INTRODUCTION TO STORMWATER ISSUES

4. *Stormwater contaminants*

4.2. Urban stormwater contaminants

The effects of urbanisation, and particularly those arising from associated contaminant discharges, have been widely studied both in New Zealand and overseas. This research indicates that stormwater derived **pollution** can be insidious; building up over extended timeframes before giving rise to toxic effects (see Figure 4.2.1). While this research has drawn upon the monitoring of stormwater discharges in order to assess contaminant loads and discharge quality, comparatively little work has been undertaken to separate contributions from various sources within a given **catchment**, most notably that made by roads, until relatively recently. Consequently, research which categorically and directly assesses the actual effects of runoff that roads might have upon the environment in New Zealand has only begun to become more readily available since 2002. In that year research reported by O'Riley et al, Kennedy et al, and Kennedy, Gadd and Moncrieff all sought to address this issue. More recent research has been reported by Gardiner and Armstrong (2007), Depree (2008), Moores et al (2008), Reed et al (2008), Moores et al (2009) and Moores et al (2010). This research now provides a substantial body of work on the effects of stormwater discharges from roads on the environment.

This section overviews the generic loadings of contaminants that may arise from land development, discusses what is known about road discharges, and then considers the effects of long term contaminant discharges on the environment.

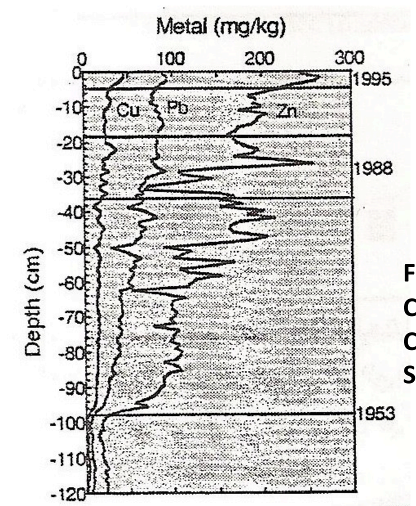


Figure 4.2.1: Stormwater Contaminant Concentrations with Sediment Depth
Source: Williamson, 2000

Research in New Zealand in the early 1990s by Williamson (1993) and Macaskill and Williamson (1994) identified stormwater from urban sources as a major contributor to declining receiving environment quality.

This includes effects arising from both physical changes(e.g. arising from increased **imperviousness**), and those arising from chemical or contaminant discharges (discussed below). Typical contaminants within urban stormwater and their primary sources are overviewed within Table 4.2.1.

Table 4.2.1: Typical Urban Stormwater Contaminants and Sources

Parameter	Likely Sources
Sediment / solids	Construction, road surfaces (road grit through to fines from metalled surfaces), particulates from emissions (vehicles, domestic fires, industrial), vehicle wear.
Copper	Vehicle brake pads, industrial activities, plumbing and guttering.
Lead	Industrial activities and residues from historic activities (plumbing, paint, petrol, sprays), tyre balancing weights, roof flashing.
Zinc	Vehicle tyres, galvanised building materials (including unpainted rooves), paint, industrial activities.
Hydrocarbons	Vehicle emissions, lubricating oils.

Parameter	Likely Sources
Polycyclic aromatic hydrocarbons	Domestic fires, industrial emissions, vehicle exhaust, lubricating oils.
Plasticisers	Building materials, plumbing, litter, sprays.
Herbicides, pesticides, fungicides	Sprays, paint. Chlorinated compounds from residues from historic practices.
Rubber	Tyre wear.
Detergents / surfactants	Wash down areas, domestic discharges (e.g. car washing), paints, industrial discharges.
Nutrients	Wastewater discharges and overflows, fertilisers, lawn clippings, compost heaps.
Faecal matter	Wastewater discharges and overflows, stock truck discharges, illegal stormwater connections.
Litter	Discarded material, windblown materials, illegal disposal and dumping.

Marked differences in key contaminant indicators have been measured in discharges from urbanised catchments compared with less developed catchments. An example of overseas data assembled in the late 1980s is summarised within Table 4.2.2 and compared to New Zealand research by Williamson (*Urban Runoff Data Book*) (1993), which also considered stormwater quality from urban catchments.

Table 4.2.2: Comparison of In-Stream Water Quality

Parameter	Forested Catchment[1]	Agricultural Catchment[1]	Urban Catchment[1]	NZ Urban Catchments[2]
Total Phosphorus (mg/L)	0.09	0.27	0.10	0.42
Dissolved Phosphorus (mg/L)	<0.01	0.05	0.02	0.04
Total Nitrogen (mg/L)	1.70	2.11	1.42	2.5
Dissolved Nitrogen (mg/L)	0.08	0.59	0.41	-
Total copper (µg/L)	7.9	5.0	12.5	40
Total lead (µg/L)	5.1	6.6	14.4	110
Total zinc (µg/L)	31.0	23.0	39.0	260
Mean Stream Temperature (°C)	14	15	15.5	-
Max. Stream Temperature (°C)	22.5	23	25	-
Sediment Discharge (kg/ha/year)	292	696	1,325	375

Sources: 1. Modified from Watershed Protection Techniques (Based on data from Crawford and Lenat, 1989).
2. Williamson. 1993. Urban Runoff Data Book

In his assessment of urban stormwater quality, Williamson (*1993*) noted that:

> *"Urban runoff is typified by high concentrations of solids. At the start of the storm, much of this is floating material (trash, leaves, twigs, oil) but as flow increases, the water becomes quite muddy from the high load of suspended material. Most of this is soil, accumulated in drain sediments, plant litter and eroded roading material. This soil-like material is the major source of nutrients, organic matter and bacteria. Urban runoff is not unique in this respect as high concentrations of these substances are also found in storm runoff from other developed land uses ... What does distinguish urban runoff is the material derived from motor vehicles, chiefly lead (Pb), zinc (Zn), copper (Cu) and oil ...Whatever the source, most potential pollutants are associated with particulate material"* .

Since this was written, lead has been removed from petrol. Nonetheless, lead is expected to remain a contaminant of interest in road runoff due to its presence in vehicle components and residues in fuel tanks, and in urban stormwater directed on to the road from adjacent properties, from historic protective surfaces. Further research has also been undertaken since 1993 to identify the source of zinc and other contaminants. This has contributed to an improved understanding of contaminant sources, such that it is becoming apparent that roads may not necessarily be the primary contaminant source within urban environments, even for contaminants initially perceived as being derived from road runoff.

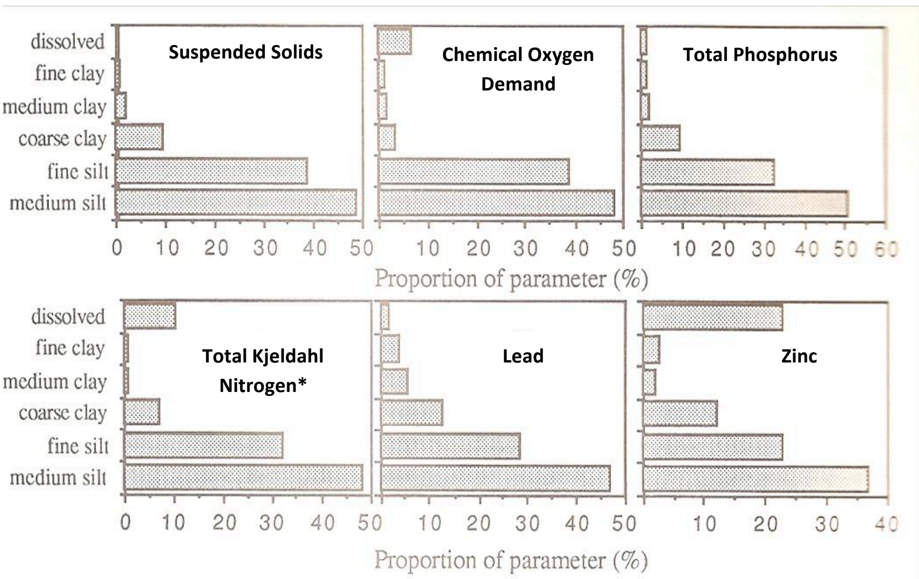


Figure 4.2.2: Proportion of Potential Pollutant by Particle Size
Source: Williamson, 1993
(see Glossary for definition)*

Williamsons's assessment was consistent with overseas research , and the basis for stormwater quality improvement (both in New Zealand and overseas) has focused on sediment and sediment adsorbed contaminants in the first instance. Attention has more recently turned to the importance of the very fine **particulate materials** and **dissolved contaminants**. Both fractions typically pass through conventional stormwater quality improvement devices (**SQIDs**), and can be proportionately more toxic than coarser sediments. In the case of the fine particulates, this is due to the increased surface area, and therefore the relatively higher concentration of contaminants by weight. In the case of dissolved contaminants, increased toxicity is associated with increased **bioavailability** (Timperley, 2002). Williamson (1993) suggests, however, that understanding the toxic effects of these constituents can be problematic and may vary considerably between the discharge point and receiving environment:

> *"In urban runoff, metals are ... 'added' as highly-reactive forms (e.g.* $PbCl_2$*,* $PbBr_2$[4] *in vehicle emissions) but the complex sediment-rich environment ensures their rapid conversion to less reactive, less toxic forms."*

[4] Being lead chloride and lead bromide respectively.

Table 4.2.3: Summary of Overseas Data - Mass Emissions from Motorways and Roads

Parameter	M1 England	N1 Switzerland	A2/ A6 France	I-95 USA	Highway 794 USA	Highway 45 USA	Harrisburg USA	Nashville USA	Denver USA	Street England
Vehicles per day (vpd)	32,000	26,500	-	101,500	53,000	85,000	24,000	88,000	149,000	500
kg/ ha /mm of rain										
Suspended Sediment	2	1.1	1.3	1.5	1.5	5.7	1.1	2.3	4.0	1.0
COD	-	-	-	-	0.9	1.9	0.7	1.1	2.4	-
BOD	-	-	-	-	1.12	0.16	0.08	0.19	0.23	-
Hydrocarbons	1.17	-	-	0.126	0.086	0.067	0.02	0.045	0.032	-
g/ ha /mm of rain										
PAHs	0.025	-	-	0.055/ 0155	-	-	-	-	-	-
Dissolved Phosphorus	-	-	-	-	3.1	7.6	8.5	20.0	7.6	-
Total Nitrogen	-	-	-	-	25.0	69.0	37.0	42.0	43.0	-
Total copper	-	-	-	2.7	0.84	1.9	0.7	0.82	1.2	0.04
Total lead	5.9	3.5	2.4	11.5	16.0	14.0	16.5	5.9	6.8	0.25
Total zinc	11.5	2.7	3.8	-	3.8	8.5	1.4	2.6	5.6	0.19

Source: Williamson. 1993. Urban Runoff Data Book.

Timperley (2002) also noted that dissolved metal **bioavailability** may be reduced by increasing concentrations of **dissolved organic matter**. Notwithstanding this point, research undertaken by both Williamson and Timperley identified significant issues with dissolved zinc concentrations in urban runoff. Whereas roads had been identified as the likely major contributor of dissolved contaminants such as zinc, subsequent research by Timperley (ARC, 2005) indicated that this issue may be attributable to galvanised roofing:

> *"Roof run-off could account for almost all the zinc in the catchment stormwater. Galvanised iron roofing contributed the major part of the roof run-off zinc load. .... Road run-off is a relatively small source of zinc in all* [study] *catchments".*

In a large number of urban areas, roof runoff is discharged into the 'road stormwater network', where the contaminant source is attributed to road related sources, when clearly this is not the case. Notwithstanding this, dissolved metal may account for approximately half of the total zinc load, and a quarter of the copper load in stormwater from a road (ARC, 2005). Moores et al (2010) found the range of the median percentile for dissolved zinc was from 15% to 69% of the total load and for dissolved copper from 22% to 82% of the load from roads deliberately selected to isolate the contribution from road run-off only.[5]

In 1996, the Ministry of Transport (**MoT**) reported that the contribution of road generated contaminants in stormwater was unclear. Road run-off was, nonetheless, assumed to account for 40-50% of urban metal contamination to aquatic ecosystems (Transfund, 2004). Studies quantifying 'road only' **loads** were rare within New Zealand at that time, so the MoT concluded that research about the environmental effects of road transport on water quality was not well-enough advanced to quantify the contribution that road transport made to any specific effects.

The substantial body of research built up since 2002 has specifically sought to adress the issue of the contribution made by road transport to environmental effects, and to quantify the contaminant loads coming from roads and traffic. Depree (2008) sampled receiving environments near state highways and Reed et al (2008) sampled the major treatment device in Grafton Gully for the urban motorway crossing central Auckland. Recent work has tried to identify a consistent calculation of the pollutants contributed by individual vehicles (Moores et al, 2010). The number of variables involved makes such a calculation complex and uncertain.

The *Integrated Stormwater Management Guidelines for the New Zealand Roading Network* (Transfund New Zealand Research Report No 260, 2004) identifies six main groups of "road related contaminant sources", as follows:

- Vehicle exhaust emissions:
  These contain a wide range of metals and organic compounds. The particulate component was cited as being most relevant to the road corridor and diesel based emissions were identified as important contributors of polycyclic aromatic hydrocarbons (**PAHs**);

- Tyre wear:
  Tyres are an important source of zinc and possibly lead, and also contain a wide range of organic compounds;

- Brake lining wear:
  Brake pads are an important source of copper, lead, and antimony as well as containing a wide range of organic compounds;
- Transport fuels:
  Fuels contain a wide range of volatile and semivolatile organic compounds (**VOCs** and **SVOCs**), and **heavy metals**. It was the assessment of the Guideline that "*fuel losses are probably not a significant factor in the overall load of contaminants that enter stormwater and are generated by motor vehicles*";

- Lubricant losses:
  Lubricants, greases and coolants contain a range of contaminants including heavy metals (particularly zinc), as well as a range of organic compounds. As with fuels, the Guideline assessment was that these were largely contained and unlikely to be a significant contributor to road related stormwater contamination.

- Road surface wear:
  This was identified as a source of particulate matter and some organic compounds. Bitumen surfaces were noted as containing "*PAHs in low concentrations*".

[5] NZTA Research Report 395, 2010

In research undertaken for the MoT, the extent to which these aspects contribute to road related contaminant loads varied according to a wide range of factors, not least of which includes road and driving conditions (e.g. driving style, pavement type, weather). Furthermore, as noted in **Section 1**, the range of potential contaminants encountered within the stormwater system of an operational road can in fact vary more widely than this (refer also to Williamson, Timperley, MoT). Potentially, contaminants could include any transported goods as well as contaminants generated on adjacent properties. These contaminants may be discharged directly (e.g. spills or roof water discharges into kerbs) or indirectly (e.g. wash water or yard run off) to the road, or as a consequence of flooding, or as dust or spray.

The assessment of road related effects is consequently more complex than 'simply' extrapolation of emission data. Notwithstanding this, an understanding of the relative contaminant loads contributed by roads can assist the understanding of the magnitude and likely significance of the issue. In the *Urban Runoff Data Book*, Williamson provided a summary of mass emissions data from overseas motorways and roads (refer to Table 4.2.3). Unfortunately the summary is presented as a mass loading per millimetre of rain, and as such does not relay information regarding matters such as intervening dry spell or traffic intensity, and is not directly comparable to later monitoring of New Zealand conditions by Williamson and others (refer to Table 4.2.4).

Table 4.2.4: Contaminant Concentrations in Urban and Motorway Stormwater in New Zealand

Parameter	Urban Catchment				Motorway	
	Hillcrest	NZ-wide	Pakuranga	Southdown	Otahuhu	Porirua
Average Daily Traffic (ADT)	-	-	-	-	90,000	50,000
mg/ L						
Suspended Sediment	-	170	17	52	91.4	-
µg/ L						
PAHs	-	-	-	-	15.6	308
Total copper	23	40	15	42	53	80
Total lead	95	110	55	82	108	<50
Total zinc	190	260	444	446	159	60

Source: *Integrated Stormwater Management Guidelines for the New Zealand Roading Network* (Transfund New Zealand Research Report No 260, 2004).

While this later research does include data from outside Auckland, where most of the research has been undertaken to date, it is still limited for the remainder of the country. As such, this highlights both the inherent uncertainty of assessments which rely on these estimates, and the likely low level of accuracy when applied to the assessment of effects in catchments outside Auckland.

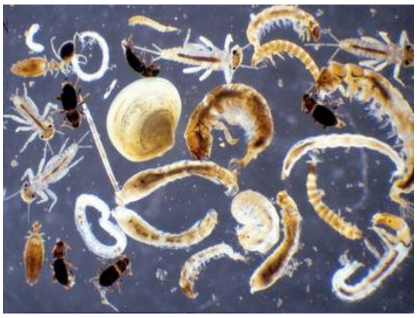
This later research did improve the level of understanding associated with road and urban related contaminant loads. However, it underlined the need for additional assessment of discharges, predictive models, and management regimes that rely on these. Careful handling of the data was required to avoid undue reliance on, or a perceived high level of accuracy of model results which used any of the research overviewed above as the basis of predicting discharges in other situations.

In 2005, a model of likely stormwater contaminants based on average daily traffic (**ADT**) counts was developed (refer Land Transport New Zealand[6] Research Report 264). The modelled loads have been compared within Table 4.2.5 against the average loads reported by:

- Williamson (within the *Urban Runoff Book* for urban stormwater);
- Timperley (within ARC document TP04104 *Sources and Loads of Metals in Urban Stormwater*. ARC Technical Publication No.04104); and
- NIWA (in a study undertaken for the Rotorua District Council *Rotorua City Urban Stormwater Quality and Prediction of Environmental Impacts: Technical Addendum*. NIWA, 2003).

Additional contaminant load information, obtained as part of TP04104, is further summarised within Table 4.2.6[7]. While these loads have been derived from only one catchment[8], they indicate that roads are capable of producing much greater heavy metal loads than predicted by the Land Transport research model (also included again within Table 3.6), but a much smaller overall contribution to that generated by the total catchment (refer to Figure 4.2.3). This was echoed in general terms by the Rotorua assessment (NIWA, 2003).

As noted above, as a consequence of the difficulty in directly quantifying and separating road related contaminant discharges, studies considering the effects of road contaminants have either assessed the effects independently of the actual discharge (i.e. 'what is the toxicity of zinc?') or involve state of the environment monitoring (in which the contaminant sources are difficult to separate). Aside from the variables affecting the discharge itself, the nature of environmental effects will depend on that of the receiving environment. In other words, whether the discharge is into a freshwater stream, lake or other impounded system (e.g. wetland), or to the marine environment (and whether that is, for example, sheltered, exposed, brackish, soft shore or rocky).



New Zealand Freshwater Macroinvertebrates
Source: NZfreshwater.org

The level of disturbance within the receiving environment is also a factor. However, simply because an environment is degraded does not necessarily equate to a greater tolerance of contaminated discharges. Nor does it necessarily indicate the appropriateness (or otherwise) of such discharges. Many degraded systems have a high ecological potential and may benefit disproportionately from an investment in additional protection or restoration. An overview of New Zealand fish species and a more detailed description of the effects upon these from urban runoff, is provided in the MfE document *Lake Manager's Handbook: Fish in New Zealand Lakes* (MfE, 2002). Obviously this will not be applicable to the marine environment, or directly applicable to moving water bodies; however, this does provide a general overview of the range of species, their tolerances, and likely effects of contaminant discharges. As such it provides a useful introduction to the range of specific effects of concern to native fisheries.

[6] Now the NZ Transport Agency (NZTA).

[7] It is understood that these results were used to inform the ARC's Contaminant Load Model (available from the Auckland Council web site; refer to **Section 5** for the URL).

[8] Being a 500m length of Richardson Road conveying approximately 17,000vpd.

ntaminant Load Estimates for Stormwater in New Zealand

	Estimated Motorway Loadings Based on Average Daily Traffic Count(ADT)[1]				Estimated Urban Contaminant Loadings[2]			Measured Urban Contaminant Loads - Auckland[3]			Measured Urban Contamina Rotorua[4]		
	<1,500	1,500 – 5,000	5,000 – 10,000	>10,000	Low	Average	High	Central Business District	Mission Bay	Mt Wellington	Residential		
ment	365	730	1,095	1,460	90	375	1,750	310	620	252	197	219	820
TPH)	0.1	0.6	1.3	3.2	-	-	-	-	-	-	-	-	-
	0.01	0.05	0.10	0.24	0.02	0.09	0.20	0.14	0.08	0.14	0.033	0.085	0.317
	-	-	-	-	0.07	0.2	0.4	0.12	0.06	0.14	-	-	-
	0.06	0.26	0.58	0.13[5]	0.25	0.75	2.0	1.63	0.57	5.17	0.18	1.13	3.12
	-	-	-	-	-	-	-	-	-	-	0.10	0.87	2.28

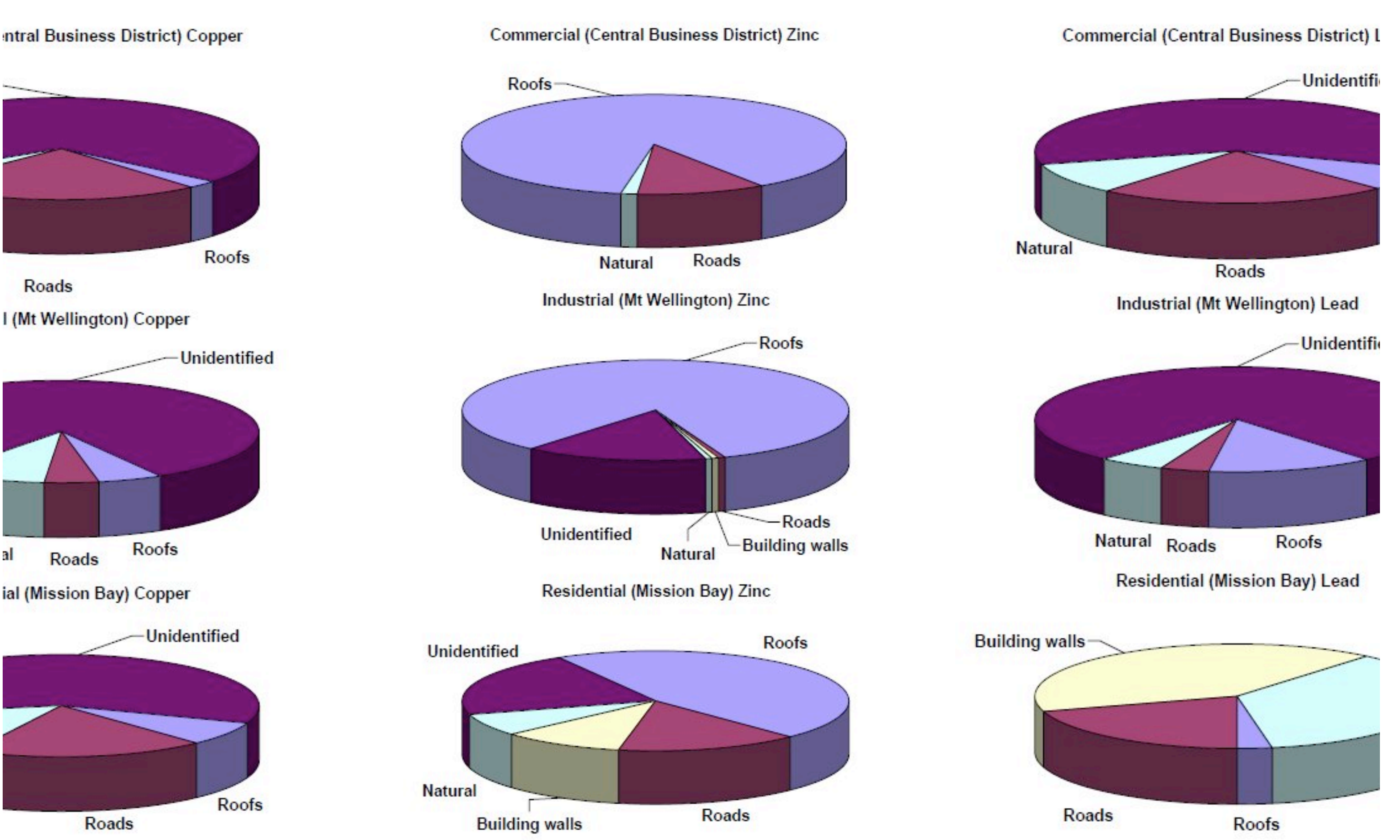
Land Transport Research (2005).

Williamson. 1993. Urban Runoff Data Book.

ARC. 2005. *Sources and Loads of Metals in Urban Stormwater*. ARC Technical Publication Nº.04104. Note study sites all within greater Auckland.

NIWA. 2003. *Rotorua City: Urban Stormwater Quality and Prediction of Environmental Impacts: Technical Addendum*.

Note that the reason for the decrease in zinc load with increased ADT was not reported within the Land Transport Research article and this may be a transposi outlier within the data.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Roads
Commercial (Central Business District) Zinc
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Table 4.2.6: Model Contaminant Load Results – TP04104

Parameter	Modelled Road Contaminant Loads		
	Copper	Lead	Zinc
mg / vehicle / km			
Particulate metal	0.041	0.046	0.180
Dissolved metal	0.014	0.001	0.188
Total metal	0.055	0.047	0.368
kg / ha / year			
TP04104[1]	0.47	0.4	3.15
Land Transport Research	0.24	-[2]	0.13[3]

Source: ARC. 2005. *Sources and Loads of Metals in Urban Stormwater*. ARC Technical Publication Nº.04104.

Notes: 1. *Based on a vehicle distance of 500m and 17,000vpd*

2. *The Urban Data Runoff Book gives a 'high' annual load figure for lead of 0.4kg / ha / year.*

3. *Refer to possible erratum as noted at Table 3.5.*

Recent research, especially by NIWA (Reed, Moores, Depree, Pattinson et al) has sought to quantify the road source contaminants entering receiving environments and vehicular source contaminants being deposited on the road. The variables discussed previously have made arriving at a consistent vehicle emissions factor (VEF) for vehicle kilometres travelled for specific metals particularly problematic (refer to Table 3.7).

Table 4.2.7: Estimates of contaminant load per vehicle kiometre travelled in New Zealand studies

Author	Year	Catchment	ADDT	Total metal (mg/VKT)	
				Cu	Zn
Sheriff	1998	Tawa	19,750	0.08	0.07
Kennedy & Gadd	2003	Waitakere	38,178	0.16	0.18
Kennedy	2003	Otahuhu	90,000	0.06	0.17
Larcombe	2003	Silverdale	17,990	0.06	0.19
Timperley et al.	2005	Richardson Rd	17,000	0.078	0.45
Gardiner & Armstrong	2007	Richardson Rd	17,354	0.15	1.60
Moores et al	2007	Silverdale	6,387	0.06	0.33
Moores et al	2007	Silverdale	6,387	0.029	1.64
Moores et al	2007	East Coast Rd	20,040	0.02	0.15
Moores et al	2008	Silverdale	21,124	0.08	0.45
Moores et al	2008	Silverdale	33,500	0.13	0.87
Moores et al	2009	Westgate	36,088	0.099	0.56
Moores et al	2009	Northcote	50,849	0.028	0.08
Moores et al	2009	Huapai	13,866	0.052	0.23
Moores et al	2009	Redvale	41,541	0.078	0.42

Source: Enhancing the control of contaminants from New Zealand's roads: results of a road runoff sampling programme, J. Moores, P. Pattinson & C. Hyde, NIWA, 2009 (NZTA Research Report No 395, 2010)

From their research Moores et al have suggested a guideline VEF for normally flowing traffic of 0.047 mg/VKT for copper and 0.28 mg/VKT for zinc. For congested traffic these guideline values increase to 0.095 mg/VKT for copper and 0.62 mg/VKT for zinc. These values neatly bracket the TP04104 modelled contaminant loads (refer to Table 3.6) as well as many other estimates of contaminant load per vehicle kilometre travelled derived from earlier studies (refer to Table 4.2.7). This suggests that traffic behaviour is likely to be a more significant variable than traffic volume in determining contaminant loads in road run-off.