1.9	0.41
# 199	<0.02	<0.008	0.018	0.56	<0.07	<0.02	<0.10	0.16	1.8	0.33	<0.20
# 202	<0.10	<0.02	0.055	1.1	<0.06	<0.02	<0.30	0.24	2.3	0.45	<0.30
# 205	<0.07	<0.03	<0.03	0.15	<0.10	<0.04	<0.10	0.091	0.39	0.18	<0.40
# 206	<0.20	<0.05	0.16	3.5	<0.20	<0.08	<0.50	0.38	1.9	0.61	<0.10
# 208	<0.10	<0.03	0.043	0.76	<0.10	<0.02	<0.20	0.089	0.45	0.14	<0.10
# 209	12	<0.05	<0.09	0.37	<0.20	<0.02	<0.20	0.12	0.077	0.12	0.20
Sum	20.7	0.838	32.3	173	0.165	5.13	42.3	648	677	235	54.5

Table A2-12: PCB congeners in 60-249 µm particulate fraction (all data ng/g).

congener	WRUSI-01	WRUSI-02	WRUSI-03	WRUSI-04	WRUSI-05	WRUSI-06	WRUSI-07	WRUSI-08	WRUSI-09	WRUSI-10	WRUSI-11
# 1	<2.0	<0.60	<0.80	<0.60	<0.30	<3.0	<1.0	<4.0	<0.90	0.26	0.24
# 3	<0.90	<0.20	<0.40	<0.60	<0.40	<5.0	<2.0	<5.0	0.50	0.46	0.57
# 4	<10.0	<3.0	<3.0	<2.0	<0.90	<5.0	<3.0	<30.0	1.3	1.3	0.77
# 15	<5.0	<1.0	<1.0	<2.0	<2.0	<20.0	<8.0	<100.0	2.2	2.9	1.4
# 19	<2.0	<0.60	<0.50	<0.70	<0.30	<3.0	<0.60	<20.0	0.61	0.71	<1.0
# 28	<10.0	<4.0	<4.0	<7.0	<6.0	<100.0	<30.0	<500.0	12	13	4.1
# 37	<3.0	<1.0	<1.0	<2.0	<2.0	<60.0	<10.0	<300.0	8.1	7.1	1.8
# 44	<3.0	<0.70	<1.0	<3.0	<1.0	<30.0	<10.0	<200.0	17	5.0	2.2
# 49	<2.0	<0.70	<1.0	<2.0	<1.0	<30.0	<8.0	<200.0	11	3.8	1.5
# 52	<4.0	<1.0	<3.0	<7.0	<2.0	<40.0	<10.0	<200.0	33	7.1	3.2
# 54	<0.30	<0.09	<0.09	<0.04	<0.10	<1.0	<0.40	<1.0	<0.20	<0.20	<0.40
# 70	<6.0	<2.0	<3.0	<8.0	<3.0	<100.0	<30.0	<500.0	43	13	3.1
# 74	<3.0	<0.90	<1.0	<3.0	<1.0	<60.0	<10.0	<300.0	13	5.6	1.3
# 77	<0.90	<0.20	<0.40	0.67	<1.0	<6.0	<3.0	<40.0	4.0	1.7	0.37
# 81	<0.30	<0.10	<0.40	0.13	<0.05	<7.0	<0.30	<4.0	1.3	0.21	<0.30
# 99	<20	<0.30	0.96	3.3	<0.50	<10.0	<5.0	27	20	3.9	0.84
# 101	<7.0	<0.90	<4.0	12	<1.0	<20.0	<10.0	<200.0	65	15	2.4
# 104	<0.20	<0.06	<0.04	<0.03	<0.03	<0.60	<0.20	<0.50	<0.06	<0.10	<0.10
# 105	<4.0	<0.50	1.3	4.2	<0.50	<10.0	3.6	30	29	7.4	0.73
# 110	7.2	<0.90	3.5	36	<1.0	<20.0	8.4	87	89	17	2.4
# 114	<0.30	<0.08	<0.08	0.16	<0.08	<1.0	<0.40	<4.0	1.4	0.33	<0.20
# 118	<8.0	<1.0	3.7	9.3	<1.0	<20.0	<20.0	64	68	18	1.8
# 123	<0.30	<0.08	<0.09	0.61	<0.08	<1.0	<0.40	<4.0	<4.0	0.47	<0.10
# 126	<0.30	<0.10	<0.10	0.19	<0.09	<1.0	<0.40	<1.0	0.51	0.24	<0.20
# 138	8.9	<1.0	5.0	30	<0.90	<10.0	<20.0	76	77	34	2.8
# 153	6.5	<1.0	3.7	21	<0.90	<10.0	<20.0	59	63	28	2.1
# 155	<0.2	<0.10	<0.03	<0.05	<0.02	<1.0	<0.20	<0.70	<0.07	<0.06	<0.08
# 156	0.79	<0.02	0.47	2.1	<0.06	<2.0	1.1	7.5	8.4	3.2	0.28
# 157	<0.50	<0.07	0.14	0.85	<0.06	<2.0	<0.40	2.1	1.8	0.67	<0.30
# 167	2.0	<0.30	0.87	<4.0	<0.06	<2.0	<1.0	5.3	2.7	1.4	<0.30
# 169	<0.30	<0.30	<0.10	<0.10	<0.07	<2.0	<0.50	<1.0	<0.20	<0.30	<0.30
# 170	<0.80	<0.10	0.79	3.6	<0.10	<2.0	<3.0	10	12	7.7	0.58
# 180	<0.80	<0.10	<0.10	9.4	<0.30	<2.0	<8.0	20	36	16	1.2
# 183	<0.80	<0.10	<0.10	2.3	<0.10	<2.0	<2.0	5.2	9.0	4.1	<0.40
# 187	<2.0	<0.30	0.87	6.3	<0.10	<2.0	<5.0	8.6	22	7.4	0.47
# 188	<0.60	<0.07	<0.08	<0.10	<0.10	<2.0	<0.40	<1.0	<0.20	<0.20	<0.30
# 189	<0.70	<0.10	<0.10	0.23	<0.10	<2.0	<0.40	<2.0	0.49	0.40	<0.30
# 194	<0.50	<0.07	0.22	4.1	<0.06	<2.0	0.87	3.4	8.4	3.1	<0.30
# 196	<0.10	<0.05	0.15	8.1	<0.06	<2.0	<2.0	4.4	11	2.0	<0.20
# 199	<0.10	<0.05	<0.04	0.67	<0.04	<1.0	<0.40	<2.0	1.6	0.31	<0.10
# 202	<0.30	<0.10	<0.09	1.5	<0.04	<1.0	<0.40	<2.0	2.3	0.55	<0.20
# 205	<0.20	<0.07	<0.07	0.18	<0.07	<2.0	<0.40	<1.0	0.36	0.19	<0.20
# 206	<0.20	<0.07	0.15	4.5	<0.07	<2.0	<0.70	<2.0	1.9	0.63	<0.10
# 208	<0.10	<0.06	<0.04	1.1	<0.05	<2.0	<0.30	<1.0	0.41	0.12	<0.10
# 209	<0.20	<0.04	<0.10	0.44	<0.06	<1.0	<0.70	11	0.10	<0.09	<0.10
Sum	25.4	0	21.8	164	0	0	13.9	421	678	234	36.1