



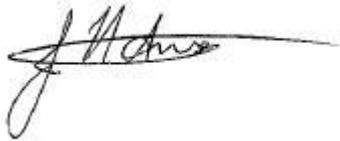
Urban Sources of Copper, Lead and Zinc

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Urban Sources of Copper, Lead and Zinc

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Prepared for
Auckland Regional Council

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Abbreviations

ANZSIC	Australian and New Zealand Standard Industrial Classification
ARC	Auckland Regional Council
ATF	automatic transmission fluid
BC	Before Christ
CBD	central business district
CCA	copper chrome arsenate
EPCRA	Emergency Planning and Community Right-to-Know Act
ERMA	Environmental Risk Management Authority
EU	European Union
g	gram
Gg	gigagram (10 ⁹ gram)
ha	hectare
HCV	heavy commercial vehicle
HSNO	Hazardous Substances and New Organisms
ITP	Industrial and Trade Process
kg	kilogram
km	kilometre
LCV	light commercial vehicle
LoS	level of service
m	metres
m ²	square metres
m ³	cubic metres
µg	microgram
mg	milligram
mL	millilitre
mm	millimetres
NIS	New Independent States
NPDES	National Pollutant Discharge Elimination System
NPI	National Pollutant Inventory

NSQD	National Stormwater Quality Database
PAHs	polycyclic aromatic hydrocarbons
PARP:ALW	Proposed Auckland Regional Plan: Air, Land and Water
PM ₁₀	particulate matter (of 10 micrometers or less)
ppm	parts per million
PVC	poly vinyl chloride
SIC	standard industrial classification
t	tonne
TCLP	toxicity characteristic leaching procedure
Tg	teragram (10 ¹² gram)
TR	total recoverable
TRI	Toxics Release Inventory
TSS	total suspended solids
US	United States
USEPA	United States Environmental Protection Agency
VKT	vehicle kilometers travelled
VPD	vehicles per day
WSDE	Washington State Department of Ecology
yr	year
ZDDP	zinc dialkyl dithio phosphate

1 Introduction

1.1 Overview

A recent study commissioned by the Auckland Regional Council (ARC 2005) provided information on sources and loads of copper, lead and zinc in stormwater from three urban catchments in Auckland City. However, the work was not able to define or match the measured loads and assessed loads from known sources (of copper and lead in particular) with a high degree of certainty. This is likely to be attributable to uncertainty about where the copper, lead and zinc is coming from and the uncertainty associated with the load estimates for these sources, resulting in the high proportion of “unknown” contributions present in the load calculations.

To illustrate this, the mass budgets for copper detailed in ARC (2005) were shown to be relatively incomplete, with loads from unidentified sources totalling approximately 60 per cent of the measured catchment load for the residential catchment, 70 per cent for the commercial catchment, and 80 per cent for the industrial catchment. The mass budgets for lead were somewhat better for the residential catchment, with loads from unidentified sources totaling approximately eight per cent of the catchment load; however large unknowns were identified for the commercial catchment, and the industrial catchment load estimates (60 per cent and 80 per cent respectively) (refer Section 2.4.2 for more detail). In comparison, the mass budgets for zinc appeared to be relatively well understood.

Urban environments are complex sources of contaminants such as copper, lead and zinc. In New Zealand there is no inventory of metal usage or metal flow through our society. Information about what products are made from or what products contain these metals helps define their fate (ie, how the particular contaminant is transported through our society, how it is released into the environment etc.). It also assists if source control is required (eg as has occurred for toxic metals such as cadmium internationally).

1.2 Project scope

Auckland Regional Council (ARC) engaged Golder Associates (NZ) Limited to undertake a study to identify sources of copper and lead, and to a lesser extent zinc, in the urban environment. The issued scope required a review of the available information about the urban sources and their yields of copper and lead, an estimation of the relative magnitudes of each of the identified sources, and identification of specific investigations necessary to fill the gaps in knowledge of the sources and yields of these metals.

The scope also detailed some specific matters to be addressed in the review, these key areas of work included:

- Road run-off as a source of zinc, copper and lead. In this part of the review zinc was included, because of the three metals, the estimate of the rate at which vehicles deposit zinc on road surfaces is considered to be the most accurate. The intention was that if the review does not uncover adequate data from which to estimate the copper and lead yields directly from vehicles, but does identify sufficiently consistent data for the copper/zinc and lead/zinc ratios in road run-off, then it might be possible to use these ratios and the zinc yield to derive more accurate estimates of the copper and lead yields.
- Copper and lead in roof run-off. The scope specifies that this work is to include a summary of the ARC (2004) study of roof run-off, along with an update of any more recent information, particularly on copper yields from copper sheet roofing, spouting and down pipes.
- Copper from the residential use of copper-based fungicides. If possible, the review needs to include a review of sales figures of these products within the Auckland region, and from this data estimate the yield from this source.
- Copper and lead from industrial emissions to both air and stormwater. This is to include smelters, but of particular interest are industrial sources of lead. According to the ARC's scope, there appear to be few industries other than battery manufacture and recycling using large amounts of lead.
- Copper and lead in Auckland's soils, including the natural background levels and any added from other sources such as leaded petrol and leaded paint.

1.3 Report contents

This report is set out in six sections following this introduction:

- Section 2 presents a summary of information on copper, lead and zinc contributions to urban stormwater from different sources. This includes a summary of the work to date by ARC (2005) and other relevant international literature.
- Section 3 systematically identifies the key sources of copper, lead and zinc in some example residential, commercial and industrial catchments in Auckland.
- Section 4 identifies and discusses a range of common and unique sources of copper, lead and zinc to stormwater, and the importance of these sources. It also identifies what is known about the loads generated by these sources wherever possible.
- Section 5 provides an overview of the key sources of copper, lead and zinc identified in Section 4 of this report, and assigns a significance and uncertainty ranking to each source where possible.
- Section 6 discusses the key sources where it is considered that there are significant gaps in knowledge required to calculate catchment loading rates.

- Section 7 provides the conclusions of this assessment of urban sources of copper, lead and zinc to stormwater, and provides any recommendations for further investigations.

2 Sources of Metals

2.1 Introduction

To define where metals such as copper, lead and zinc are sourced from in New Zealand urban environments, it is necessary to have an understanding of how metals are used and how they are distributed. In addition, some information on possible historical use and distribution may also be required for some metals where there have been significant changes in use and distribution. Information on the sources of metals can be examined at four key levels. These are:

- Global sources and budgets.
- Regional sources and budgets.
- Catchment scale sources and budgets.
- Street scale sources and budgets.

Having some knowledge at these different levels assists in understanding how metals are used in our society (ie, in New Zealand). Global source assessments help place our general use into perspective, as do the regional source assessments. However, in terms of understanding the actual effects of uses on stormwater quality it is the catchment and street scales that are important. To set the scene, some background information is presented below.

2.2 Global scale studies

In assessing the extent that man has released elements such as copper, lead and zinc to the environment, various studies have looked at the mobilisation and release to the environment at a global level. Andreae (1984), for example, discusses changes in the geochemical cycle of metals that have arisen from their use by society identifying:

- That, for lead, changes are and have been significant and have occurred on global, regional (100-1000 km) and local (<100 km) scales. This occurs because lead, which was historically smelted and more recently was present (in New Zealand) in vehicle petrol, is volatile (hence transported in the atmosphere) and highly mobile as an organic complex (alkyl lead).
- That, for copper, changes have occurred at the level of “enrichment” on a regional and local scale. This occurs because copper is volatile (hence transported in the atmosphere) and is soluble.
- That, for zinc, changes have also occurred at the level of “enrichment” on a regional and local scale. This occurs because zinc is volatile (hence transported in the atmosphere) and is soluble.

Lead, copper and zinc have an extensive history as regional (>2000-3000 yrs BC) and significant global pollutants (<100 yrs). Typically those elements that have high volatility (eg lead) have more significant global perturbations. To place a useful historic perspective on the presence of metals in our environments, only 2.5 per cent of the 400 Tg (1 Tg - 1 million metric tons) of copper produced during past millennia by human society was mined and smelted prior to 1900 (Gordon et al. 2006).

Nriagu (1990) provides a summary of the human impacts on global metal cycling and discusses rates of change in consumption and emission of metals. Contributions to soil constitute the largest component of the copper (87 per cent), lead (63 per cent) and zinc (79 per cent) emissions. Contributions to water for all three metals ranged from 10-13 per cent.

2.3 Regional scale studies

2.3.1 Atmospheric emissions studies

There have been a range of studies undertaken in a number of countries that provide assessments of possible sources of key metal contaminants in urban environments. There have also been a number of national and continental inventories, such as those undertaken by Environment Canada (eg Environment Canada 1981) and Pacyna (1983), documenting emissions to air. Pacyna (1983) described sources of emissions of trace elements from anthropogenic sources in Europe. Table 2.1 provides a simple summary of the data in that report.

The data in Table 2.1 provides information on the relative importance of certain sources within a particular regional framework. The published example provided is "dated" in that lead emissions from petrol combustion dominated emissions to the environment at that time. With the vehicle lead source effectively removed, this reduces the total lead emissions by 60 per cent to 48,700 t/year, and as a consequence (assuming other sources remain unchanged) metals industries become the dominant current emitters.

Metal emission fluxes for the 12 New Independent States (NIS) (former Soviet Union) have been made based on data from earlier years (1990, 1995 and 1997) (Kakareka et al. 2004). For lead, the assessed emissions were shown to have reduced significantly due to the removal of ethylated petrol from the market, resulting in a shift in the sources contributing the greater proportion to the atmosphere. In the European NIS countries, the contribution of lead from ferrous metals industry rose from 33 to 63 per cent. In the Asian NIS countries non ferrous metals emissions rose from 60 to 71 per cent.

Table 2.1.

Summary of copper, lead and zinc emissions to the atmosphere in Europe (From Pacyna 1983).

Source	Copper t/year	Lead t/year	Zinc t/year
Thermal power	1377	1138	1316
Ind. combustion coal/oil	2038	1652	1824
Wood combustion	1500	562	4590
Gasoline combustion	-	74,300	-
Mining	192	1090	460
Primary non-ferrous metals	8410	27,580	51,480
Secondary non-ferrous metals	61	442	3440
Iron, steel making	1710	14,660	10,250
Refuse incineration	260	804	5880
Phosphate fertilisers	77	6	230
Cement production	-	746	-
Total	15,500	123,000	80,000

Data produced by studies such as those of Pacyna (1983) and Kakareka et al. (2004) demonstrate that contributions from key sources vary geographically due to resource distributions and primary industry location. In addition, contributions change over time from changes in resource utilisation, technology, and politics.

2.3.2 Stock studies

There have been few studies that have undertaken source and use studies to understand where elements such as copper, lead and zinc are being used in urban areas. Sorme et al. (2001) quantified the diffuse emissions arising from the use of metal containing “goods” in Stockholm (Table 2.2). They noted that many metals are used in “protected environments” and are typically not subject to corrosion and degradation and hence release. Metals may be used in dissipative sources, in that their use results in their direct release to the environment (it is these sources which are the subject of this report). Copper and zinc dominated metal emissions in Stockholm. The key factors identified in the Sorme et al. (2001) study were:

- The tap water system and roofs (copper) are the goods with large exposed surfaces but low release rates to the urban environment.
- Brake linings, aerial lines and electrical groundings (copper) and tyres, brake linings and chemicals (zinc) are goods with high release rates but limited exposed stocks.
- High yearly emissions were identified for lead because of the use of lead ammunition and sinkers.
- Emissions from brake linings (copper, lead and zinc), tyres (lead and zinc) and asphalt wear (copper, lead and zinc) were considered to be of “large” importance for total emissions.

The main use of copper in urban areas was considered by Sorme et al. (2001) to be in electrical goods (cables etc.) and equipment, the majority of which are in protected

environments. Aerial copper wire used for trams and trains was considered to be an important source. Four other significant sources of copper in Stockholm were roofs, brake lining wear, marine paints and timber treatment.

Table 2.2

Summary of copper, lead and zinc stocks in goods in Stockholm in 1995 (From Sorme et al. 2001, all data tons).

Source	Copper stock	EX*	EM*	Lead stock	EX*	EM*	Zinc stock	EX*	EM*
Electrical equipment	50,000	N	N	-	-	-	-	-	-
Power cable, buildings	28,000	N	N	-	-	-	-	-	-
Power cable shielding	-	-	-	21,000	N	N	-	-	-
Tube and pipe joints	-	-	-	9400	9400	N	-	-	-
Telecom cables, shielding	-	-	-	8900	8900	N	-	-	-
Accumulators	-	-	-	7800	N	N	-	-	-
Brass	22,000	14,000	P	-	-	-	15,000	9600	P
Vessel keels	-	-	-	1100	N	N			
Tap water system	6500	6500	4300	-	-	-	-	-	?
Galvanised steel	-	-	-	-	-	-	5600	5600	-
- buildings	-	-	-	-	-	-	-	-	2100
- other structures	-	-	-	-	-	-	-	-	5000
- telephone cables	4200	N	N	-	-	-	-	-	-
Roofs	4200	4200	1200	-	-	-	-	-	-
Cars	3100	1200	P	-	-	-	1100	1100	P
Pressure cast goods	-	-	-	-	-	-	3500	N	N
Consumer electronics	2700	N	N	-	-	-	-	-	-
Chemicals	-	-	-	-	-	-	2600	2600	P
Electronics (TVs, VCRs, PCs)	970	N	N	440	N	N	-	-	-
Glass	-	-	-	970	N	N	-	-	-
Chimney collars	-	-	-	630	630	6-70	-	-	-
PVC, cables etc.	-	-	-	590	114	P	42	N	P
Radiation protection hospitals	-	-	-	220	N	N	-	-	-
Wood preserving	570	570	9	-	-	-	-	-	-
Telephone stations	500	N	N	-	-	-	-	-	-
Electrical grounding	430	430	40-900	-	-	-	-	-	-
Aerial lines	200	200	200	-	-	-	-	-	-
Wheel balance weights	-	-	-	30	20	P	-	-	-
Steel bridge painting with lead paints	-	-	-	28	28	P	-	-	-
Light bulbs/fluorescent tubes	-	-	-	29	N	N	-	-	-

Source	Copper stock	EX*	EM*	Lead stock	EX*	EM*	Zinc stock	EX*	EM*
Printed circuit boards	-	-	-	20	N	N	-	-	-
Protection painting	16	16	16	-	-	-	-	-	-
Asphalt wear	?		400	-	-	100	-	-	1000
Brake lining wear	?		3900	-	-	560	-	-	900
Tyre wear	-	-	200	-	-	300	650	650	10,000
Petrol	-	-	-	-	-	140	-	-	-
Sinkers	-	-	-	-	-	5000	-	-	-
Ammunition	-	-	-	-	-	5500	-	-	-
Batteries	-	-	-	-	-	-	80	N	N
Anodes	-	-	-	-	-	-	3	3	1500

(as identified by Sorme et al. (2001).)

Note: * EX = Exposed part of the "stock"; Em = Emission in kg/year; N = Negligible. P = Potential.

Sorme et al. (2001) identified that zinc was dominantly used in brass and galvanised metal products such as roofs, road barriers and chemicals (eg zinc oxide in paints). The majority of lead in urban areas was associated with shielded cables and lead joints in pipes (in Stockholm this was estimated to be 60 per cent of the total amount). These sources are typically isolated under protected layers or in ducting. Prior to the elimination of lead from petrol, vehicle emissions were the major source of lead. They also considered the loss of fishing sinkers and wheel balance weights a major source of lead to the aquatic environment. The latter source is discussed later in this report. Fishing sinkers are not discussed further as they are lost "external" to the stormwater system.

Ayres et al. (2002) presented a very detailed assessment of the life cycle of copper, its products and by-products. The report assessed copper stocks in the environment and dissipative sources of copper (to sewage, tap water etc.) but did not directly provide any information on losses via stormwater.

Van Beers & Graedel (2004) undertook an assessment of the magnitude and spatial distribution of in-use zinc stocks in Cape Town. The study estimated a total stock of 57 Gg (57 million kg) of zinc, with predicted end of life for current stocks being several decades. In addition, by 2030 it was estimated that the stock would have risen by 100 per cent. It was noted that the zinc stock was distributed unevenly over a wide range of poorly quantified products. In a prior paper, Van Beers & Graedel (2003) estimated the copper stock as 110 Gg.

Van Beers & Graedel (2007) carried out further work examining the stock of copper and zinc in Australia as 4.3 Tg (4,300 million kg) and 3.8 Tg respectively. This equated to 240 kg copper/capita and 205 kg zinc/capita. As expected, the authors showed that the bulk of the metals stock in Australia is located in the key urban centres.

2.3.3 Flux assessments

Although the studies such as those of Sorme et al. (2002) provide very useful information on the amounts and distribution of products containing metals such as copper, lead and zinc, they do not provide information on losses to the environment, or how much is lost to waste. There appear to be few published studies that have examined the passage of copper, lead or zinc through human society to the environment (eg in routes such as stormwater).

Harper et al. (2006) report on a “stocks and flows” project at Yale University. The work undertaken to date has included a flow analysis of copper and zinc at a range of “levels” (city to global). Kapur et al. (2003) showed that Asia was a net importer of copper with copper building up at a rate of 3 Tg copper/year. The per capita generation of copper waste (0.4 kg copper/capita-year) was considered low compared to elsewhere in the world. Graedel et al. (2005) assessed the zinc cycle from 1994 across a wide range of countries. They showed the accumulation ratio is typically large (at country and global level), with 2/3 of zinc entering society being added to the zinc stock.

Overall, it appears that copper, lead and zinc stocks (the total mass of that metal) are increasing within our society (or within a given city). A proportion of that stock is emitted to the environment, some of which is transferred to downstream aquatic ecosystems (eg the Waitemata Harbour). The amount of stock and the “availability” of the stock materials will change over time and this will need to be factored into long-term evaluations of inputs of contaminants such as copper, lead and zinc to the environment. This is not considered in this report.

2.4 Local scale source studies

2.4.1 Overseas studies

There appear to have been few local studies (catchment or street) carried out to evaluate contributions of metals to stormwater or other environmental compartments.

Steuer et al. (1997) examined sources of contamination in an urban “basin” in Marquette, Michigan. The study assessed stormwater quality from specific sources within that catchment including high, medium and low traffic street, parking lots, residential driveways, residential rooftops, commercial rooftops and lawns. Lawns (private and public) made up 62.4 per cent of the basin area. The data in Table 2.3 provides information on a range of broad impervious surface types which contributed most of the catchment surface area within the Marquette basin.

The data for that catchment study showed that when the data was aggregated, roofs contributed 16, 28, 31 per cent of the copper, lead and zinc and streets contributed 31, 23, 37 per cent of the copper, lead and zinc respectively.

Table 2.3

Summary of copper, lead and zinc contributions in the Marquette Basin study (Steuer et al. 1997).

Source	Copper	Lead	Zinc
High traffic street	6 ± 4	5 ± 3	10 ± 5
Medium traffic street	8 ± 3	3 ± 2	8 ± 2
Low traffic street	17 ± 6	15 ± 14	19 ± 7
Residential roof	5 ± 4	18 ± 33	15 ± 7
Commercial roof	11 ± 9	10 ± 10	16 ± 10
Commercial parking lot	22 ± 15	19 ± 14	30 ± 15
Residential drive	18 ± 10	14 ± 12	18 ± 12
Grass area	-	-	-
Sum of sources	87	83	116

Note: Units: Mean % ± one standard deviation.

Parking and residential driveways were identified as contributing 40, 34 and 48 per cent of the copper, lead and zinc respectively. No contribution was identified for copper, lead and zinc from the 62 per cent of the basin that was in grass. The grassed areas were identified as having only contributed 4 per cent of the suspended solids compared to 48 per cent from streets.

Davis et al. (2001) examined the loads of copper, lead and zinc (and also cadmium) in urban stormwater run-off. The authors isolated potential contributing sources (various vehicle sources, building sides and roof run-off) and conducted experimental work to quantify source contributions. The results of the Davis et al. (2001) study has been summarised in ARC (2004). The study showed that the proportional contributions from the sources investigated varied considerably depending on whether the buildings involved were constructed from brick, vinyl or were "commercial". It concluded that source apportionment is complex and requires a great deal of information.

Steinberg & Myers (2001) examined urban non-point sources of lead contributing to stormwater. They showed that where houses were coated with paint containing lead that the surfaces could contribute to the lead in local run-off. Both painted walls and roofs were found to contribute lead.

2.4.2 Local New Zealand studies

As reported in the introduction, ARC (2005) assessed sources and loads of metals in urban stormwater. That assessment utilised information from earlier studies and focused on contaminants sourced from roads, roofs, building walls and uncontaminated soil. Mass budgets for copper, lead and zinc were calculated for three catchments. The catchments were the Auckland Central Business District (CBD) catchment (a commercial catchment), Mission Bay (a residential catchment) and Mt Wellington (an industrial catchment).

Copper

The copper budgets were poor for all catchments, with the difference between total catchment loads and the sum of assessed sources being 58-81 per cent (of the total catchment load). No explanation for the unidentified amount was offered and it was considered unlikely that any one of the loads utilised had significant errors.

Lead

In the residential catchment of Mission Bay, the key sources appeared to account for all of the lead measured in the catchment load. Building walls and uncontaminated soil were important contributors (Figure 2.1). In the Mt Wellington industrial catchment, the assessed sources only accounted for 22 per cent of the total catchment load, and only 40 per cent in the CBD catchment. It is likely that the sources contributing to the differences in the two catchments are different.

Zinc

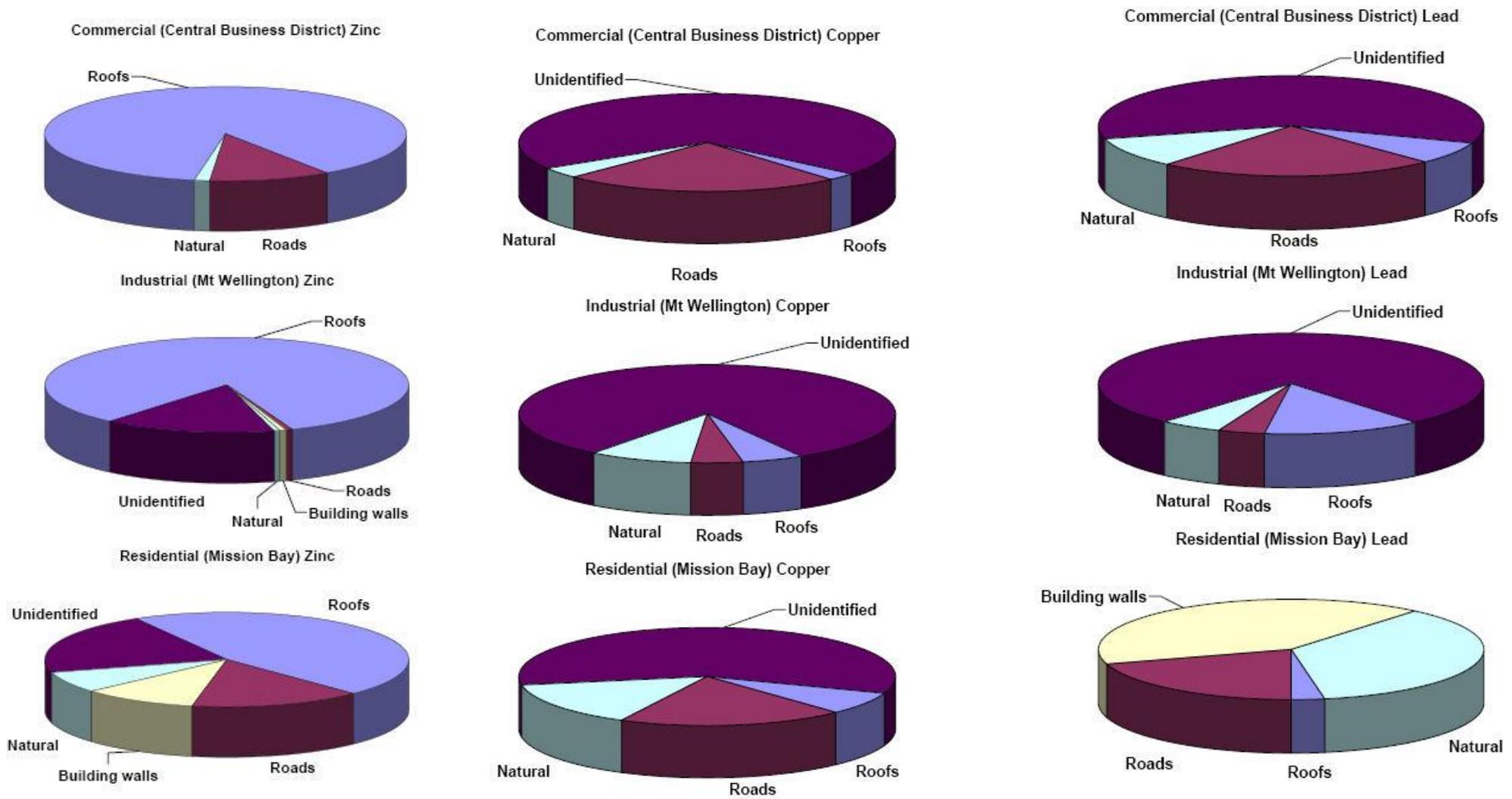
Roof run-off was identified as contributing almost all of the zinc in stormwater draining from the commercial and industrial catchments and about 46 per cent of the zinc in stormwater drainage from the residential catchment (Figure 2.1). The load estimates did not identify any significant unidentified portion in the commercial catchment. The sum of sources was slightly higher than the catchment load (6-12 per cent), and it is possible that this uncertainty could hide some unidentified sources.

2.5 Summary

There is an abundance of data that details the primary uses of copper, lead and zinc within global industrial/urban societies. Information on global emissions to the environment shows that the primary industries produce the bulk of the metallic copper, lead and zinc. As a consequence, the most detailed information relates to emissions to the atmosphere. In recent years, some studies have assessed the stocks of metals within society. These have estimated the amounts of a given metal present in our society and mapped its distribution. However, assessments of individual metal's fate and inputs to the environment are very crude at present. More recent studies have tried to estimate the flow of metals through society.

The various stocks and flows studies have provided information on "dissipative" sources that potentially result in losses of metals to the environment. The bulk of the stock studies have been conducted at the regional level (eg studies in Cape Town and elsewhere).

Figure 2.1 Mass budgets for zinc, copper and lead in Auckland catchments (From ARC 2005).



These studies have identified the very important fact that stocks of zinc, copper and lead are building up within our society through their continued use in new materials and products, but inputs to the environment are still poorly understood. It is also evident that there is a lack of co-ordinated information on the uses of copper, lead or zinc in urban environments that assists in identifying the dissipative sources. This is dealt with further in following sections of this report.

In the context of stormwater in the Auckland region, it is the dissipative sources that are important and information on these determines how much of any metal is present and potentially available to contribute to emissions (losses to stormwater). Examination of published and un-published grey literature suggests that there are few studies that have attempted to assess dissipative sources or emissions at a "local" (catchment or street) level.

The Marquette Michigan basin study reported good mass balance between source sampling and outlet sampling for copper lead and zinc. No specific studies have been identified that successfully and comprehensively assessed local dissipative stocks of copper, lead or zinc; the most comprehensive study in New Zealand being the ARC's own study (ARC 2005); the basis for this present report.

3 Sources in the Urban Environment

3.1 Introduction

As described in Section 2, copper lead and zinc are common metals used in a wide range of materials and products present within the urban environment. These elements are present in protected and exposed stocks. Protected stocks are significant and include, for example, underground copper cables, protective lead cable sheaths, copper cabling inside buildings, copper pipes and lead and zinc within motor vehicles. Some of these, such as motor vehicles, will be discussed in more detail later. However, in relation to the potential contribution to stormwater quality, it is predominantly the exposed stock that is of interest.

Through monitoring, it is recognised that stormwater quality varies significantly across urban areas due to a variety of factors (eg land use). As identified in Section 2.4, source contributions have been assessed in various studies. In addition to the literature review of sources of copper, lead and zinc some additional field survey work was undertaken to provide further information on possible sources.

Preliminary surveys (to look at potential sources) were carried out in residential, commercial and industrial areas in North Shore City and visits were subsequently made to the residential, commercial and industrial catchments used in the ARC (2005) study. The following sections summarise the identified key sources of materials and their likely metal contributions within each of the three principal land uses.

3.2 Residential areas

An initial survey was undertaken in a typical residential suburb in Takapuna, North Shore City. For this, a section of houses (in Pupuke Road) were surveyed on foot. Properties were not inspected from within the property and access was not sought. Sources identified were limited to what could be easily viewed from the front of the property (this general approach was adopted to rapidly obtain a general overview of materials involved). However, it was considered that this approach gave a good understanding of the potential metal sources on each property. A field sheet was used to record the important characteristics of the houses surveyed, and a series of digital photographs were taken.

For each house, the following items were noted – roof type, roof gutter type, any visible exterior metal products, and any other surfaces that were connected to the stormwater system, that could contribute metals. In addition, any roadside uses of metals were also noted. Later the digital photographs were reviewed in the office to determine if all visible potential metal sources had been identified. Figure 3.1 presents pictures of two typical residential houses that were taken during this survey. The key sources of metals have been identified, and summarised in Table 3.1.

Figure 3.1

Exterior views of two typical residential houses.

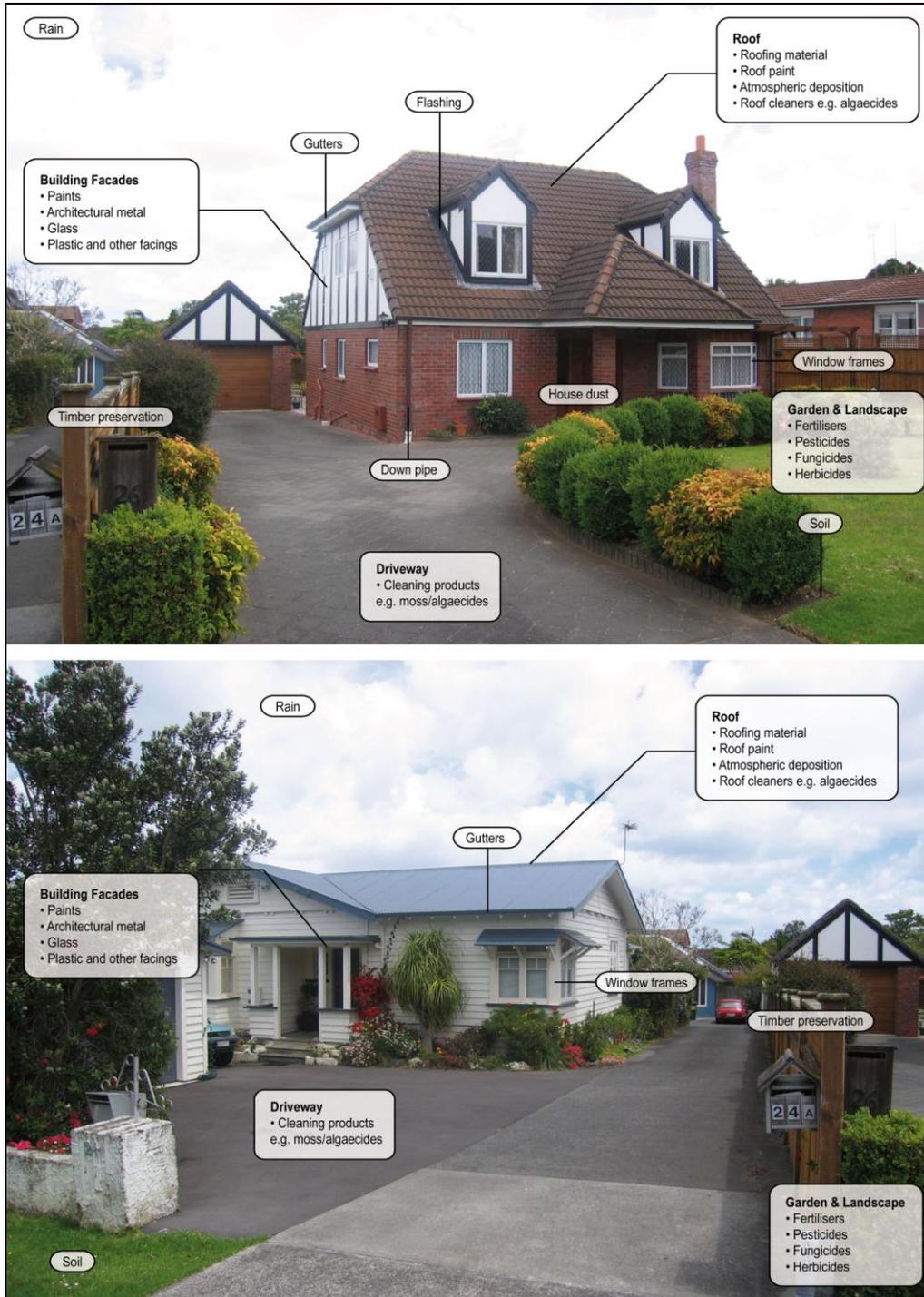


Table 3.1

Key urban sources of copper, lead and zinc in residential areas.

Land use	Generic source	Principal source	Copper source	Lead source	Zinc source
All	Rain		Y	Y	Y
Residential houses	Building facades	Paints	Y	Y	Y
		Exposed architectural metal	Y	Y	Y
		Glass	UL	UL	Y
		Plastic and other facings	UL	Y	Y
	Building roofs	Metal roofing products	Y	Y	Y
		Metal gutters	Y	UL	Y
		Metal flashings	P	Y	P
		Roofing paints	Y	Y	Y
		Atmospheric deposition	Y	Y	Y
		Roofing biocides (inhibitors and cleaners)	Y	UL	Y
Internal building uses	Appliances, paint etc. (dust in houses)	Y	Y	Y	
Road		See Table 3.3			
Other residential sources	Garden and landscape	Fertilisers	Y	N	Y
		Pesticides	Y	N	UL
		Fungicides	Y	N	Y
		Herbicides	Y	N	P
		Soil	Y	Y	Y
	Driveway	Cleaning products (eg moss/algaeicides)	Y	UL	Y
	Domestic water loss	Pool, spa, home water use etc.	P	UL	UL
	Timber preservation	Historical uses	Y	UL	UL
	Metal traffic lights		UL	UL	Y
	Metal street lamps		UL	UL	Y

Note: Y = yes, N = no, P = possible, UL = unlikely.

The first picture shows a house where the building façade drained directly onto the driveway, and into the stormwater system. However, it was more common to see houses where the building siding run-off drained to a garden or other pervious area, rather than directly discharging to the stormwater system, as shown in the second picture.

Following the initial survey, three further residential areas in the Mission Bay catchment (ARC (2005) study catchment) were selected for further surveys.

These surveys were planned to cross-check the presence of the exterior use of copper, lead and zinc on residential properties. In order to provide more detailed information about residential properties, properties were inspected by walking around each property to observe all of the building sides. This involved obtaining permission from each property owner to access the property.

In total, three separate areas of ten residential properties were inspected. Any exterior material on the house which contained or was suspected to contain copper, lead or zinc was recorded, along with the frequency it was observed (as a per cent of the number of properties), an estimate of the proportion of exposed material, and the drainage area (ie drains to a pervious or impervious surface). For the purposes of this survey, any material on an individual property that totalled <1 m² in surface area was classed as minor, 1-10 m² was classed as medium, and >10 m² was classed as major.

In addition, any material in the footpath/roadside area which contained copper, lead or zinc was also recorded. Possible sources of metals are summarised in Table 3.2.

Table 3.2

Potential source materials identified in the Mission Bay residential catchment.

Source	Material	Metal	Frequency	Proportion	Drainage area	Cross reference
On residential – properties						
House roof	Galvanised steel P	Zinc	13%	Major	Impervious	4.6.2
	Colour steel	Zinc	7%	Major	Impervious	4.6.2
	Decramastic tile – galvanised steel	Zinc	10%	Major	Impervious	4.6.2
	Corona shake - Zinalume	Zinc	3%	Major	Impervious	4.6.2
Section of roof above door	Galvanised steel P	Zinc	10%	Medium	Impervious	4.6.2
	Galvanised steel UP	Zinc	7%	Medium	Impervious	4.6.2
House guttering	Galvanised steel P	Zinc	10%	Medium	Impervious	4.6.2
	Galvanised steel UP	Zinc	7%	Medium	Impervious	4.6.2
	Colour steel	Zinc	10%	Medium	Impervious	4.6.2
	Copper	Copper	13%	Medium	Impervious	4.6.3
House downpipes	Galvanised steel	Zinc	17%	Medium	Impervious	4.6.2
	Copper	Copper	3%	Medium	Impervious	4.6.3
Garage roof	Colour steel	Zinc	10%	Medium	Impervious	4.6.2
	Galvanised steel P	Zinc	10%	Medium	Impervious	4.6.2
	Galvanised steel UP	Zinc	7%	Medium	Impervious	4.6.2
	Decramastic tile – galvanised steel	Zinc	3%	Medium	Impervious	4.6.2
Garage/carport door	Galvanised steel P	Zinc	30%	Medium	Impervious	4.6.2
	Colour steel	Zinc	7%	Medium	Impervious	4.6.2
Garden shed	Galvanised steel UP	Zinc	13%	Medium	Pervious	

Source	Material	Metal	Frequency	Proportion	Drainage area	Cross reference
	Galvanised steel P	Zinc	10%	Medium	I/P 2:1	
	Colour steel	Zinc	3%	Medium	Impervious	
	Zincalume	Zinc	3%	Medium	Impervious	
Fence	Galvanised steel P	Zinc	3%	Medium	Pervious	
	Galvanised steel UP	Zinc	7%	Medium	Pervious	
	Galvanised steel UP	Zinc	20%	Medium	I/P 2:4	4.12.3
	Treated timber	Copper	30%	Medium	I/P 1:8	4.8.2
Decking	Treated timber	Copper	13%	Medium	Pervious	4.8.2
Soakers	Galvanised steel P	Zinc	27%	Minor	Impervious	
Flashing	Lead	Lead	33%	Minor	Impervious	4.12.3
Terneplate	Steel coated with lead	Lead	3%	Minor	Impervious	
Ballustrade	Galvanised steel P	Zinc	20%	Minor	I/P 5:1	
	Galvanised steel UP	Zinc	13%	Minor	I/P 2:2	
Glass comes	Lead, copper or zinc	All	20%	Minor	Impervious	
Chimney	Galvanised steel	Zinc	10%	Minor	Impervious	
TV aerial	Galvanised steel UP	Zinc	93%	Minor	Impervious	
Satellite dish	Galvanised steel P	Zinc	40%	Minor	Impervious	
Overflow pipe – on roof	Copper	Copper	20%	Minor	Impervious	
Clothesline	Galvanised steel UP	Zinc	20%	Minor	Pervious	
Letterbox	Galvanised steel	Zinc	53%	Minor	Pervious	
	Copper	Copper	3%	Minor	Impervious	
Gate	Galvanised steel P	Zinc	3%	Minor	Impervious	
Residential – roadside						
Street signs	Galvanised steel P	Zinc	3	Minor	I:P 1:2	4.14.3

Note: P = painted, UP = unpainted, ¹Chain link fence, ² Minor < 1 m² surface area, Medium 1 – 10 m² surface area, Major > 10 m² surface area, ³ If a combination of pervious and impervious drainage areas were observed then the ratio is provided as I:P = ratio of impervious to pervious; ⁴ Total numbers.

Residential buildings were found to have a wide variety of surfaces made of copper, lead or zinc. The largest source of zinc, in terms of the surface area of exposed material, was the house roof. Several houses were found to have galvanised steel (23 per cent), colour steel (7 per cent) or Zincalume (3 per cent) based roofing materials, which are a source of zinc.

Of the 30 buildings surveyed, four had copper gutters, three had colour steel gutters, three had painted galvanised steel and two had unpainted galvanised steel. Galvanised steel downpipes were the most common metal downpipe (17 per cent), and copper downpipes were observed on one house. The rest of the buildings in the area surveys had PVC guttering and downpipes.

Many houses had a separate garage (9 out of 30 houses). Commonly the garage roof was made of painted galvanised steel (4 observed), or colour steel (3 observed), smaller proportions were found to be unpainted galvanised steel (2 observed). The

garage door was commonly a painted galvanised steel roller door (30 per cent) or colour steel (7 per cent).

Nine of the 30 houses surveyed also had a garden shed. Of these nine, four were unpainted galvanised steel, three were painted galvanised steel and one colour steel and Zinalume shed were also observed. More often these sheds were located on an impervious surface, and therefore as considered to be a source of zinc.

Most residential properties had a boundary fence. Treated timber was common (30 per cent) and unpainted galvanised chain link fence (20 per cent). However, generally the fences were located in a pervious area. In addition, treated timber decking was identified on some properties (13 per cent), which also drained to pervious areas, and therefore was not considered as a source.

Many minor sources were identified in the residential area surveys. These included examples such as:

- Zinc – painted galvanised soakers, ballustrades and satellite dishes. Unpainted galvanised ballustrades, chimneys and television aerials. Galvanised steel letterboxes, and clotheslines were common, but all drained to pervious areas, and therefore were not considered a source.
- Copper – overflow pipes.
- Lead – flashing and terneplate.

The only potential sources identified in the residential area footpath and roadside were painted galvanised signposts. However, two out of the three signposts were located in the grass verge; therefore any run-off from these products would drain into the soil, and is unlikely to directly contribute to stormwater.

3.3 Commercial areas

A preliminary visual survey was undertaken in Barrys Point Road, a busy commercial area in Takapuna, to identify potential urban sources of copper, lead and zinc in commercial areas (Figure 3.2). Potential sources of metals are summarised in Table 3.3.

As shown in Figure 3.2, the commercial area contained several of the sources identified in the residential suburb, including building roof sources, building façade sources, vehicle and road sources. However, there were a greater proportion of impervious surfaces in the commercial areas, which meant that most, if not all of the run-off from these potential sources drained directly to the stormwater system. In addition, there were a number of other sources identified that were common to commercial areas, including metal signs, and a greater proportion of other metal exterior surfaces (eg galvanised building sides).

Figure 3.2

View of a typical commercial street.



Table 3.3

Key urban sources of copper, lead and zinc in commercial areas.

Land use	Generic source	Principal source	Copper source	Lead source	Zinc source
All	Rain		Y	Y	Y
Commercial buildings	Building facades	Paints	Y	Y	Y
		Exposed architectural metal	Y	Y	Y
		Glass	UL	UL	Y
		Plastic and other facings	UL	Y	Y
	Building roofs	Metal roofing products	Y	Y	Y
		Metal gutters	Y	UL	Y
		Metal flashings	UL	Y	UL
		Roofing paints	Y	Y	Y
		Atmospheric deposition	Y	Y	Y
		Roofing biocides (inhibitors)	Y	UL	Y

Land use	Generic source	Principal source	Copper source	Lead source	Zinc source
		and cleaners)			
Road	Vehicles	Tyres	Y	Y	Y
		Brake pads/linings	Y	Y	Y
		Wheel weights	N	Y	N
		Surface treatments/coatings	UL	Y	Y
		Emissions	Y	Y	Y
		Fluid losses, drips and spills	Y	Y	Y
		Air bag initiators	UL	Y	UL
	Roads	Road dust	Y	Y	Y
		Road paint	Y	Y	Y
Road surface (eg bitumen)		P	P	UL	
Other	Commercial site run-off	On-site activities leading to contamination of run-off	P	P	P
	Signs	Metal surfaces	P	P	Y
	Soil	Erosion and transport of near-road soils	Y	Y	Y
	External transport-related sources	Tram lines, electric rail overhead, cabling and sheathing etc.	P	UL	UL
	Metal traffic lights		UL	UL	Y
	Metal street lamps		UL	UL	Y
Commercial buildings	Building facades	Paints	Y	Y	Y

Note: Y = yes, N = no, P = possible, UL = unlikely. ¹The road sources identified will be found in all land use areas, however they have been identified in this table as they are discernable from the commercial area picture.

A block of 20 buildings in the Auckland CBD catchment (ARC (2005) study eastern catchment) were selected for further surveys. These surveys were planned to cross-check the presence of the exterior use of copper, lead and zinc on commercial properties. These surveys were undertaken from the footpath/driveway. For many of the commercial properties, access could be obtained from the front and the rear of the property. Sources identified are limited to what could be easily viewed from the front and rear of each property.

Any exterior material which contained copper, lead or zinc was recorded, along with the frequency it was observed, an estimate of the proportion of exposed material, and the drainage area (ie drains to a pervious or impervious surface). For the purposes of this survey, any material that totalled <1 m² in surface area was classed as minor, 1-10 m² was classed as medium, and >10 m² was classed as major.

In addition, any material in the footpath/roadside area which contained copper, lead or zinc was also recorded. Potential sources of metals are summarised in Table 3.4.

Table 3.4

Potential source materials identified in the CBD commercial catchment.

Source	Material	Metal	Frequency	Proportion	Drainage area	Cross reference
On commercial – properties						
Roof	Galvanised steel P	Zinc	22%	Major	Impervious	4.6.2
	Galvanised steel UP	Zinc	11%	Medium	Impervious	4.6.2
	Colour steel	Zinc	44%	Major	Impervious	4.6.2
Structures on the roof						
Large aerial structure	Galvanised steel UP	Zinc	5%	Medium	Impervious	4.12.4
Pipes	Galvanised steel UP	Zinc	5%	Medium	Impervious	4.12.4
Shed	ZnAl/galvanised steel UP	Zinc	5%	Medium	Impervious	4.12.4
On the sides of building						
Windows etc.	Glass	Zinc?	45%	Major	Impervious	4.8.2
Pipes	Galvanised steel UP	Zinc	5%	Minor	Impervious	4.12.4
Window/door guards	Galvanised steel P	Zinc	5%	Medium	Impervious	
	Galvanised steel UP	Zinc	15%	Medium	Impervious	
Guttering	Galvanised steel UP	Zinc	5%	Medium	Impervious	4.6.2
	Copper	Copper	5%	Medium	Impervious	4.6.3
Downpipes	Copper	Copper	5%	Medium	Impervious	4.6.3
Cladding	Colour steel	Zinc	5%	Medium	Impervious	4.6.2
Extraction vent	Galvanised steel UP	Zinc	5%	Medium	Impervious	4.12.4
Fence	Galvanised steel UP	Zinc	60%	Major/medium	I:P 10:2	4.12.4
	Galvanised steel UP	Zinc	25%	Medium	Impervious	
	Galvanised steel P	Zinc	25%	Medium	Impervious	
Retaining wall	Treated timber	Copper	25%	Major/medium	Impervious	4.8.2
Flashing	Lead	Lead	5%	Minor	Impervious	4.6.4
Handrails	Galvanised steel UP	Zinc	15%	Minor	Impervious	
	Galvanised steel P	Zinc	10%	Minor	Impervious	
Vents	Galvanised steel P	Zinc	5%	Minor	Impervious	4.12.4
Vents	Galvanised steel P	Zinc	5%	Major	Impervious	4.12.4
Exterior stairwell	Galvanised steel P	Zinc	10%	Medium	I:P 1:1	
	Galvanised steel UP	Zinc	5%	Medium	Impervious	
Rollerdoor – bars	Galvanised steel UP	Zinc	15%	Minor	Impervious	
Miscellaneous						
Frame around a/c unit	Galvanised steel UP	Zinc	5%	Medium	Impervious	
Barrier around driveway	Galvanised steel UP	Zinc	5%	Minor	Impervious	
Carpark entry structure	Galvanised steel UP	Zinc	5%	Medium	Impervious	
TV aerial	Galvanised steel UP	Zinc	20%	Minor	Impervious	
Satellite dish	Galvanised steel P	Zinc	5%	Minor	Impervious	
Associated structures	Galvanised steel P/UP	Zinc	20%	Major	Impervious	4.12.4

Source	Material	Metal	Frequency	Proportion ⁶	Drainage area ⁷	Cross reference
housing a/c units, with pipes/vents/fencing						
Commercial – roadside						
Traffic light pole	Galvanised steel P	Zinc	1	Medium	Impervious	4.12.3
Street light pole	Galvanised steel UP	Zinc	3	Medium	Impervious	4.12.3
	Galvanised steel P	Zinc	4	Medium	Impervious	4.12.3
Light pole	Galvanised steel P	Zinc	15	Minor	I:P 11:4	4.12.3
	Galvanised steel UP	Zinc	5	Minor	Impervious	4.12.3
Traffic barrier posts	Galvanised steel P	Zinc	12	Minor	Impervious	4.12.3
Street sign poles	Galvanised steel P	Zinc	28	Minor	Impervious	4.12.3
	Galvanised steel UP	Zinc	1	Minor	Impervious	4.12.3
Road barrier	Galvanised steel P/UP	Zinc	2	Minor	Impervious	4.12.3
Sign frame	Galvanised steel UP	Zinc	1	Minor	Impervious	4.12.3

Note: P = painted, UP = unpainted, ¹Chain link fence, ² Minor < 1 m² surface area, Medium 1 – 10 m² surface area, Major > 10 m² surface area. ³ If a combination of pervious and impervious drainage areas were observed then the ratio is provided as I:P; ⁴ It was not possible to determine all of the roof types from the street level, the proportion of each roof type represents the proportion of identified roofs only; ⁵ Glass was only noted as a potential source when identified as a major surface area; ⁶ Total numbers.

The commercial buildings surveyed were commonly high-rise buildings. Of the 20 buildings surveyed, nine of these buildings had large areas of exposed glass on the building sides, which covered between two-thirds to the whole of the building side.

In the commercial area it was difficult to determine the roof material type. Less than half of the building roofs in the catchment were able to be viewed from adjacent buildings. Of the seven roofs that could be viewed, four were colour steel, two were painted galvanised steel, and one was unpainted galvanised steel. Most of the buildings surveyed did not have visible exterior guttering or down pipes; one building was identified to have copper gutters and copper downpipes.

One building had several large structures on the roof, including a large aerial structure, pipes and a shed, made of unpainted galvanised steel. Several other buildings (20 per cent) had associated structures (eg air conditioning units, and associated pipes, vents and fencing) in the rear of the property; these structures were commonly made of unpainted and painted galvanised steel.

Unpainted galvanised steel chainlink fences were very common in the commercial area (identified on 60 per cent of properties). These fences were generally very large, and surrounding parking areas, and property boundaries. Other unpainted and painted galvanised steel fences (bar fences) were also relatively common (identified on 50 per cent of properties).

Treated timber retaining walls were also common in the commercial area; these were observed on 25 per cent of properties.

Other medium sources of zinc included window/door guards, exterior vents, exterior stairwells. Other minor sources of zinc included handrails and rollerdoors. Several other miscellaneous sources were also identified in Table 3.4.

In the commercial area footpath and roadside, unpainted and painted galvanised steel traffic light poles, street light poles, traffic barrier posts, street sign poles, road barriers and sign frames were identified as potential sources of zinc.

3.4 Industrial areas

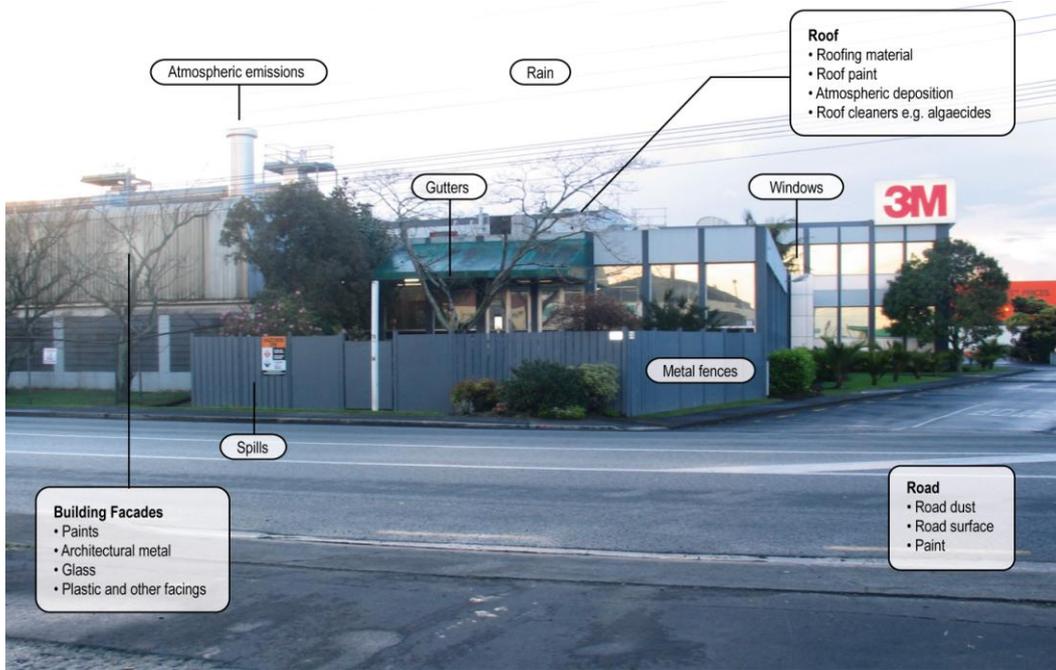
A preliminary visual survey was undertaken of an industrial area close to Wairau Road (North Shore City), to identify key urban sources of copper, lead and zinc in industrial areas (Figure 3.3). The key sources of metals have been identified, and summarised in Table 3.5.

As for the commercial areas, in industrial areas, a greater proportion of each site appeared to be impervious, and it was common for building roofs and sides to drain directly to the stormwater system (as opposed to a garden or other pervious area). Therefore there is a greater potential for this run-off to contribute metals to the stormwater system. In addition, industrial specific sources such as air emissions, industrial site run-off, and accidental spills may be important sources of metals in these areas.

Specific industries such as scrap yards, smelters and battery handlers/manufacturers that handle copper, lead and zinc may contribute on a site by site basis. Potential contributions via dust movement and transport of soil from yards to roads are very site specific and dependent on-site management practices.

Figure 3.3

Views of some typical industrial sites.



Three additional industrial areas in the Mt Wellington catchment in Auckland City (ARC (2005) study catchment) were selected for further surveys. These surveys were planned to cross-check the presence of the exterior use of copper, lead and zinc on industrial properties. These surveys were undertaken from the footpath/driveway. Properties were not inspected from within the property and access was not sought. Sources identified are limited to what could be easily viewed from the front of the property.

In total, two separate areas of ten industrial properties, and a further area of five properties were inspected. Any exterior material which contained copper, lead or zinc was recorded, along with the frequency it was observed, an estimate of the proportion of exposed material, and the drainage area (ie drains to a pervious or impervious surface).

Table 3.5

Key urban sources of copper, lead and zinc in industrial areas.

Land use	Generic source	Principal source	Copper source	Lead source	Zinc source
	Wet and dry deposition from air emissions	Emissions from local industries	Y	Y	Y
Industrial buildings	Building facades	Paints	Y	Y	Y
		Exposed architectural metal	Y	Y	Y
		Glass	UL	UL	Y
		Plastic and other facings			
	Building roofs	Metal roofing products	Y	Y	Y
		Metal gutters	Y	UL	Y
		Metal flashings	UL	Y	UL
		Roofing paints	Y	Y	Y
		Atmospheric deposition	Y	Y	Y
		Roofing biocides (inhibitors and cleaners)	Y	UL	Y
Other	Industrial site run-off	On-site activities leading to contamination of run-off	P	P	P
	Spills		P	P	P
	Metal traffic lights		UL	UL	Y

Note: Y = yes, N = no, P = possible, UL = unlikely.

For the purposes of this survey, any material that totalled <1 m² in surface area was classed as minor, 1 – 10 m² was classed as medium, and >10 m² was classed as major.

In addition, any material in the footpath/roadside area which contained copper, lead or zinc was also recorded. The key sources of metals have been identified, and summarised in Table 3.6.

Industrial buildings were found to have large areas of colour steel or painted galvanised steel cladding. These products are sources of zinc. The cladding commonly covered approximately half to two thirds of the building walls, and some buildings were totally clad in these products. Of the 25 buildings surveyed, 15 had colour steel cladding therefore, it is considered to be common. Painted galvanised steel was less common (observed on two buildings). No other cladding materials were identified as a source of these metals.

Table 3.6

Potential source materials identified in the Mt Wellington industrial catchment.

Source	Material	Metal	Frequency	Proportion ¹	Drainage area ²	Cross reference
On industrial – properties						
Cladding	Colour steel	Zinc	63%	Major	Impervious	4.6.2
	Galvanised steel P	Zinc	8%	Major	Impervious	4.6.2
Rollerdoors	Colour steel	Zinc	13%	Major	Impervious	
	Galvanised steel P	Zinc	30%	Major	Impervious	
	Galvanised steel UP	Zinc	25%	Major	Impervious	
Guttering	Colour steel	Zinc	38%	Medium	Impervious	4.6.2
	Galvanised steel UP	Zinc	8%	Medium	Impervious	4.6.2
Roof awning	Colour steel	Zinc	4%	Medium	Impervious	4.6.2
Fence	Galvanised steel UP ¹	Zinc	13%	Medium	I:P 2:1	4.12.3
	Galvanised steel P	Zinc	4%	Medium	Impervious	
Gate	Galvanised steel P ¹	Zinc	4%	Medium	Impervious	
Vents/pipes	Galvanised steel UP	Zinc	13%	Medium	Impervious	4.12.4
Waste bin	Galvanised steel UP	Zinc	21%	Medium	Impervious	
Shed	Colour steel	Zinc	4%	Medium	Impervious	
	Galvanised steel UP	Zinc	4%	Medium	Impervious	
Miscellaneous	Scrap metal – GS P/UP	Zinc	8%	Medium	Impervious	
	Refrigeration unit – GS UP	Zinc	4%	Medium	Impervious	
TV aerial	Galvanised steel UP	Zinc	21%	Minor	Impervious	
Door grills	Galvanised steel UP	Zinc	13%	Minor	Impervious	
Industrial – roadside		Zinc				
Light pole	Galvanised steel – all	Zinc	1	Medium	Pervious	4.12.3
	Galvanised steel – part	Zinc	10	Minor	Pervious	4.12.3
Utility – roof, door	Galvanised steel UP	Zinc	1	Medium	Pervious	
Utility – fence	Galvanised steel UP ¹	Zinc	1	Minor	Pervious	
Utility – pipe	Copper	Copper	1	Minor	Pervious	
Street signs	Galvanised steel P	Zinc	1	Minor	Impervious	4.12.3
Sign frame	Galvanised steel P	Zinc	1	Minor	Pervious	4.12.3
	Galvanised steel UP	Zinc	2	Minor	Pervious	4.12.3

Note: P = painted, UP = unpainted, ¹Chain link fence, ² Minor < 1m² surface area, Medium 1 – 10 m² surface area, Major > 10m² surface area. ³ If a combination of pervious and impervious drainage areas were

observed then the ratio is provided as I:P; ⁴ Total numbers. It was not possible to determine the roof types in the industrial area survey, as the majority of the buildings had a flat roof, and therefore could not be seen from ground level.

Large roller doors were commonly found in the industrial areas, with up to eight rollerdoors identified on a single site. These were predominantly made of painted galvanised steel (30 per cent), unpainted galvanised steel (25 per cent), and colour steel (13 per cent). These products are all sources of zinc.

In the industrial area it was difficult to determine the roof material type, given that the majority of roofs were flat. Therefore no assessment was provided of this as a source; however it is expected that the majority of roofs would either be colour steel or painted/unpainted galvanised steel, and they would be a major contributor of zinc in the catchment. Further discussion of roofs is provided in Section 4.6.

Many of the buildings surveyed did not have visible exterior guttering. Of the buildings which did, these were predominantly made of colour steel (38 per cent), with a smaller proportion of unpainted galvanised steel (8 per cent). Other medium sources of zinc included chainlink fences, gates, exterior vents/pipework, waste collection bins and sheds, the majority of which were unpainted galvanised steel.

Other minor sources included unpainted galvanised steel television aerials, and unpainted galvanised steel door grills.

No potential sources of copper or lead were identified in the industrial site visual surveys.

In the industrial area footpath and roadside, unpainted galvanised steel light poles, utility sheds, chainlink fencing and framing around signs were identified as sources of zinc. However the majority of these objects were located in the grassed road verge, therefore any run-off from these products would drain into the soil, and is unlikely to directly contribute to stormwater.

3.5 Overview

The examination of the potential contributing external surfaces within the Auckland CBD, Mission Bay and Mt Wellington catchments has provided additional information on what surfaces may be contributing to stormwater loads of copper, lead and zinc.

In relation to the areas examined in Mission Bay residential catchment, the key potential sources identified included:

- Copper – guttering, down pipes, treated timber.
- Zinc – colour steel, painted/unpainted galvanised steel roof material, guttering, down pipes, garage and garden shed roofs/doors.

Many minor sources were also identified, these included:

- Zinc – painted galvanised soakers, ballustrades and satellite dishes. Unpainted galvanised ballustrades, chimneys and television aerials.
- Copper – overflow pipes.
- Lead – flashing and terneplate.

Examination of areas within the Auckland CBD commercial area identified large areas of glass, large areas of predominantly unpainted galvanised steel fences, and structures next to or on the top of commercial building roofs (eg air conditioning units, and associated pipes, vents and fencing) made of unpainted galvanised steel.

Other potential sources of zinc included window/door guards, exterior vents and exterior stairwells; the majority of which were unpainted galvanised steel.

Very few sources of copper or lead were identified in the commercial site surveys. For copper, the only potential sources were treated timber retaining walls, and one building which had copper gutters/down pipes. For lead, the only source identified was a single building with lead flashing.

The examination of the Mt Wellington industrial area identified key sources including large areas of colour steel and painted galvanised steel cladding, and roofing, and large roller doors predominantly made of painted/unpainted galvanised steel.

Other sources of zinc included chain link fences, gates, exterior vents/pipe work, waste collection bins and sheds, the majority of which were unpainted galvanised steel.

No observable sources of copper or lead were identified in the industrial site surveys.

4 Key Urban Sources of Metals

4.1 Atmospheric sources

4.1.1 Introduction

Wet deposition is the process by which atmospheric particles and soluble trace gases are removed from the atmosphere by dissolution and incorporated into water droplets, either in clouds or falling raindrops. As such, wet deposition quality may be affected by both local and regional pollution sources (Gadd & Kennedy, 2001).

Many activities in urban areas emit metal contaminated particles into the atmosphere. Dry deposition is the process where these atmospheric particles, and any contaminants associated with them, settle via gravity or are deposited by wind onto the surfaces of roofs, buildings or the ground. Pitt (2000) and Pitt et al. (2004) provide an overview of contaminants in atmospheric deposition as it might affect stormwater quality. In this section, sources of emissions are described, followed by a summary of information on wet and dry deposition of contaminants in New Zealand.

4.1.2 Industrial air emissions

There is no national inventory of air emissions currently collected in New Zealand. However, the United States has a Toxics Release Inventory (TRI) which contains information on annual toxic chemicals released by industry groups. Australia manages a similar programme called the National Pollutant Inventory (NPI). The most recent data published in these two national inventories has been reviewed to highlight which of the industry groups contributes the largest amount of copper, lead and zinc to air in these countries. This information will be used to indicate which industries could potentially be key contributors of these metals to air in New Zealand.

USEPA TRI Inventory

The TRI is a publicly available United States Environmental Protection Agency (USEPA) database that contains information on toxic chemical releases and other waste management activities reported annually by certain covered industry groups, as well as federal facilities in the United States. This inventory was established under the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) and expanded by the Pollution Prevention Act of 1990.

The most current TRI data is for 2005, released by the USEPA in March 2007. In 2005, 23,461 facilities reported to USEPA's TRI program. The TRI data is grouped by industry, according to the Standard Industrial Classification (SIC) system. The 2005 TRI database was searched for releases of zinc/zinc compounds, copper/copper

compounds, and lead/lead compounds reported from industries in the United States. Tables 4.1 to 4.3 present a summary of this data according to the SIC groups.

Table 4.1

Zinc and zinc compound releases to air reported for the main industry groups in the USA for 2005 (USEPA 2007) (all data kg/year).

Industry group	Fugitive emissions	Point source emissions	Total emissions
Apparel (23)	0	0	0
Printing (27)	0	0.91	0.91
Leather (31)	2.3	2.3	4.5
Petroleum bulk terminals (5171)	4.5	5.9	10
Coal mining (12)	12	62	75
Chemical wholesalers (5169)	110	0.45	110
Furniture (25)	14	100	120
Miscellaneous manufacturing (39)	210	510	720
Computers/electronic products	190	1100	1300
Textiles (22)	810	910	1700
RCRA/solvent recovery (4953/7389)	1100	1500	2700
Lumber (24)	78	4000	4000
Cement	2000	5200	7200
Machinery (35)	4700	3800	8600
Stone/clay/glass (32)	850	11,000	12,000
Food/beverage/tobacco (20)	480	13,000	13,000
Electrical equipment (36)	5700	8800	15,000
Transportation Eq (37)	24,000	16,000	40,000
Metal mining (10)	24,000	31,000	55,000
Plastics/rubber (30)	48,000	25,000	73,000
Chemicals (28)	18,000	81,000	99,000
No reported codes	3200	12,0000	120,000
Paper (26)	270	130,000	130,000
Fabricated metals (34)	100,000	78,000	180,000
Petroleum (29)	1300	290,000	290,000
Electric utilities (49)	2600	660,000	660,000
Primary metals (33)	610,000	870,000	1,500,000

Note: All data rounded to two significant figures; totals may differ from the sum of the individual amounts because of this rounding.

Table 4.2

Copper and copper compound releases to air reported for the main industry groups in the USA for 2005 (USEPA 2007) (all data kg/year).

Industry group	Fugitive emissions	Point source emissions	Total emissions
Furniture (25)	0	0	0
Leather (31)	0	0	0
Petroleum bulk terminals (5171)	0.05	0.01	0.06
Coal mining (12)	5.0	2.3	7.3
Lumber (24)	2.7	40	43
Chemical wholesalers (5169)	230	2.3	230
Textiles (22)	64	270	330
Plastics (30)	150	260	410
Apparel (23)	0	710	710
Printing (27)	300	420	720
Paper (26)	0.07	890	890
RCRA/solvent recovery (4953/7389)	890	1100	1900
Petroleum (29)	1500	1900	3300
Measure/photo (38)	190	3300	3500
Miscellaneous manufacturing(39)	2800	720	3600
Food (20)	240	4100	4300
No reported codes	7800	2.3	7800
Machinery (35)	8100	2100	10,000
Electrical equipment (36)	5600	5100	11,000
Stone/clay/glass (32)	12,000	4800	17,000
Metal mining (10)	17,000	7800	25,000
Chemicals (28)	7900	28,000	36,000
Fabricated metals (34)	20,000	17,000	36,000
Transportation equipment (37)	27,000	13,000	40,000
Electric utilities (49)	2500	83,000	85,000
Primary metals (33)	160,000	190,000	350,000

Note: All data rounded to two significant figures; totals may differ from the sum of the individual amounts because of this rounding.

As shown, the industry group reporting to discharge the largest amount of zinc, copper and lead to air in 2005 was clearly the primary metals industries (SIC code 33). This group is made up of a number of sub-groups; however it was not possible to access more refined information about sub-group contributions from the public database.

Other industry groups which reported to discharge large amounts of zinc to air included electrical utilities, petroleum, fabricated metals, and paper industries. Other high contributors of copper to air included electric utilities, transportation equipment, fabricated metals, and chemicals industries. Other high contributors of lead included

electric utilities, metal mining, no reported codes (this is where there was no SIC code reported), and stone/clay/glass manufacture.

Table 4.3

Lead and lead compound releases to air reported for the main industry groups in the USA for 2005 (USEPA 2007) (all data kg/year).

Industry group	Fugitive emissions	Point source emissions	Total emissions
Chemical wholesalers (5169)	0.09	0.52	0.61
Chemicals (28)	6.8	8.1	15
Textiles (22)	0	49	49
Lumber (24)	0.05	55	55
Coal mining (12)	21	34	56
Petroleum bulk terminals (5171)	6.3	170	170
Measure/photo (38)	100	280	380
Miscellaneous manufacturing (39)	470	200	680
Paper (26)	45	740	790
Apparel (23)	41	2000	2100
RCRA/solvent recovery (4953/7389)	1100	1900	3100
Machinery (35)	2600	1100	3700
Leather (31)	910	2800	3700
Transportation equipment (37)	730	5000	5700
Plastics (30)	170	5900	6000
Food (20)	19	7500	7500
Furniture (25)	980	6800	7800
Fabricated metals (34)	3900	6800	11,000
Printing (27)	9.3	12,000	12,000
Petroleum (29)	760	13,000	14,000
Electrical equipment (36)	1400	14,000	16,000
Stone/clay/glass (32)	5300	19,000	24,000
No reported codes	28,000	1400	29,000
Metal mining (10)	35,000	2400	38,000
Electric utilities (49)	1500	80,000	81,000
Primary metals (33)	54,000	130,000	180,000

Note: All data rounded to two significant figures; totals may differ from the sum of the individual amounts because of this rounding.

Because the SIC code groups were not comparable to the ARC industry group classification outlined in Schedule 3 of the Proposed Auckland Regional Plan: Air, Land and Water (PARP:ALW), it was not possible to provide a direct comparison of which industries could be expected to be of concern in terms of air emissions. In addition, data from industries in the United States may not provide a fair representation of industries in New Zealand. For this reason, the Australian TRI inventory was also reviewed. A summary of this data is provided in the following section.

Australian NPI

The NPI is a cooperative programme implemented by the Australian state and territory governments. The NPI reports emissions of chemical substances (currently 93 substances) and the source and location of these emissions. Industrial facilities are required to report emissions to the NPI if they use more than a certain amount of one or more substances on the NPI reporting list, or consume more than a specified amount of fuel or electric power, or emit more than a certain amount of nitrogen or phosphorus to water. Diffuse data sources include smaller facilities that are not required to report, and mobile and non-industrial sources such as transport and domestic activities. Around 4000 facilities from a wide range of industry sectors report annually to the NPI.

The ultimate fate of the reported substances and therefore exposure to the environment cannot be determined from the NPI. Numerous factors such as height of emission, nature of receiving environment, chemical reactivity of the substance and prevailing meteorological conditions determine whether an emission is felt as ground level pollution. Since the NPI does not attempt to collect these parameters, the data can only reflect pollutant generation at source.

The NPI uses the Australian and New Zealand Standard Industrial Classification (ANZSIC)(Statistics New Zealand 1996) system. This classification system uses similar industry groups to the ARC industry groups identified in Schedule 3 of the PARP:ALW. Therefore when the data was compiled it was possible to link this data with the relevant ARC industry group. Table 4.4 provides a summary of zinc, copper and lead emissions to air in Australia for the 2005-2006 reporting year. A description of the process and trade/industry in accordance with ARC industry groups is provided along the left-hand side of the table, with the corresponding ANZSIC group along the right-hand side of the table. Some groups didn't match exactly, and where this has happened, a note is provided in the table. Also some of the ARC industry groups were not identified, and these cells have been left blank. The industry groups which emit the largest amounts of zinc, copper and lead (in this preliminary analysis this included industries that emit more than 1000 kg/year) included:

Zinc

ANZSIC category	ARC trade/Industry group
<ul style="list-style-type: none">• Basic non-ferrous metal manufacturing• Copper, lead and zinc smelting/refining• Basic Iron and steel manufacturing• Fabricated metal product manufacture• Metal coating and finishing• Electricity supply• Meat and meat product manufacturing• Inorganic industrial chemical manufacture• Alumina production• Aluminium smelting• Motor vehicle and part manufacturing• Cement, lime, plaster, concrete product manufacture• Iron and steel casting and forging.	<ul style="list-style-type: none">• Processing of metals• Sheet and structural metal products• Electrical substations• Meat and meat product manufacture• Not specified• Processing of ores• Processing of ores• Motor vehicle or parts• Cement lime, plaster and concrete products• Sheet and structural metal products.

Copper

ANZSIC category

- Copper, lead and zinc smelting
- Electricity supply
- Cement, lime, plaster and concrete product manufacture
- Basic non-ferrous metal manufacturing
- Basic iron and steel manufacturing.

ARC trade/Industry group

- Processing of metals
- Electrical substations
- Cement lime, plaster and concrete products
- Processing of metals
- Sheet and structural metal products.

Lead

ANZSIC category

- Copper, lead and zinc smelting
- Electricity supply
- Basic iron and steel manufacturing
- Basic non-ferrous metal manufacturing
- Glass and glass product manufacturing
- Iron and steel casting and forging
- Cement, lime, plaster and concrete product manufacture.

ARC trade/Industry group

- Processing of metals
- Electrical substations
- Sheet and structural metal products
- Processing of metals
- Glass
- Sheet and structural metal products
- Cement lime, plaster and concrete products.

In the absence of any relevant data from New Zealand, we can only assume that the Australian data presented in this section is roughly similar to the New Zealand situation. If this is true then the industry groups listed above could also be key sources of industrial emissions of zinc, copper and lead in New Zealand (where they occur).

While the ARC maintains a list of standard industries presently operating in New Zealand (Auckland), as part of Schedule 3, and reference has been made to them throughout this section, there are some key issues with this list worth mentioning here. In particular, the listed activities are not tied to an exact industry, and commonly incorporate more than one activity. When compared to the ANZSIC categories used in Australia, it is apparent that the ARC groups lack the definition that is necessary to differentiate between key industry groups, and therefore to distinguish the key sources of air emissions in New Zealand. This has implications to the identification of potential sources of metal emissions which may contribute via deposition and washout to stormwater.

Table 4.4

Zinc, copper and lead emissions to air, land and water reported as part of the NPI database in Australia for 2005-2006 reporting year.

ARC process	ARC trade or industry group	Zinc emissions (kg/yr)	Copper emissions (kg/year)	Lead emissions (kg/yr)	ANZSIC category
Agricultural support industries	Inorganic fertiliser manufacture, storage or handling	150	33	2.1	2531 Fertiliser manufacture
Animal feedstuffs	Pet food manufacture	0.66	0.28	0.16	2174 Prepared animal and bird feed manufacturing
	Stock food manufacture storage or handling				NCC
Chemical and associated product manufacturing	Acids, alkalis or heavy metals				NCC
	Batteries	-	-	250	2854 Battery manufacturing
	Cosmetics, toiletry, soap and other detergents	-	-	-	2545 Soap and other detergent manufacturing
		-	-	-	2546 Cosmetic and toiletry preparation manufacturing
	Explosives and pyrotechnics	2.3	1.3	9.9	2541 Explosive manufacturing
	Fungicides, herbicides, pesticides, timber preservatives, and related products	-	0.057	0.03	2544 Pesticide manufacturing
	Industrial gas	-	0.018	0.01	2532 Industrial gas manufacture
	Medicinal, pharmaceutical or veterinary products	1.0	0.14	0.085	2543 Medicinal and pharmaceutical product manufacturing
	Paint, pigment, inks and dyes	230	66	160	2542 Paint manufacturing; 2547 Ink manufacturing
	Polishes, adhesives or sealants				NCC
	Solvents				NCC
	Synthetic resins	0.069	1.5	0.84	2533 Synthetic resin manufacture
	Other Chemical Products (eg plastic manufacturing)	77	12	16	2549 Chemical product manufacturing
110		1.6	700	2534 Organic industrial chemical	

ARC process	ARC trade or industry group	Zinc emissions (kg/yr)	Copper emissions (kg/year)	Lead emissions (kg/yr)	ANZSIC category
					manufacture
		2000	960	56	2535 Inorganic industrial chemical manufacture
Commercial livestock processing industries	Slaughter				NCC
	Manufacture, store or handle products derived from animal slaughter (eg gelatin, fertiliser or meat products)				NCC
	Scouring or carbonising greasy wool or fleeces	2.7	1.1	1.1	2211 Wool scouring
	Tanneries or fellmongeries	-	-	-	2261 Leather tanning and fur dressing
	Rendering or fat extraction				NCC
Electronics	Circuit board manufacturing (excluding assembly only)				NCC
Food or beverage manufacturing or handling	Bakery products manufacturing	0.28	0.71	0.14	216 Bakery product manufacturing
	Bakery product handling				NCC
	Beverages or malt product manufacturing	6.5	83	5.1	218 Beverage and malt manufacturing
	Beverages or malt product handling				NCC
	Flour mill or cereal foods	2.5	0.15	0.088	215 Flour mill and cereal food manufacturing
	Meat and meat product manufacture (including fish)	2300	53	150	211 Meat and meat product manufacturing
	Meat product handling (including fish)				NCC
	Oil or fat product manufacturing or handling	2.1	0.7	3.9	214 Oil and fat manufacturing
	Processed dairy foods manufacturing	2.7	4.4	8.3	212 Dairy product manufacturing
	Processed dairy foods handling				NCC
	Vineyards or wine manufacturing	-	0.0036	0.0021	2183 Wine manufacturing
	Other foodstuffs manufacturing	69	18.72	440	217 Other food manufacturing
Other foodstuffs handling				NCC	

ARC process	ARC trade or industry group	Zinc emissions (kg/yr)	Copper emissions (kg/year)	Lead emissions (kg/yr)	ANZSIC category
Machinery or equipment manufacturing	Industrial machinery or equipment	-	1.4	-	286 Industrial machinery and equipment manufacturing
	Motor vehicles or parts	1400	0.82	0.47	281 Motor vehicle and part manufacturing
	Other machinery or equipment	1.4	0.042	0.024	2851 Household appliance manufacturing
Metal processing, metallurgical works or metal finishing	Metal plating, anodising or polishing				NCC
	Metal blasting or coating (excluding spray painting)	15,000	110	190	2764 Metal coating and finishing
		15,000	4.3	25	2769 Fabricated metal product manufacture
	Refinement of ores				NCC
	Processing of metals (eg smelting, casting)	1900	680	410	2721 Alumina production
		1800	380	320	2722 Aluminium smelting
		360,000	390,000	320,000	2723 Copper, lead and zinc smelting/refining
		360,000	1800	4000	2729 Basic non-ferrous metal manufacturing
Metal product manufacturing	Sheet and structural metal products	-	0.045	0.026	275 Metal sheet product manufacturing
		620	15	12	274 Structural metal product manufacturing
		-	3.4	54	273 Non-ferrous basic metal product manufacturing
		17,000	1100	6400	2711 Basic iron and steel manufacturing
		1200	22	2000	2712 Iron and steel casting and forging
		280	46	-	2713 Steel pipe and tube manufacturing
Motor vehicle services facilities	Mechanical servicing of motor vehicles	-	NS	-	532 Motor vehicle services
	Service stations with contaminant treatment	-	NS	-	532 Motor vehicle services
	Service stations without contaminant treatment	-	NS	-	532 Motor vehicle services
Non-metallic mineral product manufacturing	Cement lime, plaster and concrete products	1200	5700	1600	263 Cement, lime, plaster and concrete product manufacture

ARC process	ARC trade or industry group	Zinc emissions (kg/yr)	Copper emissions (kg/year)	Lead emissions (kg/yr)	ANZSIC category
	Concrete batching plants (ready mixed concrete)				NCC
	Glass	69	170	2200	261 Glass and glass product manufacturing
Petroleum or coal product manufacturing	Bitumen/asphalt premix or hot mix				NCC
	Coal Products				NCC
	Petroleum refining	170	230	600	251 Petroleum refining
	Petroleum hydrocarbon, oil or grease manufacturing	110	490	550	2521 Petroleum and coal product manufacturing
Power	Electrical substations	11,000	23,000	9200	3610 Electricity supply
	Gas, coal or liquid power generation				NCC
Product storage or handling centres	Bulk chemicals				NCC
	Bulk hydrocarbons (non-service station)				NCC
Recycling, recovery, reuse or disposal	Automotive dismantling				NCC
	Batteries				NCC
	Chemicals				NCC
	Crushing, grinding, or separation works (other than sand, gravel, rock or mineral) (eg slag, road base, demolition material)				NCC
	Hazardous materials storage or treatment				NCC
	Landfills				NCC
	Metals (crushing, grinding, sorting or storage)				NCC
	Non-metal recycling (eg composting, glass, paper or paper board)				NCC
	Oil, petroleum hydrocarbon wastes				NCC
	Chemical containers cleaning/reconditioning, or recycling				NCC
	Sewage solids treatment or storage facilities				NCC

ARC process	ARC trade or industry group	Zinc emissions (kg/yr)	Copper emissions (kg/year)	Lead emissions (kg/yr)	ANZSIC category
	Tyres				NCC
	Waste transfer stations	11	14	120	9634 Waste disposal services
Research or defense	Naval and air force defense activities				NCC
	Research establishments				NCC
Rubber industries	Synthetic rubber manufacturing	160	-	-	2552 Rubber product manufacturing
	Tyre manufacturing or re-treading	30	0.17	0.6	2551 Rubber tyre manufacturing
Sewage treatment and handling	Sewage treatment plants	0.70	0.69	28	3702 Sewerage and drainage services
	Sewage solids storage				NCC
Transport and related activities	Boat or ship construction, repair or maintenance	-	5100	-	2821 Ship building
		-	NS	-	2822 Boat building
	Bus depots	-			NCC
	Commercial airports	-	0.048	0.038	640 Air and space transport
		-	0.04	0.002	663 Services to air transport
	Heliports				NCC
	Marinas				NCC
	Railway workshops or refueling depots				NCC
	Road freight transport depot (non chemical) with mechanical servicing				NCC
	Road freight transport depot (bulk chemical)				NCC
	Shipping container reconditioning				NCC
	Shipping loading/unloading	0.0057	0.15	2.8	6621 Stevedoring
	Truck refueling facilities with contaminant treatment				NCC
Truck refueling facilities without contaminant treatment					
Wood or paper product storage, manufacturing or fabrication	Log storage yards (outside of forested areas)				NCC
	Particle board or other wood panel manufacturing	85	34	200	2322 Fabricated wood manufacturing
	Plywood or veneer manufacturing	16	6.4	6.6	2321 Plywood and veneer manufacturing

ARC process	ARC trade or industry group	Zinc emissions (kg/yr)	Copper emissions (kg/year)	Lead emissions (kg/yr)	ANZSIC category
	Pulp, paper or paper board manufacturing	320	93	200	233 Paper and paper product manufacturing
	Timber treatment				NCC
	Treated timber storage				NCC

Note: ¹Some milk-based stock feed manufacture covered in 212; ²Polishes/adhesives covered in 2549; ³Animal slaughter covered in 211; ⁴Rendering covered in 211; ⁵Circuit board manufacture covered in 2849; ⁶Concrete batching plants covered in 263; ⁷Bitumen/asphalt pre-mix etc. covered in 2520; ⁸Coal products covered in 2521. NCC – No comparable category identified.

4.1.3 Wet deposition

Rainfall contributes “comprehensively” to stormwater, because every impervious surface with a connection to the stormwater system will add rain run-off to stormwater. Contaminants will also be carried through to stormwater, assuming no losses (eg by sorption to surfaces). There are few studies of copper or lead concentrations in urban rainwater in Auckland, or New Zealand. Most studies of rainwater quality have focused on contaminant concentrations in rainwater collected from rural and remote locations (Settle & Patterson, 1985; Ayres et al. 1986; Nichol et al. 1997; Arimoto et al. 1990; Halstead et al. 2000). Table 4.5 summarises the available urban rainfall quality studies and provides some comparative information on the quality of rural and remote rain water quality in New Zealand.

Table 4.5

Copper, lead and zinc in New Zealand rainwater (all data mg/m³).

Element	Urban Auckland	Rural Auckland	Fiordland	Ninety Mile Beach
Copper	4.8 Parnell 3.9 Tamaki 2 Mt Eden ~0.3 Howick Res ~2. Onehunga Ind	<0.5	0.013	<0.0076
Lead	<10 Mt Eden ~0.3 Howick Res 2.2 Onehunga Ind	<0.1	0.029	<0.053
Zinc	~4 Howick Res 70 Onehunga Ind 53 Mt Eden	3	0.38	<0.18
Reference	Pennington (2004) Ogilvie (2002) ARC (2004) by difference	ARC (2004)	Halstead et al. (2000)	Arimoto et al. (1990)

Ogilvie (1984) (in Ogilvie 2002) collates rainfall composition data from three sites in the Auckland urban area. Reported trace metal concentrations were low, with average copper concentrations of <2 mg/m³, lead <10 mg/m³ and zinc from 30-89 mg/m³. However these samples of rainwater were collected over twenty years ago, and because of the limited detection limits (eg for lead) their use is limited.

More recently ARC (2004) measured copper, lead and zinc concentrations in rainfall in rural Auckland (Coatesville). Low concentrations of all three metals in the sample collected were reported (Table 4.5). Urban rainfall metal concentrations weren't measured directly by ARC (2004), however data for artificial roof run-off collected from the residential suburb of Howick and the industrial suburb of Onehunga provides some information (as the roof material had previously been found to be a minor contributor of

copper and lead as no copper or lead was detected in rainwater). For zinc, an approximation can be obtained by subtracting the rural Coatesville data from the residential roof run-off concentration data (Table 4.5). Pennington (2004) obtained copper data for rainfall in Auckland as a part of a study of run-off from copper roofs and gutters (Table 4.5).

4.1.4 Dry deposition

Dry deposition contributes “comprehensively” to contaminant loads via the wash off of accumulated contaminants during rainfall. Gadd & Kennedy (2001) found relatively little published information on dry deposition in New Zealand. There are a few relevant New Zealand studies (McLaren, 1986, Fergusson & Stewart 1988, Kennedy et al. 1988) which indicate that dry deposition is a source of trace metals, with concentrations higher in urban areas.

The work by Fergusson & Stewart (1988) demonstrated the extent to which airborne lead was deposited away from urban areas in New Zealand. A significant proportion of the lead generated in inner city Christchurch was transported 10-20 km out of the city. Figure 4.1 shows the trend in dust fall lead westward from Christchurch. Other international studies have demonstrated the deposition patterns around and away from urban areas.

Fergusson & Stewart (1988) also provided data for copper and zinc in dustfall in Christchurch (Table 4.6). They concluded that dust deposition rates were typically lower for these metals (other than lead) compared to other large industrialised cities around the world. The only published data for Auckland appears to be pre-lead removal from petrol. This work includes McLaren (1986) who assessed dust deposition within Auckland City, reporting higher deposition rates than those in Christchurch (~38 $\mu\text{g}/\text{cm}^2/\text{yr}$). There appear to be no published data available on the deposition of copper and zinc from the atmosphere in the Auckland region.

Table 4.6 summarises rural deposition rates reported by Gray et al. (2003) for a number of sites around New Zealand. It is assumed that the natural dry deposition rates are incorporated in the natural soil load estimates present in stormwater (Section 4.3).

Figure 4.1

Lead dust fall flux in and west of Christchurch (from Fergusson & Stewart 1988).

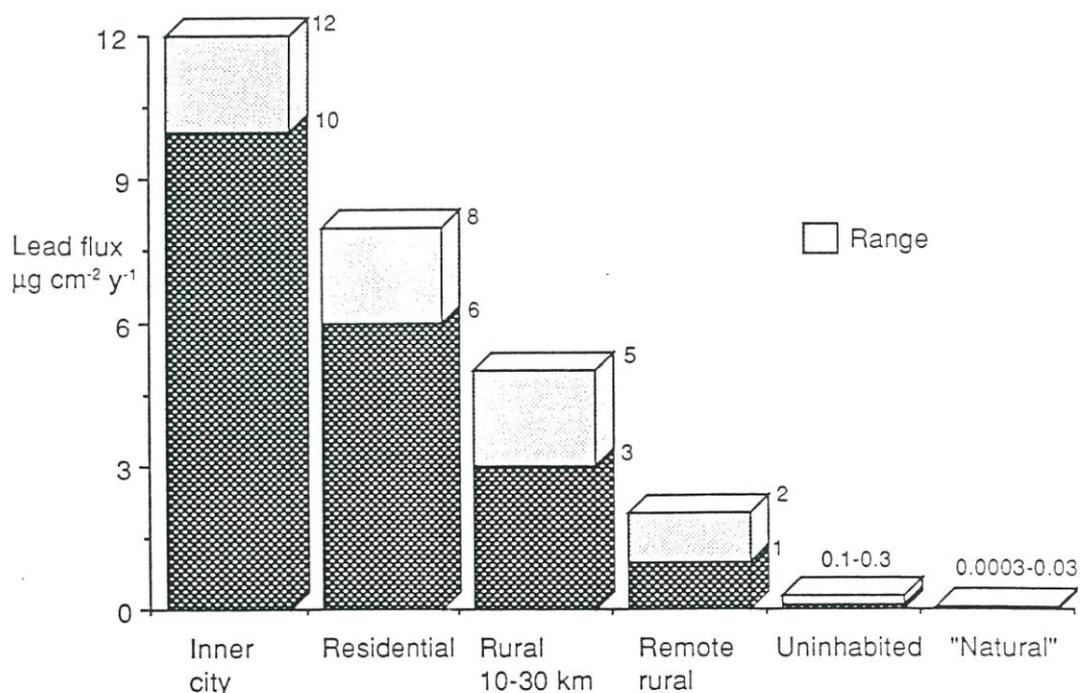


Table 4.6

Dry deposition in New Zealand (all data g/ha/yr).

Element	Christchurch City	Rural (west of Christchurch)	Rural pastoral sites in New Zealand
Copper	40-80	10-20	35.4 (17.5-55.0)
Lead	600-1200*	100-500*	23.0 (9.9-50.2)
Zinc	200-800	30-100	1025 (487-1347)
	Fergusson & Stewart (1988)	Fergusson & Stewart (1988)	Gray et al. (2003)

Note: * - Data obtained prior to the removal of lead from petrol in New Zealand.

Comparing the data of Gray et al. (2003) and the earlier data of Fergusson & Stewart (1988), shows that the data for copper are similar. The more recent lead data for rural areas is similar to the earlier measurements for uninhabited estimates in Figure 4.1 of 10-30 g/ha/year, reflecting the drop off in lead sources and dispersion. The zinc deposition rates identified by Gray et al. (2003) are however much higher than those reported by Fergusson & Stewart (1988). This is considered in the following section.

4.1.5 Contributions from atmospheric sources to stormwater

Not all of the contaminants present in rainfall and dry deposition reach stormwater systems and receiving environments, although it is likely that a high proportion does. The proportion not reaching stormwater can be assumed in the first instance to be equivalent to the proportion falling on pervious surfaces. However, for dry deposition, it is likely that the proportion contributing to stormwater may be lower than theoretically possible due to the translocation and immobilisation of particles during dry periods. There does not appear to be any data on particulate retention in urban areas. For rural catchments, Barkdoll et al. (1977) indicated that 98 per cent of the lead, 85 per cent of the copper and 75 per cent of the zinc in dry deposition was retained in the catchment, but this may not be directly relevant for urban catchments due to the greater proportion of pervious surface in rural areas.

The contribution that dry deposition might make to catchment loads is a function of deposition rate, impervious surface and the estimated loss to stormwater. Dry deposition rates in the previous section have been used in this calculation by adjusting for the per cent of imperviousness (known for each of the catchments) and a small factor (0.05), akin to a run-off factor, to account for some retention of particles within the catchment. Table 4.7 indicates that dry deposition might contribute 7-20 per cent of the copper and lead in all three catchments. For zinc, the dry deposition rates reported in the literature are variable (Table 4.6). In Table 4.7 two deposition rates were used. A higher rate from Gray et al. (2003) accounts for much of the estimated load, and thus appear too high. The second value is derived from Fergusson & Stewart (1988). However, as the contributions to atmospheric metal particulate loads are quite different in Christchurch compared to Auckland, the lower value in the range from Fergusson & Stewart (1988) was selected. In this case, the contribution of dry deposition to the total load is 0.9-16 per cent.

Table 4.7

Dry deposition contributions to catchment loads.

Element	Catchment	Catchment load (ARC 2005) (g/ha/yr)	Dry deposition rate	Adjusted deposition rate	Percentage of total catchment load (%)
Copper	CBD (commercial)	140	35.4	30.2	20.5
	Mission Bay (residential)	79	35.4	16.9	20.3
	Mt Wellington (industrial)	135	35.4	17.7	12.4
Lead	CBD (commercial)	124	23	19.6	15.0
	Mission Bay (residential)	60	23	10.9	17.2
	Mt Wellington (industrial)	135	23	10.4	7.3
Zinc	CBD (commercial)	1630	1025/200	874/170	29.3/9.9
	Mission Bay (residential)	573	1025/200	488/95.4	85.1/15.8

	Mt Wellington (industrial)	5170	1025/200	512/91	9.9/0.9
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Table 4.8 provides a summary of the estimated contributions from rainfall to the three catchments studied in ARC (2005).

Table 4.8

Rainfall contributions to catchment loads.

Element	Catchment	Catchment load (ARC 2005) (g/ha/yr)	Rainfall concentration (mg/m ³)	Rainfall load contribution (g/ha/yr)	Percentage of total catchment load (%)
Copper	CBD (commercial)	140	2.0	19.44	13.9
	Mission Bay (residential)	79	0.3	1.63	2.1
	Mt Wellington (industrial)	135	2.0	13.5	10.0
Lead	CBD (commercial)	124	2.3	24.5	19.8
	Mission Bay (residential)	60	0.4	2.2	3.6
	Mt Wellington (industrial)	135	2.3	13.4	9.9
Zinc	CBD (commercial)	1630	59	478.1	29.3
	Mission Bay (residential)	573	4	21.7	3.8
	Mt Wellington (industrial)	5170	59	398	7.7

Note: Rainfall 1.2 m in CBD, Mission Bay, 1.35 m Mt Wellington, Loads calculated using impervious % of 85.3, 47.8, 45.3% for CBD, Mission Bay, Mt Wellington (From ARC 2005). All impervious surfaces assumed to have run-off coefficients of 0.95.

Sabin et al. (2005) examined the contributions that atmospheric deposition made to stormwater in a small five hectare impervious catchment in the San Fernando Valley in Los Angeles. The examination of rainfall and dry deposition loads showed that dry deposition dominated the contributions in that catchment with rainfall contributing 1.5 per cent of the lead, 6.2 per cent of the copper and 11.5 per cent of the zinc. As Los Angeles has a very low rainfall (330 mm), it is likely that the contribution from rainfall in Auckland would be proportionally higher (1096 mm in 2007 at Owairaka). Sabin et al. (2005) concluded that atmospheric deposition (rain and dustfall) could be a significant contributor to the contaminant loads in stormwater assuming that all of the deposition was then contributed to stormwater. They noted however that all of the deposition is not contributed to stormwater due to inefficient washoff, retention of particles, sorption etc.

Based on the very low concentrations in Table 4.5, natural background rainfall contributions to stormwater in Auckland would be very small (<0.1 per cent). The

estimates of rainfall and dry deposition contributions to stormwater follow the pattern indicated by Sabin et al. (2005).

Overall, it is likely that rainfall in Auckland contributes a small to moderate proportion of the copper and lead entering residential, commercial and industrial catchments in Auckland. Estimations of the contribution that rainfall makes to the zinc load is compromised by the limited zinc rainfall quality data available. Based on industrial catchment rainfall quality presented in ARC (2004) it is likely that there is considerable spatial variability in rainfall quality-related to the distribution of zinc emissions from industries.

The data identified in this report is derived from studies where the collected data has very limited statistical reliability. That is, the data comprised limited numbers of samples collected over a limited time period. As a consequence, this introduces an unknown uncertainty to the rainfall concentration data (refer Uncertainty inset box).

Uncertainties relating to rainfall and dustfall contributions

- The assessment of rainfall contribution is very much dependent on the identification of a robust concentration for rainfall within the catchment or from a particular land use.
- The preliminary contribution assessment indicates that atmospheric contributions through rainfall could be a source of copper based on the available copper rainfall data. The surrogate rainfall data used in the calculations was the long run roofing run-off data from ARC (2004) minus the background non-detect concentration identified for rural long-run in ARC (2004). If the Parnell data of Pennington (2004) was more indicative of copper in inner city rainfall, the contribution of rainfall to the total copper load would increase significantly to 33.3 per cent. It is evident that uncertainty in the copper in rainfall has a major effect on the amount of copper that rainfall contributes to stormwater copper loads.
- For lead the per cent contribution appears to be small to moderate. A 0.2 mg/m³ change in the average rainfall lead concentration in the CBD or Mt Wellington catchments changes the contribution from rainfall by 3.6 or 2.0 per cent respectively. As such further precision in relation to the lead content of Auckland rainfall is required to refine the rainfall contribution.
- Based on the existing published rainfall quality data it is evident there is little data which has a high degree of reliability. Older published data on zinc in rainfall for Auckland identified zinc concentrations in the range 30-89 mg/m³ (Table 4.5). A rainfall concentration of 59 mg/m³ was used based on data presented in ARC (2004) (industrial median minus the rural contribution for the same artificial roof types). This data was considered to be a useful figure to use for Mt Wellington, but although used for the City CBD catchment, may not have been suitable. It is evident from the run-off data from artificial roofs in ARC (2004) that the zinc concentration in run-off from industrial sites, even within a single catchment, is quite variable. The upper concentration identified in ARC (2004) for industrial roof run-off

in Onehunga (750 mg/m^3) exceeds the “calculated load” for the Mt Wellington catchment presented in ARC (2005).

The rainfall and dry deposition contributions for the residential catchment of Mission Bay has been assessed to be 22.4 per cent, 20.8 per cent and 19.6 per cent of the catchment loads for copper, lead and zinc respectively. The median values for copper and lead are similar to the combined wet and dry deposition loading contributions identified by Davis et al. (2001) of 18 and 21 per cent respectively but lower than the 5 per cent contribution identified by Davis et al. (2001) for zinc.

In the following sections, the contributions made by a number of other sources are discussed. It is recognised that the contributions made via atmospheric deposition and rainfall include some contribution from other sources. For example, exhaust emissions will involve complex dispersion and deposition pathways but any particles contributed to catchment air will be added to stormwater through washout or dry deposition. Wherever possible these cross contributions are identified and accounted for.

4.2 Motor vehicles

4.2.1 Introduction

Motor vehicles are complex “contaminant sources” due to the number of emission sources and the range of metals used in motor vehicles. There is a wealth of information on potential sources of copper, lead and zinc in motor vehicles. Two recent studies have examined the distribution and presence of metals in vehicles in relation to life cycle analysis (Sander et al. 2000, Lohse et al. 2001). A range of studies have investigated the presence of metals in vehicle emissions and a number of studies in New Zealand have examined the concentration of metals in vehicle emission sources. In this section, some specific uses of copper, lead and zinc in isolated materials within vehicles are identified. Categorised information is combined and specifically discussed in relation to major source categories, these include:

- Vehicle body
- Vehicle exterior paints
- Wheel balancing weights
- Brake pad wear
- Tyre wear
- Exhaust emissions
- Oil and grease.

4.2.2 Vehicle body uses of copper, lead and zinc

Copper, lead and zinc are used for a variety of purposes in motor vehicles, as pure metals and as alloy components. Recently, there have been investigations in Europe into the elimination of lead from vehicles, to reduce the health and environmental risks during vehicle production, use and disposal. The sources noted below are predominantly “secure” sources and as such do not typically result in direct emission of any of the three metals to the environment during vehicle use.

- Steel used in vehicles contains lead (0.15-0.35 per cent by wt) to provide for better machining of the steel (Sander et al. 2000, Lohse et al. 2001).
- Leaded aluminium alloys are used in many vehicles. Most contain <0.4 per cent lead by weight but some (wheel rims, etc.) contain up to 4 per cent by weight (Sander et al. 2000).
- Zinc is used as a corrosion protection coating on steel surface where it forms an alloy. There may be some lead in the zinc coatings (as an impurity).
- Copper alloys with a lead content of up to 4 per cent are used in European cars in a variety of uses (bearing shells and bushes used in the engine) and brass and copper alloys are used in fixtures, locks, connectors etc. (Sander et al. 2000).
- Copper is used in electrical components within vehicles such as in wiring, motors, starters, generators and alternators and this use is increasing as vehicles have increasing amounts of electronics.
- Copper is used in engine parts, braking and steering systems. Copper is also used as an alloying element with many metals, and in particular, brass (the alloy with zinc) is used for many applications within motor vehicles such as radiators.
- Batteries represent the largest weight of lead in vehicles. Batteries typically weigh 13-15 kg and typically constitute >90-95 per cent of the lead in vehicles.
- Fuel tanks in many vehicles are made of steel with a lead-tin alloy coating. Some alternative coating systems are used by some manufacturers (these can involve zinc) and some manufactures make tanks out of plastic or mixtures of materials.
- Vibration dampers in vehicles are often made of lead. Typically the amount of lead involved is 100-300 g, but in some vehicles heavier weights are used (>1 kg).
- Lead is used as a vulcanising agent (0.1 per cent by wt) in high pressure hoses and fuel lines.
- Lead historically was used as a coating on pistons. The coating wore off over time as a consequence of use.
- Metals are used as stabilisers in a range of plastics. Polyvinyl chloride (PVC) is a common plastic used in vehicle wiring, dashboards, panelling and seat coverings (eg in some taxis) etc. Lead based stabilisers are common in these plastics, with Sander et al. (2000) noting that some 60-75 per cent of all stabilisers used in PVC products in Europe contained lead in the range 0.5-3 per cent (some 6-15 per cent of PVC is stabilised with organotin compounds – Sander et al. 2000). They note

that PVC used on the vehicle under seal does not use lead stabilisers. Sander et al. (2000) note that there are a variety of initiatives in Europe to reduce lead use in plastics used in vehicles.

- Metals are present in soldering carried out through the vehicle (eg lead in brazing alloys used for fuel tanks contain 70 per cent lead and overall contributes 30-60 g of lead/vehicle) and also on printed circuit boards in vehicle electronic systems (in Japanese cars this could amount to 50 g lead). It is understood (Sander et al. 2000) that lead is being or has been phased out as a component in solder systems used for vehicle soldering.
- Lead is present in the coatings (as a lead silicate glass) on some spark plugs. Lohse et al. (2001) note that it is likely that this lead coating will be phased out.
- Lead is used in a variety of electronic applications in vehicles (Lohse et al. 2001). These include knock sensors (which contain piezoelectric ceramics containing lead oxide), airbag shock sensors, radios, phones, navigation systems etc. The specific uses include thermistors for over-current protection in electronics, thermistors in occasional air conditioning systems and ceramic capacitors in power systems. These can amount to 4-125 g of lead/vehicle (Lohse et al. 2001).
- Lead may also be present in light bulbs (signal lamps and interior lights) in vehicles, where the glass may be a lead glass and in the solder (60 per cent lead). Lohse et al. (2001) notes that each bulb may contain 0.4-0.5 g of lead in the glass and in the solder, amounting to about 12 g/vehicle. As house light bulbs are made of lead-free glass it was anticipated by Lohse et al. (2001) that lead free glass would be introduced for vehicle light bulb glass.
- "Pyrotechnic initiators" used in air bags and seat belt pre-tensioners, commonly contain lead as lead styphnate (Sander et al. 2000). It is estimated that the amount used in vehicles is about 50-310 mg/vehicle. Lead azide is also used in air bags. It is assumed that similar initiators are used in New Zealand, although no information was readily available to confirm this. About 25 per cent of European cars use high energy systems which are lead free. Given the assumed infrequency of use of airbags and the relatively small amounts of lead involved (and assumed partial containment of the lead within the vehicle), release is assumed to be minor.

These sources have not been considered further as potential continuous contributing sources of lead, copper or zinc to stormwater. However, there is some potential for minor contributions to occur following vehicle accidents.

4.2.3 Vehicle exterior paints

There have been significant changes in automotive exterior bodywork paints over the last decades (Papasavva et al. 2001). Vehicles are now painted with waterborne and powder coatings (in contrast to solvent based paints). Vehicle paint formulations appear typically (as described in the literature) to be based upon human health considerations during the painting process and overall life cycle considerations.

Environmental fate of the paints and what is in them does not appear to feature as a key item in paint formulation assessment.

All powder, waterborne and other vehicle paints appear to use similar basic types of chemicals. These include resins and binders, pigments and modifying additives. The study by Papasavva et al. (2001) examined some specific examples of vehicle paints in some detail. These paints contained titanium dioxide, iron, aluminium and barium.

Sander et al. (2000) note that until recently lead was considered necessary in the electrodeposited coating, applied to protect the car body from corrosion. However key manufacturers have developed new lacquers which do not contain lead. Protective paints containing lead started to be phased out in the 1990s.

There does not appear to be any information on the state of paint and bodywork over time for the New Zealand vehicle fleet. However it is assumed that there is some general relationship between age and exterior condition. Historically (eg prior to 1990) it is the authors observation that there appeared to be a greater number of vehicles on the road with exterior paint work in poor condition (eg powdery), which may have resulted in losses of material from the paint during rain. It would also be expected that the amount of lead associated with paint coatings on vehicles would generally be a reflection of the average age of the vehicle fleet, as it is assumed that lead is no longer a significant component of paint on motor vehicles in New Zealand. As part of studies in Auckland to assess sources of lead intake by children (Kennedy et al. 1988) two analyses of lead in car exterior paint were carried out. The results were 1.55 per cent and 0.43 per cent. Although not a representative sample, the data confirms that significant concentrations of lead were present on the exterior paints of cars at that time (1983). It is assumed that current vehicle coatings do not contribute metals to stormwater through contact with rainfall. However this would need to be confirmed.

4.2.4 Wheel balancing weights

Use of wheel weights and their composition

Wheel balancing weights are installed on motor vehicle wheels to correct for imbalances in wheel and tyre assembly (reducing vibration and improving fuel consumption). They may be installed by the manufacturer on new vehicles, or aftermarket when tyres are replaced or repaired. Typically wheels are placed on a machine to determine the weight required and optimal location on each wheel. The majority of wheel weights are clip-on types of up to 15 mm in length that attach to the edge of the wheels rim. Some new aluminium rims require adhesive wheel weights due to their shape. Figure 4.2 illustrates where wheel weights are fixed to wheel rims.

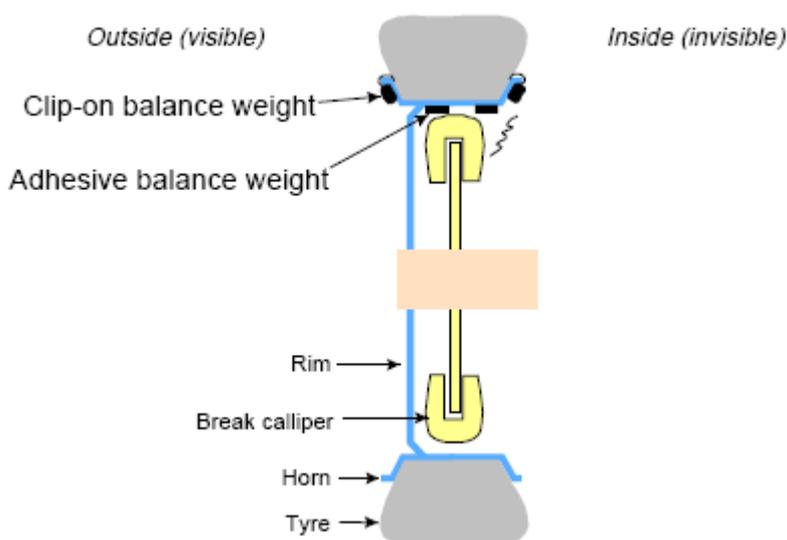
Lead has been the preferred material for wheel weights (commonly 95 per cent lead), as it is inexpensive, dense, ductile, malleable and corrosion resistant (USEPA 2005). Most cars and light trucks require 1-2 weights per tyre for balancing. The amount of lead used in wheel weights on each vehicle varies, and is estimated to range from 200-250 g (Lohse et al. 2001), based on an average of 20-25 g lead per weight and 10 weights per car.

However, this estimation allows for two wheel weights on each of the four wheels and the spare wheel. Given that only four wheels will ever be used at one time, it is reasonable to discount the spare wheel; this assumes that eight weights are exposed at any one time and on this basis there is approximately 160-200 g of exposed lead per vehicle due to wheel weights. Another estimate by USEPA (2005) assumes a slightly higher estimate of the wheel weight at 28-42 g per weight, which equates to approximately 220-340 g lead per vehicle due to wheel weights.

Discussions with wheel balancing garages in Auckland have suggested that the majority of wheel weights used in New Zealand are made of lead. Alternative materials are discussed further below.

Figure 4.2

Wheel weight fixation to wheel rims (Taken from Sander et al. 2000).



Loss of lead wheel weights

Wheel weights are a source of environmental lead as they are often lost from the wheel, falling off and onto the road (Figure 4.3). There are several factors that contribute to this loss, including traffic patterns (particularly in areas where vehicles stop and go), road conditions (pot holes, uneven pavement etc.), driving conditions (rural, highway, urban), and other possible conditions or hazards (USEPA 2005).

Root (2000) reported the results of a survey of roads for lost wheel weights in Albuquerque New Mexico. The steady state amount of lead present from wheel weights was estimated from a survey of eight six-lane road segments (19.2 km of road, 45,000 vehicles per day (VPD), no kerb-side parking). All lead found in the kerb, on the road surface or on the sidewalk was collected. The survey reported that the average weight of the lead objects recovered was 21 g, with nearly all (99 per cent) being found in the 0.6 m outer or median strip kerb area. The overall weight of lead

present was 0.5 kg/km. 97 per cent of the lead was recognisable as part or whole wheel weights. The author noted that the amounts identified are under-estimates as not all lead can be found and resurveys typically found at least 10 per cent more lead.

To assess the rate of deposition, Root (2000) surveyed a 2.4 km section of the main survey area (41,500 VPD) every two weeks for 46 weeks (Figure 4.4). At this site the steady state amount was 1.09 kg/km. On average Root (2000) reported that 0.35 kg/km was found during the surveys carried out every two weeks. Overall this amounted to 9.1 kg/km/yr. In one particular section of this road, the annual rate was estimated to be 50-70 kg/km/yr.

Figure 4.3

Wheel weight in a Takapuna street gutter.



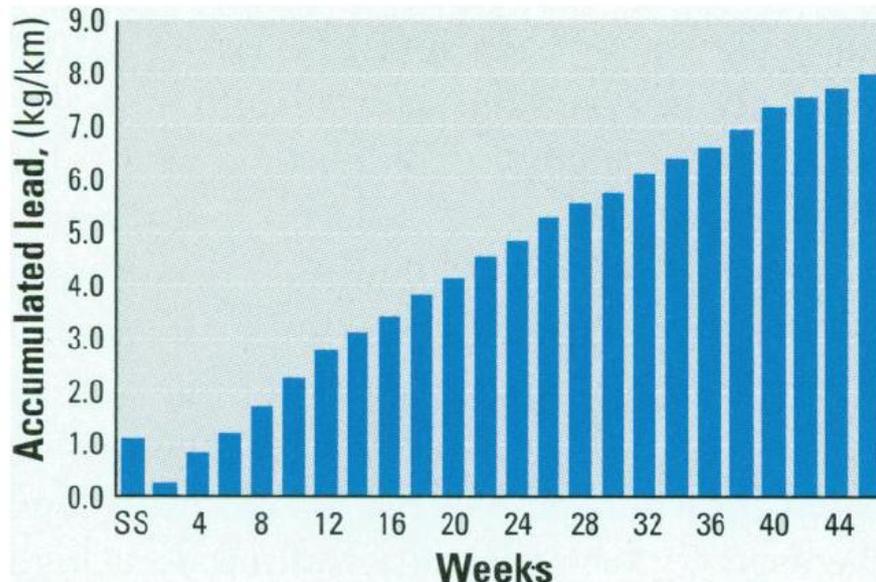
Root (2000) noted that wheel weight deposition was more frequent near businesses, side streets and intersections where rapid deceleration occurs.

Root (2000) suggested, based on his Albuquerque New Mexico surveys, that up to 10 per cent of wheel balancing weights may be lost from the vehicle in any year, and deposited onto the road. Ecology Centre (2005) surveyed a one mile stretch of road in Ann Arbor in 2002 and recorded similar deposition rates (~13 per cent).

In Auckland there were 783,706 licensed cars at the end of 2006 (LTNZ, 2006). Assuming a worst-case scenario of 13 per cent loss, then it is estimated that approximately 16,300 to 34,600 kg of lead is lost from vehicle wheel weights in Auckland each year. This assumes that all wheel weights are made of lead. It is noted that this estimate is only for licensed cars, and excludes trucks, buses, coaches and trailers/caravans, which are all also likely to use and lose lead wheel weights.

Figure 4.4

Steady state (SS) and biweekly survey results reported by Root (2000).



Wear and loss of lead from wheel weights

It can be seen from the example shown in Figure 4.3 that the surface of lead wheel weights becomes abraded, scratched and worn. Root (2000) assessed wheel weight abrasive losses in Albuquerque by clearing wheel weights from road surfaces and replacing them with wheel weights with known weights. Of the 7 kg of wheel weights placed on the road only 4.0 kg was recovered. The placement of the weights reinforced the theory that the weights are moved from the road surface to the gutter kerb. Root (2000) notes that the wheel weights move towards the kerb due to the torque of the vehicles drive wheels skidding the weights against the traffic flow.

Root (2000) concluded that the lead deposited in wheel weights in busy streets is rapidly worn away to the extent that a significant fraction of the amount deposited would not be found. Through evaluation of his data, Root concluded that 2.72 per cent of the lead deposited was worn away each day.

In addition to physical abrasion, attached wheel weights exposed to the environment (ie those not covered by hubcaps or wheel covers) would be susceptible to corrosion, and during wet weather/rainfall soluble lead would be dissolved (as the pH of rainfall is typically pH ~6.0), contributing to lead concentrations in stormwater.

There appears to be no available information on the solubilisation of lead from the surface of wheel weights. The closest parallel is the release of lead from lead sheeting on roofs. The loss of lead to stormwater from lead on church roofs has been estimated at 11 kg/m² over 800 years (Hawkins et al. 1995), or 14 g/m²/yr. Assuming that the leaching rate is the same for a lead wheel weight and that a lead wheel weight has dimensions of 10 mm by 50 mm (area of 0.0005 m² per side), the loss would be 7 mg per side or about 14 mg per weight per year through basic solubilisation from

exposure to rainfall (the calculation ignores the exposed ends and that some weights will have some lead covered if the wheel attachment is still present).

If wheel weights were transported into stormwater catchpits through vehicular or stormwater transport, it is most likely that due to their mass, they would be captured within the catchpit sump. Dissolution of lead is likely to continue within catchpits and the rate will depend on the pH and chemistry of the catchpit water.

Contributions

The Root (2000) study indicated that a steady state lead contribution from wheel weights was 1000 g/km or 100 g/100 m of road. Kennedy & Gadd (2000) identified that roads made up about 10 per cent of catchment area in residential and commercial areas and about 5 per cent in industrial areas. These areas have been used to assume that on average within a catchment the road area might correspond to 1000 m² in each hectare within residential and commercial catchments and 500 m² in each hectare within industrial catchments. Based on a two lane road width of 7 m, this corresponds to road lengths of 143 m and 71 m respectively. For these road lengths the steady state lead wheel weight mass would correspond to 143 g (6.5 weights) and 71 g (3 weights) respectively.

Table 4.9 summarises assessed contributions for the catchments based on the whole weight surface area solubilisation losses described earlier (98 mg/weight/year). The table also summarises the estimated mass of lead that might be present on road surfaces in lost wheel weights. The mass in the weights is similar to the total lead load exported in stormwater each from the catchments.

The solubilisation loss has been used rather than the total loss as an unknown proportion of weights will be removed from the road surface and as such will not contribute to the lead in stormwater.

Table 4.9

Contributions from wheel weights to catchment lead loads.

Catchment	Catchment load (kg/yr, ARC 2005)	Wheel weight mass on roads (kg)	Catchment load (from ARC 2005) (g/ha/yr)	Wheel weight contribution (g/ha/yr)	Percentage of total catchment load (%)
CBD (commercial)	3.73	2.83	124	0.6	0.5
Mission Bay (residential)	2.71	5.0	60	0.6	1.0
Mt Wellington (industrial)	4.59	1.83	135	0.3	0.2

Note: Based on assumed road length.

Overall, even though the mass of lead in wheel weights lost to road surfaces is large, the amount of lead estimated to be lost through solubilisation and therefore the load contribution/ha is relatively low compared to the total load in stormwater generated within the catchment. To ensure that this load contribution is not being

underestimated, further information is required in relation to some aspects of the fate of lead wheel weights in New Zealand (refer Section 6).

Uncertainties

There are a range of uncertainties associated with wheel weight contributions. These include the total amount of wheel weights in use on New Zealand roads, the proportion that are lead, the typical loss rate in New Zealand, the life of wheel weights on different types of New Zealand roads, the effect of street sweeping on wheel weight removal from road surfaces, the solubilisation of wheel weights on road surfaces (ie the rate of lead release).

No data on composition of wheel weights has been identified that could confirm whether copper or zinc are present as a "contaminant" in the lead, which would be solubilised at the same time as the lead.

4.2.5 Brake linings

4.2.5.1 Metal concentrations in brake linings

Brake linings (also known as brake pads and frictions linings) wear due to abrasion when applied to slow the wheels of a vehicle. The debris worn from the brake lining may be retained within the brake pad housing or released into the environment. Wear rates of brake linings depend on driving conditions (with higher wear rates with heavy use of brakes) and on the composition of brake linings used.

Wear of brake linings or friction linings are a known source of copper in road-derived stormwater because many brake linings contain copper or bronze chips or powder to provide mechanical strength. Historically, brake linings have used asbestos for the main fibre content; however this use is decreasing due to health concerns. Alternatives such as ceramic fibres, alumina silicates and phenolic resins are also being used. In non-metallic brake pads, copper sulfides may be present as a solid lubricant. Nine of the 12 brake linings analysed by Kennedy & Gadd (2000) contained between 11 and 56 mg/kg of copper, with three containing much higher concentrations, at 1945, 39,000 and 112,000 mg/kg. The highest concentration was measured in a brake pad for 4WD vehicles, however the other two brake pads with high concentrations were for passenger cars (Table 4.10).

A more recent comprehensive survey of brake pads available in Sweden found much higher concentrations of copper and zinc in branded replacement brake pads than were measured in the New Zealand study (Hjortenkrans et al. 2007). These were generally European manufacturers such as Saab, Renault, Volvo and Skoda, which have a lower market share in New Zealand than in Sweden. Non-branded replacement brake pads (independent suppliers) had much lower concentrations of copper and zinc (Hjortenkrans et al. 2007) and these were more similar to those measured in New Zealand (Table 4.10).

Table 4.10

Copper and lead concentrations in brake linings (all data, mg/kg, median and range).

Study details	Copper	Lead	Zinc	Reference
NZ brake pads (n=12)	36 (11-112,000)	7.5 (1.3-873)	694 (96-34,500)	Kennedy & Gadd 2000
NZ brake pad dust (n=6)	220 (71-1980)	39 (4-1290)	1600 (360-9630)	Kennedy & Gadd 2000
Swedish branded brake pads for front wheels (n=24)	120,000 (75,000-270,000)	66 (5-920)	25,000 (720-73,000)	Hjortenkrans et al. 2007
Swedish branded brake pads for rear wheels (n=24)	130,000 (990-220,000)	35 (1.9-27,000)	34,000 (460-130,000)	Hjortenkrans et al. 2007
Swedish independent brake pads for front wheels (n=12)	220 (26 -500)	84 (44-180)	9000 (280-10,000)	Hjortenkrans et al. 2007
Swedish independent brake pads for rear wheels (n=12)	190 (18-230)	46 (27-800)	8200 (81-8800)	Hjortenkrans et al. 2007

Debris from brake lining wear may have a different composition. Analysis of brake lining dust, collected when brake linings were being replaced, indicated highly variable copper concentrations in the dust, at 71-1980 mg/kg (median of 220 mg/kg) (Table 4.10)

The range in copper concentrations in the brake linings and in the brake dust is a considerable source of uncertainty when calculating loads of copper released from wear of brake linings. The wear rate of brake linings is a further source of error, with particle emissions estimated between 11 and 160 mg/km, depending on the vehicle type (eg passenger car or heavy duty vehicle) and driving conditions (ie low to intense brake use), however this source of error is small compared to the error in copper concentrations.

Lead concentrations in brake pads are low, but not insignificant (Table 4.10). Lead sulfide may be added to brake linings as a solid lubricant, as an alternative to graphite or other metal sulfides. Lead concentrations in New Zealand brake pads ranged from 1.34-873 mg/kg, with a median of 7.5 mg/kg. In brake dusts, the lead concentrations were typically higher, at 4.0-1290 mg/kg (median of 39 mg/kg). Lead concentrations over 20,000 mg/kg were measured in three of 24 branded brake pads analysed in the Swedish survey (Hjortenkrans et al. 2007).

4.2.5.2 Contributions from brake linings

The emission of copper and lead from brake pads in the CBD, Mt Wellington and Mission Bay catchments can be estimated based on the "simple" emission factors provided in Kennedy et al. (2002) and the traffic information provided in ARC (2005).

For the CBD catchment, the total vehicle kms travelled (VKT) per day is 35,023 and in the Mission Bay and Mt Wellington catchments the VKT are 24,290/day and 7302/day respectively.

Emission rates have been estimated as 0.005 mg/VKT for copper under moderate brake use and 0.006 mg/VKT under heavy brake use (Kennedy et al. 2002), assuming that all vehicles are passenger cars. This equates to an estimated contribution of copper from brake lining wear of 63-83 g/year for the CBD catchment. The total catchment copper load was reported to be 4210 g/year, indicating that brake wear may contribute around 1.6-2 per cent under this scenario.

If these same particle wear rates are used along with the upper range of copper concentrations reported in dust in NZ (2000 mg/kg), the contributions are greater. Furthermore, if an allowance is made for heavy duty vehicles in the assessment, then the emissions from this source increase further. For example in the CBD, the annual passenger vehicle contribution rises from 27 g/ha/year to 77.2 g/ha/year if 20 per cent of the vehicles are heavy duty vehicles (wear rates of 120 mg/km compared to 31.5 mg/km).

Kennedy & Gadd (2003) noted (in relation to assessing the concentration of copper in sediment on road surfaces) the discrepancy between the median copper concentration in the earlier Kennedy & Gadd (2000) study on brake pad composition and that in the literature. That study concluded that the dust particulate concentrations may be more appropriate, but noted that a figure of 5000 mg/kg may be more appropriate for emission assessment. This is still substantially lower than the branded average concentrations from Hjortenkrans et al. (2007) summarised in Table 4.10. These differences are very large and have significant implications in terms of estimating the actual copper loading.

To estimate the potential contribution from brake pad wear to the copper load in stormwater, estimates were made using the following scenarios:

- The median copper concentration for NZ brake pad dust from Kennedy & Gadd (2000).
- The upper copper concentration for NZ brake pad dust from Kennedy & Gadd (2000).
- A nominal 5000 mg/kg copper concentration for brake pads.

The median copper concentration for Swedish brake pads containing copper (Table 4.10) was not used as this value accounts for all the copper load in stormwater. The results for the three scenarios are presented in Table 4.11. The different examples of copper content used in the wear calculations results in large variations (a factor of 20 times, corresponding to the range in concentrations used) in the contributions to stormwater copper loads in all three catchments.

Table 4.11

Contributions from vehicle brake pad wear to catchment loads (g/ha/yr unless stated).

Element	Catchment	Catchment load (ARC 2005) (g/ha/yr)	Brake pad wear contribution from wear rates and 220 mg/kg Cu	Brake pad wear contribution from wear rates and 2000 mg/kg Cu	Brake pad wear contribution from wear rates and 5000 mg/kg Cu	Percentage of total catchment load* (%)
Copper	CBD (commercial)	140	4.64	41.8	104.5	3.3/29.8/74.6
	Mission Bay (residential)	79	0.64	5.8	14.8	0.8/7.3/18.7
	Mt Wellington (industrial)	135	2.1	18.7	46.8	1.5/13.8/34.5
Lead	CBD (commercial)	124	0.8	-	-	0.64
	Mission Bay (residential)	60	0.4	-	-	0.7
	Mt Wellington (industrial)	135	0.15	-	-	0.11
Zinc	CBD (commercial)	1630	33.4	-	-	2.0
	Mission Bay (residential)	573	11.2	-	-	1.9
	Mt Wellington (industrial)	5170	6.2	-	-	0.1

Note: * - % calculated using wear rate and average concentration and brake pad dust concentration – copper 220/2000/5000 mg/kg; lead 40 mg/kg; zinc 1600 mg/kg. Estimate likely to be low – refer text above.

The estimated contribution of lead from brake lining wear, based on the median concentration in brake pad dust, is 11-15 g/year for the CBD catchment, compared to the total catchment load of 3730 g/year, indicating that brake wear is a minor source of lead (0.1-0.7 per cent) (Table 4.11). For zinc the contributions ranged from 0.1-2.0 per cent of the catchment load.

Uncertainties

The differences between the available New Zealand data and the international studies indicate that the New Zealand data under-estimates the potential release of metals such as copper (Kennedy et al. 2002). This is reflected in the range of concentration data presented for copper wear loss in Table 4.11.

In addition to the concentration uncertainty, there is a large uncertainty arising from the differential wear rates that occur under different driving conditions. Wear rates reflect how brakes are used.

Kennedy et al. (2002) discussed brake wear rates, identifying that wear is a function of several factors including road layout, intersection control (give way, lights or roundabouts) and level of service (LoS – how free flowing the traffic is). Based on this, Kennedy et al. (2002) identified wear rates that corresponded to the three bands of LoS (A/B through E/F) used on New Zealand roads, to provide a preliminary indication of how the wear rates may vary with driving conditions. These rates ranged from low wear rates (where brake use was low) through to intense wear rates and covered a factor of four in rates of particles released/km (eg 10-42 mg/km for passenger cars).

Within any given catchment, the brake pad wear “environment” will also vary and include roads and sections of roads which fall into the range of categories identified by Kennedy et al. (2002). Given that the “average” wear rate was used in this assessment, then the uncertainty can only be a factor of two based on the data in Kennedy et al. (2002). In the majority of catchments this difference is unlikely and a factor of 1.5 may be more realistic. This level of uncertainty does however have an influence on the estimated contributions in Table 4.11. For lead the influence is minor with the contribution being under or over-estimated by up to 0.3 per cent. For zinc, the contribution could be under or over-estimated by up to 1.6 and 3.3 per cent in the CBD and Mission Bay catchments. For copper, based on the lower set of estimates, the difference could be 0.2-1.2 per cent and based on the higher estimates 1.2-7.2 per cent. As such, the wear rate variance can influence the source contribution estimates significantly.

This significant variance in copper contributions from brake pad wear resulting from driving conditions and copper content of brake pads can only be refined by obtaining better definition of the copper concentration in brake pads. This is discussed in Section 6.

4.2.5.3 Summary

Overall, the assessment of metal contributions from brake pad wear indicates that:

- Copper contributions from brake pad wear appear at first instance, based on average New Zealand brake pad copper data, to be a relatively minor per cent of the total catchment load. However, there is a large uncertainty as to what the average copper concentration is in New Zealand on-road brake pads. The use of higher estimates increase the potential contribution proportionally (eg to 7.3-29.8 per cent).
- The lead and zinc contributions from brake pad wear appear small but may be underestimated due to little data on lead and zinc in brake pad wear products. The contribution are proportional to vehicle density. The contribution of zinc in the industrial catchment was minor due to the much lower VKT and the very high roof sourced contributions.
- Brake pad wear rate characteristics within individual catchments need to be taken into account when estimating contaminant load contributions from vehicles.

4.2.6 Tyre wear

Metal concentrations in tyres

Table 4.12 presents a summary of metal concentrations measured in tyres. Tyres contain significant concentrations of zinc, as zinc oxide is added to the rubber as a vulcanisation activator, up to 2 per cent by weight (Environment Agency 1998). Kennedy & Gadd (2000) reported concentrations of 1 190 to 13,800 mg/kg of zinc in a survey of 12 passenger vehicle, 4WD, light truck and heavy truck tyres sold on the New Zealand market. Tyre wear is a significant source of zinc and is the major source of zinc in road-surface sourced stormwater.

In contrast, copper and lead are only present at minor concentrations in tyres. Copper can be present as an alloying constituent in the metallic reinforcing material and was measured at <1-3 mg/kg in New Zealand tyres (Kennedy & Gadd 2000).

Concentrations up to 38 mg/kg were measured by Hjortenkrans et al. (2007) in a survey of 52 tyres sold in Sweden, including eight retread tyres. These concentrations were similar to those measured by Hewitt & Rashed (1990) in the UK. The lower concentrations measured by Kennedy & Gadd (2000) may be due to differences in tyres sold in New Zealand, or differences in analytical techniques.

Table 4.12

Copper, lead and zinc concentrations in tyres (mg/kg).

Study details	Copper	Lead	Zinc	Reference
NZ tyres (passenger vehicles, n=8)	1 (<1-3)	3.0 (1.0-5.7)	8310 (1190-8,300)	Kennedy & Gadd (2000)
NZ tyres (range of vehicle types, n=12)	1 (<1-3)	2.7 (0.8-9.7)	8520 (4180-3,800)	Kennedy & Gadd (2000)
NZ tyres	-	0.84	5600 (based on ZnO content of 0.7%)	MoT (1996)
Swedish non-retread tyres (n=44)	6.8 (1.7-38)	8.8 (0.74-31)	9300 (700-6,000)	Hjortenkrans et al. (2007)
Swedish retread tyres (n=8)	5.4 (4.3-20)	6.3 (3.0-26)	13,000 (5600-8,000)	Hjortenkrans et al. (2007)
UK tyres	5.5-29.3	-	-	Hewitt & Rashed (1990)
French tyres	1.8	6.3	10,250	Legret & Pagotto (1999)

Lead was measured at 0.8-9.7 mg/kg in New Zealand tyres (Kennedy & Gadd 2000) and at higher concentrations in Swedish tyres (0.74 – 31 mg/kg, Hjortenkrans et al. (2007)). Bayer (2000) report that the source of lead in tyres is from impurities in the zinc oxide used, however there was only a weak relationship between zinc and lead concentrations for the Swedish data set.

Contributions from tyre wear

The loads of metals emitted from tyre wear are dependent on the driving conditions, (eg heavy braking and accelerating), tyre wear rate, road surface and tyre composition (Kennedy & Gadd 2003). Contact between tyres and the road surface causes tyres to wear, creating fine particulates that may be airborne, deposited onto the road or retained within the wheel hub either temporarily or permanently. As these particulates reach the stormwater system, they may be a significant source of contaminants. The emission of copper and lead from tyres in the CBD, Mt Wellington and Mission Bay catchments can be estimated based on emission factors provided in Kennedy et al. (2002) and the traffic information provided in ARC (2005).

For the CBD catchment, the total VKT per day is 35,023. Emission rates are estimated as 0.0001 mg/VKT for copper under interrupted driving conditions and 0.0002 mg/VKT under congested conditions (Kennedy et al 2002), assuming that all vehicles are passenger cars. This equates to an estimated contribution of copper from tyre wear of 1.2 - 2.5 g/year for the CBD catchment. The total catchment load was reported to be 4210 g/year, indicating that tyre wear is a very minor source of copper (<0.1 per cent). The estimated contribution of lead from tyre wear is 3.3-6.6 g/year for the CBD catchment, compared to the total catchment load of 3730 g/year, indicating that tyre wear is also a very minor source of lead (0.1-0.2 per cent) (Table 4.13).

Table 4.13

Contributions from vehicle tyre wear to catchment loads (g/ha/yr unless stated).

Element	Catchment	Catchment load	Tyre wear contribution	Percentage of total catchment load (%)
Copper	CBD (commercial)	140	0.04-0.08	<0.1
	Mission Bay (residential)	79	0.03-0.055	<0.1
	Mt Wellington (industrial)	135	0.8-1.66	0.6-1.2
Lead	CBD (commercial)	124	0.11-0.22	<0.1-0.17
	Mission Bay (residential)	60	0.08-0.15	0.13-0.25
	Mt Wellington (industrial)	135	0.08-0.15	<0.1-.0.11
Zinc	CBD (commercial)	1630	338.9-677.7	20.8-41.5
	Mission Bay (residential)	573	234-467.6	40.8-81.6
	Mt Wellington (industrial)	5170	70.4-141	1.4-2.7

In contrast, zinc concentrations are very high in tyres and the emission of zinc from tyre wear is estimated at 10,200 – 20,400 g/year for the CBD catchment. This is clearly a significant source of zinc when compared to a total catchment load of 47,000 g/yr (21-42 per cent). For the Mission Bay and the Mt Wellington catchments the VKT are 24,290/day and 7302/day respectively. The corresponding loads for copper, lead and zinc are summarised in Table 4.13.

Uncertainties

Calculations of tyre wear contributions in this report have been based on traffic numbers within the example catchments, assuming that all vehicles were passenger cars. Estimating contaminant release from vehicle tyres is complicated by a number of factors as identified in Kennedy et al. (2002). These factors include type of vehicle (passenger cars typically have four tyres; buses and heavy commercial vehicles (HCV) can have 6-12 tyres per vehicle) and the factors influencing tyre wear. Kennedy et al. (2002) noted that relative wear rates vary by a factor of 1-1.5 for road roughness; 2 for season (temperature) and vehicle characteristics (eg loading of vehicle, inflation pressure etc.); 4 for tyre brand and 10 for route type and driving style. Some of these factors have been confirmed for New Zealand conditions (refer Kennedy et al. 2002). Some of these wear factors can be reflected in LoS ratings for key roads in catchments. Kennedy et al. (2002) presented wear rates that varied for cars by a factor of two between different LoS (eg 60 to 240 mg/km from LoS levels A/B through to E/F). For buses or HCVs the wear rates ranged from 630 to 2520 mg/km (up to a factor of 10 above passenger cars).

As a result, in some areas such as the CBD, vehicle type is likely to be an important factor, as increased proportions of commercial vehicles and buses are likely to be present compared to catchments such as Mission Bay. As such, site specific refinement using catchment specific vehicle fleet composition and driving conditions is required to remove uncertainty and define the zinc contributions. This is discussed in Section 6.

Summary

Overall, the contribution from tyres to the amount of copper and lead in stormwater is minor. The contribution for zinc is considerably greater, with estimates for a residential catchment ranging from 41 to 82 per cent. There are still considerable uncertainties in the contributions, because they are estimated using generic average emission rates, which do not reflect key aspects of the catchments specific wear rate characteristics.

4.2.7 Exhaust emissions

Vehicle exhaust emissions contribute a wide range of contaminants to the atmosphere, including gases such as carbon monoxide and nitrous oxides, a range of organic compounds such as benzene and polycyclic aromatic hydrocarbons (PAHs), and small particulates such as that measured by PM₁₀. These contaminants are all well-studied in relation to air quality. However, exhaust emissions also contain copper, lead and zinc, which may enter the stormwater system through deposition or rainout (washout during rain events). Measurements of metals in vehicle exhaust (reviewed in Kennedy et al. 2002) indicate emissions of copper are between <1 and 16 µg/km for petrol vehicles and 1 to 20 µg/km for diesel vehicles. Lead emissions range from 2 to 27 µg/km for petrol vehicles and 2 to 90 µg/km for diesel vehicles. Zinc emissions range from 4 to 120 µg/km for petrol vehicles and 6 to 1100 µg/km for diesel vehicles.

For the CBD catchment, the emission of copper from exhaust (14.7 and 88 $\mu\text{g}/\text{km}$ for LDV and HDVs) is estimated as 188 g/yr assuming that all vehicles are light duty vehicles and 1125 g/yr based on all being heavy duty vehicles. This is between 4.4 and 26.7 per cent of the total copper load for the catchment. Similarly, for lead, the exhaust emission is estimated as 141-474 g/yr, or 4-13 per cent of total catchment lead load. For zinc, the exhaust emission is estimated as 581-1746 g/yr, or 1.2-3.7 per cent of total catchment zinc load.

Studies of lead deposition conducted when lead was added to petrol indicated that only a small percentage of lead is deposited within the roadway (Hewitt & Rashed 1990), although during rain events, this is much higher. During dry weather, the emissions may deposit on buildings and in soils within the catchment, and thereby contribute to the overall catchment load of copper, lead and zinc. However, emissions may also be transported out of the catchment. To ensure that sources are not double counted, the contributions of exhaust emissions are considered to be encompassed under rainfall and dry deposition (Section 4.1.3 and 4.1.4).

4.2.8 Vehicle oil, grease and lubricants

As described in Kennedy et al. (2002) there are a variety of oils, greases and lubricants used in motor vehicles. These materials reside in various components of the vehicle power system. Overall, the information summarised in Kennedy et al. (2002) indicated that most of these materials are not lost as part of the routine operation of the vehicle. However losses are evident as visible deposits on roads and in vehicle parking areas, demonstrating that losses do occur. Each of these materials is discussed briefly below.

Vehicle oil

Lubricating oils are used in a vehicle engine to lubricate the moving engine parts to reduce friction, minimise wear and tear and maximise performance. Lubricating oils comprise a base oil stock (mineral/synthetic oil) with additives. New motor oils contain a number of metals from additives including copper, lead and zinc (as anti-oxidants, anti-wear agents). Kennedy et al. (2002) summarised data on concentration of metals in unused oil samples, and as an example found that samples ranged from a mean of 630 to 1360 mg/kg of zinc (Zięba-Palus & Kościelniak 2000).

In addition to the additives present in new oil, used oil becomes progressively contaminated with engine metal wear materials and the products of the fuel's combustion process. This oil is a continuous contributor to the exhaust emission and directly to the road through oil leaks.

Oil loss is known to occur through carry over into the combustion zone (valve stems, piston rings), as well as through leaks and faulty seals during both vehicle operation and when not in use. Kennedy et al. (2002) estimate an oil loss of 2.8 mL/1000 km for cars and most Light Commercial Vehicles (LCVs), and 2.1 mL/1000 km for the largest LCVs, HCVs and buses. These oil loss rates were used in Kennedy et al. (2002), in conjunction with metal concentrations in used oil, to calculate simple emission factors for copper, lead and zinc. For cars and LCVs these were 0.0025 $\mu\text{g}/\text{vehicle}/\text{km}$ for

copper, 0.027 µg/vehicle/km for lead and 2.9 µg/vehicle/km for zinc. The estimated losses associated with HCVs and buses were slightly lower.

Grease and other oils

Grease is used for chassis joint lubrication, bearings (especially wheel bearings) and in the powertrain. Grease generally comprises a solid thickener mixed with liquid oil, with modern formulations also containing a number of sophisticated additives to improve their performance. These additives may include metals.

Gear oil is the lubricating oil that is used in a vehicle's gear box to reduce friction and extend the life of the gears. Gear oils may include zinc dialkyl dithio phosphates (ZDDP). Automatic Transmission Fluids (ATFs) are typically formulated to particular manufacturer specifications (eg GM – DEXRON, Ford – MERCON etc.). ATFs are normally petroleum based, with a complex blend of additives. These additives may include ZPPDs as oxidation inhibitors, metal deactivators, corrosion inhibitors and anti-wear agents.

CRRRI (1982) collected data and developed models for grease and oil consumption, however the quantity of these lubricants lost was found to be small compared with engine oil. Therefore, lubricant losses to the road from greases and these other oils were not considered a significant source in terms of vehicle contaminant loads (Kennedy et al. 2002) and are not considered further in this report.

Contributions from lost engine oil

The emission of copper, lead and zinc from vehicle oils in the CBD, Mt Wellington and Mission Bay catchments can be estimated based on the "simple" emission factors provided in Kennedy et al. (2002) and the traffic information provided in ARC (2005).

For the CBD catchment, the total VKT per day is 35,023. Emission rates for metal losses associated with engine oil loss were estimated to be 0.0025 µg/vehicle/km for copper, 0.027 µg/vehicle/km for lead and 2.9 µg/vehicle/km for zinc (Kennedy et al. 2002), assuming that all vehicles are passenger cars. This equates to an estimated contribution of copper, lead and zinc from engine oil loss of 0.03, 0.35 and 0.37 g/year respectively for the CBD catchment. The total copper, lead and zinc loads in the CBD catchment were reported to be 4210; 3730 and 4900 g/year, indicating that engine oil loss appears to be a minor source of copper, lead and zinc within catchments (<0.1 per cent). It should be noted that there are significant differences in estimated metal contributions from oil loss in the literature. Davis et al. (2001) estimated a copper loss of 0.1 g/ha/year from oil leakage. This is considerably higher than that estimated in this study but is still a minor source. The Davis et al. (2001) estimate would increase the CBD copper contribution to ~1 per cent.

For the Mission Bay and the Mt Wellington catchments the VKT are 24,290/day and 7302/day respectively. As for the CBD catchments, engine oil loss is a negligible source of copper, lead and zinc in these catchments.

4.2.9 Contributions from vehicles to stormwater

The evaluation of vehicle contributions to stormwater contaminant loads has confirmed the importance of brake wear and tyre wear. Tyres are a significant source of zinc and this source becomes increasingly important in catchments where there is little contribution from roofing material. In catchments with significant galvanised surfaces, the vehicle tyre load appears proportionally small, as in Mt Wellington (large roof area, low VKT). Zinc emission rates from tyres are very dependent on driving conditions and other factors (temperature, tyre brand etc.) which vary between catchments. Unless these are taken into account, the use of generic zinc release rates from tyre wear introduces some uncertainty to the estimation of overall catchment zinc loading rates.

While brake pads are a significant source of copper, there remain uncertainties as to what the average copper concentration is in brake pads currently in use in New Zealand. It is possible that estimates in this report underestimate the load of copper contributed from this vehicle source. Copper emission rates from brake pads are very dependent on driving conditions, which vary between catchments. Unless taken into account, the use of average copper release rates from brake pad wear introduces some uncertainty to the estimation of overall catchment loading rates.

Lead is still contributed by a number of vehicle sources. These include, lead wheel weights, with an estimated contribution of ~1 per cent; brake pads with a possible contribution of ~0.5 per cent; vehicle tyre wear with a contribution of about 0.25 per cent; exhaust emissions (note that in terms of summing source loads, these are included in dry deposition estimates). However, further work is needed to confirm the estimated contribution of lead wheel weights to stormwater quality, because of the very high mass of total metallic load likely to be added to catchments from this source.

The major **uncertainties** in assessing vehicle contaminants load contributions to stormwater are:

- The variability associated with vehicle numbers within a given catchment.
- The variability in emission rates with driving conditions between catchments.
- The differences in emission rates for the different vehicle types.

Consequently, for most sources, there is no single emission factor or loading rate that can be used across all catchments to assess vehicle contributions to stormwater.

4.3 Soils

4.3.1 Introduction

ARC (2005) assessed the natural load of suspended solids, copper, lead and zinc discharged from the three study catchments. This involved estimating “background” concentrations based upon concentrations of metals in sub-surface soils collected from within the catchments. The report noted the variations in natural soil chemistry due to differences in composition between soils derived from sedimentary materials and basaltic volcanic materials (in Auckland). Catchment soils are likely to contribute to stormwater in a number of ways. These may include:

- Wind blown exposed soils depositing onto impervious surfaces during dry weather.
- Soils directly washed from exposed surface and subsurface soils close to the pavements, to the stormwater system.
- Vehicle tracking (soil picked up by tyres and then deposited onto pavement surfaces).
- Stormwater transports suspended and bed load solids. Additional particulate matter is derived from wear of aggregate bound into the road surface (stone chip).

ARC (2005) report the total suspended solids load for the Auckland CBD, Mission Bay and Mt Wellington catchments as 9.33, 28 and 8.57 t/year. It was identified that roading stormwater generated 2.06, 1.42 and 0.43 t/year respectively and that by difference, the soils in the catchment contributed 7.27, 26.6 and 8.14 t/year respectively. These catchment loads are used in the following sections.

Overall, soil as a contributing source of copper, lead or zinc to stormwater will depend on the natural background concentrations, the degree of their contamination and the degree of mobilisation. These are discussed further in the following sections.

4.3.2 Natural soil quality

4.3.2.1 Natural soil metal concentrations

Natural soil concentrations of copper, lead and zinc are determined by a number of factors. These factors contribute to the degree of variation in concentration in particulate material in Auckland stormwater.

1. The primary factor is the geochemistry of the geological material from which soils are derived. In Auckland there are a wide range of soil parent materials including volcanics, Waitemata materials, Quaternary sediment, greywacke, limestone, Onerahi Chaos breccia and Manukau breccia (ARC 2002).
2. Soils are additionally subject to bio-chemical changes over time due to the presence of vegetation and passage of rainfall. In certain situations soil chemistry

(eg low pH, anaerobic conditions etc.) will result in the migration and or accumulation of some elements within various horizons of the soil profile.

3. Soil trace element concentrations are also affected by particle size, which also usually reflects soil/parent material mineralogy. Within a given soil, trace element concentrations will typically change with particle size.

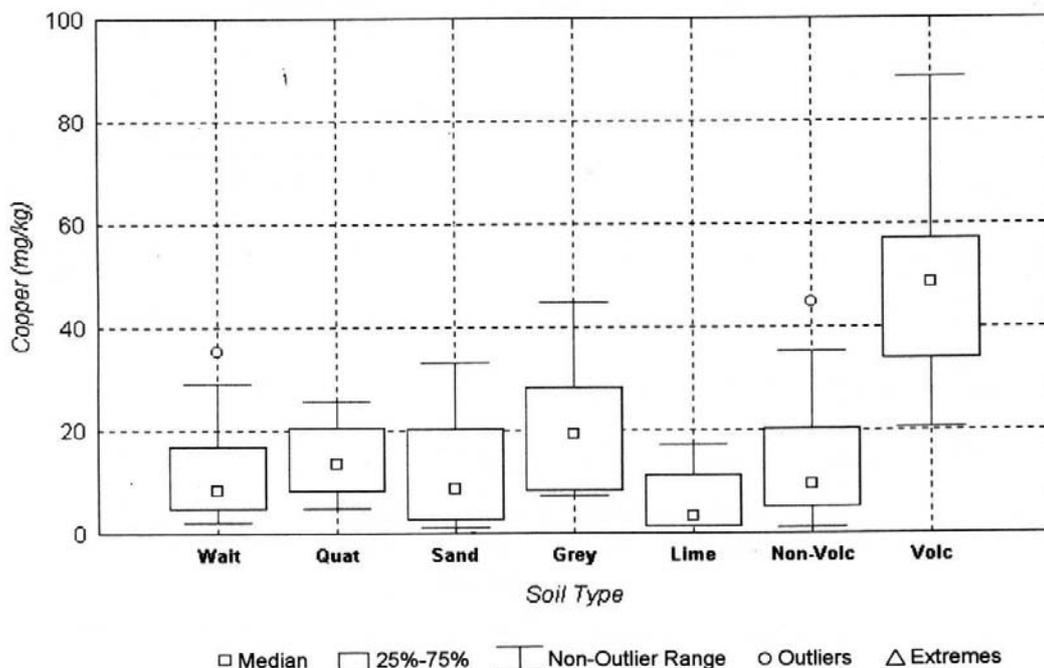
These factors combine to produce vertical and spatial variation in soil trace element concentrations. This variability increases the difficulty in defining the concentration of any element in contributing soil particles entering stormwater. ARC (2002) carried out an assessment of soil “background” trace element concentrations in the Auckland region. Here “background” is regarded as equivalent to the “natural” soil concentration. In the sections below some of the available information on the “background” concentrations of copper, lead and zinc in Auckland soils is examined and compared to the data also reported in ARC (2005).

4.3.2.2 Copper

Copper displays significant concentration differences between volcanic and non volcanic soils in the region (ARC 2002) as shown in Figure 4.5. Upper quartile values mostly below 20 mg/kg.

Figure 4.5

Copper concentrations in Auckland soils (from ARC 2002).



There does not appear to be any analysis of natural suspended particle metal concentrations in run-off in the Auckland region. To provide some additional

information on the concentration of the key metals in fine sediments, data presented in Figure 4.6 illustrates copper concentrations in sediments off East Coast Bays.

That data suggests that fine sediments (where all sediment is <0.063 mm in size) contain about 10 mg/kg copper. This concentration is close to the ARC (2004) non-volcanic background soil concentration (9.8 mg/kg, Table 4.14).

Table 4.14

Copper concentrations in Auckland soils (all data mg/kg).

Soil provenance	Location	Median	Range	N	Source
Non-volcanics	Auckland	9.8	1.1-44.8	58	ARC (2002)
Volcanics	Auckland	48.5	20.6-88.6	42	ARC (2002)

ARC (2005) provided copper in subsurface soils of 20 mg/kg for the CBD and Mission Bay catchments but 50 mg/kg for the Mt Wellington catchment. The latter higher concentration probably reflects a change in local geological conditions (volcanic soils), as it is very similar to the ARC (2002) median concentration for volcanic soils.

The natural soil concentration selected by ARC (2005) for assessing the natural soil contribution to catchment load appear elevated compared to Table 4.14. For the purpose of assessing natural soil contributions to copper loads in stormwater, the ARC (2002) background value of 10 mg/kg has been utilised to calculate loads for the CBD and Mission Bay catchments and the ARC (2005) Mt Wellington soil concentration of 50 mg/kg for that catchment.

4.3.2.3 Lead

Lead concentrations in most urban soils are typically affected by the historic use of lead in petrol in New Zealand. Figure 4.7 provides a summary of Auckland soil quality data in ARC (2002). Table 4.15 provides a comparative summary of the key Auckland data. Sampling of coastal sediments around Auckland provides some data on suspended sediment quality. Sediments off East Coast Bays contain broadly 15-25 mg/kg lead in the fine fraction (<0.063 mm). Given the proximity to the North Shore and Auckland urban areas, an unknown proportion of the 15-25 mg/kg lead measured in near shore sediments will be anthropogenic.

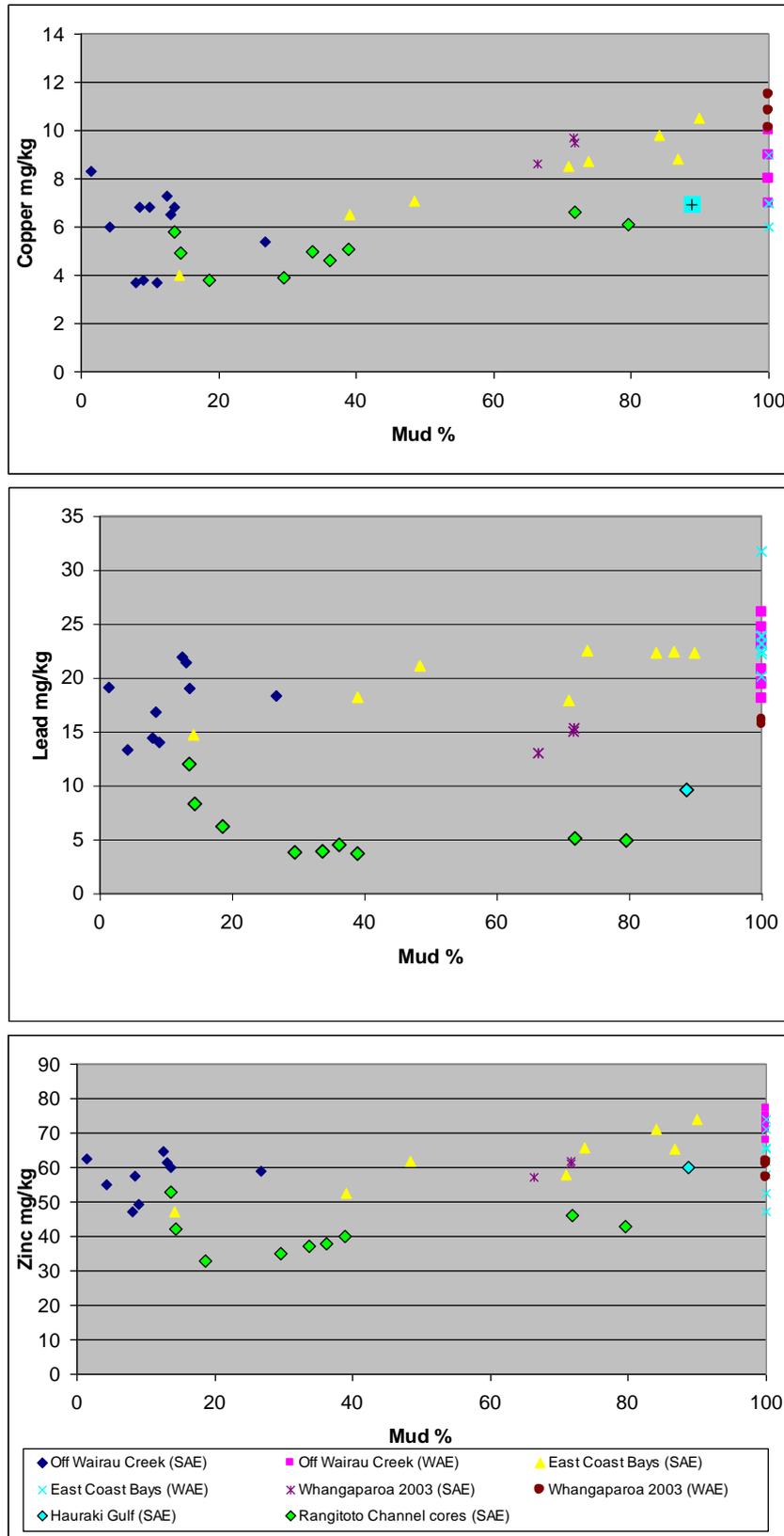
Table 4.15

Lead concentrations in Auckland soils (all data mg/kg).

Soil provenance	Location	Median	Range	N	Source
Non-volcanics	Auckland	12.7	<1.5-56.2	58	ARC (2002)
Volcanics	Auckland	17.3	3-60.2	39	ARC (2002)

Figure 4.6

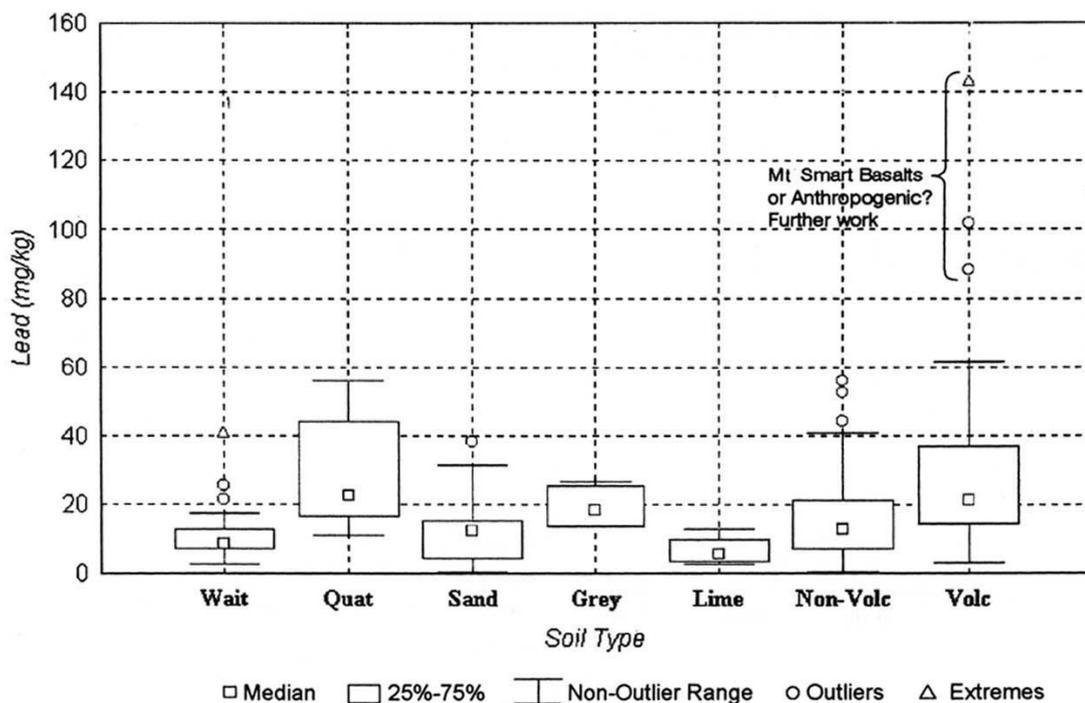
Copper, lead and zinc in sediments off East Coast Bays (From Kingett Mitchell 2003).



ARC (2005) provided sub-surface soil concentrations of lead of 50, 40 and 30 mg/kg for the CBD, Mission Bay and Mt Wellington catchments respectively. All of the median values identified by ARC (2005) are higher than the median soil values identified by ARC (2002). For the purpose of assessing natural soil contributions to lead loads in stormwater, the ARC (2002) background value of 13 mg/kg has been utilised to calculate loads.

Figure 4.7

Lead concentration in Auckland soils (from ARC 2002).



4.3.2.4 Zinc

Zinc concentrations measured in Auckland soils are summarised in Figure 4.8. Table 4.16 provides a comparative summary of the key Auckland data. Sampling of coastal sediments around Auckland provides some indicative data on suspended sediment quality. Sediments off East Coast Bays contain broadly 60-80 mg/kg zinc in the fine fraction of sediment (<0.063 mm). Given the proximity to the North Shore and Auckland urban areas an unknown proportion of the zinc measured in those sediments will be sourced from man-made sources in those urban areas.

ARC (2005) identified sub-surface soil concentrations of zinc of 80, 70 and 130 mg/kg for the CBD, Mission Bay and Mt Wellington catchments. As with copper, the Mt Wellington soil zinc concentration is likely to be the result of the volcanic soils within the catchment. Although the ARC (2005) soil concentrations are higher than the ARC (2002) average, for the purpose of assessing natural soil contributions to zinc loads in stormwater, the ARC (2002) background value of 52 mg/kg has been utilised to

calculate zinc loads transported in stormwater in natural sediment. However, for the Mt Wellington catchment the ARC (2005) value is considered to be more representative of local catchment conditions.

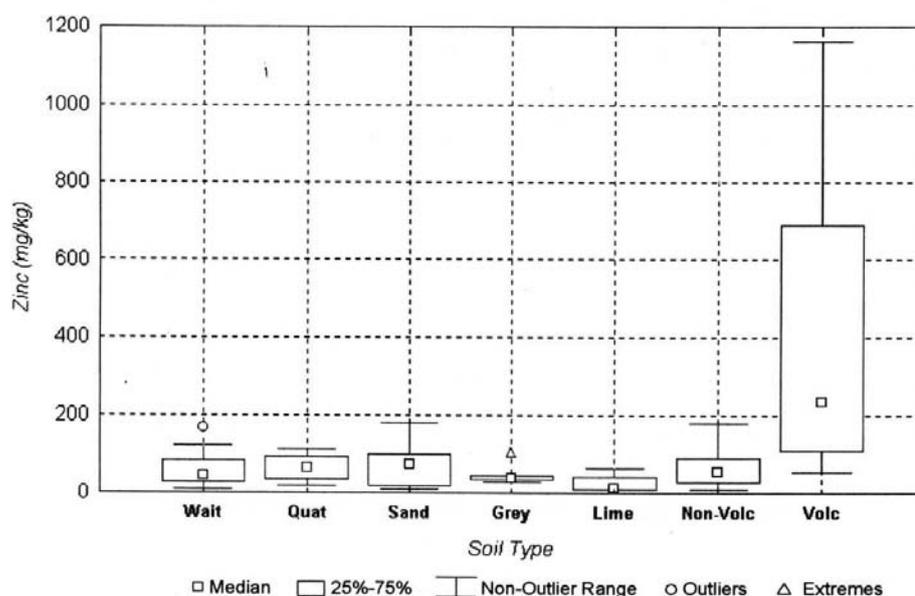
Table 4.16

Zinc concentrations in Auckland soils (all data mg/kg).

Soil provenance	Location	Median	Range	N	Source
Non-volcanics	Auckland	52.1	9.2-179	51	ARC (2002)
Volcanics	Auckland	247	54.5-1160	38	ARC (2002)

Figure 4.8

Zinc concentration in Auckland soils (from ARC 2002).



4.3.2.5 Load contributions and uncertainties

Table 4.17 summaries the contributions to stormwater in the three urban catchments (ARC 2005) from natural soils. It uses the total suspended solids (TSS) loads given in ARC (2005), and soil concentrations described above (from ARC 2002, 2005).

Table 4.17

Contributions from natural soils to catchment metal loads (g/ha/yr unless stated).

Element	Catchment	Catchment load	Load associated with TSS	Total catchment load (%)
TSS	CBD (commercial)	7.27 t/year 241 kg/ha/year	-	-
	Mission Bay (residential)	26.6 t/year 588 kg/ha/year	-	-
	Mt Wellington (industrial)	8.14 t/year 239 kg/ha/year	-	-
Copper	CBD (commercial)	140	2.4	1.7
	Mission Bay (residential)	79	5.88	7.4
	Mt Wellington (industrial)	135	11.95	8.5
Lead	CBD (commercial)	124	3.13	2.5
	Mission Bay (residential)	60	7.64	12.7
	Mt Wellington (industrial)	135	3.11	2.3
Zinc	CBD (commercial)	1630	12.56	0.8
	Mission Bay (residential)	573	30.58	5.3
	Mt Wellington (industrial)	5170	31.07	0.6

Note: Derived from ARC (2005).

Uncertainties

There are uncertainties in the natural concentrations of metals in TSS. Uncertainties of the order of 10-20 per cent in the selected soil concentrations results in a corresponding relative change in the calculated catchment contribution.

The assessment of potential contributions of natural soils to catchment copper, lead and zinc loads shows that natural soils provide a small but identifiable contribution to the load of metals in urban stormwater.

The load contributed is very dependent on the geological provenance of catchment soils, the availability of soil to contribute to suspended solids in stormwater and the total catchment load.

4.3.3 Roadside soils

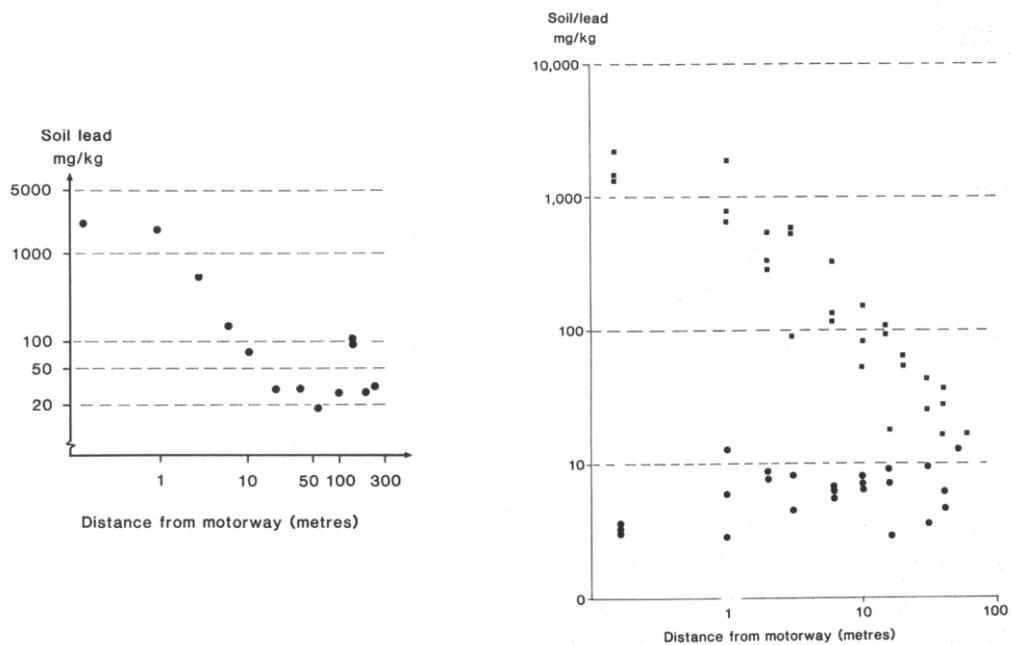
Soils in roadside grass verges and berms can be regarded as a particular category of soil in urban areas, because they are a recipient of contaminants emitted by motor vehicles, thereby creating an additional source of stormwater contamination if they are disturbed or transported to the road surface.

Most information on the contamination of roadside soils in New Zealand relates to lead contamination in terms of deposition patterns. Concentrations of metals in soils adjacent to New Zealand roads have been reported by a number of authors. Ward &

Reeves (1974), Ward et al. (1975), and Collins (1984) found most of the measurable lead within 100 m of the highway. Lead concentrations in soils near motorways in Auckland (Figure 4.9), shows a rapid decline in lead concentration with distance from the source.

Figure 4.9

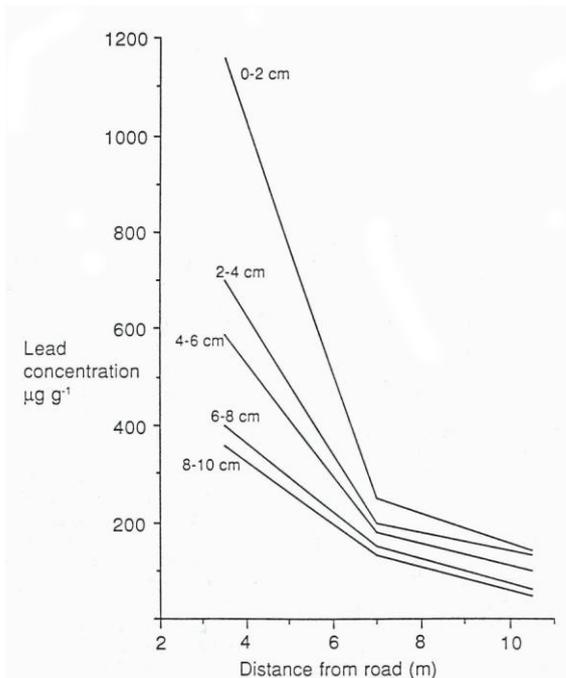
Soil lead concentrations adjacent to the new Northern Motorway at Glenfield (From Kennedy et al. 1988).



Similar soil lead distribution results have been found in Christchurch (Figure 4.10), with lead concentration considerably higher in surface soils within 10 m of busy roads. These elevated concentrations were evident to depths of at least 10 cm in those soils. The roadside contamination for copper and zinc are less evident. The concentration of lead present in soils within a few metres of road edges will be dependent on the length of time that the location was exposed to lead from vehicle emissions, the vehicle numbers in the section of road and the driving conditions (the LoS). As such, roadside soils will have different concentrations of lead. Newer verges constructed since lead was removed from petrol will have low concentrations of lead (reflecting the quality of soil used in the verge and the recent contributions from vehicles (eg lead from brake pads)). Verges that have been present prior to lead being removed from petrol may have high lead concentrations in their soil.

Figure 4.10

Soil lead concentrations adjacent to busy roads in Christchurch (From Fergusson et al. 1980).



Given that most immediate roadside soil in the Auckland area is grassed in berms/verges, it is likely that the principal route of loss to stormwater is through soil disturbance (through vehicle disturbance/tracking or through roadside utility maintenance).

There have been a range of studies that have reported on the concentration of metals in roadside soils. For the purpose of assessing contributions from roadside soil, copper, lead and zinc concentrations of 20, 600 and 100 mg/kg above the natural soil concentration have been assumed (Table 4.18). This lead concentration is a compromise between the higher concentrations that have been identified adjacent to heavy trafficked roads and the lower concentrations that will be present on roads with lower vehicle numbers. The soil contribution was nominally assumed to be 10 per cent of the non-soil TSS load identified in ARC (2005)

Overall, it is likely that should surface soil adjacent to urban roads be disturbed, that the soil addition to the catchment stormwater suspended solids load will provide a small contribution to lead loads (0.6-3.3 per cent) but would contribute negligible copper and zinc (<0.1 per cent).

4.3.4 Garden soils

The most comprehensive database on urban soils (apart from the ARC (2002) soil study) in New Zealand is on garden soils. Garden soils are potentially a source of stormwater contamination, but are also a record of historical contamination by urban activities.

Table 4.18

Copper, lead and zinc contributions from roadside soils (g/ha/yr unless stated).

Element	Catchment	Catchment load (g/ha/year unless stated)*	Assumed additional roadside soil concentration (mg/kg)	Contaminant addition (g/ha/year) based on 10% of road suspended solids load	Addition as a % of catchment load
TSS	CBD (commercial)	2.06 t/year 68.4 kg/ha/year	-	-	
	Mission Bay (residential)	1.42 t/year 31.4 kg/ha/year	-	-	
	Mt Wellington (industrial)	0.43 t/year 12.6 kg/ha/year	-	-	
Copper	CBD (commercial)	140	20	0.14	0.10
	Mission Bay (residential)	79	20	0.06	0.08
	Mt Wellington (industrial)	135	20	0.02	0.01
Lead	CBD (commercial)	124	600	4.1	3.3
	Mission Bay (residential)	60	600	1.88	3.1
	Mt Wellington (industrial)	135	600	0.76	0.6
Zinc	CBD (commercial)	1630	100	0.68	0.04
	Mission Bay (residential)	573	100	0.31	0.05
	Mt Wellington (industrial)	5170	100	0.13	<0.01

Note: * - Derived from ARC (200%), Additional roadside concentration above natural concentration.

Soil quality can vary depending upon previous land use and land use history, proximity to roads (refer above) and activities occurring within property grounds. The latter includes on-site burning, rubbish disposal, use of chemicals, garden products, fertiliser, and house maintenance.

Table 4.19 summarises some unpublished data for copper, lead and zinc in samples of garden and open space soils in Lower Hutt (samples collected in late 1970's). Some rural Wellington soil quality data is included for comparison. The key points arising from the data are:

- Concentrations of lead, zinc and copper can be much higher than natural levels.
- Land use is a factor in soil metal concentrations. Concentrations increase from rural<open space<residential<industrial soils.
- Residential suburbs which are more remote (eg Point Howard in Eastbourne) have lower concentrations of metals than their counterparts in more urbanised areas.
- Differences in concentrations between land use were most evident for lead>zinc>copper.

Table 4.19

Concentrations of total copper, lead and zinc in Wellington soils (Kennedy unpublished, all data mg/kg, dry weight).

Location	Copper	Lead	Zinc
Rural Wellington			
Lake Ponui	17 (9-29)	12 (7-16)	66 (33-161)
Open space			
Gear Island golf course	23 (18-67)	55 (20-192)	92 (64-343)
Schofield St park	20 (18-22)	25 (22-27)	73 (67-83)
Residential			
Petone	37 (19-59)*	273 (48-972)	296 (76-572)
Petone	42 (20-87)	209 (69-693)	268 (84-696)
Gracefield	36 (22-69)	134 (22-385)	175 (77-589)
Point Howard	44 (30-88)	63 (18-128)	111 (63-155)
Industrial			
Gracefield	28 (13-122) (29)	323 (19-1774)	228 (64-1535)
Seaview	64 (20-439) (33)	205 (17-853)	329 (52-1950)

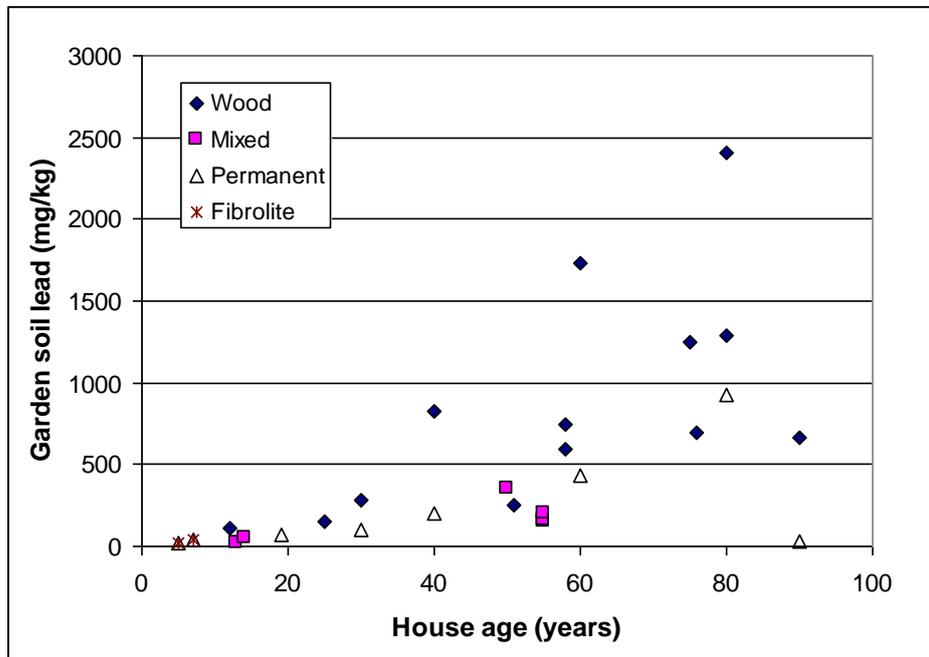
Note: Measured using x-ray spectrometry. Mean, range and number of samples.

In addition to the data summarised above, there has been a range of other soil quality surveys undertaken around New Zealand (eg Jordan & Hogan 1975, Kjellstrom et al. 1978, Reeves et al. 1982, Kennedy et al. 1988) that focus on lead concentrations in garden soils. Samples in these studies were mostly collected adjacent to house walls, where the influence of house exterior wall paint is strongest. Figure 4.11 summarises that data by age and by house exterior wall type. The data (also presented in tabular form in Kennedy et al. 1988) shows that:

- There is typically a progressive increase in lead concentration around houses as a function of age irrespective of house wall type. It should be noted that all of the soils sampled in Figure 4.11 were sampled prior to lead being removed from petrol in New Zealand.
- The elevated concentrations of lead in soils around older wooden walls are a function of the lead concentration in New Zealand exterior wall paints (refer Section 4.7.2). There is a parallel relationship between house age and the lead content of paints.
- Increasing concentrations of lead in soils adjacent to house walls is likely to also be a function of the role that walls play in collecting dust through particle impaction and then washoff. Over periods of years this material containing associated metals will be incorporated into soil beside the wall.
- Soil samples collected from recent subdivisions in Auckland (in Kennedy et al. 1988) were prior to that time in farmland. The land had no significant history of lead contamination from previous occupancy. The concentrations measured in locations where walls were painted fibrolite (lead free) were similar to concentrations measured in rural locations in New Zealand.

Figure 4.11

Lead in garden soils in New Zealand as a function of house age (data from Kennedy et al. 1988).



In summary, garden soils may have high concentrations of copper, lead and zinc. There is also high variability both at a large geographic scale (eg inner city and new housing developments) and at a local on-site scale. The local within-garden soil variability probably arises from a number of activities on-site. Exterior lead based paints have been shown to have a strong influence on the lead concentration in garden soils close to exterior walls.

ARC (2005) identified some near building and distant from building soils concentration data for lead. For the Mission Bay catchment, they identified concentrations of 982 and 35 mg/kg respectively and for Mt Wellington 96 and 55 mg/kg respectively. To account for some contribution from "near building" soils sources, ARC (2005) assumed a 10 per cent contribution from that source. It should be noted that the Mission Bay soil data reported in ARC (2005) ranged from 25 to 4460 mg/kg with a median concentration of 634 mg/kg. This concentration is very similar to the lead concentration in Remuera garden soils of 592 mg/kg reported by Reeves et al. (1982). ARC (2005) used a lead concentration of 500 mg/kg for the 10 per cent of soils that might be derived from near building walls.

There is no published information on the processes that result in any contribution that garden soil may make to stormwater quality. To reach stormwater, garden soil particulates need to be transported to the stormwater system. Transport can take the form of, tracking of soil (via boots and vehicles) to impervious surfaces with subsequent loss to stormwater, on-site works with loss by overland flow or tracking and wind. As the movement is influenced by "behaviour" and good sediment control management practices, it was not possible to identify a specific loss rate. To provide

some preliminary information it was assumed that a specific per cent of the identified TSS load might be sourced from garden soil.

Table 4.20 provides a summary of potential contributions for three scenarios where the TSS in stormwater is sourced from “contaminated” garden soil with elevated concentrations of contaminants (using soils quality data from Table 4.19, as those soils are general garden soils). Background concentrations as defined earlier were subtracted from these soils concentrations. The calculations indicate that where TSS loads are high, contributions from garden soils can be potentially large.

Table 4.20

Summary of potential contributions derived from garden soils (g/ha/yr unless stated).

Element	Catchment	Total catchment load*	Natural soil contribution	Contaminant addition (mg/kg) based on garden soil minus natural concentration	Percentage of total catchment load based on % soil being contaminated (%)		
					10	20	30
TSS	CBD (commercial)	310 kg/ha/year	-	-	-	-	-
	Mission Bay (residential)	620 kg/ha/year	-	-	-	-	-
	Mt Wellington (industrial)	45.2 kg/ha/year	-	-	-	-	-
Copper	CBD (commercial)	140	3.1 (2.2%)**	35.6	2.8	3.3	3.9
	Mission Bay (residential)	79	6.2 (7.8)	29.5	9.4	10.9	12.4
	Mt Wellington (industrial)	252	0.45 (0.3)	35.6	0.4	0.5	0.6
Lead	CBD (commercial)	124	4.0 (3.2)	197	7.85	12.5	17.1
	Mission Bay (residential)	60	8.0 (13.4)	156	28.2	43.0	57.8
	Mt Wellington (industrial)	135	0.6 (0.4)	197	1.0	1.7	2.2
Zinc	CBD (commercial)	1630	16.2 (1.0)	174	1.2	1.45	1.7
	Mission Bay (residential)	573	32.2 (5.6)	160	6.8	8.0	9.1
	Mt Wellington (industrial)	5170	2.35 (<0.1)	174	<0.1	<0.1	<0.1

Note: * - From ARC (2005). * - () = percentage natural soil contribution to total catchment load.

4.3.5 Contributions from urban soils to stormwater

The previous sections have discussed contributions from the natural metal component of soils and the potential contributions from historic contamination of soils within the catchment. These included soils near roads contaminated by vehicle emissions; soils beside house walls contaminated by lead on house exteriors; garden soils contaminated by atmospheric deposition and local garden activities. In addition to these described above, contamination of soils may result from industrial emissions. There are a range of uncertainties in the concentrations present in garden soils and these are described in the inset box.

Variation and uncertainties

The available data shows that there are distinct differences in the concentrations of copper, lead and zinc between different urban areas based on land use (whether it is or has been residential, commercial or industrial) and age of suburb.

If the natural soil element concentration within a catchment is known, then the load exported as part of the stormwater TSS can be calculated. The calculation assumes that the TSS has a similar characteristic to fine inorganic soil particles.

In this assessment the "background" soil quality average data described in Section 4.3.2 were used to assess natural loads and these were summarised in Table 4.17. Soils exposed and contributing to the TSS load in stormwater can be derived from surface soils or exposed subsurface soils.

The proportion of soil types exposed and contributing to TSS will vary between catchments and locations within catchments depending upon construction and ground works locations. The extent of soil contamination for copper, lead or zinc in catchment soils will vary between catchments and with the history of "occupation" of catchment soils.

The contribution of contaminated soils to the copper, lead or zinc loads in stormwater is in addition to that from the natural soil copper, lead or zinc concentration. Due to the variability in the concentration of copper, lead or zinc in urban soils, it is not possible for a simple factor to be used to estimate soil contaminant contributions to stormwater.

In Auckland there are inner city catchments with more than 100 years of urban occupancy and there are suburban catchments less than 10 years old which have been built on farmland.

This spatial and historical difference will result in a net difference in the potential contribution from catchment soils to stormwater. In the case of copper, lead or zinc, available New Zealand data indicates that for a given soil contribution:

- Copper contributions are likely to vary by a factor of two to 10 between residential and commercial/industrial soils.
- Lead contributions from urban catchment soils may vary by up to five to 30 times between inner city catchments and suburban catchments. Lead concentrations are noticeably elevated in soils within 10 m of roadways where the road was built prior to the removal of lead in petrol. There is less conclusive information about increases in copper and zinc in roadside soils. However, given the parallel contamination patterns for copper, lead and zinc in releases from vehicles, it is highly likely that similar soil profiles are also present.
- Zinc contributions are likely to vary by a factor of at least five between inner city residential and commercial/industrial soils.

In summary, there appears to be no specific information to quantify the movement of roadside soil (garden soils, roadside verges) to road surfaces. As such, the contribution from roadside berms that accumulated lead from the period of historical lead use cannot be specifically quantified. However, hypothetical assessments using

actual sediment loads reported for Auckland catchments by ARC (2005) and an assumed range of contributions from contaminated soils (using a typical concentration derived from soil surveys in urban areas in New Zealand) has shown that soil could contribute 3-15 per cent of the catchment copper loads, 8-87 per cent of the lead and 1-12 per cent of the zinc. The derived per cent is dependent upon whether the soil contributed is subsurface (assumed uncontaminated) or surface (contaminated).

4.4 Building interiors as sources of metals

Activities within buildings can release metals inside the building. For completeness, in the assessment of 'sources', information on the quality of the environment inside houses and other buildings was examined to check whether the inside environment of buildings could contribute to the external environment and hence stormwater.

There have been a number of studies that have examined lead in New Zealand house interior environments. Many of these are identified and described by Hay & DeMora (1993). Information from two of these studies is presented below as they provide further information on the geo-spatial variability in metal concentrations and fluxes in urban environments. Kennedy & Kjellstrom (1988) reported data for lead in house dusts in Auckland (Table 4.21). That study, which involved many of the suburbs identified earlier (in relation to garden soil quality), demonstrated that although garden soil lead concentrations were low and the exterior paints were lead free, dust within the house still had high concentrations of lead.

Kennedy et al. (1988) examined lead in house dust in the Auckland area to assess the influence of high traffic volumes from motorways, by comparing Otara and Clover Park (SH-1 motorway) with Mangere (new motorway) and Clendon Park (new suburb away from the motorway). The study showed that there were differences between Clendon Park and the motorway locations. The Clendon Park data showed that even remote from the motorway, lead in house dust was still evident at moderate concentrations (refer Section 4.1.4 – dry deposition and the comments below). Two studies have reported lead concentrations in dust samples from isolated communities (Table 4.21). These showed that lead was still present but at levels lower than Clendon Park.

Fergusson & Schroeder (1985) identified that in new houses, 90 per cent of the lead came from lead in petrol and in older houses about 50 per cent was estimated as being petrol derived. In houses without lead paint, 30 to 50 per cent was derived from aerosols and 40 to 70 per cent from street dusts. In painted houses these percentages change to 15 to 25 per cent and 15 to 20 per cent. Lead aerosols were important in that although they were a small mass (1 per cent) they contained 1.3 to 2 per cent lead. Fergusson & Schroeder (1985) also showed that lead concentration was correlated with increasing traffic density rising from a base concentration of around 460 mg/kg to >1000 mg/kg in areas with high traffic density (Fergusson 1988).

Table 4.21

Lead in interior house dusts in New Zealand (from Kennedy & Kjellstrom 1988, all data mg/kg, dry wt).

Location	Lead concentration	Number of samples	Reference
Remote locations			
Motoroa Island*	250 (90-567)	5	Kennedy et al. (1988)
Chatham Islands	287	17	Malpress et al. (1988)
Auckland			
Otara	827 (489-1944)**	5	Kennedy et al. (1988)
Clover Park	750 (275-1313)**	19	Kennedy et al. (1988)
Mangere	615 (196-784)**	11	Kennedy et al. (1988)
Clendon Park	343 (106-995)	21	Kennedy et al. (1988)
Christchurch			
Avonhead	359	11	Fergusson & Schroeder (1985)
Riccarton	412	11	Fergusson & Schroeder (1985)
Hornby/Sockburn	438	10	Fergusson & Schroeder (1985)
Richmond/Shirley	768	10	Fergusson & Schroeder (1985)
Woolston/Opawa	650	12	Fergusson & Schroeder (1985)
Spreydon	674	11	Fergusson & Schroeder (1985)

Note: All data median and (range) except Malpress et al. (1988) which is average. * Bay of Islands.

**Adjacent to motorway.

There have been a number of studies (relating to child health) that have shown that under some circumstances house dust levels can become very high. Jordan & Hogan (1975) identified that in houses with an average soil lead concentration of 5010 mg/kg, the average house dust concentration was 1060 mg/kg. Studies such as those of Reeves et al. (1982) and Hinton et al. (1988) have shown that lead concentrations in house dusts where lead is present on exterior walls or has been released into the interior of houses as a consequence of renovations can be very high (>2000 mg/kg).

Table 4.22 presents some international data for copper, lead and zinc concentrations in house dusts. The data appears to show some geographical variability between studies, with copper concentrations higher in Hong Kong, high zinc concentrations in Hong Kong and Warsaw and variable lead concentrations.

Table 4.22

Copper, lead and zinc in interior house dusts (data mg/kg, dry wt).

Location (source, suburb etc.)	Copper	Lead	Zinc	Reference
House dusts				
Nevada – old attic dust	81 ± 4	860 ± 40	860 ± 50	Cizdziel & Hodge (2000)
Nevada – new attic dust	51 ± 4	140 ± 10	320 ± 20	Cizdziel & Hodge (2000)
Hong Kong – Mei Foo	296.6	168.6	1261.5	Tong & Lam (2000)
Hong Kong – Tai Po	240.2	71.5	1108.0	Tong & Lam (2000)

Location (source, suburb etc.)	Copper	Lead	Zinc	Reference
Hong Kong – Kwun Tong	806.1	308.4	2119.7	Tong & Lam (2000)
Hong Kong – Tsing Yi	304.0	133.8	1503.6	Tong & Lam (2000)
Warsaw 63-125 µm	109 (48-336)	124 (64-318)	1070 (534-4080)	Lisiewicz et al. (2000)
Warsaw 32-63 µm	132 (56-294)	169 (80-318)	1020 (592-2450)	Lisiewicz et al. (2000)
Warsaw <32 µm	149 (76-609)	206 (91-334)	1070 (609-2100)	Lisiewicz et al. (2000)
Road surface particulates				
Waitakere City <63 µm	297 (142-539)	276 (151-559)	723 (267-2690)	Kennedy & Gadd (2003)

The Nevada study also suggested a difference between older and newer dust, implying that interior dusts can be a reservoir of historic contaminant activity (in the Nevada study the old dusts also contained pesticides that had been phased out whereas they were not detected in the new house dusts).

The study in Warsaw (Lisiewicz et al. 2000) suggested that copper concentrations were higher (by a factor of 2) in flats with occupants, compared to un-occupied flats. The difference was considered to be possibly due to the release of copper from electrical equipment (eg the copper in the electrical windings of vacuum cleaners).

Table 4.21 also contains some comparative data in fine road surface particulates from a New Zealand study (Kennedy & Gadd 2003). The comparison of the fine road dust with the fine dust within houses shows that:

- If the copper house dust concentrations identified overseas are similar to those that might be present in New Zealand, then house dust or activities within houses are not likely to be a significant factor influencing the concentration of copper in any external location.
- For zinc, the interior concentration may be higher in some locations than that found on road surfaces. As such, building interior dust could contribute to external zinc concentrations. The contribution would be dependent upon the mass of interior dust reaching an external location contributing to stormwater quality.
- The concentrations of lead in house dust sampled in New Zealand prior to the removal of lead from vehicle fuels is high (Table 4.22), compared to lead in fine road dusts sampled subsequent to the removal of lead from petrol (median 276 mg/kg Table 4.22). The comparison indicates that for most residential dwellings, lead concentrations in interior dusts would not be high enough to contribute to external lead concentrations. However, as noted above, some older wooden houses in New Zealand with a history of leaded paint on exterior walls and renovations may retain a pool of high lead containing dust. Buildings with elevated lead concentrations within their interiors would be present in higher numbers in older inner city suburbs in Auckland (eg Ponsonby etc.) where exterior walls were painted wood.

There appears to be little published information on the quality of interior dusts in commercial and industrial premises relating to copper, lead and zinc. It is likely, however, that in circumstances where copper, lead and zinc are utilised within the premises for industrial processes and manufacturing that there is potential for interior

building dust to become contaminated. This leads to potential for interior to exterior tracking of copper, lead or zinc to occur. This may result in the contaminants entering the stormwater system on-site or off-site if tracking occurs through the site exits to external roads. Some examples of this were discussed earlier in Section 3.

In summary, houses and other buildings (commercial and industrial) may contain reservoirs of copper, lead and zinc in their interior dusts. Data for residential dwellings indicates that copper concentrations are elevated but not when compared to the concentrations on road surfaces. For zinc however, data suggests that zinc concentrations in interior building dusts may be greater than those measured on road surfaces. As such, building dust could contribute to concentrations in stormwater. Lead concentrations in most dwellings have been historically high but concentrations in houses with lead free paints are similar or lower than those found on road surfaces. However concentrations of lead in the dust within older houses that contained lead in paint can be very high.

There is no information to indicate that interior house dusts contribute in any significant way to stormwater quality apart from an exchange of dust particles between inside and outside of buildings. Reviews to date (such as Fergusson 1988) have focused on the contribution of aerosols and road particulate materials to inside dust composition. It should be noted however, that the most significant time that contributions might occur from interior building dusts would be during building demolition. In older buildings, there may be a significant store of dust in attics and inside walls (with cavities) that may contain elevated concentrations of copper, lead or zinc.

4.5 Road and pavement surface materials

4.5.1 Introduction

The material used to construct roads and pavements may contribute to stormwater contaminant loads through road surface wear during the passage of motor vehicles over these surfaces. The materials used in road construction are primarily bitumen, stone chip (aggregate) and cement. While many reports on stormwater state that wear of road surfaces is a source of contaminants, there is actually very little information on the presence of "contaminants" in road surface materials (other than information on the metal concentration in natural greywacke etc.). It is also difficult to isolate material derived from road surface wear from that of debris from other sources such as tyre wear. The proportion of concrete used in road surfaces in Auckland is minor and as such contributions from this road type are not considered further. The importance of concrete as a non-road surface within urban environments is considered further in Section 4.9.

4.5.2 Road surface materials

Analysis of raw bitumen (Herrington 1993, 2001; Kennedy & Gadd 2000) indicates that bitumen is not a source of copper, lead or zinc as concentrations were below detection limits for copper and lead (0.4-1 mg/kg for copper and 0.2-0.4 mg/kg for lead) (Table 4.23). Metal-enriched bitumen is found however in some countries, and Parnell (1988), reported that copper may be present at up to several thousand parts per million (ppm) in bitumen sourced from Wales and Scotland.

Table 4.23

Copper, lead and zinc concentrations in bitumen and roading materials (all data mg/kg).

Source	Copper	Lead	Zinc	Reference
Raw bitumen (n=6)	<1	<0.2	5.5 (<2-99) *	Kennedy & Gadd (2000)
Road bitumen dust (n=5)*	46.3 (40.0-60.1)	8.3 (1.9-146)	53.5 (47.5-79.9)	Kennedy & Gadd (2000)
Bitumen (B 180)	<17	NM	<17	Lindgren (1996)
Gabbro (roading material)	70.5	21.9	149	Lindgren (1996)
Porphyry (roading material)	2.75	24.9	36.3	Lindgren (1996)
Reclaimed asphalt pavement	11	7	48	Legret et al. (2005)
New asphalt pavement	20	3	86	Legret et al. (2005)
Natural aggregates	14	5	46	Legret et al. (2005)
Roading rocks and gravels (n=9)	11=63	3.3-10.7	38.5-114	Tossavainen & Forssberg (1999)

Note: * Data is median (range). NM – not measured.

It is therefore possible that bitumen used on New Zealand roads may, at times, contain higher concentrations of copper. Very few bitumen samples from Great Britain contained measurable concentrations of lead or zinc (Parnell 1988), similar to the New Zealand results.

Kennedy & Gadd (2000) reported concentrations of copper, lead and zinc in bitumen samples collected from roads following road milling (the process of taking up the bitumen surface during road works) after removal of road aggregate, dust and soil. Copper, lead and zinc concentrations were higher in the bitumen particles examined (Table 4.23) (Kennedy & Gadd 2000). The difference in metal concentration to those of raw bitumen in Table 4.23 is attributed to the incorporation of worn aggregate fines due to the action of vehicles driving on the road surface and the contributions from the contaminants present on the surface of the bitumen contributed by vehicle sources (particulates and soluble contaminants).

A number of studies have measured low concentrations of metals in other roading materials including asphalt (Lindgren 1996; Tossavainen & Forssberg 1999; Legret et al. 2005). Two of these studies also measured the leachability of metals from the roading materials, to investigate this as a source of stormwater contamination. Copper and lead concentrations were typically below detection in leachate from reclaimed asphalt pavement, with a maximum copper concentration of 13 mg/m³ (Legret et al. 2005). Tossavainen & Forssberg (1999) report that 0.3-7.2 per cent of copper found in

roading materials could be leached with water at pH 4. Leaching of lead was similarly low for most materials (0.4-4.5 per cent), though 22 per cent of total lead was leached from one gravel sample. This latter study data is not considered relevant, because such low pH is not found in New Zealand.

Based on the low concentration of copper in present day New Zealand bitumen samples and the relatively low concentration in road bitumen dust, it is unlikely that road bitumen is a major source of copper, lead.

4.5.3 Road marking paint

A range of road marking paints and surfacing materials (eg for Transit lane marking etc) are used on New Zealand roads. Yellow road marking paint is widely used on paved roads in New Zealand. This paint is known to consist of beads, calcium material and $PbCrO_3$ particles (Adachi & Tainosho 2004). The weight (per cent) of lead in road marking paint in Japan was reported to be 13 per cent \pm 5.3 per cent (Adachi & Tainosho 2004).

Murakami et al. (2007) compared the ratios of lead and chromium in a wide range of particle types from road surfaces including yellow road line markings, exhaust soot, brakes and tyres. They identified yellow road marking paint particles as a source of lead and chromium.

Of the identified sources, yellow road line markings were found to contain lead at higher concentrations than heavy traffic road dust and may contribute to stormwater through road surface wear. This suggests that yellow road marking paint could be a possible source of lead in road dust. Estimating the contribution would require information on marking paint wear losses, which is not available.

4.5.4 Road surface materials wear

The wear rate of roading surfaces depends on the construction material and the traffic movement over the surface. Much of the international information on road wear rates relates to the de-icers or studded tyres, used during winter, which is clearly not applicable to the Auckland road situation. Wear rates for New Zealand roads have been previously estimated as 0.09-0.44 g/km (Kennedy et al. 2002).

Although discussed in the sections above, the material worn from road surfaces includes physical particulate material derived from the road construction (the aggregate, bitumen), road marking paints and material forced into the surface through the action of vehicle tyres or infiltrating through the action of water on the road.

ARC (2005) identified that the TSS load from the CBD, Mission Bay and Mt Wellington catchments were 7270, 26,600 and 8140 kg/year respectively. Based on the VKT in each of the catchments, the calculated wear rate contributions are 1150-5624 kg/year for the CBD (ARC (2005) estimated 2060 kg/yr), 798-3901 kg/year for Mission Bay (ARC estimated 1420 kg/yr) and 240-1172 kg/year for the Wellington catchment (ARC estimated 430 kg/yr). These wear rate loads are 16-77 per cent, 3-14.6 per cent and 3-

14.3 per cent of the estimated catchment TSS loads. In the case of each catchment, the ARC (2005) road contribution is within the wear rate estimate presented here. The wear rate contributions are higher in the CBD due to the lower TSS load and the higher VKT load (and hence calculated TSS wear contribution).

If the “average” potential road surface wear rates were used, then in two of the ARC (2005) catchments, wear of road surfaces could contribute 10 per cent of the TSS load that has been measured as leaving the catchment. In the CBD catchment, the estimated proportion is higher but may not be unreasonable as there are limited sources of TSS within that catchment.

4.5.5 Contributions from road surfaces wear to stormwater

Road surface wear contributes particulate material and contaminants to stormwater. The contribution of particles from aggregate wear to stormwater will have been accounted for in the TSS load calculated for each of the three ARC catchments (ARC 2005) as the TSS includes many sources including road wear. The contaminant contribution becomes important if the wear contributes copper, lead or zinc in amounts greater than that seen in catchment soil.

Overall, road surface wear is unlikely to be more than a minor source of copper, lead or zinc to stormwater. Available data implies that road marking paints may be a source of lead. Further information on road marking paint composition in New Zealand is required and information on road marking paint wear rates is also required to assess load contributions.

The data in Table 4.23 does not provide sufficient information to establish what additional contaminant load road surface wear might contribute to stormwater. The lead and zinc data from Kennedy & Gadd (2000) is lower than that found in catchment soils, so a contribution from wear cannot be identified. For copper the concentration of 46 mg/kg is greater than that in estimated background of 20 mg/kg in the CBD and Mission Bay but similar to the background estimated for Mt Wellington. The estimated contribution of road wear to copper in stormwater is 3 per cent for the CBD and Mission Bay catchments and 1.6 per cent for the Mission Bay and Mt Wellington catchments. No estimate is provided for lead or zinc.

4.6 Building roofs

4.6.1 Introduction

Roofs in urban areas are complex components of impervious surfaces which contribute to stormwater quantity and quality. Roof run-off typically contains elevated concentrations of trace metals such as copper, lead and zinc, leached from weathered metal roofing material, and from deposited particles on the roof surface (Good 1993; Quek & Förster 1993; Förster 1996, 1999; Zobrist et al. 2000; Michels et al. 2002).

While roof run-off quality has been identified as a significant factor in urban stormwater quality, there is little published information on this in New Zealand. ARC (2004) investigated roof run-off quality in the Auckland region, including the effect of roof type and surrounding land use on roof run-off quality. This study looked at a range of common roof types, including concrete tile, decramastic tile, painted steel tile and long-run colour steel. In addition, Pennington (2004) has investigated copper concentrations in the run-off from copper roofs and copper gutters, also in the Auckland region. The key findings of these studies are described in the following sections.

4.6.2 General roof run-off

The ARC (2004) study involved two modules of work. The first module of work investigated the effect of roof type on run-off quality, and involved the collection of run-off samples from new artificial roof panels, and existing roofs within the rural environment, in the absence of other land use effects. The second module of work investigated the influence of land use on roof run-off quality.

New roofs

ARC (2004) constructed artificial roof structures, comprising of wooden frames approximately 4 m x 1.2 m onto which the test roofing material and a section of guttering was attached. Concrete-tile, decramastic tile, painted steel-tile and long-run colour steel roofing were selected as the test roofing materials, in accordance with the trends in roofing material adopted on new houses in the Auckland region. Samples were collected from each roof type across four rain events and examined for pH, conductivity, suspended solids and total recoverable copper, lead and zinc. In addition, one first flush/post-first flush sample was collected from each roofing material and examined for the above parameters and dissolved zinc. Table 4.24 presents a summary of the copper, lead and zinc concentrations measured in the run-off from the artificial roof panels.

The data shows that some roof surfaces are relatively un-reactive while others contribute significant concentrations of zinc as a result of oxidative wear and acidic corrosion (ARC 2004). Concentrations of zinc varied by a factor of 10 between events and roof types, however the decramastic and colour steel tile roofs were shown to have on average the highest concentration of total recoverable (TR) zinc in roof run-off (43 and 29 mg/m³ respectively). In contrast, the concentration of copper and lead were low in most run-off samples. This demonstrates that the roof types commonly used on new houses in Auckland are not a significant source of either copper or lead.

Table 4.24

Total recoverable (TR) and dissolved metal concentrations in run-off from artificial roofs (ARC 2004).

Roof type	TR copper	TR lead	TR zinc	Dissolved zinc
Colour steel tiles	<0.5 (<0.5-2.0)	<0.1 (<0.1-0.3)	29 (17-37)	29*

Roof type	TR copper	TR lead	TR zinc	Dissolved zinc
Concrete tile	0.5 (<0.5-1.4)	0.2 (<0.1-0.8)	20 (6.0-25)	1.2
Decramastic	0.8 (<0.5-1.6)	<0.1 (<0.1-<0.1)	43 (30-55)	22
Long run colour steel	<0.5 (<0.5-0.9)	<0.1 (<0.1-0.8)	11 (9.0-26)	1.6

Note: All data mg/m³. Data reported: median (range). Count: n = 5, except for dissolved zinc where n = 1.
*calculated from the concentrations in the first flush and bulk samples.

Existing roofs – galvanised iron

This module of work undertaken by ARC (2004) involved the collection of run-off samples from existing roofs within the rural environment. This work focussed on galvanised iron roofing, as it was found to be the dominant type of roofing in rural Auckland. Run-off samples were collected from 25 painted galvanised iron roofs (in a range of grades of weathering), along with five unpainted galvanised roofs and five Zinalume roofs.

Samples were collected from up to five rain events for each roof grading and examined as per the artificial roof sampling schedule described above. Table 4.25 presents a summary of total recoverable and dissolved copper, lead and zinc concentrations measured in the run-off from the existing galvanised iron roofs (for the five roof grades) and unpainted galvanised iron from ARC (2004).

The results show that potentially high concentrations of zinc can be found in roof run-off where the protective paint layer has deteriorated, even only marginally (ie to visible paint oxidation with minor flaking – Grade 4). In addition, unpainted metal roofs had variable, but typically high concentrations of zinc.

Copper was not detected in half of the run-off samples, (detection limit 0.5 mg/m³). For those samples where copper was detected, the concentrations were low; median concentration was 1.3 mg/m³, while the maximum concentration was only 4.7 mg/m³. For lead, the median concentration measured was about 13 mg/m³, but moderate concentrations could be found (up to 148 mg/m³). The source of lead was thought to be dry deposition or lead fittings (eg lead-head nails), but this was not confirmed in this study.

Table 4.25

Total recoverable (TR) and dissolved copper, lead and zinc in run-off from galvanised iron roofs (From ARC 2004).

Roof type	TR copper	Dissolved copper	TR lead	Dissolved lead	TR zinc	Dissolved zinc
GI (5)	< 0.5 (<0.5-0.5)	< 0.5 (< 0.5-0.5)	0.8 (0.3-62)	0.2 (<0.1-7.6)	151 (45-201)	100 (37-150)
GI (4)	0.7 (<0.5-2.1)	-	1.0 (0.5-10)	-	900 (200-2900)	-
GI (3)	<0.5 (<0.5-2.1)	<0.5 (<0.5-3.0)	18 (6.6-35)	2.9 (1.0-9.3)	1130 (890-2600)	1400 (700-2400)
GI (2)	< 0.5 (<0.5-2.4)	<0.5	14 (6.9-45)	1.6	1000 (600-2000)	1200

Roof type	TR copper	Dissolved copper	TR lead	Dissolved lead	TR zinc	Dissolved zinc
GI (1)	1.3 (0.6-2.2)	0.9 (0.6-1.3)	20 (7.5-148)	4.2 (1.4-6.9)	2700 (1400-3300)	2000 (1300-2800)
GIU	< 0.5 (<0.5-0.5)	<0.5 (<0.5-<0.5)	3.2 (0.7-24)	2.6 (0.4-4.7)	2500 (100-3100)	2100 (1700-2500)

Note: Data reported: mg/m³, mean (range). ¹ These refer to the condition of the roof, GI (5) excellent, GI (4) good, GI (3) moderate, GI (2) deteriorating, GI (1) poor, GIU unpainted galvanized iron, more details provided in ARC (2004). Total metals count: n = 5 (GI (5), GI (3), GI (2) and GIU); n = 4 (GI (4) and GI (1)). Dissolved metals count: n = 3 (GI (5) and GI (3)); n = 2 (GI (1) and GIU); n = 1 (GI (2)).

Modern galvanised roofing and galvanised building components

Information on the quality of run-off from modern Zinalume roofing materials has been collected and reported in ARC (2004) and also in Tonkin & Taylor (2004). However, the combined data set does not include many real roofs or many older roofs.

Data in ARC (2004) from four building roofs indicates median copper and lead concentrations of 0.9 and 0.5 mg/m³ in run-off. For zinc, the total number of roof samples was three (one not suitable and a duplicate) with a median value of 0.19 g/m³. Similar data was presented by Tonkin & Taylor (2004).

Washington State Department of Ecology (WSDE) (2006) investigated potential sources of zinc in stormwater run-off from industrial facilities. This study found that many industrial facility roofs supported galvanised metal surfaces including ductwork, heating/ventilation/air-conditioning equipment, ventilation fans, turbines, or pipes, which could contribute zinc to the stormwater system. These galvanised metal structures are normally unpainted. However, given that these structures are of various shapes and orientations (as opposed to the roofs), there may be some differences in contact time of rainwater with the structure surface leading to lower concentrations in the run-off.

Effect of land use

The second module of work by ARC (2004) investigated the influence of land use on roof run-off quality. Run-off samples were collected from three artificial long run colour steel roofs, which were located in representative industrial and residential land use locations in Auckland. Samples were collected for up to five rain events, and examined as per the artificial roof sampling schedule. Table 4.26 presents a summary of the copper, lead and zinc concentrations measured in the run-off from the long run artificial roof panels in each land use area.

Table 4.26

Total recoverable (TR) and dissolved copper, lead and zinc in run-off from long run artificial colour steel roofing in industrial, residential and motorway land use areas (From ARC 2004).

Land use	TR copper	Diss. copper	TR lead	Diss. lead	TR zinc	Diss. zinc
Industrial	2.5 (1.0-22)	1.1 (0.6 - 1.8)	2.3 (0.7-69)	0.2 (0.1- 0.8)	85 (29-750)	69 (30-78)
Residential	0.8 (<0.5-2.3)	<0.5 (<0.5-<0.5)	0.4 (0.1-3.5)	<0.05 (<0.05-<0.05)	15 (10-46)	6.4 (4.4-8.6)

Land use	TR copper	Diss. copper	TR lead	Diss. lead	TR zinc	Diss. zinc
Motorway	2.3 (0.9-5.8)	0.7 (0.7-0.9)	0.8 (0.2-2.4)	0.1 (0.1-0.1)	17 (10-33)	11 (11-12)

Note: Data reported: mg/m³, mean (standard deviation); Number of samples - Total recoverable metals industrial, n=15; residential and motorway, n=14; Dissolved metals, n = 3.

The results show that the concentration of total recoverable copper in run-off collected from the industrial sites was more variable and generally higher than run-off from other urban and rural locations. Copper concentrations were generally low (usually a few mg/m³), but occasionally elevated concentrations were found in the first flush or at the industrial sites. No first flush effect was seen for the rural site because the concentration of total recoverable copper was below detection limits in both the first flush and post first flush collections. These results suggest that urban land use increases the concentration of total recoverable copper in roof run-off, especially in the first flush.

The concentrations of total recoverable lead in run-off from the industrial sites was generally higher than those in run-off from residential urban locations, which in turn, were greater than concentrations recorded at the rural-land use site. The median total recoverable lead concentrations at industrial sites were similar (~12 mg/m³), and more than double those recorded at other urban sites. The median concentration of total recoverable lead in run-off at the rural site was 0.8 mg/m³, with the concentrations measured at this site below detection limits (<0.01 mg/m³) on two out of five sampling occasions. The concentration of total recoverable lead in the run-off at one industrial site was more than a magnitude higher than measurements at the two other industrial sites. The results suggest that the concentration of total recoverable lead in the run-off at the first industrial site was strongly influenced by activities specific to the site. The effect of first flush on the concentration of total recoverable lead across the different land use types was variable. No first flush effect was evident for dissolved lead and most dissolved lead concentrations were below detection limits (<0.00001 g/m³) on most occasions, at all three residential sites.

The effect of land use on concentrations of total recoverable zinc in run-off was significant, with the concentration of zinc in run-off from the industrial sites higher and more variable than that from the residential and rural locations. The concentrations of total recoverable zinc in run-off between replicates from the other urban and rural land uses were similar. In contrast, the median concentrations between the industrial site replicates differed considerably, as did the variation in concentration between rain events. For example, one site recorded maximum and minimum concentrations of 0.75 g/m³ and 0.04 g/m³ respectively. The effect of first flush on the concentration of total recoverable zinc in run-off from the industrial and urban sites was strong (ARC 2004). The first flush total recoverable zinc concentration was at least twice that of the post first flush concentration at all industrial and urban locations, and on one occasion ten times greater. In contrast, the rural site did not demonstrate a first flush effect. A significant proportion of the zinc in run-off collected from the industrial sites sampled in ARC (2004) was dissolved (range of six samples, 85–100 per cent).

Overall, the results of analyses for total recoverable zinc in roof run-off from different land uses suggest that both general industrial activities and those operations specific

to individual industrial sites influence the concentration of total recoverable zinc in roof run-off. Overall, local atmospheric emissions can affect roof run-off quality with the concentration of zinc, copper and lead increasing by 2, 3.5 and 12 times that found in other industrial sites.

Uncertainties

The information presented in studies such as ARC (2004) has been utilised to derive catchment roof run-off loads for key contaminants in subsequent reports such as ARC (2005). Estimated contaminant loads from roof run-off are only as good as:

1. The assessment of roof types within the catchment and the estimation of mean roof type run-off quality concentrations for the key contaminants.
2. The land use within the catchment.

Roof type assessment is essential to accurately assess contributions of metals in roof run-off. This is especially the case where copper, lead or zinc is used as primary roof surface materials. Lead is not an important roofing material in New Zealand. As discussed elsewhere, lead is used in some situations on roofs (eg in flashings and lead headed nails – refer Section 4.6.4 below) and copper is used currently in minor amounts on roofs, facades and down-pipes (refer next section).

For the assessment of zinc loads, the assessment of roof condition is very important where galvanised iron is a common roofing material within the catchment. ARC (2004) showed that the zinc concentration in run-off can vary by a factor of 10-20 (for TR and dissolved zinc). As such, errors in assessing galvanised iron roof condition can lead to moderate errors in estimated zinc concentration and hence loads. The actual loads depend upon the per cent roof area in any given galvanised iron category (Table 4.25). It must be assumed that there are errors associated with the assessment of roof type that could bias roof type identification slightly. There is limited data on zinc concentration by roof condition (refer ARC 2004).

In situations where estimates of zinc loads in catchment run-off are being made without any quantified roof type information (with a focus on condition of galvanised iron roofs), the errors associated with roof run-off zinc loads will be large – the error increasing as the proportion of galvanised iron roofs increases. Due to the limited data for run-off quality from galvanised iron roofs there must be some error associated with the zinc concentration data. Given that the grade GI 2-4 roofs have similar concentrations, this error is unlikely to be <10 per cent or <100 mg/m³.

The measurement of roof run-off quality in different land uses (ARC 2004) showed that there could be a five fold variation in the TR lead and zinc concentration due to the presence of metal emitting industries. The contaminant loading variation resulting from industry emissions manifests itself in changes in dry deposition loading and as such affects all impervious surfaces rather than just roofs.

Although the concentrations identified in the land use effects are low compared to the concentrations measured from galvanised iron roofs, this spatial difference adds to the uncertainties in estimating metal contaminant loadings between and within catchments. These two uncertainties will consequently provide a minimum level of error to load estimates. This uncertainty will be at least 10 per cent but could amount to 20 per cent or greater.

Overall, to reduce the uncertainty in the roof run-off zinc load estimates, further work would need to be carried out to confirm the variation in zinc concentration as a function of the condition in galvanised iron roofs. Further data would also need to be collected on zinc concentrations in Zinalume roof run-off, given that Zinalume roofs are becoming increasingly important as a substitute for galvanised iron roofs.

4.6.3 Copper roofs

Traditionally, New Zealand has been a relatively small market for copper roofing, with copper roofs most commonly used on churches, schools, and other public buildings. However, there is evidence to suggest that copper use is increasing, with copper roofs being installed as a residential roofing product and copper guttering being used as a more aesthetically-pleasing alternative to plastic or galvanised iron spouting on new domestic and institutional dwellings (Pennington, 2006). In the last 10 years, a series of papers in the international literature have revealed relatively high concentrations of copper in copper roof and gutter run-off (Barron 2000; Boulanger et al. 1999; Michels et al. 2002; Mottier & Boller 1996; Nikolaidis 1999; Wallinder & Leygraf 1997; Wallinder & Leygraf 2001; Wallinder et al. 2000; Zobrist et al. 2000).

More recently in New Zealand, Pennington (2004) investigated copper levels in the run-off from copper roofs and a copper drainage system (guttering and down pipes) in the Auckland urban area. This study found high concentrations of copper. For example, full copper roofs generated run-off with concentration of up to 7690 mg/m³ copper, predominantly present as dissolved, free copper ion (Cu²⁺), due to the low pH of the rainwater run-off (Pennington, 2004). With a maximum of 590 mg/m³ copper, concentrations in the run-off from the concrete tile roof with copper guttering and down pipes were lower than those of full copper roofs, but still considerably elevated and of concern, given the escalating use of copper gutters with a variety of different roofing types in New Zealand. In the run-off from this roof, the portion of dissolved and free Cu²⁺ was less due to the pH buffering effect of the cement-based roofing material (Pennington, 2004). A "first flush" effect was demonstrated in most rain events; this was thought to be due to the removal of particulate copper corrosion products and organic copper-rich aggregates on the roof surface, however copper concentrations were shown to remain relatively high throughout the rain event. Results from Pennington (2004) show that copper concentrations were in the upper range of literature values reported previously in studies overseas for full copper roof run-off composition (Table 4.27). Copper concentrations in copper gutter run-off were in the lower range of literature values (Table 4.28). However, only a single copper gutter was examined in Pennington (2006).

Table 4.27

Comparison between average copper concentrations in copper roof run-off (all data mg/m³) (Pennington 2006).

Acid-soluble copper	Roof description	Reference
900	6 yr old, 1100 m ² roof	Nikolaidis (1999)
2100	6 yr old, 1100 m ² roof	Boulangier et al. (1999)
3630 ± 1760	10 yr old, 1800 m ² roof	Michels et al. (2002)
1460 ± 840	71 yr old, 1258 m ² roof	Michels et al. (2002)
2320 (825-7690)	8 yr old, 384 m ² roof	Pennington (2006)
1010 (457-4000)	37 yr old, 102 m ² roof	Pennington (2006)
1220 (839-2050)	45 yr old, 370 m ² roof	Pennington (2006)

Note: Data reported: Average (range, where provided). Count: Michels et al. (2002) n ~ 384, this study n = 215. ¹Cited in Barron (2000).

Based on the copper roof run-off work carried out by Pennington (2006), the small area of copper roof material (138 m²) in the CBD catchment (ARC 2005) would produce 1220 mg/m³ copper in run-off. This equates to a discharge of 192 g/yr from the catchment, or 4.6 per cent of the CBD catchment load.

Table 4.28

Comparison between average copper concentrations in copper gutter run-off (all data mg/m³) (Pennington 2006).

Acid-soluble copper	Roof/Sample description	Reference
230	New gutter	Mottier & Boller (1996)
842	New gutter – first flush	Zobrist et al. (2000)
217	New gutter – levelling off concentration	
304	15-year-old gutter – first flush	Zobrist et al. (2000)
71	15-year-old gutter – levelling off concentration	
280	10-year-old gutter – first flush	Pennington (2004)
170	10-year-old gutter – established flow	

Note: Count: Zobrist et al. (2000) n = nine rain events, sample numbers were not disclosed. ¹Mean 0 – 2 mm run-off depth; ²T = 0 mins, ³T ≥ 4 mins, mean of n = 11.

4.6.4 Other roof materials

4.6.4.1 Lead head nails and lead flashing

Lead has historically been used on lead headed nails to fix metal roofing materials such as galvanised iron to roofs. Lead flashing has also been used on roofs to assist in waterproofing.

To provide an initial indication of contribution from lead nails on a house roof, a hypothetical example is provided. With potentially 250-450 nail heads on a roof, each

with a surface area of 2 cm², would provide 0.005-0.009 m² of surface area. If it was assumed that solubilisation rates were of the order of 14 g/m²/yr, (see Section 4.2.4) these lead head nails would contribute about 0.07-0.13 g/yr to roof run-off for each house with lead head nails still in use.

Lead head nails use is likely to be predominantly historic and associated with older galvanised roofed dwellings. As such their use is likely to be patchy though older communities, with their presence declining as galvanized roofs are replaced. Table 4.29 summarises a possible lead head nails contribution based on the house contribution noted above and a contribution from 10 house roofs per hectare. For Mission Bay this may be realistic, but for the CBD and Mt Wellington catchments the number of lead headed nails present is unknown. For the purpose of this assessment the numbers of houses used per hectare for Mission Bay is assumed.

Table 4.29

Summary of possible contributions from lead headed nails (g/ha/yr unless stated).

Catchment	Catchment load	Lead headed nail contribution	Percentage of total catchment load (%)
CBD (commercial)	124	0.7-1.3	0.6-1.0
Mission Bay (residential)	60	0.7-1.3	1.2-2.2
Mt Wellington (industrial)	135	0.7-1.3	0.5-1.0

Note: Catchment load data from ARC (2005).

The summary suggests that lead head nails may provide a small but measurable contribution of lead to stormwater run-off. No quantitative information is available at this stage on the amount of lead sheet flashing on buildings in Auckland catchments. In the field surveys, lead flashings were noted on a range of buildings especially in residential areas.

4.6.4.2 Shingles

Some composite roofing shingles are treated with ceramic-coated copper or zinc fortified granules to retard moss and mildew growth. The copper/zinc granules will be subject to atmospheric corrosion, releasing the copper/zinc into the run-off from the roof.

Limited test carried out in California indicate that ordinary composite shingles contain about 12.7 mg/kg of copper, although only a limited amount appears to be released via rainfall (0.01-0.04 mg/m³; Barron 2000). Algicide treated shingles were found to contain approximately 24.5 mg/kg of copper, much of which is positioned as granules on the surface where it is released via rainfall for at least 10 years (0.1-1.0 mg/m³; Barron 2000).

Overall, visual observations suggest that there are few shingle roofs in the Auckland region, so the significance of this type of roofing product as a source of copper/zinc in Auckland is considered to be negligible.

4.6.4.3 Anti-growth agents

Some other roofing tiles used in New Zealand are also impregnated with copper in the surface materials to control the growth of plants on the tiles. This may also be included in the materials used to re-coat and clean roof surfaces. No quantitative information on the use of these products was available.

The use of copper mesh (on the apex of roofs) was also noted on some internet websites as a means of retarding lichen growth on roof surfaces through the ecotoxicological properties of copper.

If the loss rates for other products noted above are utilised, and it is assumed that five houses in a given one hectare catchment area have these products, then copper anti-growth agents on roofs could contribute 250 mg copper/ha/year. This is about <0.5 per cent of the catchment loads measured at the three urban catchments in the ARC (2005) study.

4.6.5 Paint on roofs

4.6.5.1 Paint quality

A variety of inorganic elements may be present and used in paints. Inorganic compounds and organic compounds containing metals have a variety of uses in paint formulations. A number of trace elements have been used as fungicidal or biocidal agents in the paints to prevent the growth of fungi and other micro-organisms. The exact usage of such biocides in roof paints is not known, but compounds such as cupric hydroxide, zinc oxide and a variety of other compounds have been used.

Primers often contain metals as part of the protective barrier formulation that the paints provide to the underlying roof surface. This was one of the reasons why red-lead was used as much as a primer. Paints may also include metal phosphates to provide anodic or cathodic protection. Over time compounds such as zinc phosphate, zinc/iron phosphate, various chromates and a range of molybdates have been used for these purposes. Zinc-rich primers are used on metals to provide cathodic protection.

ARC (2004) report on the presence of copper, lead and zinc in new roof primers, roof paints and in "old" paints on rural roofs. Table 4.30 summarises the data presented in ARC (2004). The analysis of a cross-section of currently available new roof paints shows that lead was only present at low concentrations. Copper was found in moderate concentrations in many of the paint samples analysed; concentrations ranged up to 1090 mg/kg. The results of this study show that zinc is still an important component of paints and six of the 21 paint samples (~30 per cent) examined in this study contained high concentrations of zinc.

Table 4.30

Summary of trace elements concentrations in new primers, paints and paint samples from rural galvanised iron roofs (ARC 2004).

Element	New primer	New paint	Old paint
Copper	4.8 (1.2-41.8)	67.7 (0.6-1090)	52.5 (15.9-338)
Lead	1.0 (0.4-57.1)	1.15 (<0.2-3.8)	3525 (571-153,000)
Zinc	26,931 (77-180,000)	39 (<5-4410)	17,700 (12,600-446,000)
Number of samples	6	14	8

Note: All data mg/kg dry weight; median (range).

The analysis of the old paints indicated that there are some significant differences in metal content between the old paint samples compared to the new surface paints and primers. The data indicates that many trace elements are present in higher concentrations in the roof paints already on roofs compared to paints currently sold for use on roofs in New Zealand. Of particular note is the higher lead concentration in the old roof paints. The high lead concentrations probably reflect the presence of primer in the sampled roof paints.

So while the use of lead-based primers in house paints has ceased, there is an unknown amount of lead present on house roofs as a result of the historic use of lead-based primers, which may be a significant source of lead to urban stormwater. In addition, zinc was shown to still be an important component of roof paints. The presence of low concentrations of copper in older roof paints and significant amounts of lead implies that old paints on roofs could contribute to their loads in stormwater. Information in ARC (2004) shows that galvanised iron roofs contribute lead to stormwater with an average contribution of 0.017 g/m³ for types GI 1-3 (refer ARC 2004). The copper and lead concentrations from new unpainted galvanised iron were low compared to older painted iron roofs. Zinc concentrations in unpainted galvanised roofs were similar or higher than for older painted roofs.

4.6.5.2 Loads and uncertainty

Overall, old paint (on roofs) may be contributing to the load of lead in stormwater in catchments where older galvanised iron roofs are in use (Table 4.31). The estimates have an unknown uncertainty as it is not possible to tell whether the paints were present on older galvanised iron roofs have lead in them or not.

Table 4.31

Contributions from lead in paints on roofs (all data g/ha/yr unless stated).

Element	Catchment	Catchment load	Paint "wear" contribution	Percentage of total catchment load (%)
Copper	CBD (commercial)	140	nil	<0.1
	Mission Bay (residential)	79	nil	<0.1

Element	Catchment	Catchment load	Paint "wear" contribution	Percentage of total catchment load (%)
	Mt Wellington (industrial)	135	nil	<0.1
Lead	CBD (commercial)	124	4.0	3.2
	Mission Bay (residential)	60	3.3	5.5
	Mt Wellington (industrial)	135	3.0	2.2
Zinc	CBD (commercial)	1630	nil	<0.1
	Mission Bay (residential)	573	nil	<0.1
	Mt Wellington (industrial)	5170	nil	<0.1

Note: Catchment load data from ARC (2005).

Uncertainty

The variability in lead concentrations in paints reported by ARC (2004) in roof run-off from poor to moderate condition galvanised iron roofs was about 100 per cent (mean concentration $26 \pm 37 \text{ mg/m}^3$ - range 4.8-148 mg/m^3) (note for a further description of the galvanised iron roof grading system refer to ARC 2004). This potential uncertainty is considered significant given the apparent high contribution from roofs in the CBD and Mission Bay catchments, which have a high proportion of older metal roofs within the catchment.

The estimate of lead contribution is based on the lead concentration for GI-grade 1-3 roof run-off data from rural areas in ARC (2004). The concentrations were applied to the areas of GI 1-3 roofs and catchment rainfall identified in ARC (2005).

Given the apparent contributions that may be coming from old paint on roofs, further information on the occurrence of old paints on building roofs (arising from old leaded paints remaining on roofs or being over-painted) and further information on lead in roof paints or the concentration of lead in roof run-off would be of value. Ideally, information on lead in run-off from roofs where the lead concentration in paint from the roofs was known would be of value.

4.6.5.3 Summary

Available data shows that there are still old paints on roofs that contain lead. New roof paints (those currently sold) do not contain any significant amounts of lead. Six of eight samples of paint from galvanised iron roofs in rural Auckland contained lead concentrations over 1000 mg/kg, with three of eight over 25,000 mg/kg. These high concentrations may be evident as sorbed or particulate lead (in some cases paint fragments) in roof run-off. These elevated concentrations may be present in older urban roof paints. The uncertainty in the concentration in run-off from any given roof has been identified as being relatively high. Roof run-off paints also contribute zinc but their contribution cannot easily be separated from that derived directly from galvanised metal roofing surfaces.

4.6.6 Overview of roof run-off

Common roof materials do not contribute significantly to the copper or lead loads in urban stormwater. However, older roofs may contribute significantly to the lead load in stormwater if the roof surfaces are coated in older paints containing elevated concentrations of lead, or old lead fittings are used, such as lead headed nails and lead flashings. Table 4.35 provides a summary of the roof run-off contributions to catchment loads. The contribution was estimated using the roof run-off loads derived by ARC (2005) (based on roof types and data from ARC 2004) and correcting them for estimated rainfall contributions.

Copper roofs and copper guttering have relatively high concentrations of copper in run-off and could be a substantial contributor to copper loads if they were installed more frequently than at the present time.

For zinc, roof surfaces can be a significant contributor to the zinc load in stormwater, which is probably derived from the interaction of rain with both roof paints and roof metal. This was shown to be especially pronounced for older, unpainted galvanised iron roofs (or painted roofs where the paint layer had deteriorated marginally but not substantially). Concentrations of zinc have been shown to be noticeably elevated in roof run-off from industrial areas.

Table 4.32

Roof run-off contributions to catchment loads (all data g/ha/year, unless stated).

Element	Catchment	Catchment load*	Roof run-off contribution*	Roof run-off contribution (corrected for rainfall contribution)	Percentage of total catchment load (%)
Copper	CBD (commercial)	140	3.65	>>	<2.6
	Mission Bay (residential)	79	5.97	10.33	13.1
	Mt Wellington (industrial)	135	7.0	>>	5.2
Lead	CBD (commercial)	124	8.97	>>	7.2
	Mission Bay (residential)	60	1.77	>>	<2.9
	Mt Wellington (industrial)	135	17.9	4.5	3.3
Zinc	CBD (commercial)	1630	1541	831	51
	Mission Bay (residential)	573	265.5	243.8	42.5
	Mt Wellington (industrial)	5170	4297	3873	75

Note: * - Catchment load and roof runoff data from ARC (2005). A shaded cell identifies catchments where rainfall contribution appears greater than roof run-off contribution. >> indicates that the roof contribution using this calculation method is greater than the catchment loading.

In Section 4.6.5.2 a separate estimate of lead in roof run-off was made assuming that lead in paints (on GI roofs) was a direct contributor to lead in run-off. However, it is likely that other sources of lead such as lead head nails (Section 4.6.4.1) and lead flashing might be contributing to the lead concentrations measured.

Roof run-off data in ARC (2004) indicates that specific industrial activities have the potential to increase the contaminant loads in roof run-off above and beyond the generally higher loading within industrial areas, and this points to the importance of individual site management of roof run-off in industrial areas. Concentrations of copper and lead were also relatively elevated in industrial areas, but based on the limited data, it is unlikely that this is a major source of copper or lead to stormwater.

4.7 Building walls

4.7.1 Introduction

Building sides are another potential source of trace metals in urban stormwater run-off. Building side sources commonly include the building wall material, along with window frames, glass and other fillers and sealants (See Chapter 3). There have been a few published papers that have examined run-off from various building side materials and building paints. A summary of these papers are also provided in this section. Most residential house exterior timber and fibrolite walls are painted. The action of the rainwater on the wall can result in:

- The washing off of impacted grime that results from the deposition of atmospheric particulates on the wall.
- The washing off of paint fragments or the fragments of oxidised paint on walls in poor condition (chalking).
- The dissolution of metals such as copper, lead and zinc from the paint.

4.7.2 Wall run-off quality

On many residential properties, the rainwater run-off from building walls will be intercepted by a pervious surface such as soil or lawn in the garden and not reach the stormwater system. Any trace metals in this run-off will then be mostly adsorbed onto soil particulates. However, in some cases such as commercial and industrial areas, where the water flows from the building side onto a paved surface (eg driveway or footpath); the rainwater will flow into the stormwater system.

No information has been identified that has examined the ability of tall buildings (which have large surface areas) to “capture” particles through impaction. Large surfaces may be able to concentrate particles through impaction which are then washed off by rainwater.

As discussed for roof paint, building wall exterior paint historically contained lead. The most common form of lead used historically in paint was basic lead carbonate ($\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$). This lead compound is weathered over time and lead can be released from the paint, either in particulate form or through dissolution mechanisms (Davis et al 2001). Details on lead release in run-off from painted buildings in Auckland have been presented by Kennedy et al. (1988) and earlier sections. Figure 4.12 shows

the typical concentrations of lead in exterior wall house paint in various Auckland suburbs.

Figure 4.13 shows the relationship between the lead concentrations in the wash running down the walls with the lead concentration in the paint. Davis & Burns (1999) also showed that most of the lead in the washes from building walls was particulate in origin. The particulate material was considered to be small colloidal sized particles derived from paint where the organic binders have been removed through aging processes (chalking). Roof run-off concentrations were comparatively low (5.2 mg/m^3).

Figure 4.12

Lead concentrations in paint. (a) Percentage lead in paint in various Auckland suburbs. (b) Percentage lead by year of construction (From Kennedy et al. 1988).

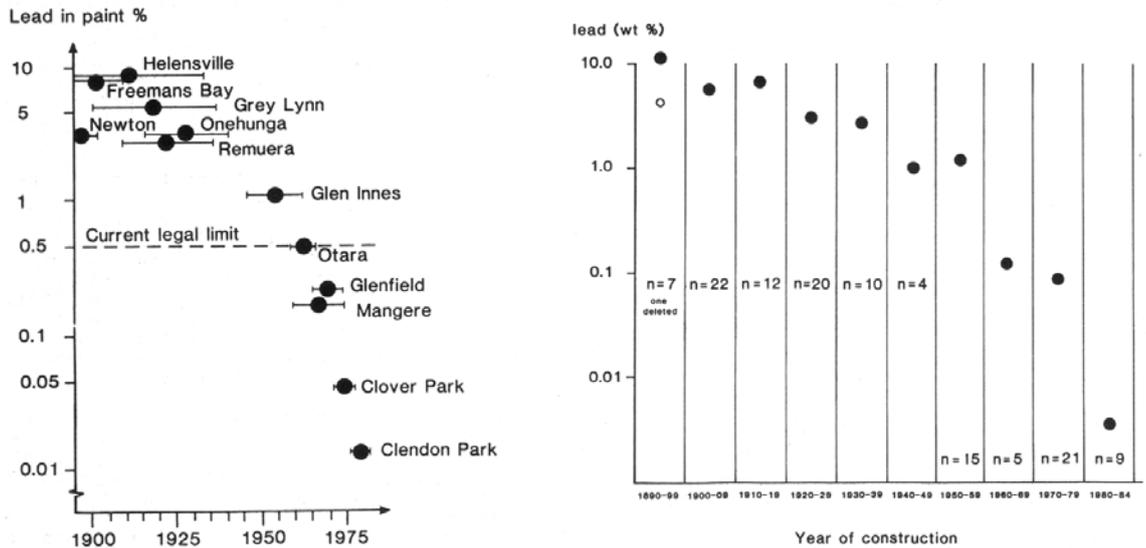
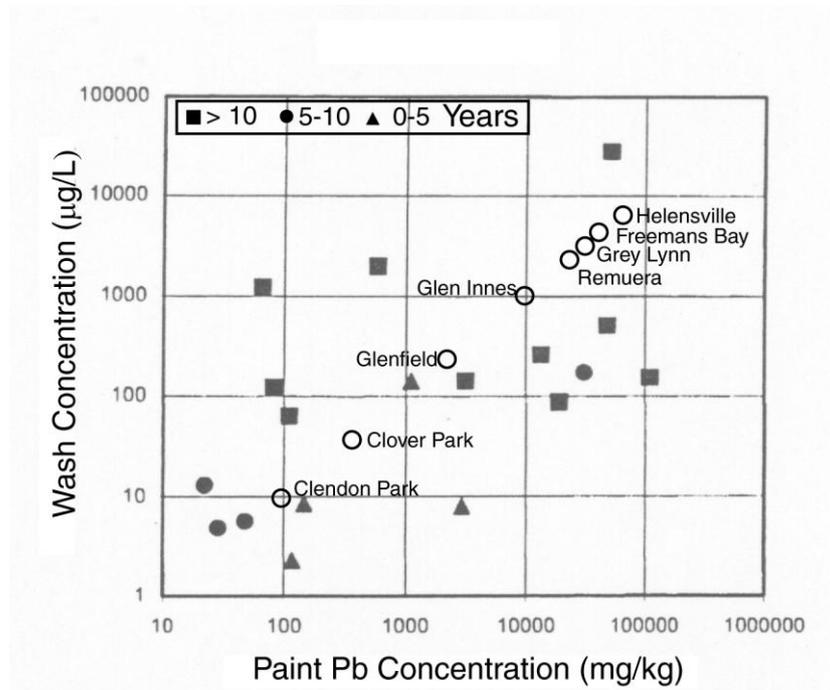


Figure 4.13

Lead concentrations in paint and lead in wall wash water (categorised by paint age) (from Davis & Burns 1999) with the lead in paint data for Auckland suburbs superimposed on it (from Kennedy et al. (1988).



As noted earlier and shown in Figure 4.12, the concentration of lead in house wall paints varies significantly with age and with suburb (which is related to house age). These results can be linked to the results of Davis & Burns (1999) to infer that the concentration of lead in run-off from the walls of buildings painted with lead containing paints will be a contributor to the overall load of lead in stormwater from older catchments where the building wall run-off is able to enter the stormwater system. Figure 4.13 takes the average suburb concentration data and overlays it onto the Davis & Burns (1999) data to provide an inferred indication of what the likely lead in wash water concentrations could be.

A study by Steinberg & Myers (2001) also indicated a high level of lead present in the natural rain wall run-off from lead-based painted buildings in Louisiana, ranging from 1202-1492 $\mu\text{g}/\text{m}^3$. However, this study only reported two samples of wall run-off, due to a lack of rainfall events during the course of the research. Mielke et al. (2001) examined metal contamination of the environment arising from wall paint removal in New Orleans. Although the focus of their work was on lead, they provided data on a range of other metals in wall paint which is provided in Table 4.36.

Table 4.33

Copper, lead and zinc in paint samples from New Orleans houses (n=31, mg/kg) (from Mielke et al. 2001).

	Lead	Copper	Zinc
Minimum	112	5	52
10th percentile	416	8	1343
Median	35,248	21	31,101
90th percentile	126,022	178	72,707
Maximum	256,797	667	98,056

There is little other published information on the composition of paints used historically and currently on New Zealand house walls. Many of the historic and modern white paints are titanium dioxide based and use a range of organic pigments. However, it is likely that low concentrations of a range of metals are present as purposely added materials. Typically concentrations of metals present as contaminants of paint ingredients are low. As with lead released from ageing chalky paints, it is likely that ageing and the influence of acidic pH in rainfall will result in the dissolution/removal of some amounts of other metals present.

There is some information on the washoff of copper and lead in an overseas study. Davis et al. (2001) in Maryland, USA evaluated six different building siding materials, including brick, painted wood, concrete, metal, unpainted wood and vinyl. Sample results represent the metal removed per wall surface area, after it was sprayed with a synthetic rainwater solution (Table 4.37).

Table 4.34

Metal concentrations in run-off from building sides (all data µg/m).

Siding type	Copper	Lead	Zinc	Reference
Painted block	-	8 (<2-590)	-	Davis & Burns (1999)
Painted brick	-	16 (<2-28,000)	-	Davis & Burns (1999)
Painted wood	-	49 (<2-1900)	-	Davis & Burns (1999)
Brick	23 (6-280)	76 (7-4500)	720 (26-23,000)	Davis et al. (2001)
Painted wood	34 (<1-280)	110 (<1-3000)	1600 (36-8400)	Davis et al. (2001)
Concrete	16 (<1-170)	20 (<1-89)	1400 (220-1900)	Davis et al. (2001)
Metal	<1 (<1-4.6)	4.0 (<1-31)	120 (26-2500)	Davis et al. (2001)
Unpainted wood	23 (4-320)	8.9 (<1-270)	200 (56-730)	Davis et al. (2001)
Vinyl	7.6 (4.3-35)	7.6 (7.6-17)	66 (24-91)	Davis et al. (2001)
All siding	19 (<1-320)	50 (<1-4500)	820 (24-23,000)	Davis et al. (2001)
Painted wall	-	1202; 1492	-	Steinberg & Myers (2001)

Note: ¹ Median (range), n = 50-63; ² Median (range); ³ n = 2.

Davis & Burns (1999) investigated the lead concentrations in run-off from roofs and buildings painted with lead paint in Prince George County, Maryland. Concentrations in run-off from the painted walls ranged from <2 to 28,000 µg/L, with medians of 8.0, 14 and 81 µg/L for paints of 0-5, 5-10 and >10 years of age. The presence of older painted surfaces resulted in higher concentrations of lead in the run-off. This was attributed to the fact that older paint is more likely to contain high amounts of lead, and older paint is likely to peel more easily, thus yielding more particulate lead (Davis & Burns 1999).

Davis et al. (2001) show copper concentrations were highest in the run-off from brick (median: 23 µg/m²) and painted/unpainted wood buildings (median: 34 and 23 µg/m² respectively). Copper used in wood preservative was identified as a possible source of copper in the run-off from wood building sides. Lead concentrations were shown to be highest in the run-off from painted wood (median: 110 µg/m²), and to a lesser degree from brick buildings (median: 76 µg/m²). Values for unpainted wood siding were much lower. This suggests that the lead may come from lead-based paint which was commonly used to paint building exteriors, as discussed previously. Zinc was found at levels one to two orders of magnitude higher than copper and lead; the highest levels were from brick, concrete and painted wood structures with typical values near 1000 mg/m³.

4.7.3 Contributions and uncertainty

Although there is some published data on metal concentrations in run-off from building sides, the applicability of the data to New Zealand catchments is uncertain given the variability in wall/side/surface characteristics and composition. Communication with R Pitt and S Clark (Penn State University) did not identify any additional published information on the quality of run-off from building sides or materials used on buildings, especially multi-storey buildings. However to provide some initial information on possible building side contributions the following assumptions were made in relation to the three catchments.

Central business district

The Auckland CBD catchment contained a significant number of tall buildings of varying number of floors. The catchment information included in ARC (2005) was used to provide some preliminary information on the scale of sidings present in the catchment. In the eastern sub-catchment of the CBD area, buildings had a total sidings length of about 2900 m. A quick assessment of floors indicated that the average number of floors was six and seven. This equates, based on an assumed 3 m a level to a total siding area of 56,355 m². The western sub-catchment was assumed to have the same siding area per unit area, resulting in an area of 59,443 m². The total area for the CBD catchment is 115,798 m². It is not known how much "shielding" effect there is from buildings located adjacent to each other.

Examination of the catchment which has about 85 per cent imperviousness, indicated that much of the siding run-off could enter the stormwater system. For the purposes

of this assessment a conservative figure of 60 per cent to stormwater has been used. This corresponds to an equivalent area of 69,480 m².

No quantitative assessment of sidings materials was carried out in the CBD. Based on general observations the following percentage siding material was used: glass 40 per cent, concrete 30 per cent, colour steel/Zincalume 20 per cent and painted wood 10 per cent.

Mission Bay

In the residential catchment of Mission Bay there are approximately 643 dwellings. That corresponds to a density of 14 dwellings per ha. The houses within the three surveyed areas examined to assess potential source materials, comprised wood (30 per cent), brick (20 per cent unpainted, 17 per cent painted) and stucco of various types (23 per cent). Of those dwellings, 50 per cent were single storey and 50 per cent two levels.

For the purpose of assessing run-off from building sides, it has been assumed that each house has a footprint of 200 m² corresponding to a wall area of 168 m² for a single storey dwelling (56 m length, 3 m vertical) and 336 m² for a two level building. Based on the approximate proportion of one and two level dwellings, the total siding area is 161,868 m² for this catchment

Examination of houses in Mission Bay and elsewhere indicates that only a small proportion of walls are directed adjacent to impervious surfaces and some of those (eg pavements) then run to pervious surfaces. For this assessment it was assumed that 5 per cent of the sidings ran to impervious surfaces linked to the stormwater system. Some sidings (eg on second levels of buildings) run to roof gutters on lower levels. This corresponds to a total siding area of 8093 m² connected to the stormwater system. Calculations put forward by Davis et al. (2001) appear to have assumed that all of the siding was connected to the stormwater system. In the Mission Bay catchment this was not the case with very little wall area having any direct connection. It should be noted that the siding areas identified above are very preliminary and not based on any field measurements of building dimensions.

Mt Wellington

A preliminary examination of the catchment information in ARC (2005) identified that building sides had an approximate length of 5380 m. With an average estimated building height of 6 m this corresponds to a siding area of 32,300 m². As with the CBD, the catchment has a high proportion of impervious surfaces and most building walls run directly to impervious surfaces. As with the CBD catchment a conservative figure of 60 per cent running to stormwater has been used. This equates to an equivalent area of 19,380 m².

No quantitative assessment of sidings materials was carried out in the Mt Wellington catchment. Based on general observations made in the field, most of the buildings in the catchment had metal sidings of either colour steel or Zincalume. The following percentage siding material was used: colour steel 60 per cent, galvanized steel 20 per cent painted, 20 per cent unpainted.

Uncertainties

As stated in the sections above, there are a significant number of assumptions, uncertainties and preliminary data involved in the sidings calculations.

It is likely that the lead contribution will be an underestimate if sidings still contain any leaded paint on surfaces.

In addition if any of the sidings in the industrial and commercial comprise “weathered” galvanised products or older colour steel etc., it is likely that the estimate from this component of the sidings surfaces will be underestimated.

Loadings

For the purpose of this assessment, the data presented by Davis et al. (2001) and summarised in Table 4.37 was used to assess loads of copper, lead and zinc derived from sidings for identified surfaces (Table 4.38). For colour steel, the data from ARC (2004) was used, converted to a $\mu\text{g}/\text{m}^2$ value to match the units in Davis et al. (2001). Wash off was assessed in terms of the number of events that might contribute to the stormwater system. For the purpose of this assessment 60 events were used to calculate preliminary estimates.

The most significant uncertainty in assessing contributions from building sides is whether the building side has connectivity to the stormwater system. The greater connectivity between walls and the stormwater system was assumed in the CBD and industrial catchment compared to the residential catchment.

Table 4.35

Estimates of copper, lead and zinc contributions from building sidings.

Element	Catchment	Catchment load (kg/year)*	Contributing siding area	Siding load (kg)	Percentage of total catchment load (%)
Copper	CBD (commercial)	4.21	69,480 m ²	0.17	4.0
	Mission Bay (residential)	3.57	8093 m ²	0.008	0.2
	Mt Wellington (industrial)	4.59	19,380 m ²	<0.012	0.3
Lead	CBD (commercial)	3.73	69,480 m ²	0.066	1.8
	Mission Bay (residential)	2.71	8093 m ²	0.022	0.8
	Mt Wellington (industrial)	4.59	19,380 m ²	<0.026	0.6
Zinc	CBD (commercial)	47	69,480 m ²	2.49	5.3
	Mission Bay (residential)	26	8093 m ²	0.446	1.7
	Mt Wellington (industrial)	176	19,380 m ²	0.468	0.3

Note: Catchment load data from ARC (2005).

Overall, the assessment of sidings contribution via wash off has shown that sidings do not appear to be a major source of contaminants. This conclusion contrasts with that of Davis et al. (2001) who identified that sidings were a significant contributor to the loadings of lead (79 per cent) and less so for copper and zinc (~20 per cent). Even if the connectivity in the CBD and industrial catchments increased by 20 per cent this would only increase the load estimates by 20 per cent.

4.7.4 Summary

Overall, the results suggest that brick and painted wood building sides contribute the highest concentration of all three trace metals to urban stormwater run-off. While Davis et al. (2001) identify the building material as the only source of these metals, it is considered here that the high concentration of lead and other metals associated with brick sidings (unpainted) is probably associated with the deposition through impaction of emission particles from motor vehicles and other sources. The presumably rough brick surfaces may be more efficient than the smoother vinyl sidings at retaining deposited particulates. Unless painted, the bricks themselves are not likely to be a significant source of metals such as lead or zinc.

It is considered that given the diversity of materials associated with building sides/walls in urban catchments that there will be some contribution of copper, lead and zinc to stormwater. A preliminary assessment of possible contributions from sidings in the three catchments indicated minor contributions from these sources. However it is still considered that there are large uncertainties associated with these sources. It is possible that the presence of un-identified leaded paints on some older buildings and or primer may result in the contributions being under-estimated. It is likely that painted surfaces on sidings will be a minor source of zinc. However there is no information to verify the contribution that zinc in paints makes to the zinc load via building wall wash off.

4.8 Other building materials

4.8.1 Materials and tests

In Section 3, examples of the types of materials observed on the outside of buildings in residential, commercial and industrial catchments in Auckland were described. The observations confirmed that the range of materials was diverse. Built environments are relatively complex. Urban catchments such as the Auckland CBD are known to be dominated by multi-storey office buildings, hotels and apartments. These buildings are externally clad with a variety of materials (eg refer www.smarterhomes.org.nz/materials/exterior-building-materials). These materials include wood, stainless steel, aluminum, glass, polycarbonate, PVC and other plastics, reflective and other glazing, stone of various kinds, concrete etc.

Laboratory studies involving common building and construction materials have shown that many have potential to leach metals (and other contaminants) into stormwater and the environment (Pitt 2000; Clark 2005). The following section summarises the available data on the main groups of material used on buildings and exposed surfaces in urban areas.

Although the purpose of this section is to discuss building materials other than those sources already described, the summary tables include information on materials described in other sections. The laboratory studies undertaken have used different extraction media. The most common extracts used have been deionised water and the Toxicity Characteristics Leaching Procedure (TCLP) test. These can be considered to mimic extraction under neutral conditions but can be modified to give acidic conditions. However not all authors report the pH in such modified TCLP test procedure (eg Clark et al. 2005).

4.8.2 External wood

Wood is a common building product. Most wood in residential, commercial and industrial buildings is not exposed, except where timber is used in roofing shakes. However, exposed timber is commonly found, especially on residential properties, where it is used for fences, decking, sheds, gates etc. Most of this wood is chemically treated and one of the most common timber treatment chemicals used in New Zealand is copper, chrome, arsenate (CCA). Usually the timber is factory-preserved, that is the wood is pressure treated with CCA, dried, and then shipped to timber suppliers. This treated timber is used in situations where exposure to moisture is expected, such as exterior decks, retaining walls, timber power poles etc. Copper is known to leach from CCA treated timber (Table 4.39 and 4.40).

Table 4.36

Trace metal concentrations leached in de-ionised water from various construction materials (Pitt & Lalor (2000).

Sample type	Copper	Lead	Zinc
Silica caulk	29	<dl	14
Formica and silica caulk	54	<dl	26
Treated plywood	1300	33	93
Untreated plywood	79	<dl	67
Washed PVC and PVC cement	36	<dl	32
Washed geotextile filter fabric	44	<dl	32
Washed fiberglass window screen	32	<dl	88

Note: All units mg/m³; <dl: less than detection limit (not defined by authors).

Table 4.37

Trace metal concentrations in TCLP run-off from various construction materials (Clark et al. 2005).

Sample type	Copper	Lead	Zinc
Asphalt/tar shingles	0.66	0.34	1.22
Roofing felt	0.026	0.11	0
Red vinyl roofing	0	0	0
Fibreglass roofing	0.017	0.005	0.53
White plastic roofing	0.076	0	1.42
Cedar roofing shingles	0.033	0.11	0.64
Galvanised metal roofing	0.44/0	0.16/1.61	16,500/11,900
Waterproof wood	161	0.29	3.72
Pressure treated wood	191	0	1.35
Fake slate roof shingle	0.2	0.42	1.81
Leak stopper roof patch	0.13	3.78	2.61
Kool seal acrylic cement	0.15	0.65	2.94
Commercial roofing patch material	0	0.094	0
Aluminium roof coating	1.14	0.3	0

Note: Authors presented data as mg/kg; 0 = <dl: less than detection limit (0 presented and not defined by authors).

In situations where the run-off from the product discharges onto an impervious surface, this could be a direct source of copper to the stormwater system. Where the run-off discharges to a pervious area, such as a garden, the copper in the run-off may accumulate in the surface soils. Of course, these soil particulates can erode and contribute contaminated sediments to the stormwater, while others can adversely affect groundwater).

Pitt & Lalor. (1999) also examined the leaching effects associated with other building materials that may affect run-off quality. For this, samples of the various materials were left to soak in de-ionised water for set periods of time, and then the water was analysed for a range of constituents of interest. Treated plywood was found to be a source of high concentrations of copper in leachate/soakage water. All other materials that were examined leached copper at concentrations ranging from 29-79 mg/m³ (Table 4.39). Lead was only detected in the treated plywood sample. No other construction materials examined were found to be a source of lead. Zinc was detected in samples from all materials that were tested, at concentrations ranging from 14-93 mg/m³ (Table 4.39). Clark et al. (2005) also reported that water proof and pressure treated wood contained high concentrations of "releasable" copper (Table 4.40).

4.9 Concrete

4.9.1 Concrete use and composition

Concrete is a very common building material especially on residential properties (driveways, parking areas), and on large commercial buildings and sites (structural building framework, pedestrian pavements etc.). It is also used in cement roof tiles (refer Section 4.7). During the construction phase of large multi-storey buildings very large surface areas of concrete are exposed to rainfall.

Concrete (cement) contains a range of metals. There does not appear to be any published data on metal concentrations in New Zealand concrete. PCA (1992) reported that Portland cement contained an average lead concentration of 12 mg/kg (range 1-75 mg/kg). Other studies such as Hillier et al. (1999) reported 75.3 mg/kg lead in Portland cement.

Hohberg et al. (2000) reported some trace element data for Portland cement and concretes. They reported 28 mg/kg copper for Portland cement and 11-12 mg/kg for concretes; 22 mg/kg lead for Portland cement and 14-87 mg/kg for concretes; 311 mg/kg zinc for Portland cement and 80-219 mg/kg for concretes. Pierrard et al. (2002) reported 7.4 and 43 mg/kg lead and 45-63 mg/kg for two mortar samples.

4.9.2 Concrete run-off

ARC (2004) however reported data for copper, lead and zinc in run-off from concrete roof tiles. They reported a median concentration of 0.5 mg/m³ for copper, 0.2 for lead and 20 mg/m³ (range 6.0-25 mg/m³) for zinc.

Leachability of metals from concrete is expected to be very pH dependent. The solubility of copper, lead and zinc are all pH dependent. All three metals have increasing solubility under acidic (low pH) conditions. Solubility for copper and lead decreases to neutral and alkaline conditions but for zinc, increasing pH from a low in solubility at pH 9 to pH 10 and higher results in an increase in solubility.

Van der Sloot (2000, 2002) discussed and reported leachability results for copper, lead and zinc in ground mortar and stabilised cement aggregates. Van der Sloot (2000) reported end of life leaching of copper, lead and zinc as 540, 1275 and 2100 mg/m² respectively as identified in the Dutch Building Materials Decree, 1995. Zinc release was shown to be pH dependent with high leaching under acidic conditions. PCA (1992) report TCLP concentration for lead of 9 mg/m³ (range 2-29 mg/m³). Hillier et al. (1999) reported no leachable lead at a detection limit of 5 mg/m³. Leachability will be dependent upon test conditions. No specific information was found on the quality of leachate from concrete as the concrete surface ages.

Overall, from data on concrete composition and concrete leachability data it is evident that concrete may be a potential source of lead and zinc and a minor source of copper. The amounts released to stormwater when rain falls onto and runs over concrete is dependent on the pH of the rainwater and the pH following interaction with the

concrete. In the absence of any other data, the ARC (2004) concrete roof tile stormwater quality data can be used to provide indicative data on concrete surface run-off quality.

4.9.3 Contributions

There does not appear to be any data on the proportion of impervious surfaces in Auckland (or in the three key catchments) that are in concrete. In addition, the contribution made from horizontal building surfaces (not included in impervious surface area calculation) is not known. ARC (2004) reported that non roof impervious surfaces amounted to 56.2 per cent in the CBD and 30 per cent in each of the Mission Bay and Mt Wellington catchments.

For the purpose of assessing preliminary source loads, 20 per cent of this impervious area total was assumed to be in concrete surfaces. Further work will be required to refine this figure (ie 11.2 and 6 per cent of the surface area respectively). Based on the rainfall (1.2 m) and run-off coefficient (0.95), the 20 mg/m³ zinc concentration noted for concrete tiles, the load contributed by concrete surfaces in the CBD catchment would be 0.77 kg/year (1.6 per cent of the catchment load), 0.325 kg/year in the Mission Bay catchment (1.25 per cent of the catchment load) and 0.24 kg/year in the Mt Wellington catchment (about 0.1 per cent of the catchment load). These are minor contributions.

4.10 Garden and household cleaning products

4.10.1 Introduction

There are a wide range of garden products and other exterior household products on the market that are likely to contain metals. It is expected that these would include pesticides, herbicides, fertilisers and outdoor cleaning products. However, relatively little published information could be found to identify these products.

The New Zealand Environmental Risk Management Authority (ERMA) maintains an online register of hazardous substances. The ERMA register was searched for registered products containing copper, lead or zinc in New Zealand that could be used as garden products and other exterior household products. Several copper-containing products and zinc-containing products were identified; these are discussed further in the following sections. No products containing lead could be identified. In addition, a selection of garden centres and hardware stores were surveyed by the authors, to help identify what copper, lead and zinc containing garden and outdoor products are currently available for sale in the Auckland region.

4.10.2 Copper products on ERMA register

Table 4.41 presents a summary of the copper-containing garden or household products listed on the ERMA Hazardous Substances and New Organisms (HSNO) register at

January 2007. As shown, the majority of copper-containing products are fungicides, and are used to protect plants against fungus and other bacterial diseases. These products are either sold as a liquid concentrate or as water dispersible granules or powder. Of those products listed on the ERMA register, the liquid concentrates contain between 50-650 g/L copper, and the granules/powders contain between 125-800 g/kg copper.

Table 4.28

List of copper-containing products taken from the ERMA HSNO register (data from ERMA 2007).

Product name(s)	Active ingredients	Primary use	Form and volume
Flo-Bordo	50 g/L copper as bordeaux mixture	Fungicide	Soluble concentrate
Liquicop copper fungicide	92.8 g/L copper as a copper ammonium complex	Fungicide	Soluble concentrate
Champ flowable Champ formula 2 flowable	180 g/L copper as copper hydroxide	Fungicide	Suspension concentrate
Headland copper	248 g/L copper as copper oxychloride	Fungicide	Suspension concentrate
Agpro cupric hydroxide 350SC Headland choice Kocide 2000 LF Kocide 2000 DS	350-360 g/L copper as copper hydroxide	Fungicide	Suspension concentrate
Nordox oleo 40 copper	650 g/L copper as cuprous oxide	Fungicide	Suspension concentrate
ManKocide	300 g/kg copper as copper hydroxide	Fungicide	Water dispersible granule
Nordox 75 WG	750 g/kg copper as cuprous oxide	Fungicide	Water dispersible granule
Kocide DF Blue shield DF Hydro-pro WDG Kocide 2000 Champ DP Champion Copper Kocide 2000 DS	350-500 g/kg copper as copper hydroxide	Fungicide	Water dispersible granule
Yates Copper Oxychloride Fruitfed Copper Oxychloride Copper Oxychloride 50WP Gardrite Copper Oxychloride Agpro Copper Oxychloride 800WP CC Copper Oxychloride 50% WP General Disease Spray Fruit Fed Copper Oxychloride DF Garden King Copper Oxychloride Copper Oxychloride 50 WDG Koprox	500-800 g/kg copper as copper oxychloride	Fungicide	Water dispersible granule
Cuprofix Disperss	200 g/kg copper as bordeaux mixture	Fungicide	Water dispersible granule

Product name(s)	Active ingredients	Primary use	Form and volume
Garden King Multipest	250 g/kg copper as copper oxychloride	Fungicide /Insecticide	Wettable powder
Garden King Dry Bordeaux	125 g/kg copper as copper sulphate	Fungicide	Wettable powder
Cuprofix	200 g/kg copper as bordeaux mixture	Fungicide	Wettable powder
Yates Nature's Way Fungus Spray	350 g/kg copper as copper oxychloride	Fungicide	Wettable powder
Nordox Super 75 Ag Copp 75	750 g/kg copper as cuprous oxide	Fungicide	Wettable powder
Yates Bluestone Copper Sulphate	250 g/kg copper sulphate	Fertiliser and algaecide	Crystalline powder
Moss Off Winter Cleanup Spray Moss and Algae Killer	112 g/litre copper sulphate	Moss/algaecide	Soluble concentrate
Flo-Bordo	50 g/L copper as bordeaux mixture	Fungicide	Soluble concentrate
Liquicop Copper Fungicide	92.8 g/L copper as a copper ammonium complex	Fungicide	Soluble concentrate
Champ Flowable Champ Formula 2 Flowable	180 g/L copper as copper hydroxide	Fungicide	Suspension concentrate
Headland Copper	248 g/L copper as copper oxychloride	Fungicide	Suspension concentrate
Agpro Cupric Hydroxide 350SC Headland Choice Kocide 2000 LF Kocide 2000 DS	350-360 g/L copper as copper hydroxide	Fungicide	Suspension concentrate
Nordox Oleo 40 Copper	650 g/L copper as cuprous oxide	Fungicide	Suspension concentrate
ManKocide	300 g/kg copper as copper hydroxide	Fungicide	Water dispersible granule
Nordox 75 WG	750 g/kg copper as cuprous oxide	Fungicide	Water dispersible granule
Kocide DF Blue Shield DF Hydro-pro WDG Kocide 2000 Champ DP Champion Copper Kocide 2000 DS	350-500 g/kg copper as copper hydroxide	Fungicide	Water dispersible granule
Yates Copper Oxychloride Fruitfed Copper Oxychloride Copper Oxychloride 50WP Gardrite Copper Oxychloride Agpro Copper Oxychloride 800WP CC Copper Oxychloride 50% WP General Disease Spray Fruitfed Copper Oxychloride DF Garden King Copper	500-800 g/kg copper as copper oxychloride	Fungicide	Water dispersible granule

Product name(s)	Active ingredients	Primary use	Form and volume
Oxychloride Copper Oxychloride 50 WDG Koprox			
Cuprofix Disperss	200 g/kg copper as bordeaux mixture	Fungicide	Water dispersible granule
Garden King Multipest	250 g/kg copper as copper oxychloride	Fungicide /Insecticide	Wettable powder
Garden King Dry Bordeaux	125 g/kg copper as copper sulphate	Fungicide	Wettable powder
Cuprofix	200 g/kg copper as bordeaux mixture	Fungicide	Wettable powder
Yates Nature's Way Fungus Spray	350 g/kg copper as copper oxychloride	Fungicide	Wettable powder
Nordox Super 75 Ag Copp 75	750 g/kg copper as cuprous oxide	Fungicide	Wettable powder
Yates Bluestone Copper Sulphate	250 g/kg copper sulphate	Fertiliser and algaecide	Crystalline powder
Moss off Winter Clean-up Spray Moss and Algae Killer	112 g/litre copper sulphate	Moss/algaecide	Soluble concentrate

The fungicides are generally sprayed onto the foliage/buds/stems of a plant, and therefore there is limited potential for the fungicide to enter the stormwater system. It is expected that some of the applied fungicide could be washed off the plant during rain or when a plant is watered; exact quantities are uncertain, however any copper fungicide which is washed off is unlikely to be mobile once released onto the surrounding soils.

TDC Environmental (2004) also concluded that only a small fraction of the copper applied to landscaping is washed off in storm water run-off, because copper tends to bind to soil and vegetation. They reference a study by Dietrich & Gallagher (2002) which investigated copper run-off from tomatoes treated with copper fungicides. This study suggested very low rates of approximately 1 per cent of applied copper was washed off of a tomato cultivation study area. The run-off fraction is consistent with known washoff rates of many other pesticides, which are typically less than 0.5 per cent of the amount applied (Wauchope 1978).

However, there were two copper-containing products identified on the ERMA register which are used primarily as algaecides, these included Yates bluestone copper sulfate and Mossoff. These products contained 250 g/kg and 112 g/L copper sulfate respectively. These products are typically applied directly to paths, roofs, decks, cobblestones and other exterior surfaces to control algae. Therefore there is a much greater potential for these products to be washed off and enter the stormwater system, or to be stored in adjacent soils for later mobilisation.

4.10.3 Zinc products on ERMA register

Several zinc-containing products were identified in the ERMA HSNO register (Table 4.42). All of these products were fungicides, and contained zinc as a component of the active ingredients mancozeb and ziram. The standard formulation of mancozeb is not listed on the ERMA HSNO register, however other sources suggest that it is an 80 per cent wettable powder containing 16-20 per cent manganese and 2 per cent zinc (IPCS, 1967; APVMA 2004). Also, the FAO (1992) specifies that zinc content of ziram is between 21 per cent and 22.5 per cent. As discussed in the previous section these fungicides are generally applied onto the foliage/buds/stems of a plant, and therefore there is limited potential for the fungicide to enter the stormwater system. In addition to those products listed above, zinc chloride is registered on the ERMA register as a herbicide. It is used to control lichen and moss growing on the roofs of houses and other domestic dwellings, along walks, driveways, fences, and wherever moss grows. Therefore, there is a greater potential for this product to enter the stormwater system.

4.10.4 Garden centre and hardware store survey

In addition to the ERMA register search discussed in the previous section, three garden centres and hardware stores were surveyed to identify what copper, lead and zinc containing garden and outdoor products are currently available for sale in the Auckland region. All products containing any of these metals were recorded, along with the active ingredients, primary use, form, volume and the recommended dose (Table 4.43).

Table 4.39

List of zinc-containing products taken from the ERMA HSNO register (ERMA 2007).

Product name(s)	Active ingredients	Primary use	Form and volume
Nautile	680 g/kg mancozeb	Fungicide	-
Kotek	-	Fungicide	-
Max MZ	-	Fungicide	-
Agronica Mancozeb Fungicide	750 g/kg mancozeb	Fungicide	-
Chipco Fore Flo Manex II Fore Flo	480 g/L mancozeb	Fungicide	-
ManKocide	150 g/kg mancozeb	Fungicide	-
Ridomil Gold MZ WG	640 g/kg mancozeb	Fungicide	-
Manzate 200 DF Manco	750 g/kg mancozeb	Fungicide	-
Penncozeb DF Mancozeb 80W Manzate WP Dithane DF Rainshield Fungicide Dithane DF Rainshield Neotec	750-800 g/kg mancozeb	Fungicide	Water dispersible granule Wettable powder

Product name(s)	Active ingredients	Primary use	Form and volume
fungicide DuPont Manzate Evolution Fungicide			
Sereno	500 g/kg mancozeb	Fungicide	Water dispersible granule
Manzate Super	640 g/kg mancozeb	Fungicide	Water dispersible granule
Acrobat MZ 690	667 g/kg mancozeb	Fungicide	Wettable powder
Galden M8-65	650 g/kg mancozeb	Fungicide	Wettable powder
Mizar Granuflo	760 g/kg ziram ²	Fungicide	Water dispersible granule

Note: ¹ Mancozeb is a manganese ethylenebis(dithiocarbamate) (polymeric) complex with zinc salt; ² Ziram is zinc dimethyl-bis-dithiocarbonate.

The results of these surveys showed that most commonly available garden products could be grouped into four main categories; these were fertilisers, fungicides, moss/algaecides, and slug killers. The fertilisers generally contained only trace quantities of copper and/or zinc, ranging from 0.003-0.85 per cent copper and 0.003-0.8 per cent zinc. Therefore, this group is a relatively low risk source of these metals to stormwater, given the very low quantities of copper and zinc in these products (<1 per cent). Also, these products would generally only be applied to individual plants or lawn areas, with relatively low risk of run-off to stormwater.

Table 4.40

List of commonly available garden products which contain copper or zinc from a survey of three hardware stores and garden centres in the Auckland region.

Product name	Zinc and copper content	Primary use	Form and volume	Recommended dose
Fertilisers				
Butlers Complex Plant Food	0.02% zinc	Plant food	3 kg granules	75 g/m ²
Butlers Time Release Fertiliser	0.04% copper; 0.03% zinc	Fertiliser	500 g granules	40 g/m ²
McGregor's Foliar Nitrophoska	25 ppm copper; 5 ppm zinc	Fertiliser	200 ml liquid	-
Osmocote Plant Food	0.05% copper; 0.015% zinc	Plant food	5 kg granules	100-200 g/tree
Osmocote Plus – Azaleas/camellias	0.5% copper; 0.015% zinc	Fertiliser	700 g granules	-
Osmocote Plus – Garden Beds	0.5% copper; 0.015% zinc	Fertiliser	700 g granules	80 g/m ²
Osmocote Plus – Native Gardens	0.025% copper; 0.01% zinc	Fertiliser	700 g granules	15-30 g/plant
Osmocote Plus – Pots/planters	0.5% copper; 0.015% zinc	Fertiliser	700 g granules	10-80 g/plant
Osmocote Plus – Trees/shrubs	0.05% copper; 0.015% zinc	Fertiliser	700 g granules	15 g/plant
Scotts' Lawn Builder	4.1 mg/kg lead	Lawn fertiliser	2.5 kg powder	2.5 kg/140 m ²
Tui Acid Fertiliser	0.85% copper chelate	Fertiliser	3 kg granules	100-200 g/plant

Product name	Zinc and copper content	Primary use	Form and volume	Recommended dose
	0.3% zinc chelate			
Tui – Citrus and Fruit Tree Fertiliser	0.3% zinc chelate;	Fertiliser	3 kg granules	150 g/m ²
	0.8% copper chelate			
Tui – Rose Fertiliser	0.3% zinc chelate	Fertiliser	3 kg granules	150 g/m ²
	0.85% copper chelate			160 g/plant
Tui – General Garden Fertiliser	0.3% zinc chelate	Fertiliser	10 kg/3 kg granules	350 g/m ²
	0.85% copper chelate			
Tui – Nitrophoska Blue	Zinc 100 ppm; copper 10 ppm	Fertiliser	2.5/8 kg granules	80 g/m ²
Watkins Nitrophoska Blue Perfekt	0.01% zinc	Plant food	2.5 kg granules	40-80 g/m ²
Yates Dynamic Lifter	0.03% zinc	Plant food	7 kg pellets	100 g/m ²
Yates Nutricote Outdoor Garden	0.012% copper sulphate	Fertiliser	500 g granules	20-60 g/plant
	0.003% zinc sulphate			
Yates Nutricote Subtropical Fern	0.012% copper sulphate	Fertiliser	500 g granules	20-60 g/plant
	0.003% zinc sulphate			
Yates Thrive (azalea, camellia)	0.005% copper sulphate			
	0.005% zinc sulphate	Plant food	3/8 kg granules	-
Yates Thrive Granular Rose Food	0.005% copper sulphate	Rose food	8/3 kg granules	100-200 g/m ²
	0.005% zinc sulphate			
Yates Thrive Hose On All Purpose	0.003% copper chelate	Fertiliser	2 L liquid	-
	0.003% zinc chelate			
Yates Thrive Lawn Food	0.005% copper sulphate	Lawn food	3/8 kg granules	-
	0.005% zinc sulphate			
Yates Thrive Soluble Plant Food	0.005% copper sulphate	Fertiliser	500 g powder	-
	0.02% zinc sulphate			
Yates Trace Elements	0.8% copper sulphate	Fertiliser	600 g powder	50 g/m ²
	0.8% zinc			

Product name	Zinc and copper content	Primary use	Form and volume	Recommended dose
	sulphate			
Fungicides				
Wally's Liquid Copper	350 g/L copper hydroxide	Fungicide	250 mL liquid	3.5 ml/L water
Watkins – General Disease Spray	500 g/kg copper oxychloride	Fungicide	200 g powder	-
Yates Champ DP	375 g/kg copper hydroxide	Fungicide	100 g powder	-
Yates Copper Oxychloride	500 g/kg copper oxychloride	Fungicide	200 g powder	-
Yates Nature's Way Fungus Spray	350 g/kg copper oxychloride	Fungicide	200 g wettable powder	5 g/L water
Moss/algacides				
30 Seconds – The Boss of Moss	99% zinc sulphate monohydrate	Moss remover	1.25 kg powder	1.25 kg/50 m ²
	Eq. to 36% zinc as metallic			
Yates Bluestone Copper Sulphate	250 g/kg copper sulphate	Algacide (paths etc)	Powder	100 g/100m ²
Tui Bluestone Copper Sulphate	Not listed	Algacide	-	-
Slug killer				
Slug Off	2.8 g/L copper as buffered copper complex	Slug killer	500 mL liquid	-

There were five fungicides identified which contained copper. Four of these were powders which contained between 350-500 g/kg copper, and one was a liquid, containing 350 g/L copper. The composition of these fungicides is similar to the fungicides that were identified on the ERMA register. As discussed in Section 4.10.2 the fungicides are generally applied directly to a plant, and therefore there is limited potential for the fungicide to enter the stormwater system.

There was one moss remover identified which contained 99 per cent zinc sulfate. This product was a powder, and according to the product directions it was recommended that 1.25 kg of the product be applied to 50 m² of roof/path/other exterior surface to remove moss. It was not clear whether this product needed to be washed away following application or not. Obviously this product could be a significant source of zinc to the stormwater system, as any residual product that was left on the surface could be washed into the stormwater system during the next rain event, or may be deliberately washed off into the stormwater system by the householder. All other outdoor moss/mould cleaners contained no metal active ingredients. There was only one slug killer identified as part of this survey which contained 2.8 g/L copper.

There were also two copper sulphate products identified in the survey, which were used to control algae on exterior surfaces. One of these was also identified in the ERMA register search. As discussed in Section 4.10.2, these products are typically applied directly to paths, roofs, decks, cobblestones and other exterior surfaces to

control algae. As a consequence, there is a greater potential for the products applied to garden/section impervious surfaces to be washed off and enter the stormwater system.

Estimating the contribution of garden products to stormwater loads will require knowledge of the amount applied to impervious surfaces (directly or indirectly) and the residual available for wash off during storm run-off. This information is not available and will require further work.

4.10.5 Contributions from garden and cleaning products to stormwater

Most of the products identified on the ERMA register and in the shop surveys that contained significant quantities of copper were fungicides. While some of these products contained very high concentrations of copper (up to 80 per cent), their typical application onto the foliage/buds/stems of a plant limits potential for the fungicide to enter the stormwater system. As discussed, it is expected that some of the applied fungicide could be washed off the plant during rain or when a plant is watered; exact quantities are expected to be low (0.5 to 1 per cent), however any copper fungicide which is washed off is unlikely to be mobile once incorporated, adsorbed, or absorbed into the surrounding soils. These products can be one of the sources of contamination contributing to garden soil quality (refer Section 4.3.4)

Of more interest are the copper-containing algacides that are applied directly to paths, roofs, decks, and other exterior household surfaces to control algae, as these products could easily be washed off deliberately or by rainfall into the stormwater system. This could potentially be an important source of copper in areas where the target surface is directly connected to the stormwater system.

Most of the zinc-containing products identified on the ERMA register were fungicides and contained zinc as a component of the active ingredients Mancozeb and Ziram. As for copper fungicides, the risk to stormwater from these products is considered to be low given the type of application. The moss remover identified during the shop survey is an example of a potentially high risk source of zinc (99 per cent zinc sulfate). This product could be a significant source of zinc to the stormwater system, as any residual product that was left on the surface after application could be washed into the stormwater system during the next rain event, or may be deliberately washed off by the householder. Apart from fungicides, the fertilisers appear to be a relatively small source of copper and zinc to stormwater, given the very low quantities of copper and zinc in these products (<1 per cent) and application to pervious areas. Lead was not identified as an ingredient of any household garden product.

Lawns and gardens on private property and public parks receive a range of supplements such as fertilisers and pesticides as a part of their upkeep and management. Hartwell (2006) provided an overview of stormwater issues associated with fertiliser use on lawns as it might relate to New Zealand, but noted that there was no specific New Zealand data on nutrient loss from lawns. Hartwell (2006) noted a US study in Virginia (Aveni 1994) that indicated 79 per cent of lawns were fertilised each year and 66 per cent had pesticide applied to them. Baker et al. (2007) summarised a

number of studies undertaken in Minnesota that showed that 29-62 per cent of households fertilised their lawns every one to two years. The authors also summarised that 69-81 per cent of households either mulched or composted lawn clippings on-site.

Quantification of this source (in Auckland) will require information on sales of products and the rates of use and general location of use. Unless specific information is available, there will be a high degree of uncertainty in relation to the mass of product used. In addition, there appears to be no reliable information on the movement of copper and zinc in garden products from garden to receiving environments.

Contributions to stormwater from this source can occur via:

1. Accidental losses to impervious surfaces adjacent to garden and lawn areas during use.
2. Diffuse run-off from lawns adjacent to impervious surfaces.
3. Loss to groundwater and then infiltration to nearby stormwater pipes.

Overall, there are a range of commercial products that contain copper and zinc that are used on impervious surfaces on residential and other properties that may be used in situations that could result in direct loss to the stormwater system. The contribution is "unknown" at this stage, but an indication as to whether a contribution is possible can be obtained from looking at the possible use of the products. For example:

- At a concentration of 0.1 per cent copper or zinc in a plant fertilizer product, the loss of 1-5 kg of product to impervious surfaces over the course of a year would contribute 0.15 and 0.02 per cent of the copper and zinc stormwater load in the Mission Bay catchment. Zinc contributions from fertilizer products have been assessed as <0.1 per cent at this stage.
- A path cleaner containing 250 g/kg copper sulphate used at a rate of 100g/100m² of path would contribute 9.9 g of copper for every 100 m² of path cleaned. Cleaning 10 areas of 100 m² path within the Mission Bay catchment would add 99 g of copper (assuming that it was all washed to the stormwater system) which would equate to 2.7 per cent of the calculated stormwater copper load (2.3 and 2.2 per cent in the CBD and Mt Wellington respectively). If a similar product was used on a house roof (assume 175 m²) then washing the product to the stormwater system would contribute 17.3 g copper or 86.6 g for every five roofs cleaned. This could account for 2.4 per cent of the copper in stormwater load from the Mission Bay catchment.
- A path cleaner containing zinc (as 36 per cent metallic zinc) used at a rate of 1.25 kg product /50 m², would result in the application of 450 g zinc with each application. As such five applications in any catchment per year would contribute 4.8 per cent of the zinc stormwater load in the Auckland CBD, 8.6 per cent in the Mission Bay catchment and 1.3 per cent in the Mt Wellington catchment.

The examples presented above have been used to identify whether the products, if used on impervious surfaces, could contribute copper or zinc. As noted it has been assumed that all the product is washed off and none retained at source through

sorption. More specific information on usage patterns is required to refine these potential losses.

Overall, it is likely that the surface (roofs, paths) cleaning algicides will be more significant contributors to copper and zinc loads than fertilizers.

4.11 Industrial activity

In New Zealand, stormwater quality assessments have shown that land use activity influences stormwater quality for a range of contaminants (Kennedy 2003). Table 4.44 provides information on reported stormwater quality data for different land uses in Rotorua and Auckland.

Table 4.41

Copper, lead and zinc concentrations from different land uses in New Zealand (all data mg/m).

Element	Location	Residential	Commercial/ Industrial	Reference
Copper	Rotorua	13.3	8.9, 30.6	Macaskill et al. (2003)
	Auckland	3.4, 9, 10, 13, 15, 22	2.2, 29, 42	Refer Kennedy (2003)
Lead	Rotorua	18.7	8, 13.1	Macaskill et al. (2003)
	Auckland	1.4, 2, 2.5	0.8	Refer Kennedy (2003)
Zinc	Rotorua	62	137, 252	Macaskill et al. (2003)
	Auckland	42, 61, 80, 110, 117, 128, 260, 285, 330,444,	93, 383, 466	Refer Kennedy (2003)

Examination of data such as that in Table 4.43 indicates that stormwater from catchments of industrial land typically have higher concentrations of copper and zinc compared to residential land use. In recent data (post removal from petrol) lead concentrations are typically low across land uses.

Activities carried out on particular sites within areas of industrial land use have the potential to contribute trace metals to stormwater. Through discussions with the pollution prevention staff at ARC, it was found that the ARC holds information about stormwater quality from a range of industrial sites in Auckland. This is predominantly through compliance monitoring requirements for Industrial and Trade Process (ITP) consents, and through information submitted to ARC by industries as part of a consent application.

To facilitate the investigation of industrial stormwater quality, the ARC was requested to provide all available stormwater quality data (with specific regard to samples that were analysed for copper, lead or zinc) on an anonymous site basis. Information was provided for 18 industrial sites, across a range of ARC industry groups. In total, this included between 98 to 207 stormwater samples for each parameter.

Table 4.45 provides a summary of the total copper, lead and zinc concentrations measured in industrial stormwater in Auckland. For comparison, Table 4.45 also provides the median concentration of total copper, lead and zinc measured in a

selection of industrial stormwater studies in New Zealand and the median concentration reported for industrial land use by the National Stormwater Quality Database (NSQD)(Pitt et al. 2004) in the USA. This database summarises data collected from the National Pollutant Discharge Elimination System (NPDES) stormwater permit holders.

Table 4.42

Summary of total metal concentrations measured in industrial stormwater in Auckland and general stormwater quality.

	Copper	Lead	Zinc
Minimum	0.00060	0.00010	0.00070
Median	0.018	0.038	0.20
Maximum	8.79	1.0	19
Total number of samples	203	98	207
NZ industrial stormwater median	0.029	0.013	0.383
NSQD industrial stormwater median	0.022	0.025	0.21

Note: Units g/m³. The majority of sample results provided by ARC were total metals; however two samples were unspecified. ¹ National Stormwater Quality Database (Pitt et al. 2004), median concentration provided for industrial land use in USA.

Figs. 4.14 to 4.16 show the range of concentrations of copper, lead and zinc measured in industrial stormwater. Because the range of concentrations reported was so broad, each figure also includes an inset diagram (A) which illustrates the concentrations measured in the first column of each figure.

Overall, the data shows a wide variability in concentrations of all three trace metals. Median concentrations of copper and zinc measured in industrial stormwater in Auckland were lower than the New Zealand stormwater median (in Table 4.45), while lead concentrations were slightly higher. A comparison of the data with the NSQD industrial stormwater median shows the concentrations measured in Auckland industrial stormwater to be very similar. As shown in Figs. 4.14-4.16, high concentrations of all three trace metals have been reported by some industry groups, this indicates that site-specific sources maybe an issue at times. The evaluated data also suggests that specific industry types are likely to be primary contributors. In particular the following ARC industry groups were identified to be key contributors: (that is they reported the highest concentrations of copper, lead or zinc in stormwater from their site)

- Copper – metal processing, metal product manufacturing and boat maintenance. Note that this latter category is not specified in the ARC industry group list.
- Lead – chemical and associated product manufacturing (paint manufacturing), metal processing, and boat maintenance.
- Zinc – metal processing, boat maintenance, and metal product manufacturing.

As shown, there are similarities across industries, with metal processing industries and boat maintenance industries being identified as a key source of all three metals.

Overall, the examination of specific site stormwater data held by ARC showed that median concentrations of copper and zinc in that data set were generally similar and slightly lower than the median of other published New Zealand data.

Lead concentrations were higher in the ARC industrial stormwater dataset compared to other data. In addition, the ARC data contained a small percentage of high concentration data (refer outliers in Figs. 4.14 to 4.16).

The data reinforces the need to consider land use effects in load calculations, but does show that particular activities on-sites with specific copper, lead or zinc usage have the potential to contribute additionally to stormwater catchment loads beyond that assessed using generic catchment loading rates.

4.12 Miscellaneous sources

4.12.1 Introduction

There are a wide range of other potential and actual sources that have not been included in the major source categories described above. A number of these are identified and discussed in the following sections.

4.12.2 Litter

A variety of litter is generated in urban areas. This litter often ends up within the road environment where it is exposed to rainwater and transported by stormwater. Contact between litter and rainwater (with acidic pH) has the potential to dissolve a proportion of any copper, lead or zinc incorporated in litter.

There have been a number of studies in New Zealand that have collected information on the nature of "litter" on road surfaces or in stormwater. A brief summary of this information is provided below to determine whether there is potential for metal contributions from these materials.

Kennedy & Gadd (2003) examined road surface materials at 21 sites on Waitakere City roads. Litter on the road surfaces sampled ranged from 0.1-3.9 g/m² (or 70-2700 g/100 m section of road). Figure 4.17 provides a summary of the materials identified in the samples. Of the identified materials, it is evident that a number are relatively common (both in terms of numbers of items and mass) and many are composed of metal. Of the materials identified, metal fragments, glass and cigarette butts were very common. Similar information was reported for road gutter samples by ARC (1992).

Figure 4.14

Copper concentrations in industrial stormwater in Auckland (Data source ARC).

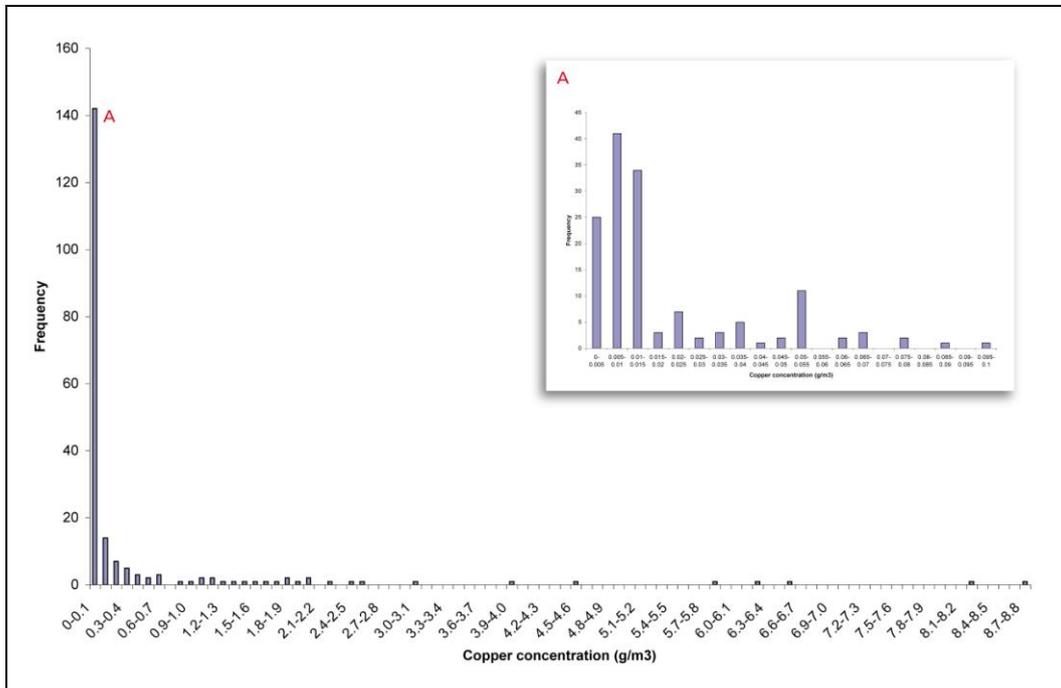


Figure 4.15

Lead concentrations in industrial stormwater (data source ARC).

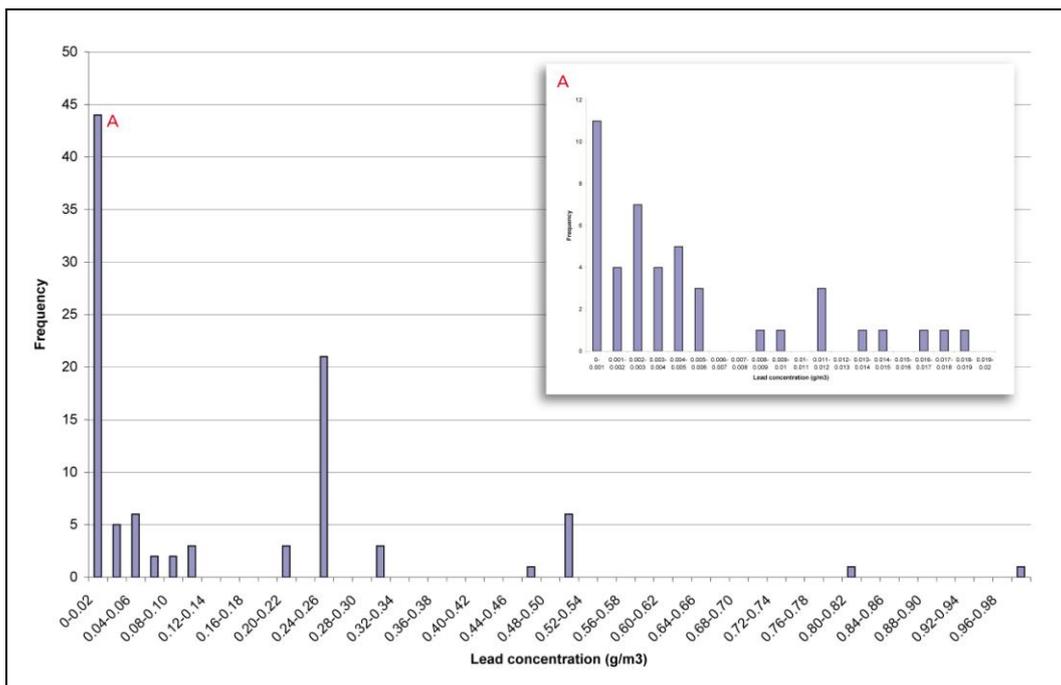
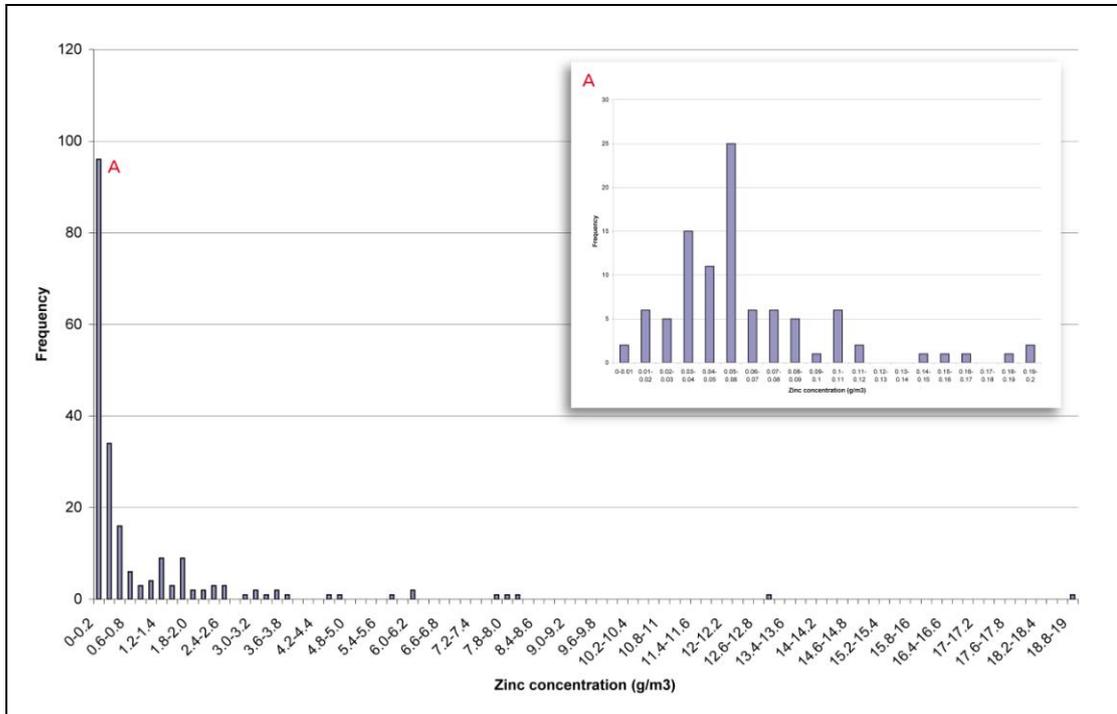


Figure 4.16

Zinc concentrations in industrial stormwater (data source ARC).

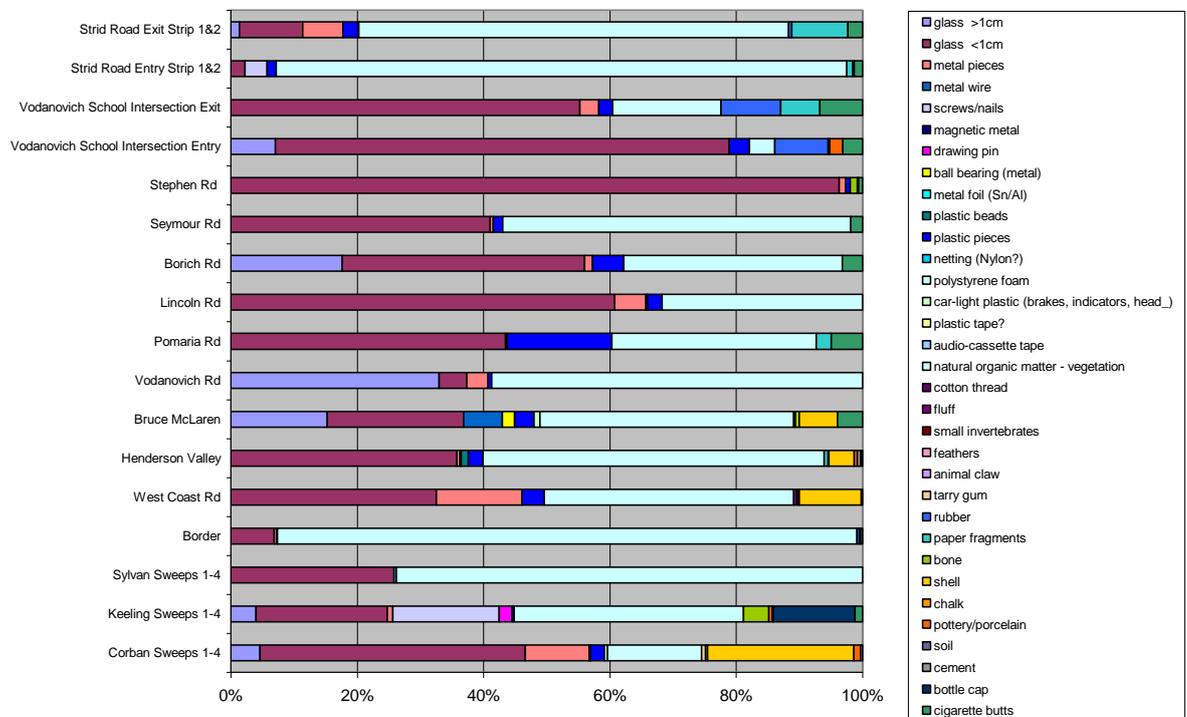


Based on what has been seen on road surfaces, the following observations can be made:

- Cigarette butts are a common component of litter on road surfaces. Butts contains metals both in the original tobacco and in the ash remaining in the butt. Analysis of tobaccos reveals small amounts of metals such as lead (eg 1.66 mg/kg – Pesch et al. 1992). No information is available on the contribution of ash from smokers in vehicles. For the three key elements examined in this study this source is considered trivial.
- Glass fragments are very common and may contribute metals through contact with rainwater. Contributions will be dependent upon the type of glass. Most glass found on road surfaces is either bottle glass or vehicle windscreen glass.
- Use of matches will produce residue containing metals. Information on copper, lead and zinc in match heads has not been identified.
- Plastic fragments (eg from headlights, light protectors on vehicles; pipe and other non road plastics etc.), will contain lead depending on the age and type of plastic. Loss rates of lead from plastic fragments are not known.
- Non tyre rubber may contribute zinc but this source will be extremely small compared to the contribution from vehicle tyres.
- Metals and metals with solder attached may contribute copper, lead or zinc depending on the metal or alloy and its age.

Figure 4.17

Litter on Waitakere City Roads (all data mass per cent, unpublished data from Kennedy & Gadd 2003).



4.12.3 Galvanised light poles and other metal structures adjacent to roads.

Within or immediately adjacent to the road corridor (eg on property boundaries adjacent to the pavement) there are often a range of structures that have metal finishes. These are typically unpainted galvanised metal, but may include copper and lead under some circumstances. Copper and lead were dealt with in Section 4.6 and 4.7 (roofs and building sides). Structures that may have galvanised coatings include:

- Light poles/standards
- Fence poles
- Fence chain link
- Road guard barriers
- Road sign poles
- Road sign frames.

There is very little information concerning the concentration of zinc in the run-off from these types of galvanised structures. In many cases, drainage from these structures (especially light poles, fence poles, and fence chain link) will run into a grassed area, before reaching an impervious surface, and therefore the significance of these as sources of metals to the stormwater system are difficult to assess. Van Beers &

Graedel (2004) provided information on the amounts of zinc associated with some key items of roading infrastructure. They identified that:

- Light poles may have as much as 0.595 kg/m^2 of zinc associated with the coating on the pole surface. With large poles estimated to have a surface area of 34.8 m^2 and small poles 3.8 m^2 , the poles may carry as much as 20.7 kg and 2.2 kg of zinc each. These estimates have not been checked for New Zealand light poles.
- Road safety barriers are also zinc coated. Based on the 0.595 kg/m^2 , a kilometre of barrier (two sides, 1224 m^2) would carry 728.3 kg of zinc.

In relation to fence chain link, WSDE (2006) found that the area of galvanised material in a chain-link fence can be considerable, estimating that a six-ft high, six-gauge (industrial thickness) chain-link fence has an exposed area of approximately 220 cm^2 per linear cm of fence ($2.2 \text{ m}^2/\text{m}$). In addition, as outlined above, drainage from fencing may run across impervious surfaces to the stormwater system but may also run to soil or across vegetated strips before reaching paved surfaces, and therefore the significance of this source is difficult to assess.

In Section 4.6.2, zinc concentrations in roof run-off from unpainted galvanised roofs were shown to be very high, with an average concentration of 2.5 g/m^3 ($0.10\text{-}3.1 \text{ g/m}^3$). It is not unreasonable to expect similar concentrations in other galvanised products.

Tobiason & Logan (2004) measured concentrations of dissolved zinc in run-off from galvanised road guard barriers. First flush concentrations of up to 20 g/m^3 zinc were measured in direct run-off, decreasing to approximately 1 g/m^3 with increasing amounts of simulated rainfall. These results imply that road guard barriers may be an important source of zinc.

Contamination of run-off from galvanised structures vary depending upon the type of galvanising; the condition of the surface and its age; the intensity of the rainfall etc. Assessment of zinc roofing run-off rates in studies such as He et al. (2001) report steady state zinc losses of about $3 \text{ g/m}^2/\text{yr}$. Conservatively assuming that this rate can be applied to the areas noted above for light poles, then each small and large light pole might contribute 11.4 and 104 g/yr respectively. In Auckland not all street light poles are galvanised with many being concrete. For the purpose of providing a possible zinc loss figure for light poles along one side of a 100 m long section of road, it is assumed that there are five poles contributing 57 and 520 g/yr respectively for small and large poles.

Road barriers occur only on particular roads. In a catchment where they are present, a single section of 100 m barrier would contribute 367 g/yr of zinc based on the loss rate identified above.

It is not possible to make reasonable estimates at this stage and further information is required on the extent of galvanised infrastructure in urban areas and on zinc releases/contributions to stormwater.

4.12.4 Building infrastructure

There are a variety of equipment and structures installed on buildings and roofs which have an effect on roof run-off quality. These include air conditioning units and vents, exhaust hoods, ventilation extractors etc.

Contributions to the concentration/load of zinc in roof run-off will depend on the exposed surface area of the structures on a given roof. These contributions would typically be included in the roof run-off. However, where roof run-off type concentration/load estimates are derived from the use of artificial roof surfaces (as in the case of ARC 2004), the contributions from other on-roof sources of zinc would not be included. This would result in an underestimate of the contribution of zinc from roof run-off. The galvanised structures are not expected to affect copper or lead loads contributed from roofs.

Clearly these sources are important and have the potential to be significant contributors to catchment zinc loads. As with roading infrastructure, further information is required on the contribution that galvanised building/roof infrastructure on roofs etc., in urban areas makes to zinc releases/contributions to stormwater.

4.12.5 Road accidents

In Section 4.2, the range of uses for copper, lead and zinc in motor vehicle components was described. Accidents involving motor vehicles have the potential to release contaminants that would not normally be emitted through routine vehicle usage. It would be expected that the amount of additional copper, lead or zinc released to the road environment during and following a vehicle accident would be accident/vehicle specific. Following accidents, the accident scene is usually cleaned of all large scale debris. However, any liquids spilled or small fragments generated and left on the road surface or able to be washed to the stormwater system may contribute to the copper, lead or zinc present. Specifically, this may include vehicle paint, lubricant loss, plastic, glass and metal fragments. No information has been sighted that defines the amount of materials lost during vehicle accidents. On-road accidents involving loss of vehicle components/damage are relatively common. However, due to lack of information, this source is identified as minor. A component of this source is covered under the litter section (eg a component of glass on roads) however this source contributes a range of other materials not identified through the on-road litter surveys. This includes spilled liquids and other less visible materials.

4.12.6 Flares and fireworks

Fireworks and flares are generally composed of an oxygen-producer, fuel, binder and a colour producer, with metals commonly used to produce colour. Copper is a common constituent of fireworks, used to produce blue and purple (in conjunction with strontium) colours. Some information is available on the internet from fireworks chemicals distributors (Table 4.43). That information shows that copper and zinc compounds and zinc metal are key ingredients in fireworks. Lead is prohibited in

consumer fireworks in Countries such as the United States and can be a trace ingredient in New Zealand fireworks (Hazardous Substances (Fireworks) Regulations 2001). However lead tetraoxide is identified as being used in fireworks overseas (Table 4.43).

Potential load contributions to urban environments could be estimated from commercial sales and assumed release/consumption rates should this information be required. Further information on deposition and washout and residue fate would be required.

Generally, fireworks use in New Zealand is limited to the weeks around Guy Fawkes, or specific organized displays (eg events, concerts etc.) and other holiday seasons (eg New Years Eve). The relative contribution of this potential source is therefore likely to be highly variable based on the time of year. Not all of the contribution would be to the stormwater system because a number of displays are held over Harbour waters.

Table 4.43

Copper, lead and zinc uses in fireworks.

Compound	Use/Colour
Copper (II) carbonate ($\text{CuCO}_3 \cdot \text{Cu(OH)}_2$)	Used as a blue color agent
copper acetoarsenite (Paris Green) $\text{Cu}_3\text{As}_2\text{O}_{13} \cdot \text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2$	Blue
Copper (I) chloride, (CuCl)	Blue, turquoise blue colour agents
Copper (II) Oxide (CuO)	Blue color agent
Copper (II) Oxychloride ($3\text{CuO} \cdot \text{CuCl}_2 \cdot 3.5\text{H}_2\text{O}$)	Blue color agent
Copper Benzoate ($\text{C}_6\text{H}_5\text{CuO}_2 \cdot x\text{H}_2\text{O} \cdot (\text{C}_6\text{H}_5\text{CO})_2\text{Cu} \cdot x\text{H}_2\text{O}$)	Turquoise colored powder Blue coloring agent for colored stars and rockets.
Lead Tetraoxide, (Pb_3O_4)	Noted as being used to make crackling stars and in hot burning primes.
Zinc Oxide (ZnO)	Used in smoke compositions and as a pyro-adhesive
Zinc Powder (Zn)	Has a variety of uses in fireworks and in rockets.

Sources; <http://www.bigfireworks.com/t-fireworks-chemicals.aspx>;

<http://www.skylighter.com/mall/chemicals.asp>

The presence of copper, lead or zinc in products such as on-road flares has not been ascertained in this study. Overall, it is likely that fireworks are a contributor potentially of copper and zinc. However further evaluation of the amount of fireworks sold, their content, release and distribution would be required to provide a clearer picture. At this stage the contribution to stormwater is considered to be minor.

4.12.7 Potable water

Earlier in this report, potable water was identified as a known source of copper in urban environments due to the use of copper pipes within the urban water supply system (particularly in houses). This copper enters the water supply and is discharged to a wastewater treatment system (eg Mangere and Rosedale wastewater treatment plants) and then to receiving environments (eg Manukau Harbour). However, potable water is used for a number of external uses (exterior building washing, roof cleaning, cleaning pavements and driveways, vehicle washing etc.), where it may reach the stormwater system. Some ancillary losses may occur during garden watering. Water from the potable supply is also used for street cleaning (referred to as flushing) particularly in the commercial area of Auckland. Street flushing in Auckland City commercial areas occurs twice per week but does not occur in smaller satellite commercial villages (eg Mt Eden).

Apart from the water that is sorbed by surfaces and or evaporates, this water drains to the stormwater system. Losses to stormwater also occur during firefighting, water system testing and system repairs etc.

Copper concentrations in water prior to entering the household water supply system are typically about 1 mg/m³. Concentrations will increase depending upon the amount of copper piping and fittings, water chemistry and temperature and flow through of water in the piping. Copper contributed from disposal of potable water is a function of the total volume used (eg for vehicle cleaning, street cleaning, private property and roof cleaning etc.) and the copper concentration at the location the water is sourced from. In the three catchments identified in ARC (2005) it is likely that potable water loss to the stormwater system will be quite different.

1. Losses in the Auckland CBD are likely to be dominated by street flushing and exterior commercial cleaning.
2. In the Mission Bay residential catchment disposal will be dominated by vehicle cleaning and exterior uses for cleaning and garden watering.
3. In the industrial Mt Wellington catchment, losses are likely to relate to external building and vehicle cleaning.

At this stage, an assessment of total potable water use in various land uses or for particular uses has not been carried out. However for every 10,000 m³ of potable water lost, contributions at concentrations of 1 mg/m³ for lead and 5 mg/m³ for copper and zinc would be 10 and 50 g respectively (Table 4.47). The potential losses of copper and zinc are much higher because of copper and brass plumbing.

Table 4.44

Potable water contribution to stormwater.

Element	Catchment	Catchment load	Potable water concentration (mg/m ³)	Assumed potable water load (10,000 m ³ /year)	Percentage of total catchment load (%)

Copper	CBD (commercial)	4.21	5	0.042	1.1
	Mission Bay (residential)	3.57	5	0.036	1.4
	Mt Wellington (industrial)	4.59	5	0.046	1.1
Lead	CBD (commercial)	3.73	1	0.037	0.3
	Mission Bay (residential)	2.71	1	0.027	0.4
	Mt Wellington (industrial)	4.59	1	0.046	0.2
Zinc	CBD (commercial)	47	5	0.047	0.1
	Mission Bay (residential)	26	5	0.026	0.3
	Mt Wellington (industrial)	176	5	0.176	0.3

Note: Catchment load data from ARC (2005).

5 Sources Overview

5.1 Introduction

This section of the report uses the ARC (2005) assessment of copper, lead and zinc contributions from primary sources to stormwater (refer Figure 2.1) as a starting point and examines additional information on potential sources and their loads. The questions being addressed in this section are:

- Is there any information that would suggest that there are other significant sources contributing to the loading of copper, lead or zinc?
- Is there any information that would suggest that there are a range of minor sources that are contributing to the loading of copper, lead or zinc, that when assessed on an additive basis contribute the equivalent of larger sources?
- For the assessments carried out to date, is there any information that suggests that the use of generic emissions rates is inappropriate and is a part contributor to the levels of uncertainty identified in ARC (2005)?

In the following section each contributory load is given a significance and an uncertainty ranking. The uncertainty ranking is based on a combination of a “lack of data” or factors that drive variability in contaminant emissions at a local level (eg driving conditions), or uncertainty in selection of values to be used in emission calculations. The uncertainty ranking is based on a five point scale as follows:

Rank 1 Data has high degree of acceptability (emission factors and concentrations).

Rank 2 Data has moderate degree of acceptability.

Rank 3 Data has reasonable acceptability.

Rank 4 Data has moderate degree of uncertainty.

Rank 5 Data has high degree of uncertainty (emission factors and concentrations).

The significance ranking used in Tables 5.1 to 5.3 is major source (>20 per cent), moderate source (10-20 per cent), minor source (1-10 per cent), negligible source (<1 per cent). These are colour coded orange, pink, yellow and green respectively.

In the tables where no data is available the abbreviation ND is used and where the estimation is not applicable the abbreviation NA is used.

In undertaking the load contributions assessment, the total discharged catchment load as identified by ARC (2005) has been assumed to be correct. This data is the most “factual” component of the load assessment as it is based on a comprehensive stormwater quality dataset. The contributing loads from each identified source are presented as calculated in ARC (2005).

Where copper, lead or zinc contributions to loads exceed 100 per cent, this is a strong indication that there are sufficient sources identified that could contribute all of the contaminant load identified by ARC (2005). In contrast, if the contributions are well below 100 per cent, this indicates that there are still significant uncertainties in the emission rates or that there are still unknown sources within the catchment.

5.2 Copper sources

The copper mass budgets from ARC (2005) had large differences between the estimated and measured mass balances. In all cases, the differences were negative, with the calculated load being lower than the measured load. Differences ranging from 58 per cent for the residential catchment in Mission Bay to 81 per cent for the industrial catchment in Mt Wellington.

The total catchment loads for copper identified by ARC (2005) were, 4.21, 3.57, 4.59 kg/yr for the CBD, Mission Bay and Mt Wellington catchments. This corresponds to 0.14, 0.078, 0.135 kg/ha/yr for those catchments. ARC (2005) reported that the summed source contributions amounted to 30, 42 and 39 per cent of the measured loads in each catchment. In Table 5.1, the summed source contributions for the three catchments based on the information presented in this report are 81.3-126.1, 66.1-77.5, 56.3-77.6 per cent for the CBD, Mission Bay and Mt Wellington catchments respectively. It is evident that the summed sources have improved considerably in the CBD and Mission Bay catchments, but less so in the Mt Wellington industrial catchment.

Table 5.1

Summary of copper contributions to stormwater.

Primary source	Secondary source	Commentary on source contribution	Estimated contribution (%)			Level of uncertainty
			CBD	Mission Bay	Mt Wellington	
Atmosphere	Rainfall	Minor - moderate: uncertainty lies in the concentration of copper in rainfall in areas such as the CBD.	13.9	2.1	10	3
	Dry deposition	Moderate - major	20.5	20.3	12.4	4-5
Vehicles	Exterior paints	Negligible (assumed), no data	ND	ND	ND	5
	Wheel weights	Negligible: (assumed) no copper data for wheel weights.	ND	ND	ND	3
	Brake linings	Major: estimates of copper contributions from brake pad wear are confounded by the difficulties in determining a reasonable median copper	29.8-74.6	7.3-18.7	13.8-34.5	3-5

Primary source	Secondary source	Commentary on source contribution	Estimated contribution (%)			Level of uncertainty
			CBD	Mission Bay	Mt Wellington	
		concentration for the New Zealand vehicle fleet				
	Tyre wear	Negligible - minor	<0.1	<0.1	0.6-1.2	3
	Oil and grease	Negligible	<0.1	<0.1	<0.1	3
Vehicular accidents		Negligible (assumed)	ND	ND	ND	5
Catchment soils	Natural soils	Minor: contribution estimated from local background	1.7	7.4	8.5	3
	Roadside soil	Negligible: based on 10% of soil being contaminated	0.1	<0.1	<0.1	4
	Garden soil	Negligible - minor: based on 10% of soil being contaminated	2.8	9.4	0.4	3
Road and pavement wear	Road surface wear	Negligible - minor: Contribution depending on wear rates and other factors	3.0	3.0	1.6	4
	Road marking paints	Negligible (assumed)	ND	ND	ND	4
Buildings and private property	Principal roofing materials	Minor - moderate	<2.6	13.1	5.2	4
	Roof infrastructure	Negligible	ND	ND	ND	4
	Lead head nails	Negligible (assumed no copper source)	ND	ND	ND	4
	Walls	Negligible - minor: Unreliable estimate at this stage due to significant uncertainties involved	4.0	0.2	0.3	4-5
	Site infrastructure (fences etc.)	Minor (assumed)	ND	ND	ND	5
Public water supply losses		Minor: assumed arbitrary volume loss	1.1	1.4	1.1	5
Garden and household products		Minor: copper contributions are possible through use on paved surfaces and roofs. Rough order estimate made.	2.3	2.7	2.2	5
Litter		Negligible (assumed)	ND	ND	ND	5
Public utility street infrastructure	Galvanised light poles etc.	Negligible (assumed, no data on copper)	ND	ND	ND	4
	Copper cables and wiring	NA (assumed, no data on copper)	ND	ND	ND	5
	CCA treated	Minor: (assumed)	ND	ND	ND	5

Primary source	Secondary source	Commentary on source contribution	Estimated contribution (%)			Level of uncertainty
			CBD	Mission Bay	Mt Wellington	
	timber	unknown surface area for leaching.				
TOTAL %			82.0-126.8	66.2-78.6	56.9-77.6	

Examining the source information in relation to the copper load estimates the following points can be made:

- The estimates of copper-related to suspended solids (soil) exports are very dependent on the solids load estimates.
- The Mt Wellington catchment has a low solids load estimate and consequently has a lower soil copper-related contribution.

Overall, the copper estimates are low compared to the catchment load estimates in ARC (2005), but the assessment has improved the difference between the assessed and measured loads significantly. It is likely that the copper emission contribution from brake pads is a significant source of copper. It is likely that the emissions assessment is underestimating copper contributions to stormwater from this source. Figure 5.1 summarises the source contributions presented in Table 5.1.

5.3 Lead sources

The lead mass budgets identified by ARC (2005) had significant differences between the estimated and measured mass balances for the industrial (Mt Wellington) and commercial (Auckland City CBD) catchments. In the case of the CBD and Mt Wellington, the differences were negative with the calculated load being lower than the measured load, at 40.2 and 22.4 per cent. In the Mission Bay catchment the assessed load was 108 per cent of the measured load. In the current assessment the assessed loads have increased in the CBD and Mt Wellington catchments to 64 and 76.8 per cent and the Mission Bay estimate has declined to 28.5 per cent.

An initial examination of the load assessments for lead presented by ARC (2005) shows that the contribution from soil and building walls in the older Mission Bay catchment dominated the calculated load. Table 5.2 sets out comments on the key lead sources and the assessed catchment contributions.

Table 5.2

Summary of lead contributions to stormwater.

Primary source	Secondary source	Commentary on source contribution	Estimated contribution (%)			Level of uncertainty
			CBD	Mission Bay	Mt Wellington	
Atmosphere	Rainfall	Minor - moderate: estimated contributions	19.8	3.6	9.9	3

Primary source	Secondary source	Commentary on source contribution	Estimated contribution (%)			Level of uncertainty
			CBD	Mission Bay	Mt Wellington	
		for lead from rainfall are very dependent on rainfall concentration				
	Dry deposition	Moderate	15.0	17.2	7.3	4-5
Vehicles	Exterior paints	Negligible (assumed)	ND	ND	ND	5
	Wheel weights	Negligible - minor: represents one of the few obvious metallic lead emissions. Identifiable but small contributions in all three Auckland catchments	0.5	1.0	0.2	3
	Brake linings	Negligible: contributions from brake pad wear are small. The lower % in the Mt Wellington catchment arises because of the elevated total catchment load	0.6	0.7	0.1	3
	Tyre wear	Negligible	0.17	0.25	0.11	3
	Oil and grease	Negligible	<0.1	<0.1	<0.1	3
Vehicular Accidents		Negligible: (assumed)	ND	ND	ND	5
Catchment soils	Natural soil	Minor - moderate: contribution estimated from local background	2.5	12.7	2.3	3
	Roadside soil	Negligible - minor: based on 10% of soil being contaminated	3.3	3.1	0.6	4
	Garden soil	Minor - moderate: based on 10% of soil being contaminated	7.85	28.2	1.0	3
Road and pavement wear	Road surface wear	Negligible: contribution depends on wear rates and other factors	ND	ND	ND	4
	Road marking paints	Negligible: (assumed) however a possible source	ND	ND	ND	4
Buildings	Principal roofing materials	Minor	7.2	<2.9	3.3	2
	Roof infrastructure	Negligible: (assumed)	ND	ND	ND	4
	Lead head nails (not included in total)	Minor	(1.0)	(2.2)	(1.0)	4
	Lead roof paints	Minor	3.2	5.5	2.2	4

Primary source	Secondary source	Commentary on source contribution	Estimated contribution (%)			Level of uncertainty
			CBD	Mission Bay	Mt Wellington	
	(inclusive of lead head nails)					
	Walls	Negligible: unreliable estimate at this stage due to significant uncertainties involved	1.8	0.8	0.6	5
	Site infrastructure (fences etc.)	Minor: (assumed)	ND	ND	ND	5
Public water supply losses		Minor: (assumed) arbitrary volume loss	0.3	0.4	0.2	5
Garden and household products		Negligible: lead was not identified in household and garden products.	NA	NA	NA	5
Litter		Negligible: (assumed)	ND	ND	ND	5
Public utility street infrastructure	Galvanised light poles etc.	Negligible: (assumed, no data on lead)	ND	ND	ND	4
	Copper cables and wiring	NA: (assumed, no data indicating lead present)	NA	NA	NA	5
	CCA treated timber	Minor: (assumed) unknown surface area for leaching	ND	ND	ND	5
TOTAL %			62.5	76.2	27.9	

Overall, the data in Table 5.2 indicates that the sum of sources is still lower than the measured loads. It is likely that the contributions from roofs (particularly older roofs) has a high uncertainty associated with it. Given that soils appear to be contributing upwards of 30 per cent of stormwater loads, any moderate error associated with this source will be reflected in errors in the final contribution estimates when compared to measured loads.

Examination of the stormwater quality discharged from industrial sites in Auckland indicated that lead concentrations may be higher than average urban stormwater quality (38 compared to 13 mg/m³). As such industrial sites may contribute further lead above that identified within the various sources. This difference has the potential to contribute significantly to the catchment lead load in an area such as Mt Wellington (10 per cent of the catchment contributing at the identified rate would contribute a further 10 per cent to the assessed loads).

Figure 5.2 summarises the source contributions presented in Table 5.2.

5.4 Zinc sources

The zinc mass budgets identified by ARC (2005) had relatively small differences between the estimated and measured mass balances for the industrial (Mt Wellington)

and commercial (Auckland City CBD) catchments compared to the differences found for copper and lead. The differences in that assessment were both positive and negative with the calculated being lower than the measured load for Mission Bay and Mt Wellington (78 and 85 per cent) and for the CBD the assessed load was higher than the measured load (112 per cent). In the current assessment the summed loads are 119, 125 and 84.6 per cent respectively. Table 5.3 sets out comments on the key zinc sources and the assessed catchment contributions.

Table 5.3

Summary of zinc contributions to stormwater.

Primary source	Secondary source	Commentary on source contribution	Estimated contribution (%)			Level of Uncertainty
			CBD	Mission Bay	Mt Wellington	
Atmosphere	Rainfall	Minor - major	29.3	3.8	7.7	3
	Dry deposition	Moderate	9.9	15.8	0.9	4-5
Vehicles	Exterior paints	Negligible: (assumed)	ND	ND	ND	5
	Wheel weights	Negligible: (assumed no zinc present)	NA	NA	NA	3
	Brake linings	Negligible - minor: the lower % in the Mt Wellington catchment arises because of the large total catchment load compared to other catchment loads	2.0	1.9	0.1	3
	Tyre wear	Minor - major	20.8-41.5	40.8-81.6	1.4-2.7	3
	Oil and grease	Negligible	<0.1	<0.1	<0.1	3
Vehicular accidents		Negligible: (assumed)	ND	ND	ND	5
Catchment soils	Natural soil	Negligible - minor: contribution estimated from local background	0.8	5.3	0.6	3
	Roadside soil	Negligible: based on 10% of soil being contaminated	<0.1	<0.1	<0.1	4
	Garden soil	Negligible - minor: based on 10% of soil being contaminated	1.2	6.8	<0.1	3
Road and pavement wear	Road surface wear	Negligible: Contribution	<0.1	<0.1	<0.1	4

Primary source	Secondary source	Commentary on source contribution	Estimated contribution (%)			Level of Uncertainty
			CBD	Mission Bay	Mt Wellington	
		depends on wear rates and other factors				
	Road marking paints	Negligible: (assumed)	ND	ND	ND	4
Buildings	Principal roofing materials	Major	51	42.5	75	2
	Roof infrastructure	Minor: (assumed)	ND	ND	ND	4
	Lead head nails etc	Negligible: assumed no zinc source	<0.1	<0.1	<0.1	4
	Walls	Negligible - minor: unreliable estimate at this stage due to significant uncertainties involved	5.3	1.7	0.3	5
	Site infrastructure (fences etc.)	Minor - moderate: (assumed)	ND	ND	ND	5
Public water supply losses		Minor: assumed arbitrary volume loss	0.1	0.3	0.3	5
Garden and household products		Negligible: zinc contributions are possible. Rough order estimate made	4.8	8.6	1.3	4
Litter		Negligible: (assumed)	ND	ND	ND	5
Public utility street infrastructure	Galvanised light poles etc.	Minor: (assumed)	ND	ND	ND	5
	Copper cables and wiring	Negligible: (assumed not to be a zinc sources)	NA	NA	NA	5
	CCA treated timber	Negligible: (assumed)	ND	ND	ND	
TOTAL %			125.4-146.1	127.8-170.5	88-89.3	

Overall, there appears to be more zinc generated within the catchment than identified in the assessed loads. This is not surprising considering the significant errors/uncertainty associated with the emission rates from the two key sources – tyre wear and metal roof run-off.

Figure 5.3 summarises the source contributions presented in Table 5.3.

Figure 5.1

Assessed proportions of sources contributing copper to stormwater.

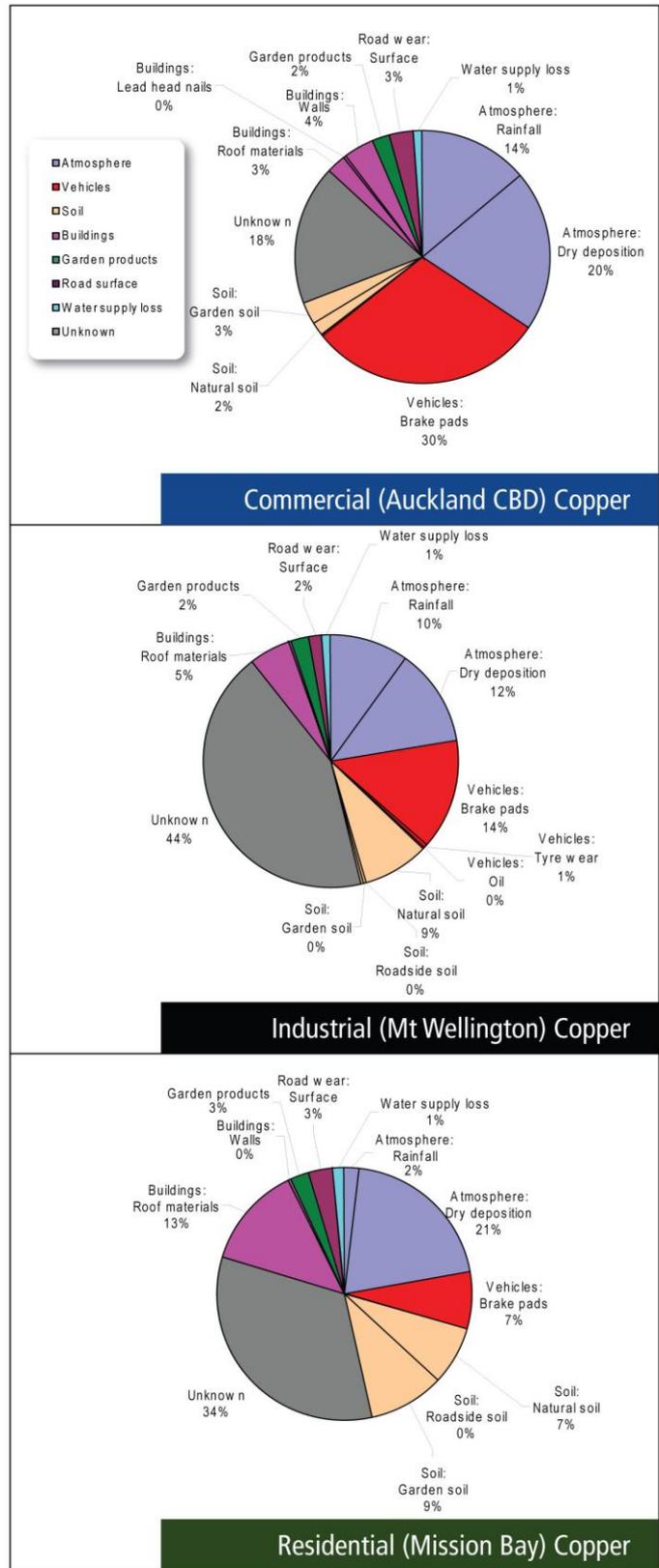


Figure 5.2

Assessed proportions of sources contributing lead to stormwater.

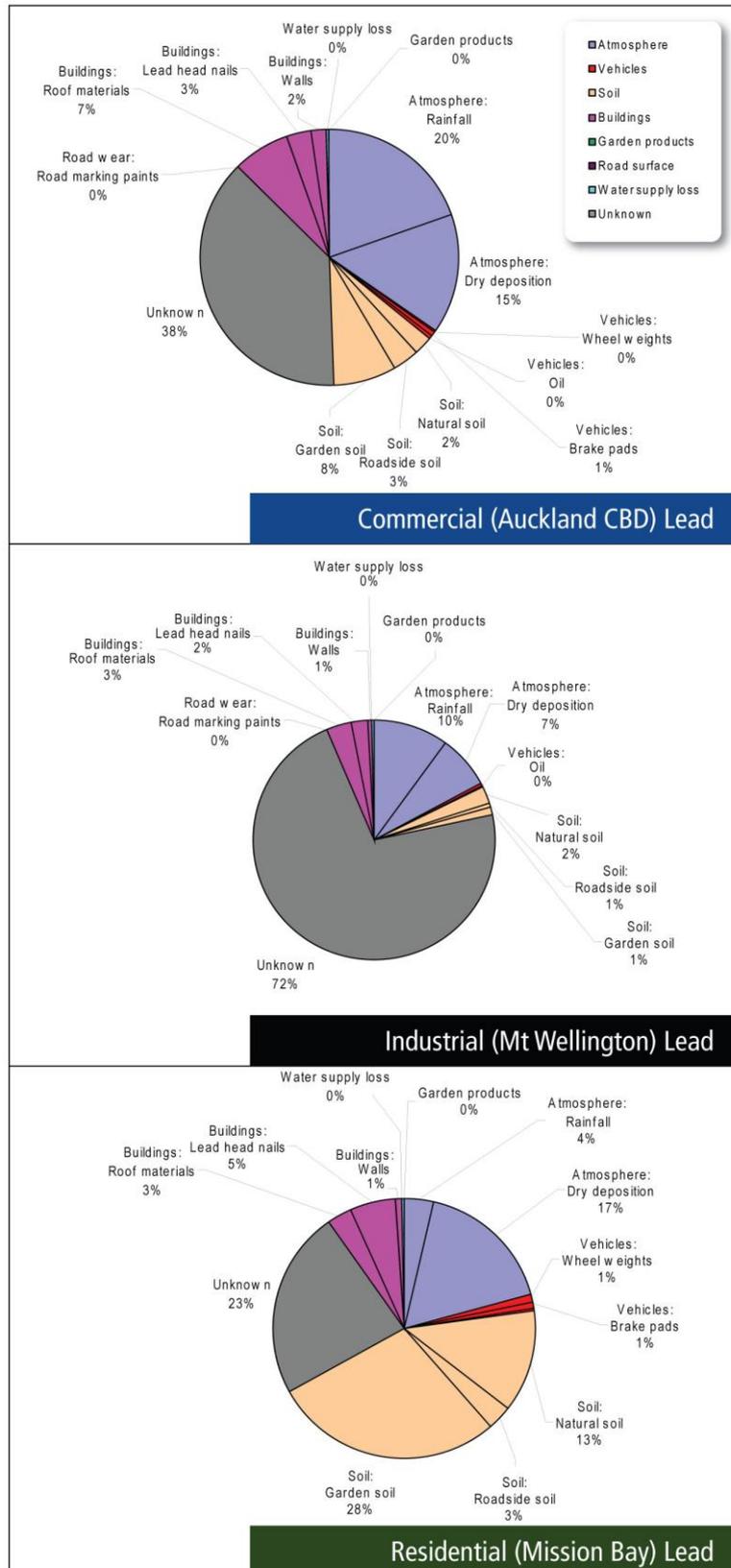
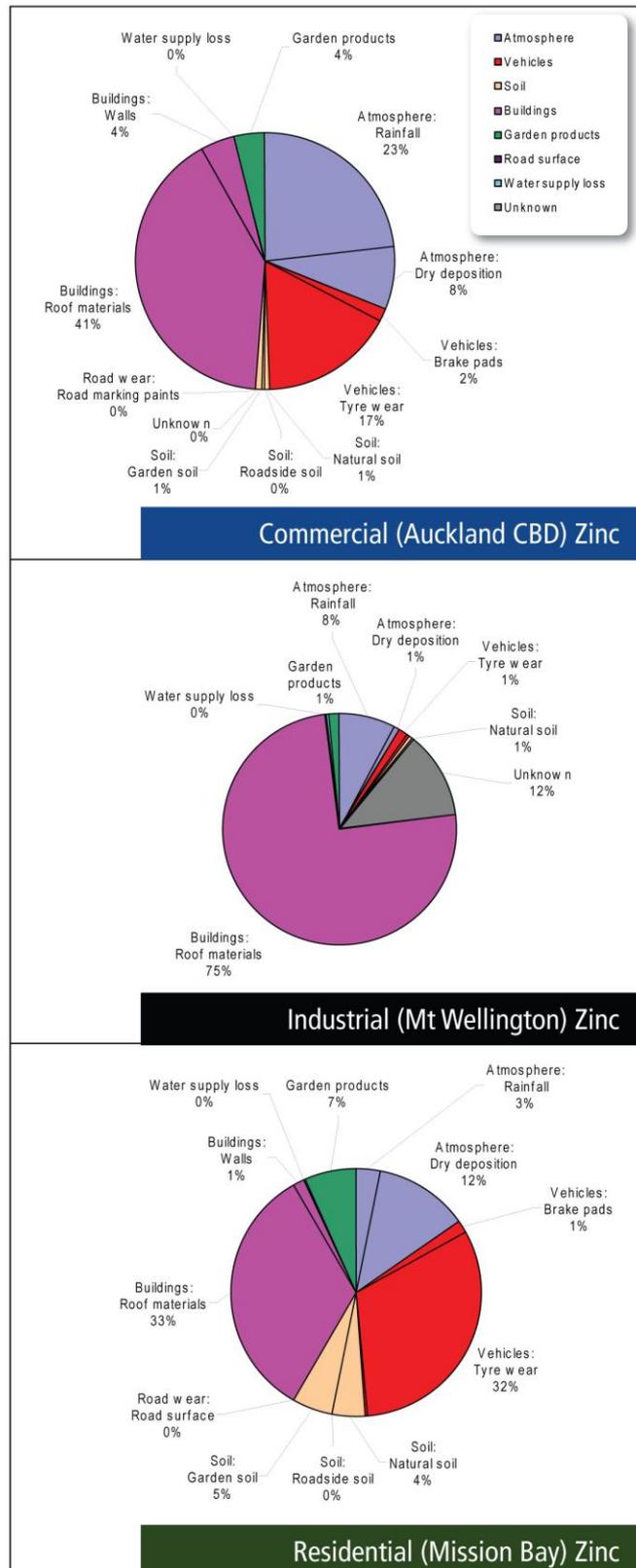


Figure 5.3

Assessed proportions of sources contributing zinc to stormwater.



6 Gaps In Information

6.1 Introduction

In the previous sections, the uncertainties and gaps in information relating to contributions to the catchment loads of copper, lead and zinc to stormwater have been discussed. There are a number of key sources where it is considered that there are significant gaps in knowledge required to calculate loading rates. These are discussed below.

6.2 General gaps

There are significant “gaps” in the quality of available information on the concentration of copper, lead and zinc in rainfall. In addition, there also appears to be no recent published information on the concentration of the three elements in dry deposition in the Auckland region. The assessment of contribution based on the limited current information indicated that the proportional contribution from these two sources appears to be significant, with the combined proportions being 34.4, 22.4 and 22.4 per cent for copper in the CBD, Mission Bay and Mt Wellington catchments; 34.8, 20.8 and 17.2 per cent for lead in the three catchments respectively and 39.2, 19.6 and 8.6 per cent for zinc in the three catchments respectively. As such improved data quality would result in improvements in the certainty associated with this source.

Based on the ARC work (2004), some areas of industrial land use in Auckland appear to generate roof run-off of poorer quality than other land uses. Further information in relation to contributions from areas of industrial land use would assist in refining the contributions in this area.

6.3 Copper

Wear of brake pads on vehicles is identified as a key source of copper in stormwater. Available data indicates that there is a high degree of uncertainty in the concentration/load of copper released through brake pad wear in New Zealand. The significant variance in copper contributions from brake pad wear from driving conditions and copper content of brake pads can only be refined by:

- Obtaining better definition of the copper concentration in brake pads.
- Obtaining better vehicle fleet composition information within catchments (ie does a catchment have a higher proportion of vehicles such as trucks and buses).

- Obtaining a better picture of driving conditions within a catchment (ie factors that affect the wear rates of brake pads – generating more wear and increasing copper loss).

Potable water was identified as a potential source of copper. Although the source was identified as minor, the assessed contribution was based on assumptions rather than actual concentration data for copper in tap water and likely volumes of water discharged. Better definition of the contribution will require data on copper concentrations in Auckland tap water and definition of sources of potable water being contributed to stormwater (any further work should also include lead and zinc in analysis).

6.4 Lead

It was identified earlier in this report that although the mass of lead in wheel weights lost to road surfaces is large, the amount of lead lost through solubilisation and therefore the load contribution/ha appears to be relatively low compared to the total amount generated within the catchment. To ensure that this load contribution is not being underestimated, further information is required in relation to some aspects of the fate of lead wheel weights in New Zealand. This work could include assessments of mass lost to roads and obtaining information on the rate of lead lost through solubilisation.

Lead headed nails (and flashings) have been identified as a potential source contributing to lead in roof run-off. Although this contribution is potentially caught in the overall roof run-off lead concentration/load, it would be valuable to assess their contribution to roof run-off. Any work assessing lead dissolution should confirm that copper and zinc are not contributed from this source.

Given the apparent contributions that may be coming from old paint on roofs, further information on, the occurrence of old paints on building roofs (arising from old leaded paints remaining on roofs or being over-painted), concentrations of lead in roof paints, or the concentration of lead in roof run-off would be of value. Ideally, information on lead in run-off from roofs where the lead concentration in paint on the roofs was known would be of most value. Any work assessing lead contributions from paints on building roofs should also collect information on the copper and zinc contributions at the same time.

Lead in inner city garden soil was identified as a likely source of some of the lead in stormwater run-off. Further information is required in relation to the mechanisms of garden soil loss to stormwater, to quantify the amount of lead derived from this source.

6.5 Zinc

Zinc is an important component of vehicle tyres and as such is recognised as a key contributor to zinc in stormwater run-off. Evaluation of the sources of tyre wear has

shown that the significant variance in zinc contributions from wear resulting from driving conditions and zinc content of tyres can only be refined by:

- Obtaining better vehicle fleet composition information within catchments (ie does a catchment have a higher proportion of vehicles such as trucks and buses and therefore more tyres).
- Obtaining a better picture of driving conditions within a catchment (ie factors that affect the wear rates of tyres – generating more wear and increasing zinc loss).

Further work is recommended to reduce the uncertainty in the variation in zinc concentration with the condition/nature of roof surfaces.

Further data would also need to be collected on zinc concentrations in Zinalume roof run-off, given that Zinalume roofs are becoming increasingly important as a substitute for galvanised iron roofs. Information collection should focus on obtaining data for aging Zinalume roof surfaces.

Field surveys identified galvanised coating as common on utilities and structures on buildings. Further work is required to refine the contribution from these varied sources.

Zinc coated surfaces have been identified as a significant component of building sides especially in industrial areas. No information on zinc concentration in run-off from building sides appears available. Some information should be collected on zinc concentrations in siding run-off.

In residential and other catchments, timber materials and walls can be coated in paint which may contain zinc. Currently there is no information on potential contributions to zinc load from this paint. Although the preliminary assessment presented in this report has indicated that contributions from such sidings is small, there is considerable variation around estimates.

7 Conclusions

The re-evaluation of possible sources of copper, lead and zinc contributing to urban stormwater revealed several sources that had not been accounted for in prior evaluations (ARC 2005).

There are a number of identified sources of these three key trace elements that have very little information available in relation to the amounts released into stormwater. Further work will be required to refine the contributions from those particular sources. The key findings of this evaluation are:

Copper

1. Copper in rainfall contributes significantly to the load in stormwater. More precise data is required on copper concentrations in urban rainfall to refine this contribution.
2. Brake pad wear is identified as a significant contributor to copper load, but there are still significant uncertainties of the copper concentration in brake pads currently in use in New Zealand and these uncertainties lead to underestimates in the contribution from this source. A better definition of copper concentration in brake pads in New Zealand is required. Further refinement on the amount of copper released from brake pads and captured within the road/stormwater catchment is required.
3. Other sources of vehicle emissions are not considered significant sources of copper. Exhaust emissions are not specifically included, as that contribution is likely to be covered by other sources (eg dry deposition, rainfall) contributing to the stormwater load.
4. Catchment soils are a minor to moderate contributor to the copper load. It is possible that soils that have historic copper contamination may be a much greater source than presently estimated. To refine the contribution, the information used and the method used to identify the contribution needs further work.
5. Small changes in the number of copper roofs can affect total loads contributed to stormwater.
6. Copper is also used in some roofing treatments. This will provide a direct contribution to stormwater. This source needs to be quantified.
7. Most non-copper roofs do not contribute significant copper. The presence of copper in roof paints can contribute small amounts of copper. The presence of paints containing copper on galvanised iron roofs may need further assessment due to the moderate-high proportion identified.
8. There is insufficient information on treated wood surfaces in Auckland to quantitatively identify how much copper may be lost through contact with water.

9. Copper is used in a wide range of garden products. Preliminary estimates of possible contributions indicate that roof and pathway cleaning products have the greatest potential to contribute copper. No specific information is available on the amount used per year so no accurate estimates of rates of loss have been made.
10. Potable water has been identified as a possible contributor of copper. Further work is required on the copper concentrations in household water and the uses that result in loss to stormwater need to be quantified.

Overall, the current data presented in this assessment still indicates that copper loads to stormwater from known sources are still underestimated. However at this stage it is considered that the largest contributor to this unknown may be an under estimation in the contribution from brake pad wear.

Lead

1. Although concentrations of lead are low in rainfall, lead in rainfall contributes moderately to the load in stormwater. More precise data on lead concentrations in urban rainfall is needed to confirm and refine this contribution.
2. Loss of wheel weights from vehicles results in a contribution to stormwater through solubilisation of lead on the wheel weight surface. The load contribution of lead from lead wheel weights appears to be relatively low compared to the total lead in the catchment. However, to ensure that this load contribution is not being underestimated, further information is required on the fate of lead from wheel weights in New Zealand.
3. Brake pad and tyre wear is identified as only a minor contributor to lead loads.
4. Other sources of vehicle emissions are not considered significant sources of lead. Exhaust emissions are not specifically included as that contribution is likely to be covered by other sources (eg dry deposition, and road dust) contributing to the stormwater load.
5. Catchment soils are a moderate contributor to the lead load. Further information (as per copper point 4 above) is required.
6. Lead is present in older paints on roofs painted prior to the removal of lead based paints from the general market. Based on the high proportion of older galvanised iron on buildings within the study catchments, lead in paint may be a significant contributor. Further refinement of the load estimates would require specific testing to look for cases of old paints on roofs.
7. A contribution may occur from the use of lead head nails on house roofs. To refine the available data, further assessment of the release of lead from in-situ nail heads and other lead uses such as flashings would be required.

Zinc

1. Zinc concentrations in Auckland rainfall appear locally variable so to refine the rainfall contributions will require better data on zinc in Auckland rain.

2. Brake pad wear is a minor contributor of zinc and tyre wear a major contributor. Tyre wear contributions to stormwater in the CBD and Mission Bay catchments were high.
3. Other sources of vehicle emissions are not considered significant sources of zinc. Exhaust emissions are not specifically included as that contribution is likely to be covered by other sources (eg dry deposition and road dust) contributing to the stormwater load.
4. Catchment soils are a relatively minor contributor to the stormwater zinc load. Zinc is a common contaminant in urban soils. Refinement of the zinc contribution from soils with historic zinc contamination should refine the accuracy of the soils contribution estimates. Wear of natural materials in road surfaces is assumed to be captured under natural soils contributions.
5. Zinc roof surfaces can be a significant contributor to the zinc load in stormwater. This was shown to be especially pronounced for older, unpainted galvanised iron roofs or painted roofs where the paint layer had deteriorated marginally.
6. Concentrations of zinc have been shown to be noticeably elevated in roof run-off from industrial areas. This suggests that specific industrial activities have the potential to increase the contaminant loads in roof run-off above and beyond the generally higher loading within industrial areas.
7. Zinc is a common constituent in old and new paints. Data on roof run-off quality from galvanised iron roofs may mask the contribution from zinc based paints.

Although zinc source contributions are over estimating the measured zinc loads, there appear to be other sources which are contributing zinc but not yet quantitatively included in the source assessment summation. Further refinement of this information is required.

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