Environment B·O·P
Environmental Report 2001/06
March 2001

Urban Stormwater

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Dr Joanne Deely carried out the Stormwater Project, while she was employed as an Environmental Scientist with Environment B·O·P. Two students, Tony Hickling and Brett Osborne, assisted in carrying out field work.

Environmental Data Services and Laboratory staff of Environment B·O·P collaborated in the field and analytical needs of the project.

Cover Photo: Mount Maunganui, Commercial District

Executive Summary

Environment B·O·P staff carried out a project to examine the effects of stormwater discharge on the environment of the Bay of Plenty. Because of the difficulties involved in sampling stormwater, simultaneously, over extended areas of the Bay of Plenty a method of sediment sampling was employed.

A matrix of sites was set up in three urban centres, Tauranga/Mt Maunganui, Rotorua and Whakatane, with 5 replicate sites in selected residential, commercial and industrial areas (Whakatane sites had less replicates).

A surface sample from freshly deposited sediment was sampled in stormwater catchments after storm events. Contaminants levels in the sediment were determined. The fine portion of this sediment would have represented the suspended load from the storm event, therefore, all results were 'normalised' to the fine portion of the sediment for comparison. A calculation (section 2.3) was applied so that a value could be obtained, from the deposited sediment, that would represent a permissible suspended solids load from the point of discharge. This permissible load was based on the aquatic ecosystems standards of ANZECC (1992). The median of all the results has been considered for each site.

Contaminant levels in urban stormwater are elevated above background levels coming from rural environments. Generally, these levels have been found to be typical for particular land uses. Industrial and commercial land use generates the greatest quantity of contaminants. Even in a smaller community such as Whakatane, the commercial and industrial sector had considerable effect on contaminant levels in the environment.

The analysis in this report has attempted to quantify the typical contamination levels that urban stormwater imposes on the environment and to relate these levels to the suspended sediment in the storm water. It is also proposed that stormwater controls could be based on limitation of suspended sediment. This would obviate the need to require the analysis of a wide range of elements, unless it was appropriate to specify contaminants known to represent a risk.

The suspended solids limit in Environment B·O·P's stormwater general authorisation of $150g/m^3$ is justified (less for commercial areas) on the basis of the investigation. However, flexible policy development can proceed with reference to a large range of 'best management practices'. The division of catchment types used in the investigation also provides a basis for management. Different styles of management could be applied in residential, commercial and industrial areas.

Contents

Chapter 1: Introduction

Urban and industrial stormwater systems carry run-off from road surfaces and developed areas via pipes and drains, and discharge to the coast, to lakes and rivers, or to land soakage. These flows can carry metals, hydrocarbons, litter and other contaminants, which accumulate in receiving environments. The expansion of urban areas and roading reduce the natural infiltration of rainwater, leading to greater volumes of stormwater run-off, flowing at increased rates, with less filtering by natural processes.

A community perception that stormwater systems can be used for waste disposal has tended to lead to environmental degradation at times. Contaminants, including sewage overflows, warm water, swimming pool water, industrial wastes, and wash down water, are often discharged to stormwater systems. With appropriate treatment some of these fluids may be suitable for discharge to stormwater systems but the stormwater system is primarily for clean stormwater.

There has been limited knowledge about stormwater quality from urban areas in the Bay of Plenty, and therefore whether treatment methods are appropriate and what treatment is necessary. Effective and efficient management of stormwater has been difficult where detailed information is not available. There has also been a lack of information on the effect of changing land use (e.g. from urban to industrial) on stormwater quality.

Where natural and modified watercourses are used as the primary treatment and receiving channel for stormwater discharges, ecological, cultural and amenity values have become an issue that needs to be dealt with.

In the Bay of Plenty, minor stormwater discharges have been allowed under a General Authorisation, which is incorporated, in the Transitional Regional Plan. Discharges that do not comply with the requirements below are discretionary.

General Authorisation No 8 is for the discharge of clean stormwater (excluding waste) into natural waters, provided that:

(a) The maximum discharge shall not exceed the flow from a 300 mm pipe on a flat grade or equivalent of 80 litres/second.

(b) The suspended solids concentration of the water discharged does not exceed 150 g/m^3.

(c) The water discharged is substantially free of grease and oil.

(d) The works shall be designed, constructed and maintained in such a manner so as not to cause erosion or flooding or to adversely affect any land or property owned or occupied by another person.

The study set out to characterise urban stormwater quality and develop a framework whereby policy might be made to safeguard ecological values in receiving environments.

The approach taken in this investigation has been to define a suspended solids concentration that could be discharged to surface waters from areas of different land use and still ensure protection of aquatic ecosystem values.

1.1 Objective

The objective of the study was;

(a) to determine if the suspended solids load of the stormwater general authorisation could be justified by scientific investigation;

(b) to determine a suspended solids load that would be appropriate to apply as a limit to urban stormwater discharges from different types of urban catchments.

Note: The results of the study are not to be interpreted as Environment B·O·P's policy. The results were to be a basis on which policy could be developed in the Regional Water and Land Plan.

Chapter 2: Methods

2.1 Description of Method

Three centres in the Bay of Plenty, Rotorua, Tauranga and Whakatane, were selected for investigation of the contaminant load from urban stormwater. The centres were divided into residential, commercial and industrial components. Control sites were selected for each centre so that the contaminant load generated from each impact type could be separated from the typical background load.

The method involved collection of the fresh sediment deposited after rainfall events and analysis of the sediment for particle size distribution, metal, bacterial and organic contaminants. Five different sites of each impact type (control, residential, commercial, industrial) were selected at each centre (Tauranga, Rotorua, Whakatane) and these were sampled on five occasions (except for Whakatane sites). Each final result quoted in the report is the median of 25 independent samplings (except for Whakatane sites).

The sampling and data handling strategy is set out below along with the assumptions used to take the environmental information and develop the framework for a stormwater policy.

2.1.1 Sampling and Data Handling Strategy

A 1 cm surface layer of fresh sediment was sampled immediately after storm events.

The particle size distribution and the concentration of contaminants was determined.

The assumption was made that only the fraction of sediment that was of size < 65 microns would have been the suspended sediment load during the storm event. Sediment of size > 65 microns[1] would have been part of the bed load.

The assumption was made that all the contaminant was absorbed in the fraction of sediment that was of size < 65 microns. Therefore, the concentration of contaminant in the sediment, was divided by the proportion of sediment < 65 microns to 'normalise' the data *ie* convert all results to a common basis.

[1] The clay/silt portion of a sediment sample is usually classified as the < 63 micron fraction. The particle size analysis that was carried out in this investigation reported a < 65 micron size. This was the closest result to 63 microns. Therefore, the < 65 micron fraction has been used as the division between clay/silt and sand.

The assumption was made that the proportion of contaminant dissolved in the water would be small compared to the load absorbed to particulate matter so this load was ignored.

The suspended solids concentration from the control site sediment was subtracted from the receiving environment value so that the magnitude of the actual impact was isolated.

The assumption was made that the difference between the control sites and the impact sites could be treated as additive.

ANZECC (1922) water quality guidelines were used to calculate the suspended solids concentration in the stormwater discharge that would just comply with aquatic ecosystem, water quality limits *ie* a suspended solids concentration was calculated for each contaminant.

The objective was to enable aquatic ecosystems in a receiving environment to be protected by setting a suspended solids limit on the stormwater discharge.

NB Each consent application is different and consent conditions will need to deal with specific contaminants on a case by case basis.

2.2 Sample Sites

The general areas where sampling was conducted are shown in Table 2.1, below. Site maps are shown in Figures 2.1, 2.2 and 2.3.

Table 2.1 Urban areas in the Bay of Plenty where stormwater contaminants in sediments were analysed

	Tauranga	Rotorua	Whakatane
Residential	Bellevue	Utuhina/ Mangakakahi Streams	Wainui-te-whara (Town)
Commercial	Mt Maunganui	Rotorua City	Kakahoroa Drive
Industrial	Maleme St	Utuhina and tributary drains/ Mangakakahi Stream	
Control	Te Mania Stream	Upper Utuhina/ Mangakakahi Streams	Wainui-te-whara (Gorge)

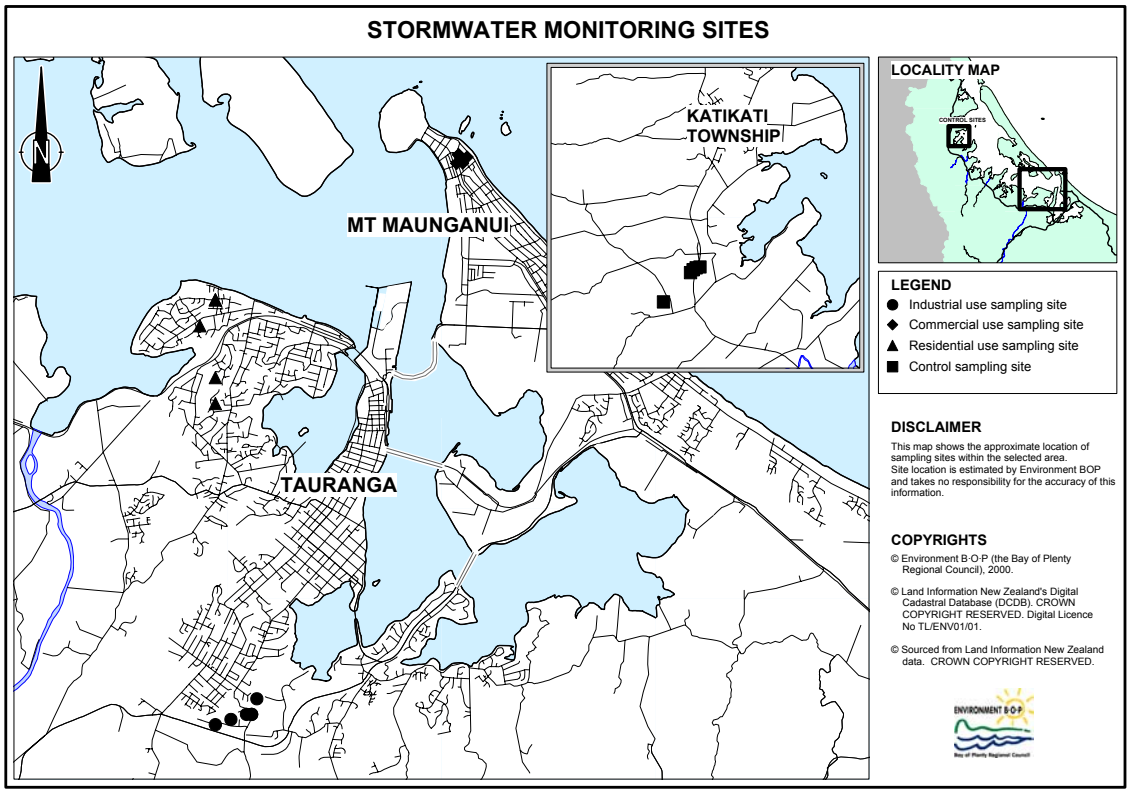

Figure 2.1 Stormwater Monitoring Sites around the Tauranga Area

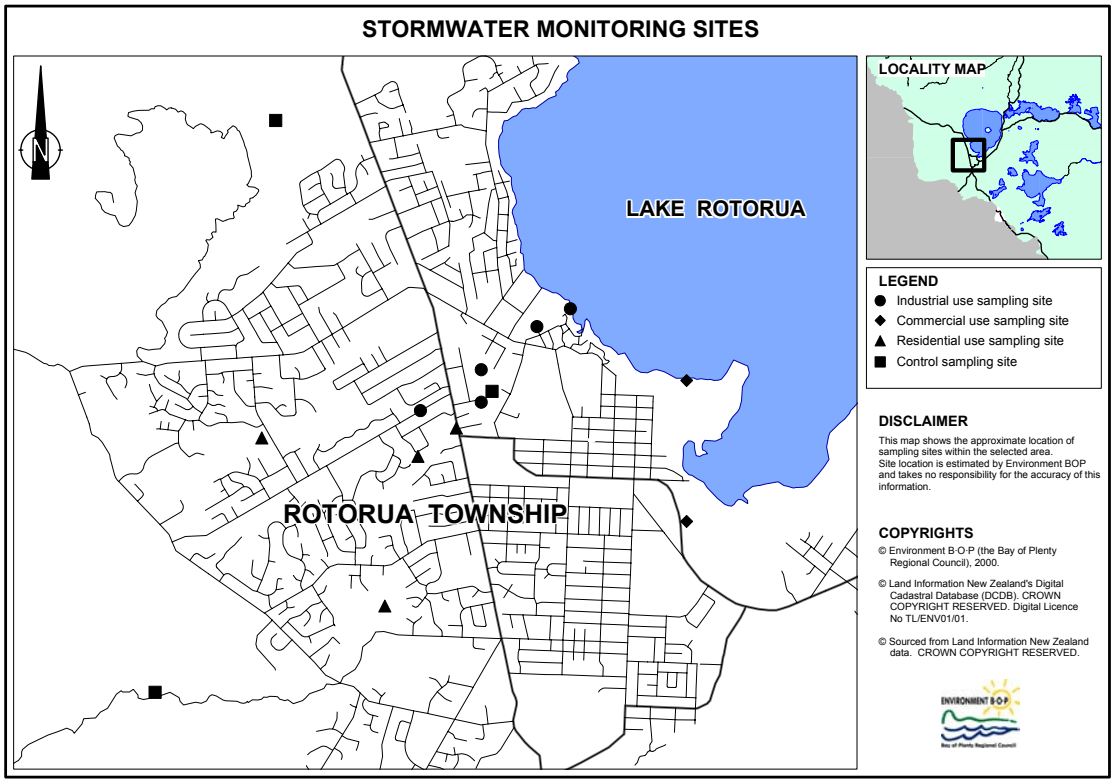

Figure 2.2 Stormwater Monitoring Sites around the Rotorua Area

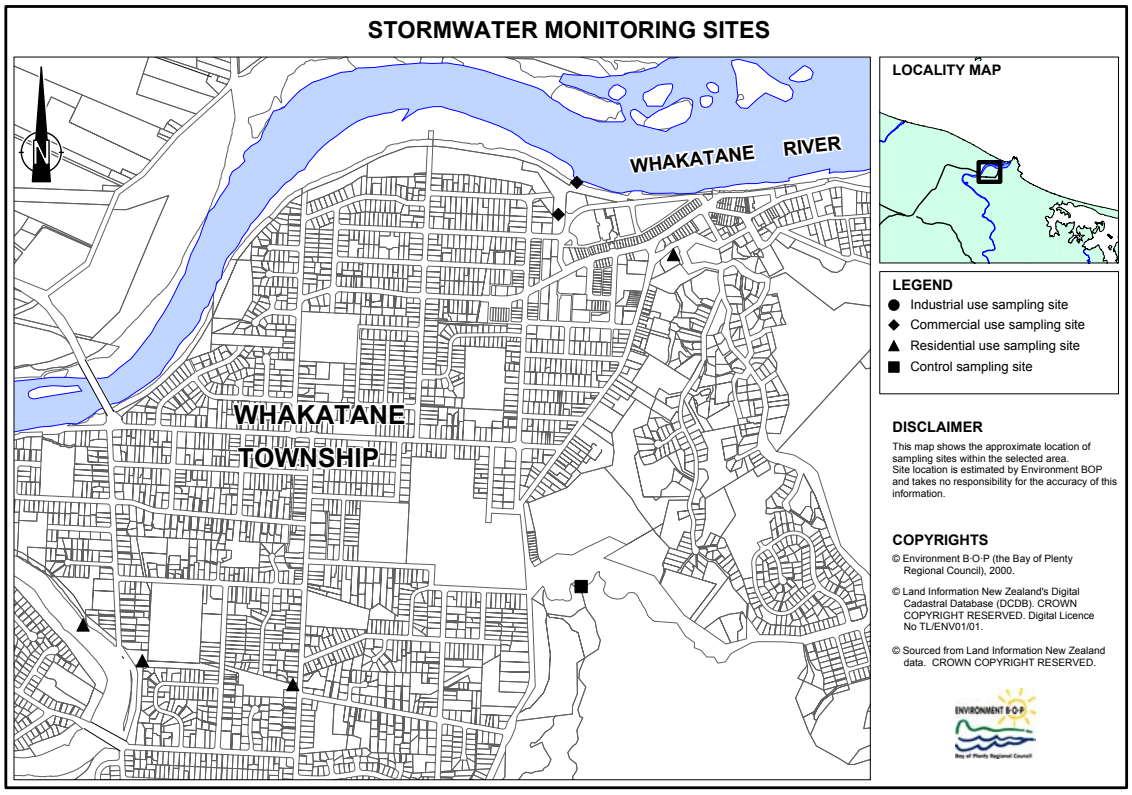

Figure 2.3 Stormwater Monitoring Sites around the Whakatane Area

2.3 Calculation

The calculation of a suspended solids concentration that would be permissible for a stormwater discharge was calculated using the formula below.

C = concentration of contaminant in sediment (mg/kg dry wt).
P = proportion of sediment sample < 65 microns.
A = ANZECC (1992) water quality guideline for aquatic ecosystems (mg/m^3).
S = permissible suspended solids concentration in stormwater discharge (g/m^3).

$$S = A/[(C/P)_{impact} - (C/P)_{control}]*1000$$

2.4 Guidelines

ANZECC (1992) water quality guidelines for aquatic ecosystems have been used to determine a permissible suspended solids concentration for a stormwater discharge. The ANZECC (1999) is still in draft form and does not specify a level where a contaminant will have a high probability of causing an adverse effect on aquatic ecosystems. Trigger levels are set at a lower level so that environmental investigations can be initiated.

A reference is made to the (draft) ANZECC (1999) guidelines for sediment quality, to provide a benchmark for the sediment contaminant concentrations. The approach in developing ANZECC (1999) has been to provide a low set of values below which there is little probability that there will be effects on benthic organisms. There is also

a set of higher values above which there is a high probability that there will be toxic effects.

2.5 Chemical Methods

Sediments were analysed by R J Hill Laboratories Limited.

Ash	Ignition in a muffle furnace at 600^{o}C for six hours followed by gravimetric analysis.
Dry matter	Air dry, grind, gravimetric analysis.
Volatile solids	100% - ash = organic matter.
Carbon banding	GC-FID
Metals	Aqua regia digestion, ICP-MS.

Particle size analysis

Waikato University	Malvern Instruments Mastersizer

Chapter 3: Results

3.1 Sediment Contaminant Levels

Sediment concentrations of metal contaminants and total petroleum hydrocarbons are set out in the Tables 3.1, 3.2 and 3.3 below and compared to the low and high draft ANZECC (1999) sediment quality guidelines for aquatic ecosystems. The results given are the median of the replicates for the general area over the five samplings. These values have been adjusted or normalised to the < 65 micron fraction *ie* the actual concentration was divided by the proportion of the sample that was of size < 65 microns. Appendix I contains a table of more detailed results.

The metal contaminants zinc, lead and copper are ubiquitous in urban stormwaters. Other metals of common industrial usage were also analysed for. Total petroleum hydrocarbons indicate the degree of contamination from automotive sources. Poly aromatic hydrocarbons (PAHs) are also found as contaminants in stormwater from industrial and automotive sources. These are used later in the report as a test of the hypothesis developed (data is in Appendix II).

3.1.1 Tauranga

Table 3.1 Median contaminant levels in the surficial sediment at sites representing four different land-uses at Tauranga normalised to the < 65 micron particle size fraction

Contaminant	Control mg/kg	Residential mg/kg	Commercial mg/kg	Industrial mg/kg	draft Anzecc (1999) low mg/kg	draft Anzecc (1999) high mg/kg
Arsenic (As)	8.7	15.5	36.4	17.5	20	70
Cadmium (Cd)	0.282	0.299	1.924	0.351	1.5	10
Chromium (Cr)	23.5	15.1	138.7	34	80	370
Copper (Cu)	22.2	30.7	134.3	47.7	65	270
Lead (Pb)	21.1	84.9	509.8	49.2	50	220
Zinc (Zn)	75	214	1726	419	200	410
Total petroleum hydrocarbons (TPH)	95	541	1877	401		

The control site on the Te Mania Stream compares very favourably with the low level of the draft ANZECC (1999) guidelines. The urban sites all demonstrate to some extent the cumulative effects of urban land-use. For the residential sites only zinc and lead are shown to be at a level of marginal risk. Zinc was very high at the industrial sites. At the commercial sites all the contaminants tested were at a level where some risk to aquatic ecosystems was possible. Excessive levels of lead and zinc were noted.

3.1.2 Rotorua

Table 3.2 Median contaminant levels in the surficial sediment at sites representing four different land-uses at Rotorua normalised to the < 65 micron particle size fraction.

Contaminant	Control mg/kg	Residential mg/kg	Commercial mg/kg	Industrial mg/kg	draft Anzecc (1999) low mg/kg	draft Anzecc (1999) high mg/kg
Arsenic (As)	57.9	118.1	18.8	210.9	20	70
Cadmium (Cd)	0.289	0.427	0.823	1.083	1.5	10
Chromium (Cr)	16.2	17.1	40.4	56.8	80	370
Copper (Cu)	20.6	29.8	88.4	92.3	65	270
Lead (Pb)	51.0	96.5	138.0	317.8	50	220
Zinc (Zn)	249	298	646	1040	200	410
Total petroleum hydrocarbons (TPH)	467	557	3295	619		

Table 3.2 shows that the geothermal influence is apparent in Rotorua where arsenic was elevated in the control sites. A geothermal control was also included and the results indicate that general urban contamination may have been present at this site *eg* total petroleum hydrocarbons were quite elevated. Arsenic was, in fact, elevated at all sites except the commercial site, which was surprising. However, this could simply indicate that geothermal liquid does not run to waste anywhere within the commercial zone where sampling took place. In the residential area lead and zinc levels were between the low and high risk values of ANZECC (1999) as were copper and lead in the commercial area. But in the commercial area zinc exceeded the level of high risk. Copper presented some risk in the sediment of the industrial area while lead and zinc exceeded the level of high risk.

3.1.3 Whakatane

No contamination was evident at the Whakatane control site, (as shown in Table 3.3), while in the residential area only lead and zinc were slightly elevated above the level of low risk. Arsenic, copper, lead and zinc were elevated at the commercial site.

Table 3.3 Median contaminant levels in the surficial sediment at sites representing three different land-uses at Whakatane normalised to the < 65 micron particle size fraction.

Contaminant	Control mg/kg	Residential mg/kg	Commercial mg/kg	Industrial mg/kg	draft Anzecc (1999) low mg/kg	draft Anzecc (1999) high mg/kg
Arsenic (As)	5.2	15.0	38.0		20	70
Cadmium (Cd)	0.208	0.173	0.447		1.5	10
Chromium (Cr)	9.2	22.9	46.7		80	370
Copper (Cu)	13.7	33.5	94.2		65	270
Lead (Pb)	24.2	60.0	138.8		50	220
Zinc (Zn)	88	248	655		200	410
Total petroleum hydrocarbons (TPH)	70	154	266			

3.1.4 Total Petroleum Hydrocarbons

No sediment limits have been found for total petroleum hydrocarbons and only an indirect reference to limits in water for drinking water supply and fisheries protection (0.01 and 0.1 g/m^3 respectively – see Appendix III).

From examining the data, a level of 100 mg/kg appears to be consistent with a control situation or background level, for sediments. The urban areas of Whakatane are only slightly affected by impact from petroleum hydrocarbons. However, in Tauranga and Rotorua greater effects are noted. Commercial areas were found to show the greatest effects.

3.2 Data Adjustment for Control Sites

Table 3.4 shows a summary of contaminant data with the concentration of contaminants in the sediment of control sites subtracted from the concentration in the impact sites. The values have been rounded to whole numbers except for cadmium. In this step it is assumed that the control or background load can be adjusted for by treating the concentrations as additive. This is not strictly accurate but to separate the load from each source a labour intensive sediment gauging would be required. This was not a practical consideration for the number of diverse sites that were needed to adequately sample the Bay of Plenty.

Table 3.4 Contaminant concentrations for urban impact sites adjusted by removal of background concentration

Catchment type	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Zn mg/kg	TPH mg/kg
Tauranga Residential	7	0.017	*15**	9	64	139	446
Rotorua Residential	60	0.138	1	9	45	49	90
Whakatane Residential	10	0.173	14	20	36	160	84
Tauranga Commercial	28	1.642	115	112	489	1651	1782
Rotorua Commercial	*19**	0.534	24	68	87	396	2828
Whakatane Commercial	33	0.238	37	81	115	567	196
Tauranga Industrial	9	0.069	11	26	28	344	306
Rotorua Industrial	153	0.794	41	72	267	790	151

* The Rotorua commercial district would have demonstrated a negative concentration of arsenic if the adjustment for the control site were made. In this instance the actual concentration has been inserted in Table 3.4 (in italics) without subtracting the control value. The same occurs for chromium in the Tauranga residential sites.

3.3 Calculation of Suspended Sediment Discharge Concentrations

The data in Table 3.4 represents the concentrations of contaminants that are typically discharged in stormwater from residential, commercial and industrial areas of the Bay of Plenty. In Table 3.5 the calculation in section 2.3 has been applied to back calculate the concentration of suspended solids that could have been discharged to just meet the ANZECC (1992) guidelines for aquatic ecosystem protection. These values have been rounded. The guideline for total petroleum hydrocarbons has been taken from the reference in Appendix III.

Table 3.5 Theoretical calculation of suspended solids concentration that could be discharged in stormwater to just meet ANZECC (1992) aquatic ecosystems water quality values in the receiving environment

Catchment type	Suspended solids concentration (g/m^3) to protect aquatic ecosystems in receiving environment						
	As	Cd	Cr	Cu	Pb	Zn	TPH
Tauranga Residential	7400	120000	660	600	80	360	220
Rotorua Residential	830	14000	12000	550	110	1000	1100
Whakatane Residential	5100	12000	730	250	140	310	1190
Tauranga Commercial	1800	1200	90	45	10	30	60
Rotorua Commercial	2600	3700	400	75	60	130	35
Whakatane Commercial	1500	8400	270	60	45	90	510
Tauranga Industrial	5700	29000	950	200	180	150	330
Rotorua Industrial	330	2500	250	70	20	65	660

Table 3.5 can become the basis on which policy decisions are made to protect the aquatic ecosystems of receiving environments from the effects of contaminants in urban stormwater.

The main points that come out of the analysis are:

(i) Certain elements are critical and control of toxic effects is likely to focus on these elements. Copper, lead and zinc were demonstrated to be the metal elements most likely threaten aquatic ecosystems in receiving environments.

(ii) The degree of risk to aquatic ecosystems is related to the nature of the land-use.

(iii) The division between commercial and industrial is less distinct than the difference between either of those land uses and residential.

(iv) Commercial sites represent a higher risk to aquatic ecosystems from stormwater discharge than industrial sites. This could be because more controls are exercised over stormwater discharge from industrial sites so the actual contaminant levels are less.

(v) Total petroleum hydrocarbons were very high in stormwater runoff from commercial areas.

(vi) Lead appears to be a critical element but use of lead in petrol is decreasing and these contaminant levels may reflect what will become an historic benchmark.

Chapter 4: Discussion

4.1 Concept for Control of Stormwater Discharge

The intention below is not to suggest limits for discharges but to indicate how the data could be condensed to provide a meaningful guideline for developing stormwater control policy.

Lead contamination is mainly sourced from leaded petrol. With the change from leaded fuels this source of contamination is likely to decrease. Consequently, in the following assessment less weight is given to lead levels than to other contaminants.

In the residential areas copper and total petroleum hydrocarbons provided the critical elements over which control should be exercised. There are commercial and light industrial enterprises in the catchment of the Wainui te Whara Stream at Whakatane so that could have been the source of the copper contamination. The copper result at Whakatane could therefore be uncharacteristic of purely residential areas. Total petroleum hydrocarbon contamination at the Tauranga residential site greatly exceeded the levels at Rotorua or Whakatane. This also may relate to a non-residential land use.

The median value for copper in Table 3.5 could be regarded as an appropriate control level to place on the suspended solids concentration being discharged from residential areas. A lower limit could be used if land–use was mixed in the stormwater catchment.

A suspended solids concentration limit, of 300–500 g/m^3 would protect aquatic ecosystems from the effects of common urban contaminants from residential catchments.

Chrome, copper, zinc and total petroleum hydrocarbons were critical contaminants in sediment from the commercial areas. Control of copper and total petroleum hydrocarbons is achieved at a discharge level of 60 g/m^3 (median from Table 3.5). Attaining suspended solids this low in stormwater would be difficult. Improved management of contaminants in commercial areas may also be required.

A suspended solids concentration limit, of 100 g/m^3 would protect aquatic ecosystems from the effects of common urban contaminants from commercial catchments.

Industrial sites were investigated at only two of the regional centres, but the data shows that the impacts are lower than at commercial sites. Copper and zinc were found to be critical elements. Many industrial sites have controls on the use of production chemicals and contaminants in stormwater. Continued control of specific sites would be needed to avoid spillages or careless discharge of contaminants.

A suspended solids concentration limit, of 100–150 g/m^3 would protect aquatic ecosystems from the effects of common urban contaminants from industrial catchments.

4.2 Typical Suspended Solids Concentrations in the Bay of Plenty

Most rivers and streams are comparable to the control sites used in this study. Very high, suspended solid loads are typical of major storm flow events and aquatic ecosystems are considered to recover from this type of impact. However, accelerated erosion is an extreme example of the natural process and downstream benthic ecosystems may not recover so quickly from excessive sediment being deposited.

Settling ponds from a completed subdivision at Bethlehem, Tauranga, had low suspended solids (see Table 4.1). This form of management provides good environmental protection from the effects of run-off from developed residential areas.

Suspended solids measured at commercial sites in the Bay of Plenty have ranged up to 180 g/m^3. As commercial sites were shown to have high levels of contaminants in this study, greater control of contamination sources may be more effective than requiring the reduction of sediment to a very low level.

Industrial sites are more amenable to control because they are arranged as units with individual ownership. Some industrial areas *eg* Maleme Street, had high suspended solids during a storm event. Control of these sorts of levels on-site may be possible.

Table 4.1 Typical Suspended Solid Concentrations of Streams and Rivers that Receive Stormwater and flow into Tauranga Harbour

	Low Flow g/m^3	High Flow g/m^3
Control		
Harbour inflows*	1 - 50	200 - 380
Te Mania Stream	1	360
Commercial		
Papamoa SW Outfall	11 - 25	
Mt Maunganui drains	2 - 69	
Totara Street drain	14 - 33	179
Spring Street		21-48
Tainui Street		4-76
Wikitoria Street		11-98
Residential		
Bethlehem Ponds		52-92
Mt Maunganui Stream	5 - 64	

	Low Flow g/m³	High Flow g/m³
Waikite St drains	5 - 60	
Industrial drains		
Sulphur Point	14 - 56	
Golden Bay Cement	4 - 8	
Aerodrome Mt Maunganui	8 - 22	
Maleme St		600
ICI Mt Maunganui		154

* The inflows include the following streams and rivers:
Kauri Pt Trib, Waipapa, Tuapiro, Waiaua, Waitao, Ngapeke, Kaitemako, Wairoa, Omanawa, Tahawai, Uretara, Waitekohe, Tuapo Te Rereatukahia, Wainui, Rocky, Whatakao, Kopurererua

Table 4.2 Typical Suspended Solid Concentrations of Streams and Rivers that receive stormwater and flow into Lake Rotorua

	Low Flow g/m³	High Flow g/m³
Control		
Ngongotaha Stream	10	308
Lake Rotorua inflows*	1 - 40	200 - >1500
Commercial		
RDC SW Outfalls	1-3	
Residential		
Waiowhiro Stream	5	415

* The inflows include the following streams and springs:
Hamurana, Awahou, Waiteti, Waingaehe, Puarenga,

Table 4.3 Typical Suspended Solid Concentrations of Streams and Rivers near Whakatane

	Low Flow g/m³	High Flow g/m³
Whakatane River	2 - 53	560 - >10000
Nukuhou River	5	360 – 590

Table 4.4 Ranges of Contaminant Concentrations in Stormwaters of Tauranga

	Spring St	Tainui St	Wikitoria St	ANZECC (1992) aquatic ecosystems
	mg/m³	mg/m³	mg/m³	mg/m³
Copper	3-18	1-2	1-11	2 – 5 *
Lead	9-34	1-6	1-30	1 – 5 **
Zinc	29-37	4-39	24-204	5 – 50 **
Total petroleum hydrocarbons	56-200	16-28	10-126	100 ***
Suspended Solids g/m³	21 – 48	4 - 76	11 – 98	

*depends on hardness of water ** provided iron not present as Fe(II) *** refer Appendix III*

Table 4.4 demonstrates that suspended solids concentrations at urban stormwater sites in Tauranga have been measured up to 100 g/m^3. The actual load of metal and hydrocarbon contaminants have sometimes exceeded the ANZECC (1992) aquatic ecosystems guidelines but on average these samples have complied or been close to compliance. These storm waters are not required to meet aquatic ecosystem limits, the above is a test of the model used, in this report, to suggest suspended solids guidelines for storm water control.

4.2.1 Sediment Contaminant Levels in Tauranga Harbour

Table 4.5 shows the stormwater sediment contaminant levels of Table 3.1 in comparison with the actual sediment contaminant levels for Tauranga Harbour in 1991 (Environmental Report 94/10, 1994).

Table 4.5 Median contaminant levels in the surficial sediment at Tauranga stormwater sites from this study, compared to Tauranga Harbour sediment concentration from the 1991sediment survey

Contaminant	Control	Residential	Commercial	Industrial	Harbour sediment median	Harbour sediment high
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Arsenic (As)	8.7	15.5	36.4	17.5	2.5	6 *
Cadmium (Cd)	0.282	0.299	1.924	0.351		
Chromium (Cr)	23.5	15.1	138.7	34	3.5	8 *
Copper (Cu)	22.2	30.7	134.3	47.7	1.5	8 **
Lead (Pb)	21.1	84.9	509.8	49.2	6	28 **
Zinc (Zn)	75	214	1726	419	20	73 **
Total petroleum hydrocarbons (TPH)	95	541	1877	401		

* *Non-urban*

** *Around Tauranga City*

Arsenic and chromium were highest in the northern parts of Tauranga Harbour. This possibly relates to the volcanic geology of the Kaimai Range providing the parent material of the sediment in contrast to the parent material of the catchments further south. The contaminant loads from urban stormwater, which are apparent from the results of this survey, have not caused accumulation in the harbour sediments around the city to levels that represent a threat to aquatic ecosystems.

Copper, lead and zinc, which are high in urban stormwater, are found at their highest accumulated in the sediments adjacent to the city. These levels can be compared to the draft ANZECC (1999) sediment guidelines shown in Table 3.1. Despite the level of contamination, none of the contaminants is at the low threshold where ecological effects would be expected.

Studies in Auckland have shown a gradual increase in zinc, lead and copper in many sheltered estuaries (Williamson *et al* 1999). In these studies, concentrations of zinc in 20 – 50 years are predicted to exceed sediment quality guidelines where biological effects are expected to occur. Control of the stormwater inputs provides a method for remedying the accumulation of contaminants to undesirable levels in receiving environments.

4.3 Shellfish Contaminant Levels in Tauranga Harbour

Table 4.6 compares the stormwater contaminant levels at Tauranga with the contaminants in shellfish in Tauranga Harbour from an Environment B·O·P survey in 1999 (Environmental Report 99/08, 1999). Contaminant levels in the shellfish complied with the food regulations (Environmental Report 99/08, 1999).

Table 4.6 Median contaminant levels in the surficial sediment at Tauranga stormwater sites from this study, compared to Tauranga Harbour shellfish concentrations from the 1999 shellfish survey

Contaminant	Control mg/kg	Residential mg/kg	Commercial mg/kg	Industrial mg/kg	Waikareao pipi mg/kg	Port mussel mg/kg
Arsenic (As)	8.7	15.5	36.4	17.5	23.3	14.3
Cadmium (Cd)	0.282	0.299	1.924	0.351	0.5	0.6
Chromium (Cr)	23.5	15.1	138.7	34	3.3	2.4
Copper (Cu)	22.2	30.7	134.3	47.7	10.8	9.3
Lead (Pb)	21.1	84.9	509.8	49.2	0.7	1.2
Zinc (Zn)	75	214	1726	419	83.3	78.5
Total petroleum hydrocarbons (TPH)	95	541	1877	401		

Shellfish were found to accumulate arsenic and cadmium. Chromium, copper and lead were not taken up in the flesh and zinc was at similar levels to the background sediment load of stormwater inflows.

Arsenic, chromium and copper appear to be flushed from the harbour sediment system (*cf* Table 4.5) but accumulated in shellfish flesh. In Table 4.5 the harbour sediment values were less than the stormwater concentrations from control sites. Lead and zinc levels in the 'high' harbour sediment were comparable to stormwater concentrations from control sites.

4.4 Shellfish Contaminant Levels in Lake Rotorua

The freshwater mussels from the lake front at Lake Rotorua accumulated all the contaminants measured in this study, except chromium. Levels of lead in Lake Rotorua mussels exceeded the NZ Fish and Shellfish Food Regulations (1984) for human consumption. The other contaminants complied with the regulations.

Table 4.7 Median contaminant levels in the surficial sediment at Rotorua stormwater sites from this study, compared to Lake Rotorua mussel concentrations from the 1999 shellfish survey.

Contaminant	Control	Residential	Commercial	Industrial	Rotorua mussels
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Arsenic (As)	57.9	118.1	18.8	210.9	50.0
Cadmium (Cd)	0.289	0.427	0.823	1.083	2.8
Chromium (Cr)	16.2	17.1	40.4	56.8	4.0
Copper (Cu)	20.6	29.8	88.4	92.3	38.0
Lead (Pb)	51.0	96.5	138.0	317.8	62.0
Zinc (Zn)	249	298	646	1040	480
Total petroleum hydrocarbons (TPH)	467	557	3295	619	

4.5 Polycyclic Aromatic Hydrocarbons

Sediment at 10 sites was sampled for poly aromatic hydrocarbons (PAHs). The raw data is shown in Appendix II. These analyses were utilised to test the method used in this report. The suspended solids load has been calculated for each site that would achieve aquatic ecosystem protection in the receiving environment. Note that no adjustment has been made for control sites as these were not sampled. ANZECC (1992) recommends a guideline concentration for PAH in water of 3 mg/m^3 for the protection of aquatic ecosystems. The total PAH of the samples in Table 4.8 can also be compared to the high and low sediment guideline of ANZECC (1999), which are shown in the footnote.

A Rotorua Industrial site on the Depot Street drain was sampled twice at different but nearby locations. The upstream site had the highest level of PAHs. This may have been diluted by stormwater inflows between the sites. The one sample that exceeded the high level for the ANZECC (1999) sediment quality guidelines shows a level of contamination that could not be controlled by a limit on suspended solids.

Table 4.8 PAH data from Environment B·O·P's urban stormwater project and the suspended solids concentration calculated from this data that would meet the aquatic ecosystems guideline (ANZECC, 1992)

Environment B·O·P site number	Site	Total PAH mg/kg DW	Proportion of sample < 65 microns	Suspended solids discharge to meet aquatic ecosystem guideline. g/m^3
BOP290134	Tauranga Industry	0.663	0.43	1930
BOP290150	Mt M commercial	0.902	0.12	390
BOP290151	Mt M commercial	0.700	0.3	1290
BOP290160	Rotorua Industrial	0.035	0.11	9600
BOP290161	Rotorua Industrial	1.028	0.03	80
BOP290161	Rotorua Industrial	0.111	0.04	1150
BOP290165	Rotorua commercial	1.243	0.07	175
BOP290166	Rotorua commercial	57.3530	0.36	20
BOP290170	Whakatane residential	0.387	0.22*	1140
BOP290171	Whakatane commercial	0.319	0.72*	2140

* no data available, estimate taken based on data from site.
ANZECC (1999) sediment quality guideline for total PAH, low value 4 mg/kg DW, high value 45 mg/kg DW.

Generally PAHs were not critical compounds to be controlled in stormwater. This can be confirmed by comparing the actual concentration in the fresh sediment with the low level guideline of ANZECC (1999) for sediment quality. By applying the suspended solids calculation method of this report to the PAH data, as has been carried out in Table 4.8, it can be seen that credible results are derived for a suspended solids limit to protect aquatic ecosystems in receiving environments.

4.6 Conclusion

Contaminant levels in urban stormwater are elevated above background levels coming from rural environments. Generally, these levels have been found to be typical for particular land uses. Industrial and commercial land use generates the greatest quantity of contaminants. Even in a smaller community such as Whakatane, the commercial and industrial sector had considerable effect on contaminant levels in the environment.

The analysis in this report has attempted to quantify the typical contamination levels that urban stormwater imposes on the environment and to relate these levels to the suspended sediment in the storm water. It is also proposed that stormwater controls could be based on limitation of suspended sediment. This would obviate the need to require the analysis of a wide range of elements, unless specified contaminants were used on-site.

The suspended solids limit in Environment B·O·P's stormwater general authorisation of 150 g/m^3 is justified (less for commercial areas) on the basis of the investigation. However, flexible policy development can proceed with reference to a large range of 'best management practices'.

References

ANZECC 1992: Australian Water Quality Guidelines for Fresh and Marine Waters. Australian & New Zealand Environment and Conservation Council.

ANZECC 1999: Australian Water Quality Guidelines for Fresh and Marine Waters (Draft). Australian & New Zealand Environment and Conservation Council.

Williamson B, Morrisey D, Swales A (1999): The build up of contaminants in urbanised estuaries. Comprehensive Stormwater & Aquatic Ecosystem Management. Conference Proceedings Volume 1. Auckland Regional Council, NIWA, NZ Ministry for the Environment, USEPA. Auckland Feb 1999.

Appendices

Appendix I – Metal and Total Petroleum Hydrocarbon Data

Appendix II – Polycyclic Aromatic Hydrocarbons

Appendix III – Total Petroleum Hydrocarbons

Appendix I – Metal and Total Petroleum Hydrocarbon Data

ASH	Residue from Ignition at 600 deg C for 6 hours g/100g DW
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
Pb	Lead
Zn	Zinc

Site	Description	Sample	Date	% < 65 µm	> 65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results			% grain size											
	Tauranga														
BOP290132	Waimapu Stream	982700	02/12/98	64.5	35.5	53.2	11.3	83.3	7.0	0.3	11.3	14.6	17.2	155.0	26
BOP290132		982913	08/12/98	84.5	15.5	67.2	17.3	83.5	11.0	0.2	10.8	12.7	15.0	76.6	
BOP290132		983154	21/12/98	81.1	18.9	66.1	15.0	80.8	7.0	0.1	6.4	9.8	14.5	61.7	
BOP290132		990135	19/01/99	68.5			13.5	82.9	7.0	0.1	8.1	11.7	13.6	63.9	
BOP290132		990259	25/01/99	72.5	27.5	57.9	14.7	84.5	7.0	0.2	7.1	10.0	12.9	74.1	
BOP290133	Maleme St 5	982701	02/12/98	67.7	32.3	47.5	20.3	92.7	8.0	0.2	20.9	31.7	77.2	253.0	27
BOP290133		982914	08/12/98	60.2	39.9	47.0	13.1	89.4	10.0	0.3	21.6	28.3	38.4	331.0	
BOP290133		983155	21/12/98	74.6	25.4	61.1	13.5	90.5	8.0	0.2	19.2	21.7	35.4	253.0	
BOP290133		990136	19/01/99	60.4			11.5	90.0	9.0	0.2	20.7	22.6	35.7	251.0	
BOP290133		990260	25/01/99	38.1	61.9	29.0	9.0	91.6	8.0	0.2	18.5	19.2	35.1	197.0	
BOP290134	Maleme St 4	982702	02/12/98	47.0	53.1	31.8	15.2	92.9	8.0	0.2	14.0	16.5	23.2	240.0	8
BOP290134		982915	08/12/98	66.6	33.5	53.1	13.5	88.0	15.0	0.3	27.6	34.1	38.5	410.0	
BOP290134		983156	21/12/98	65.0	35.0	49.9	15.1	89.3	12.0	0.3	22.2	25.2	36.0	331.0	
BOP290134		990137	19/01/99	52.4			10.2	87.3	13.0	0.3	22.2	30.4	37.5	387.0	
BOP290134		990261	25/01/99	42.8	57.3	32.0	10.7	91.8	10.0	0.2	16.0	20.8	30.7	289.0	23
BOP290135	Maleme St 3	982703	02/12/98	57.9	42.1	41.2	16.8	93.9	8.0	0.1	8.8	8.7	17.8	120.0	8
BOP290135		982916	08/12/98	48.3	51.7	37.9	10.4	94.2	8.0	0.2	14.7	14.2	22.1	171.0	
BOP290135		983157	21/12/98	41.5	58.5	31.8	9.7	95.5	6.0	0.1	8.2	6.8	13.5	94.8	
BOP290135		990138	19/01/99	45.6			9.0	90.9	11.0	0.2	16.8	17.8	25.9	220.0	
BOP290135		990262	25/01/99	37.5	62.5	29.2	8.3	95.2	6.0	0.1	8.3	8.7	26.0	125.0	
BOP290135		990263	25/01/99	52.0	48.0	37.8	14.2	96.2	13.0	0.1	37.2	30.4	19.0	184.0	
BOP290136	Maleme St 33	982704	02/12/98	43.1	56.9	32.2	10.9	94.6	25.0	0.2	53.3	30.9	17.1	252.0	58
BOP290136		982917	08/12/98	58.8	41.2	45.3	13.6	95.6	26.0	0.2	65.3	45.3	24.6	275.0	
BOP290136		983158	21/12/98	51.4	48.6	39.3	12.0	92.3	37.0	0.2	71.0	55.1	25.6	254.0	
BOP290136		990139	19/01/99	46.0			9.4	91.0	38.0	0.3	75.5	57.4	36.2	351.0	
BOP290137	Maleme St 55-61	982705	02/12/98	29.5	70.5	21.4	8.1	95.6	21.0	0.2	22.8	17.1	19.4	173.0	43
BOP290137		982918	08/12/98	35.8	64.2	27.0	8.8	95.0	5.0	0.1	9.6	16.2	17.1	123.0	
BOP290137		983159	21/12/98	58.5	41.5	47.2	11.3	89.3	9.0	0.3	18.1	26.4	30.2	199.0	
BOP290137		990140	19/01/99	62.9			11.1	85.1	12.0	0.7	21.2	31.6	33.0	265.0	
BOP290137		990264	25/01/99	61.2	38.8	50.0	11.2	85.9	12.0	0.4	20.7	32.5	34.0	275.0	

Site	Description	Sample	Date	% grain size %< 65 µm	>65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results														
	Tauranga														
BOP290138	Tau/Res 5	982695	02/12/98	40.1	59.9	30.5	9.6	93.2	10.0	0.1	4.9	10.1	31.5	80.9	4
BOP290138		982924	08/12/98	63.3	36.7	50.5	12.7	87.1	10.0	0.2	10.3	27.6	53.7	137.0	
BOP290138		983160	21/12/98	59.5	40.5	46.8	12.7	87.3	9.0	0.2	10.6	19.4	53.2	127.0	
BOP290138		990130	19/01/99	57.0			12.1	92.5	6.0	0.1	5.5	11.0	29.7	83.2	
BOP290138		990265	25/01/99	52.9	47.1	40.8	12.1	88.9	11.0	0.1	8.0	17.6	45.9	115.0	
BOP290139	Tau/Res4	982696	02/12/98	26.1	73.9	20.2	5.9	95.7	4.0	0.2	10.7	21.1	55.0	128.0	45
BOP290139		982925	08/12/98	42.0	58.0	33.1	8.9	90.3	8.0	0.1	7.7	12.9	24.7	76.0	
BOP290139		983161	21/12/98	45.3	54.7	35.9	9.4	90.7	7.0	0.1	6.0	13.2	34.9	84.0	
BOP290139		990131	19/01/99	46.0			9.8	89.6	6.0	0.1	5.5	10.0	28.2	88.0	
BOP290139		990266	25/01/99	17.1	82.9	12.1	5.0	96.7	4.0	0.1	6.3	5.8	38.9	54.8	
BOP290140	Tau/Res3	982697	02/12/98	13.2	86.8	9.9	3.3	98.3	5.0	0.0	1.1	2.4	7.1	29.4	3
BOP290140		982926	08/12/98	37.8	62.2	28.3	9.5	94.6	7.0	0.1	4.2	8.9	30.6	73.7	
BOP290140		983162	21/12/98	22.7	77.4	17.0	5.7	96.4	7.0	0.1	2.9	4.5	14.5	60.8	
BOP290140		990132	19/01/99	30.1			7.4	96.6	5.0	0.1	4.5	5.7	14.5	61.0	
BOP290140		990267	25/01/99	32.9	67.1	24.3	8.6	95.6	5.0	0.1	3.0	6.4	17.2	52.8	
BOP290141	Tau/Res 2	982698	02/12/98	21.0	79.0	15.9	5.1	97.0	6.0	0.1	2.1	4.5	17.3	48.1	4
BOP290141		982699	02/12/98	13.2	86.8	10.0	3.2	97.9	3.0	0.1	6.8	9.5	82.3	81.2	2
BOP290141		982927	08/12/98	18.9	81.2	13.8	5.0	97.8	2.0	0.1	2.9	4.5	25.3	42.0	
BOP290141		983163	21/12/98	22.5	77.6	17.5	5.0	97.2	3.0	0.1	3.6	5.9	34.4	51.1	
BOP290141		990133	19/01/99	31.2			7.3	98.5	2.0	0.0	3.7	4.4	23.9	48.2	
BOP290141		990268	25/01/99	26.4			5.5	97.3	2.0	0.1	3.0	5.3	36.8	49.6	
BOP290142	Tau/Res 1	982928	08/12/98	13.4	86.6	10.3	3.1	98.0	2.0	0.1	4.2	11.3	72.2	49.9	
BOP290142		983164	21/12/98	12.6	87.5	9.1	3.4	97.2	3.0	0.1	7.8	8.5	101.0	63.3	
BOP290142		990134	19/01/99	24.5			5.1	98.4	2.0	0.1	5.6	8.6	84.1	59.7	
BOP290142		990269	25/01/99	29.6			6.0	97.4	3.0	0.1	6.3	11.1	121.0	66.9	

Site	Description	Sample	Date	% < 65 µm	> 65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results			**% grain size**											
	Tauranga														
BOP290143	Tau/con 5	982690	02/12/98	78.4	21.6	51.1	27.2	78.9	25.0	0.2	22.0	23.8	20.7	96.6	1
BOP290143		982919	08/12/98	60.7	39.3	42.4	18.2	65.6	6.0	0.2	10.2	17.4	14.5	75.7	
BOP290143		983165	21/12/98	70.2	29.9	47.2	22.9	81.5	15.0	0.2	13.9	20.4	20.6	126.0	
BOP290143		990125	19/01/99	69.1			25.2	83.9	8.0	0.1	10.5	18.2	33.8	80.8	
BOP290143		990270	25/01/99	66.0			27.8	87.2	9.0	0.1	10.8	20.1	35.8	84.9	
BOP290144	Tau/con 4	982691	02/12/98	94.8	5.2	71.3	23.5	67.2	90.0	0.3	62.1	23.2	16.3	77.9	9
BOP290144		982920	08/12/98	88.9	11.1	68.6	20.3	68.7	12.0	0.3	9.5	14.8	12.1	66.5	
BOP290144		983166	21/12/98	91.6	8.4	72.8	18.7	68.2	12.0	0.3	10.9	14.9	15.5	78.6	
BOP290144		990126	19/01/99	88.8			17.3	69.1	22.0	0.2	10.2	13.4	12.7	52.5	
BOP290144		990271	25/01/99	85.0			16.0	70.3	22.0	0.2	8.9	13.4	12.7	48.9	
BOP290145	Tau/con 3	982692	02/12/98	93.0	7.0	64.5	28.4	73.9	119.0	0.2	90.0	27.0	22.3	56.2	1
BOP290145		982921	08/12/98	91.8	8.3	69.0	22.7	78.1	8.0	0.2	14.5	16.2	16.9	58.8	
BOP290145		983167	21/12/98	72.7	27.3	55.4	17.3	74.7	9.0	0.2	14.3	16.1	16.1	61.9	
BOP290145		990127	19/01/99	70.7			18.6	74.0	6.0	0.3	16.6	14.7	14.3	52.6	
BOP290145		990272	25/01/99	36.3			12.2	94.4	2.0	0.0	33.4	9.1	7.9	46.5	
BOP290146	Tau/con 2	982693	02/12/98	79.4	20.6	60.5	18.9	82.4	5.0	0.1	36.4	15.4	13.1	51.4	5
BOP290146		982922	08/12/98	48.0	52.0	34.8	13.2	88.5	4.0	0.1	42.9	14.0	10.3	55.5	
BOP290146		983168	21/12/98	58.3	41.7	39.1	19.1	88.5	3.0	0.1	46.5	14.5	13.3	38.7	
BOP290146		990128	19/01/99	62.2			15.8	88.0	3.0	0.1	34.7	13.4	11.9	44.4	
BOP290146		990273	25/01/99	63.0			18.1	87.3	3.0	0.1	38.2	14.0	13.3	39.1	
BOP290147	Tau/con 1	982694	02/12/98	42.0	58.0	29.9	12.2	88.5	4.0	0.2	25.5	13.5	8.9	60.0	3
BOP290147		982923	08/12/98	46.1	53.9	33.7	12.4	85.3	4.0	0.1	36.1	16.9	10.8	68.5	
BOP290147		983169	21/12/98	45.5	54.5	35.3	10.3	95.6	2.0	0.1	23.3	7.3	4.7	38.5	
BOP290147		990129	19/01/99	58.5			13.8	87.9	4.0	0.1	28.2	13.8	8.9	72.2	
BOP290147		990274	25/01/99	36.5			10.4	91.3	3.0	0.1	26.8	10.8	6.3	65.1	

Site	Description	Sample	Date	% < 65 µm	> 65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results			**% grain size**											
	Tauranga														
BOP290148	Tau/com 1	982635	01/12/98	8.7	91.3	6.0	2.7	98.4	3.0	0.2	8.8	43.4	102.0	559.0	3
BOP290148		982929	09/12/98	6.0	94.0	4.4	1.6	98.4	3.0	0.2	9.7	33.8	38.2	592.0	
BOP290148		983135	21/12/98	4.8	95.2	3.5	1.3	70.0	2.0	0.2	13.3	34.5	83.4	606.0	
BOP290148		990166	20/01/99	4.1			1.3	98.9	3.0	0.1	10.1	22.7	71.2	503.0	
BOP290149	Tau/com 2	982634	01/12/98	11.7	88.3	8.2	3.5	98.0	4.0	0.2	8.9	22.8	69.7	712.0	54
BOP290149		982930	09/12/98	8.6	91.5	5.9	2.6	98.1	3.0	0.4	12.2	50.2	34.8	541.0	
BOP290149		983136	21/12/98	7.7	92.3	5.2	2.5	97.7	3.0	0.2	17.3	20.8	77.7	401.0	
BOP290149		990165	20/01/99	7.9			2.6	98.2	3.0	0.1	10.7	35.8	33.7	490.0	
BOP290150	Tau/com 3	982633	01/12/98	11.7	88.3	8.9	2.8	98.0	4.0	0.2	9.7	13.9	65.3	202.0	22
BOP290150		982931	09/12/98	12.6	87.4	9.0	3.6	98.1	3.0	0.2	11.0	15.0	33.6	184.0	
BOP290150		983137	21/12/98	14.3	85.7	10.3	4.0	97.9	3.0	0.2	9.7	13.8	28.0	247.0	
BOP290150		990164	20/01/99	3.9			1.1	98.1	3.0	0.1	7.6	64.8	19.1	212.0	
BOP290151	Tau/com 4	982632	01/12/98	30.1	69.9	22.7	7.4	94.9	4.0	0.3	9.9	32.9	207.0	296.0	44
BOP290151		982932	09/12/98	17.9	82.2	13.1	4.7	96.4	3.0	0.2	6.8	21.1	102.0	269.0	
BOP290151		983138	21/12/98	21.3	78.7	15.7	5.6	95.7	4.0	0.2	8.8	36.0	131.0	361.0	
BOP290151		990163	20/01/99	19.0			4.4	95.9	4.0	0.2	8.1	28.6	141.0	356.0	
BOP290152	Tau/com 5	982631	01/12/98	1.6	98.4	1.2	0.4	98.9	7.0	0.0	2.4	0.8	2.4	15.1	2
BOP290152		982933	09/12/98	1.0	99.0	0.6	0.4	98.7	6.0	0.0	3.1	1.2	3.2	19.0	
BOP290152		983139	21/12/98	0.8	99.2	0.5	0.4	98.9	4.0	0.0	2.7	1.1	2.5	14.0	
BOP290152		990162	20/01/99	0.9			0.3	99.0	5.0	0.0	2.6	0.8	2.1	14.5	

Site	Description	Sample	Date	% < 65 µm	> 65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results			**% grain size**											
	Rotorua														
BOP290153	U/S Utuhina	982672	01/12/98	11.9	88.1	9.5	2.3	98.9	2.0	0.0	0.2	0.8	2.1	17.4	3
BOP290153	control	982910	08/12/98	10.6	89.4	7.6	3.0	98.3	2.0	0.0	0.8	0.9	2.7	20.7	
BOP290153		983140	21/12/98	20.8	79.2	17.9	2.8	97.6	3.0	0.1	0.9	1.7	3.7	33.5	
BOP290153		990111	19/01/99	8.1			1.4	98.7	3.0	0.0	0.7	1.1	2.6	23.5	
BOP290153		990245	25/01/99	19.6	80.4	16.6	3.1	97.8	4.0	0.1	1.4	2.8	3.1	31.2	
BOP290154	U/S Mangakakahi	982673	01/12/98	6.4	93.6	4.9	1.5	98.4	11.0	0.0	5.7	2.0	3.9	16.0	3
BOP290154	control	982911	08/12/98	8.6	91.4	7.1	1.5	97.7	5.0	0.0	1.4	1.5	4.4	15.6	
BOP290154		983141	21/12/98	15.0	85.0	12.7	2.3	97.7	8.0	0.0	1.0	1.9	4.1	18.2	
BOP290154		990112	19/01/99	19.3			3.3	98.4	7.0	0.3	4.3	11.4	61.9	112.0	
BOP290154		990246	25/01/99	19.9	80.1	16.2	3.7	97.3	12.0	0.0	2.6	4.1	6.3	55.5	
BOP290155	Utuhina Geothermal	982674	01/12/98	9.5	90.5	7.5	1.9	98.8	7.0	0.1	1.3	6.5	12.6	63.4	47
BOP290155	control	982912	08/12/98	18.0	82.0	14.8	3.2	98.1	16.0	0.1	4.0	15.6	34.8	66.0	
BOP290155		983142	21/12/98	11.8	88.2	9.7	2.1	97.2	20.0	0.1	3.8	21.3	31.6	89.2	
BOP290155		990113	19/01/99	15.4			2.4	98.6	6.0	0.1	2.4	10.4	14.0	48.2	
BOP290155		990247	25/01/99	15.1	84.9	12.7	2.5	98.3	9.0	0.1	4.3	114.0	26.6	148.0	

Site	Description	Sample	Date	% < 65 µm	> 65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results			**% grain size**											
	Rotorua														
BOP290156	Utuhina Res	982675	01/12/98	18.4	81.7	14.7	3.7	96.2	6.0	0.1	1.4	2.6	8.2	29.1	4
BOP290156		982906	08/12/98	14.8	85.3	11.8	2.9	95.7	6.0	0.1	2.6	2.9	9.3	31.8	
BOP290156		983143	21/12/98	16.3	83.7	13.2	3.1	96.6	5.0	0.1	2.4	3.3	18.8	43.4	
BOP290156		990114	19/01/99	22.0			4.2	96.1	5.0	0.1	2.7	4.0	18.4	38.0	
BOP290156		990248	25/01/99	14.1	86.0	11.1	2.9	95.7	7.0	0.1	2.7	4.4	10.6	36.0	
BOP290157	Utuhina Res	982676	01/12/98	4.2	95.8	-2.7	6.9	97.9	7.0	0.0	0.8	1.6	5.5	22.1	4
BOP290157		982907	08/12/98	4.3	95.7	3.6	0.8	97.9	6.0	0.0	1.2	1.4	5.1	20.4	
BOP290157		983144	21/12/98	7.5	92.5	6.3	1.2	97.3	7.0	0.1	0.9	2.6	6.9	27.7	
BOP290157		990115	19/01/99	4.0			0.7	97.7	7.0	0.0	0.9	1.5	6.0	23.6	
BOP290157		990249	25/01/99	5.6	94.4	4.6	1.0	98.2	9.0	0.0	1.2	2.5	5.8	24.5	
BOP290158	Mangakakahi Res	982677	01/12/98	15.6	84.4	12.8	2.9	95.3	340.0	0.1	241.0	35.7	7.9	26.7	4
BOP290158		982908	08/12/98	2.9	97.2	2.4	0.5	97.3	8.0	0.0	1.3	1.4	4.0	16.5	
BOP290158		983145	21/12/98	10.8	89.2	9.2	1.7	97.5	9.0	0.0	0.6	1.9	4.1	20.6	
BOP290158		990116	19/01/99	4.1			0.6	97.4	8.0	0.0	0.8	1.3	4.2	15.8	
BOP290158		990250	25/01/99	5.4	94.6	4.5	0.9	97.3	7.0	0.0	0.9	1.9	3.6	20.4	
BOP290159	Otamatea Res	982678	01/12/98	5.8			1.3	98.3	9.0	0.0	2.1	2.4	15.1	26.3	5
BOP290159		982909	08/12/98	33.3	66.7	27.3	5.9	93.9	23.0	0.1	3.7	6.9	38.3	55.3	
BOP290159		983146	21/12/98	27.5	72.5	22.6	4.8	95.0	27.0	0.1	4.4	7.6	36.0	58.2	
BOP290159		990117	19/01/99	7.3			1.1	98.9	6.0	0.0	1.4	2.4	8.8	29.5	
BOP290159		990251	25/01/99	18.5	81.5	15.9	2.6	98.7	11.0	0.1	2.3	3.8	45.5	39.0	

Site	Description	Sample	Date	% < 65 µm	> 65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results			**% grain size**											
	Rotorua														
BOP290160	Mangakakahi Str Ind	982679	01/12/98	4.9	95.1	3.9	1.0	98.2	7.0	0.0	1.2	1.7	6.2	26.5	3
BOP290160		982901	08/12/98	3.5	96.5	2.7	0.8	98.4	5.0	0.0	1.6	2.5	6.3	28.3	
BOP290160		983147	21/12/98	5.5	94.5	4.6	1.0	108.0	8.0	0.0	1.4	2.7	7.1	36.1	
BOP290160		990118	19/01/99	11.8			2.4	97.4	8.0	0.1	3.4	6.0	19.0	46.2	
BOP290160		990252	25/01/99	11.3	88.7	9.1	2.2	97.0	13.0	0.1	2.5	4.9	9.3	44.1	4
BOP290161	Depot St Drain	982680	01/12/98	3.0	97.0	2.2	0.9	98.6	17.0	0.1	16.0	15.5	17.3	157.0	25
BOP290161		982902	08/12/98	2.8	97.3	2.1	0.7	98.9	9.0	0.1	13.7	15.7	12.4	161.0	
BOP290161		983148	21/12/98	4.4	95.6	3.3	1.1	98.8	17.0	0.1	18.0	17.0	13.0	131.0	
BOP290161		990119	19/01/99	2.4			0.6	99.0	12.0	0.1	17.3	23.8	28.8	161.0	
BOP290161		990253	25/01/99	2.7	97.3	1.8	1.0	98.9	9.0	0.1	14.3	18.3	19.2	154.0	12
BOP290161		990254	25/01/99	4.2	95.8	3.2	1.1	98.9	9.0	0.2	11.8	18.2	21.7	168.0	9
BOP290162	Depot St Drain	982681	01/12/98	2.7	97.3	1.9	0.8	98.7	11.0	0.2	13.7	16.7	12.2	227.0	39
BOP290162		982903	08/12/98	3.5	96.5	2.5	1.0	98.7	10.0	0.2	15.0	18.7	18.0	202.0	
BOP290162		983149	21/12/98	5.7	94.4	4.2	1.5	98.1	20.0	0.2	17.2	22.4	17.2	168.0	
BOP290162		990120	19/01/99	4.0			0.8	98.8	11.0	0.2	14.2	17.0	14.7	146.0	
BOP290163	Utuhina d/s Ind	982682	01/12/98	45.2	54.8	38.4	6.8	87.8	23.0	0.3	9.1	18.8	37.0	143.0	25
BOP290163		982904	08/12/98	42.9	57.1	35.5	7.5	89.2	24.0	0.2	11.2	21.7	45.5	145.0	
BOP290163		983150	21/12/98	43.1	56.9	36.2	6.9	88.9	19.0	0.2	9.7	21.2	41.3	138.0	
BOP290163		990121	19/01/99	39.4			5.7	91.1	19.0	0.2	8.6	18.6	34.4	129.0	
BOP290163		990255	25/01/99	38.7	61.3	31.6	7.0	92.7	17.0	0.2	7.7	17.2	35.4	135.0	
BOP290164	Utuhina outlet to lake	982683	01/12/98	4.9	95.2	3.9	0.9	72.6	3.0	0.0	1.4	3.2	6.4	23.7	3
BOP290164		982905	08/12/98	1.2	98.8	0.8	0.4	99.2	5.0	0.0	1.0	1.4	4.8	14.6	
BOP290164		983151	21/12/98	1.1	98.9	0.9	0.2	99.1	3.0	0.0	1.2	1.7	5.6	17.3	
BOP290164		990122	19/01/99	4.2			0.7	98.6	6.0	0.0	1.1	2.8	9.7	35.7	
BOP290164		990256	25/01/99	no result			^	95.3	7.0	0.0	17.1	2.9	58.7	35.8	

Site	Description	Sample	Date	% < 65 µm	> 65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results			**% grain size**											
	Whakatane														
BOP290165	Sed trap Com	982684	01/12/98	25.0	75.0	19.8	5.2	95.8	3.0	0.2	7.5	17.0	28.1	214.0	114
BOP290165		982899	08/12/98	4.0	96.0	3.0	1.0	97.6	2.0	0.2	9.4	13.7	42.8	125.0	
BOP290165		983152	21/12/98	50.6	49.5	45.5	5.0	95.2	9.0	0.3	16.1	26.7	32.4	290.0	
BOP290165		990123	19/01/99	27.2			3.9	97.0	3.0	0.3	16.1	28.4	36.7	239.0	
BOP290165		990257	25/01/99	7.3	92.8	5.9	1.3	98.3	2.0	0.2	45.1	16.1	23.2	242.0	38
BOP290166	s/w at end o pipes Com	982685	01/12/98	20.8	79.2	16.4	4.4	96.9	4.0	0.2	4.5	15.1	35.2	71.3	5
BOP290166		982900	08/12/98	20.2	79.8	16.0	4.2	97.6	4.0	0.1	7.2	59.0	41.5	117.0	
BOP290166		983153	21/12/98	19.0	81.0	15.3	3.7	97.7	4.0	0.2	5.8	22.9	26.8	113.0	
BOP290166		990124	19/01/99	22.9			4.3	96.3	11.0	0.1	2.3	4.1	7.7	55.5	
BOP290166		990258	25/01/99	35.8	64.2	29.7	6.1	97.1	7.0	0.2	5.0	21.0	37.0	148.0	35
BOP290167	Gorge Control (Whak)	982539	30/11/98	57.2	42.9	47.1	10.1	94.0	3.0	0.1	5.1	5.8	8.7	34.1	4
BOP290167		990087	18/01/99	62.4			9.5	77.7	7.0	0.1	15.5	10.3	15.1	55.0	
		990543		22.7	77.3	17.4	5.3	96.6	1.0	0.1	2.1	3.1	7.0	22.5	
		990886						94.1	2.0	0.0	3.3	4.1	9.8	30.1	
		990995						96.3	2.0	0.0	2.6	3.4	9.3	29.8	

Site	Description	Sample	Date	% < 65 µm	> 65µm	4-65 µm	< 4 µm	ASH-	As	Cd	Cr	Cu	Pb	Zn	TPH
	Stormwater sediment results			**% grain size**											
	Whakatane														
BOP290168	King St Res	982540	30/11/98	13.5	86.5	9.5	4.0	97.4	2.0	0.0	3.2	10.2	5.4	30.4	3
BOP290168		990088	18/01/99	8.0			2.5	97.8	2.0	0.0	2.5	3.5	4.5	26.4	
		990544		15.9	84.1	11.4	4.5	97.5	1.0	0.0	1.9	2.7	7.9	32.4	
		990887						97.6	2.0	0.0	2.0	3.1	7.3	25.6	
		990996						97.5	2.0	0.1	4.5	3.7	20.4	34.5	
BOP290169	u/s Hinemoa St Res	982541	30/11/98	23.1	76.9	16.7	6.5	96.4	3.0	0.0	4.8	5.6	9.7	43.1	3
BOP290169		990089	18/01/99	11.5			3.0	97.6	2.0	0.0	3.8	4.0	7.3	32.7	
		990545		22.4	77.6	17.8	4.6	97.2	1.0	0.0	2.3	3.9	7.4	31.5	
		990888						98.0	2.0	0.0	2.3	3.4	6.2	28.5	
		990997						98.1	2.0	0.0	2.2	3.2	6.8	32.9	
BOP290170	d/s Hinemoa St Res	982542	30/11/98	22.5	77.5	17.0	5.5	95.1	4.0	0.1	6.1	8.4	16.4	57.9	4
BOP290170		990090	18/01/99	12.4			3.4	97.9	2.0	0.0	2.9	3.4	6.0	37.3	
		990546		5.8	94.2	4.3	1.4	98.5	1.0	0.0	3.3	4.3	8.2	43.5	
		990889						97.8	2.0	0.0	2.9	3.4	7.4	40.6	
		990998						94.1	3.0	0.1	5.0	10.3	16.2	80.0	
BOP290171	Kakahoroa Dr Com	982543	30/11/98	81.4	18.6	68.2	13.2	87.4	44.0	0.5	43.5	99.0	159.0	709.0	28
BOP290171		990091	18/01/99	46.4			10.5	90.9	17.0	0.2	28.3	46.6	68.2	315.0	
		990547		73.2	26.8	57.9	15.3	78.5	36.0	0.7	40.3	113.0	160.0	910.0	
		990890						83.1	25.0	0.4	26.0	69.0	117.0	564.0	
		990999						88.3	20.0	0.4	22.0	71.7	168.0	525.0	
BOP290172	Estuary end Kakahora Dr	982544	30/11/98	63.6	36.4	50.4	13.2	93.4	24.0	0.2	26.0	42.5	52.4	279.0	12
BOP290172		990092	18/01/99	59.9			14.5	87.5	16.0	0.2	22.9	52.1	85.5	337.0	
		990548		61.5	38.5	44.2	17.3	94.1	8.0	0.1	12.7	25.4	32.7	166.0	
		990891						91.4	9.0	0.1	16.0	31.1	37.2	187.0	
		991000						92.0	12.0	0.2	17.1	41.4	54.4	390.0	
BOP290173	Waiewe Stm	982545	30/11/98	26.3	73.7	18.3	8.0	96.6	4.0	0.0	5.0	7.3	10.9	45.8	3
BOP290173		990093	18/01/99	13.0			3.5	97.1	2.0	0.0	3.3	4.1	12.9	48.1	
		990549		18.9	81.1	15.2	3.8	96.3	3.0	0.0	6.1	10.1	36.4	81.0	
		990892						95.5	3.0	0.0	6.6	11.6	34.6	84.8	
		991001						95.3	3.0	0.0	12.8	10.2	41.2	89.0	

Appendix II – Polycyclic Aromatic Hydrocarbons

Ten sites were sampled once for Polycyclic Aromatic Hydrocarbon. The Mt Maunganui sites were sampled on 1 December 1998, the Whakatane sites on 18/1/99 and the Tauranga and Rotorua sites on 25 January 1999.

PAH mg/kg DW	1	2	3	4	5
Acenaphthene	0.0080	0.0006	0.0007	0.0010	0.0050
Acenaphthylene	0.0040	0.0100	0.0048	0.0030	0.0030
Anthracene	0.0190	0.0190	0.0097	0.0010	0.0130
Benzo(a)anthracene	0.0460	0.0562	0.0438	0.0010	0.1000
Benzo(a)pyrene	0.0490	0.1140	0.0949	0.0010	0.1160
Benzo(b)fluoranthene	0.0600	0.1440	0.1190	0.0010	0.1640
Benzo(k)fluoranthene	0.0090	0.0296	0.0230	0.0010	0.0510
Benzo(ghi)perylene	0.0430	0.0655	0.0773	0.0040	0.0720
Chrysene	0.0410	0.0503	0.0412	0.0010	0.0820
Dibenzo(a,h)anthracene	0.0020	0.0160	0.0192	0.0010	0.0100
Fluoranthene	0.1180	0.1270	0.0841	0.0010	0.1460
Fluorene	0.0060	0.0077	0.0020	0.0040	0.0040
Idenol(2,3-cd)pyrene	0.0290	0.0559	0.0515	0.0020	0.0560
Naphthalene	0.0020	0.0087	0.0063	0.0010	0.0010
Phenanthrene	0.0860	0.0866	0.0406	0.0070	0.0400
Pyrene	0.1410	0.1110	0.0823	0.0050	0.1650
Total PAH mg/kg DW	0.6630	0.9021	0.7004	0.0350	1.0280
Sediment < 65 microns	0.43	0.12	0.30	0.11	0.03

	6	7	8	9	10
Acenaphthene	0.0030	0.0070	0.7360	0.0024	0.0022
Acenaphthylene	0.0020	0.0050	0.0320	0.0006	0.0005
Anthracene	0.0020	0.0150	2.4500	0.0029	0.0021
Benzo(a)anthracene	0.0050	0.1010	4.3900	0.0196	0.0158
Benzo(a)pyrene	0.0090	0.1090	3.6800	0.0453	0.0408
Benzo(b)fluoranthene	0.0150	0.2060	5.1600	0.0639	0.0524
Benzo(k)fluoranthene	0.0030	0.0290	1.4900	0.0146	0.0105
Benzo(ghi)perylene	0.0090	0.1010	2.3800	0.0366	0.0351
Chrysene	0.0050	0.1000	3.6200	0.0227	0.0160
Dibenzo(a,h)anthracene	0.0010	0.0110	0.3250	0.0006	0.0005
Fluoranthene	0.0120	0.2170	11.5000	0.0460	0.0363
Fluorene	0.0030	0.0030	0.3550	0.0007	0.0008
Idenol(2,3-cd)pyrene	0.0060	0.0780	1.9200	0.0235	0.0215
Naphthalene	0.0010	0.0010	0.0650	0.0023	0.0023
Phenanthrene	0.0120	0.0410	8.1500	0.0176	0.0157
Pyrene	0.0230	0.2190	11.1000	0.0576	0.0367
Total PAH mg/kg DW	0.1110	1.2430	57.3530	0.3569	0.2892
Sediment < 65 microns	0.04	0.07	0.36	0.22 (est)	0.72 (est)

* (est) estimate

SW drain u/s of Oripi Rd.	Maleme St. Tauranga SW Drain	**1**	**BOP290134**
T COMM 3	Mt Maunganui Commercial S/W D	**2**	**BOP290150**
T COM 4	Mt Maunganui Commercial S/W D	**3**	**BOP290151**
Mangakakahi Str	Rotorua S/W Industrial Site	**4**	**BOP290160**
Depot St drain	Rotorua S/W Industrial Site	**5**	**BOP290161**
Depot St drain	Rotorua S/W Industrial Site	**6**	**BOP290161**
Sediment Trap	Rotorua S/W Commercial Site	**7**	**BOP290165**
S/W at end of pipes	Rotorua S/W Commercial Site	**8**	**BOP290166**
d/s Hinemoa St, Awatapu Lagoon	Wainui Stream	**9**	**BOP290170**
Drain of Kakahoroa Dr.	Whakatane Commercial Centre	**10**	**BOP290171**

Appendix III – Total Petroleum Hydrocarbons

A reference was found to environmental limits for Total Petroleum Hydrocarbons on http://www.epa.gov/owowwtr1/watershed/Proceed/shepp.html (see Page 43).

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Petroleum Hydrocarbon Concentrations Observed in Runoff From Discrete, Urbanized Automotive-Intensive Land Uses

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Introduction

This documents a portion of work performed by the Metropolitan Washington Council of Governments (MWCOG) for the State of Maryland Department of the Environment (MDE) and EPA's Chesapeake Bay Program Office (CBPO) pertaining to a comprehensive study of the generation and control of petroleum hydrocarbons in urban runoff. The purpose of this particular study task was to characterize the relative contribution of petroleum hydrocarbons and other typically encountered urban pollutants contained within stormwater runoff from small, single land use catchments. The following four automotive-intensive land uses were evaluated: (1) all-day parking lots, (2) streets, (3) gas stations, and (4) convenience commercial. The study was conducted from October, 1992 through December, 1993. The study area encompassed the District of Columbia and Suburban Prince George's County, Maryland.

Methodology

Due to budgetary constraints, only one site per land use was studied. The following prerequisite conditions were met for each site: (1) the selected site had to be representative of the general land use classification, (2) the selected site had to be uncontrolled from the perspective of stormwater management, (3) the selected site had to be feasible for discrete land use monitoring (e.g. all stormwater flows had to emanate exclusively from the targeted land use).

The study monitoring contractor, the Occoquan Watershed Monitoring Laboratory (OWML) suggested the use of Cashockton Wheel samplers due to their ability to sample a vertical "slice" of the influent stormwater column. Due to the known partitioning of various petroleum hydrocarbon fractions in stormwater runoff, OWML felt the Cashockton Wheel samplers were superior to traditional automated samplers in obtaining a representative characterization of petroleum hydrocarbons from each site's

runoff. They consist of a small "H" flume connected to a gravity-driven, rotating flow splitting device. As runoff flows from the impervious surface to the monitoring station, it is collected and funneled to the sampler by the "H" flume. The elevational differential between the flume and the horizontally-oriented platter-like wheel turns the wheel, via energy imparted to turning vanes from the falling inflow. As the wheel spins (similar to a record player), it splits a fraction, or "slice" of the stormwater inflow into a collection vessel through a small slot in its surface. This configuration yields a flow-weighted composite runoff sample and associated event mean concentrations (EMC) for each of the evaluated constituents. The Cashockton Wheels were deployed inside catch basins (3 sites) and within a locked fiberglass monitoring shed in a surface installation (1 site). Notable operation and maintenance constraints were encountered with the use of the Cashockton Wheel samplers in the study context. Urban grit and organics were found to impede the normal rotation of the samplers. For this reason, all samplers were temporarily removed from service and retrofitted with sealed, Teflon-coated central bearings. Even following retrofitting, the problem persisted, requiring close attention and frequent cleaning following storm events and regularly-scheduled weekly maintenance visits.

Rainfall measurements (rain depth) for 3 of the 4 sites were collected at the nearby USDA National Arboretum raingage. Due to the distance to the gas station site (located in Laurel, Maryland) an additional gage was installed on the stations' rooftop. Storm samples were retrieved following rainfall events and transported to OWML in Manassas, Virginia for laboratory analysis. A technique, utilizing non-dispersive infrared spectrometry, was developed for the purpose of evaluating the concentration of total hydrocarbons. OWML staff developed a functional relationship between petroleum hydrocarbon concentration and associated light transmittance in the infrared wavelength of 3.5 microns. It represents an improvement over standard gravimetric methods for oil and grease since it requires less lab time, reduced sample volumes and avoids "noise" from non-target solids in the sample volume. Associated limitations for this methodology include its lack of specificity (the results cannot be compared with results from studies which generate a higher degree of fractional resolution) and the potential for a lack of accounting for as much as 50% of the lighter fractions (due to their loss via volatilization during extraction); this can result in a conservative estimate of the total hydrocarbons. In a practical context, the total hydrocarbon concentration represents a changable,

dynamic index where, due to field volatilization rates, the lighter fractions escape within a few days from the surface of the water column to the atmosphere.

Results

The following include the most important findings of the study:

1. While the total imperviousness for each site was virtually equivalent (estimated values ranged from 95-100%), the observed median EMC's for each site exhibited substantial differences (see Figure 1). The observed mean EMC's for each site exhibited a similar pattern as evidenced by arraying the studied land uses in descending order of total hydrocarbon concentration: (1) Convenience Commercial, mean observation: 12.4 milligrams per liter, range: 2.7 to 56.0 milligrams per liter, (2) Gas Station, mean observation 3.7 milligrams per liter, (3) Street, mean: 2.2 milligrams per liter, range: 0.8 to 4.7 milligrams per liter, and (4) All day Parking, mean: 0.9 milligrams per liter, range: 0.3 to 4.4 milligrams per liter.

2. Analysis of variance (ANOVA) indicated that significant differences exist between the observed means. Two-sample F-Tests of significance revealed that the majority of the means were significantly different from each other. Only the comparison of street and gas station means lacked sufficient significance to accept the null hypothesis. This suggests that imperviousness is not an acceptable singular indicator for predicting total hydrocarbon concentrations associated with automotive-intensive land use.

3. Data scatter plots revealed the following observed relationships:

    - Rainfall Depth vs. Total Hydrocarbons. The All day parking, Street and Convenience commercial sites exhibited a negative relationship, whereas the gas station site exhibited a positive relationship.

    - Rainfall Depth vs Total Suspended Solids. The All day parking, Gas Station and Convenience commercial sites exhibited a negative relationship, whereas the Street site exhibited a positive relationship.

    - Total Hydrocarbons vs Total Suspended Solids. All sites exhibited a positive relationship.

4. Observed data suggests a relationship between automotive exposure and total hydrocarbon concentration. Thermal expansion and contraction of oil-bearing regions of automotive drive trains is thought to be the primary source of petroleum hydrocarbons, via seepage. Duration of automotive exposure (i.e. the time a given impervious surface is exposed to hot vehicles in a thermal expansion mode) as well as volume of automotive exposure (i.e. the number of hot vehicles in a thermal expansion mode exposed to a given impervious surface) are suggested as the principal factors in the generation of petroleum hydrocarbon pollution upon automotive intensive land uses (see Table 1).

5. Many of the highest observed concentrations were associated with rainfall depths less than 0.25 inch, with accompanying durations spanning 2 to 3 days. Concentrations associated with such low volume, low intensity events clearly underscore the relative ease of mobilization of petroleum hydrocarbons from impervious surfaces. Examination of rainfall patterns in the middle Atlantic region show that on average, (approximately every 3 to 4 days) precipitation events, with the potential to mobilize surprisingly high concentrations of petroleum hydrocarbons, occur. Furthermore, given their relative ease of mobilization, the potential for the delivery of substantial concentrations of petroleum hydrocarbons from automotive-intensive land uses to receiving waters exists both regionally and nationally for the majority of measurable annual rainfall events. The observed data suggest the principal source (automotive), its associated accumulation medium (imperviousness) and delivery mechanism (normal rainfall) central to this cycle.

6. Two separate items of information serve to provide a useful context for understanding the importance of the observed median total hydrocarbon concentrations presented in Figure 1 and the previously-mentioned range of observed concentrations for each land use (i.e. 0.3 to 2.4 milligrams per liter for the All day parking site, 0.8 to 4.7 milligrams per liter for the Street site, 1.2 to 5.5 milligrams per liter for the Gas station site, and 2.7 to 56.0 milligrams per liter for the Convenience Commercial site). First, maximum concentrations observed from the Convenience commercial site, 56.0 milligrams per liter, exceeded recently monitored observations for Hickey Run in the District of Columbia (50.0 milligrams per liter). Hickey Run has the dubious distinction as the most polluted

subwatershed in the degraded Anacostia Watershed (due primarily to a history of chronic and episodic waste oil dumping) and as one of the most polluted urban subwatersheds in the entire Chesapeake Bay drainage. Secondly, recommended maximum concentrations of petroleum hydrocarbons for drinking water supplies and fisheries protection typically range from 0.01 to 0.1 milligrams per liter; crude oil concentrations of 0.3 milligrams per liter can cause toxic effects in freshwater fish (D. Chapman and V. Kimstach, 1992).

Table 1. Automotive Exposure and Observed Hydrocarbon Concentraions by Land Use.

Land Use	Duration of Automotive Exposure	Volume of Automotive Exposure	Observed Median Conc.
ALL DAY PARKING *National Arboretum*	LONG (4 to 8 Hours per Car per Day)	LOW (1 to 2 Cars per Parking Space per Day)	0.7 mg/l
GAS STATION *Laurel Texaco*	MODERATE (5 to 10 Minutes per Car per Day**No Repair/Maint. Service Provided**Pump & Pour Your Own "Micro Spills" Anticipated)	MODERATE (A Steady Stream of Cars Throughout Day)	4.2 mg/l
STREET *20th @ Franklin St.*	BRIEF (10 to 60 Seconds, Depending on the Traffic Light Cycle)	HIGH (1,000 plus Cars Estimated; AM & PM Rush Hr. Peaks, Steady Midday Use as Secondary Roadway)	1.9 mg/l
CONVENIENCE COMM. *N.h. Ave. Mcdonald's*	MODERATE (10 to 30 Minutes per Car per Day Estimated)	MODERATE/HIGH (Breakfast, Lunch & Dinner Peaks, Steady Throughout Day)	6.6 mg/l

7. Evaluation of rank and percentile of observed rainfall and hydrocarbon concentrations occuring over the span of an entire year indicated that 23 of 30 (or 77%) of the top half, or highest, observed total hydrocarbon concentrations could be managed via effective stormwater controls designed to treat the first 0.5 inch of runoff from the studied sites. If a 0.25 inch design treatment volume was utilized, 12 of 30 (or 40%) of the top half of the highest observed concentrations could be managed. These values stand in stark contrast when compared to the

currently prevailing design rules for target treatment volumes relative to the control of petroleum hydrocarbons in urban runoff. Typical oil-grit separator design is based upon a 0.10 inch treatment volume of runoff. Utilizing the same overall dataset, this level of control equates to treating 2 of 30 (or 7%) of the highest hydrocarbon generating events of the evaluated annual rainfall.

Implications

Based upon analysis of the study observations, the following conclusions were reached:

Evaluation of the observations suggest that runoff concentrations of petroleum hydrocarbons from automotive-intensive land uses typically range from 0.7 to 6.6 milligrams per liter. Given the recommended maximum petroleum hydrocarbon concentrations of petroleum hydrocarbons for drinking water supply and fisheries protection (0.01 to 0.1 milligrams per liter) and the reported toxic effects observed in freshwater fish from crude oil concentrations of 0.3 milligrams per liter (D. Chapman and V. Kimstach, 1992), the observed total hydrocarbon concentrations suggest their substantial national impact as a nonpoint source pollutant. This suggestion is futher reinforced by the knowledge that many of the monitored automotive-intenstive land uses are commonly found throughout all, but the most rural and remote areas, of the United States.

1. Evaluation of the observations and their respective catchment areas suggest that the degree of automotive exposure (a combination of duration of exposure and volume of exposure) is the primary factor in the generation of petroleum hydrocarbons in runoff from automotive-intensive land uses. The pollutant pathway: (1) originates via drive train seepage from automotive vehicles, (2) accumulates upon highly impervious surfaces designed for automotive conveyance or parking, and (3) is readily mobilized via runoff produced by low volume, low intensity storms. The measured and visual observations gathered throughout the course of the study suggested, with the notable exception of expensive, new cars (W. Bell, et.al., 1995), virtually all motorized vehicles seep a measurable volume of petroleum hydrocarbon based lubricating agents. Casual visual observation suggests a wide range in the relative rates of seepage exists from vehicle-to-vehicle. Further visual observation suggests this variability is primarily a function of the age and relative degree of mechanical upkeep associated with a given vehicle.

2. Application of BMP's effective in the control of petroleum hydrocarbons is suggested for the treatment of runoff from automotive-intensive catchments as small as 0.5 acres. Recent performance evaluations of sand filtration BMP's , independently conducted by the District of Columbia (H. Troung, et. al.,1993) and the City of Alexandria, Virginia (W. Bell , et.al., 1995), suggest removal efficiencies for total hydrocarbons in excess of 77 per-cent. In addition to their reported removal efficiencies, the local availability of sand and gravel resources in the Middle Atlantic's Coastal Plain enhances the attractiveness of filtration-based treatment of runoff from automotive-intensive land uses. Design treatment storage volumes up to the first 0.5 inch of runoff are suggested for the treatment of petroleum hydrocarbons in the Middle Atlantic region.

3. A seepage evaluation is suggested as a new pollution prevention component of regularly-scheduled vehicular safety/emissions inspections. A simple, relatively "low tech" approach could be developed, possibly using kraft paper as an evaluation medium. The diameter and number of seepage stains accumulated over a pre-determined evaluation period could potentially be utilized to develop an evaluation metric for identifying unacceptably high petroleum hydrocarbon seepage rates. A possible hierarchy of corrective actions could include: (1) mechanical tightening of drive train mating surfaces containing petroleum hydrocarbon lubricants, (2) the external application of petroleum hydrocarbon and heat resistant flexible sealants to seeping areas and (3) replacement of deteriorated and/or hardened gaskets and seals (this represents the last choice due to its associated disassembly time and related expense). An accompanying public education/outreach initiative as an additional component of a comprehensive pollution prevention program is suggested. The effort could be specifically targeted for the general public and the automotive repair and service industry. Its focus could revolve around the need to raise the public's awareness of the ubiquitous nature and potential environmental damage associated with uncontrolled/untreated petroleum hydrocarbons in runoff from automotive-intensive land uses.

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