6 Metals loads in road run-off

6.1 Monitoring programme

Transport activities contribute chemical contaminants to urban stormwater but the size of this contribution is not well known. As part of a project on contaminants in the urban environment, NIWA conducted an intensive road run-off monitoring and modelling programme to estimate the size of this contribution.

The main requirements for a suitable monitoring site were that:

- the road run-off drains to a single point that can be instrumented for flow recording and automated sampling,
- only the road run-off reaches this point i.e., no drainage from other surfaces such as house roofs,
- the road catchment is readily defined,
- there is a supply of electricity near-by,
- the site is reasonably secure.

Sites that meet all these requirements are few and far between but one such site was located on Richardson Road in west Auckland (Timperley et al, 2003).

Richardson Road is a single carriage-way that carries about 17000 vehicles per day. The monitored section was 500m long extending from one side of a gully to the other (Figure 6). Traffic flow was interrupted by a traffic light-controlled intersection at one end. Seven gully traps drained the road to a single pipe with an accessible manhole about 30m from the edge of the road (Figure7).

A flow recorder and automatic water sampler were installed in a cabinet attached over top of the manhole. A small weir was constructed in the storm water pipe immediately below the manhole to provide level control and a pond for the sampler intake. The sampler was programmed to be initiated by water level. Flow proportional sampling then followed until either the 24 sample bottles had been filled or the flow of stormwater stopped. Traffic counters recorded vehicle type, numbers, and speed.

Over a four week period, 24 August to 18 September 2002, 74 samples from four events were collected.

Figure 6. Richardson Road site.

Figure 7. Stormwater network at Richardson Road. Arrow shows monitoring point.

6.2 Monitoring results for zinc

Figure 8 shows the run-off discharge and the sampling times marked by dots. The value of each dot on this figure is the particulate zinc concentration.

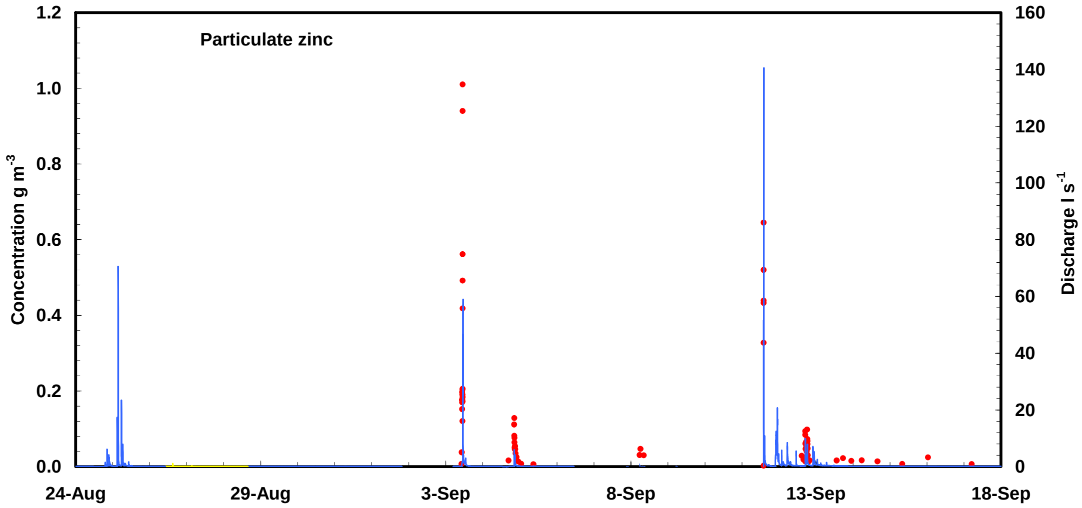

Figure 8. Particulate zinc concentrations (dots) and run-off discharge (solid line).

Figure 9 shows the results for dissolved zinc. The obvious difference between Figures 8 and 9 is that the particulate zinc concentrations decreased very rapidly after a rainfall event whereas the dissolved concentrations did not change much.

6.3 Run-off modelling

The initial aim of the project was to estimate the total mass load of metal washing off the road and reaching the stormwater network over a specific period of time. The "short-interval" mass load is obtained by multiplying the metal concentration in a sample by the discharge over the period that the sample represents. For a sequence of samples collected at relatively short time intervals, the total mass load can be obtained quite accurately by summing the "short-interval" loads because neither the flow nor the concentration change much during each interval. For large gaps in the sample collection sequence, however, the total mass load cannot be calculated because the concentrations during the gaps are unknown. Concentrations for these gaps need to be predicted and this is most accurately achieved by modelling. The model developed to achieve this is described in Section 5.

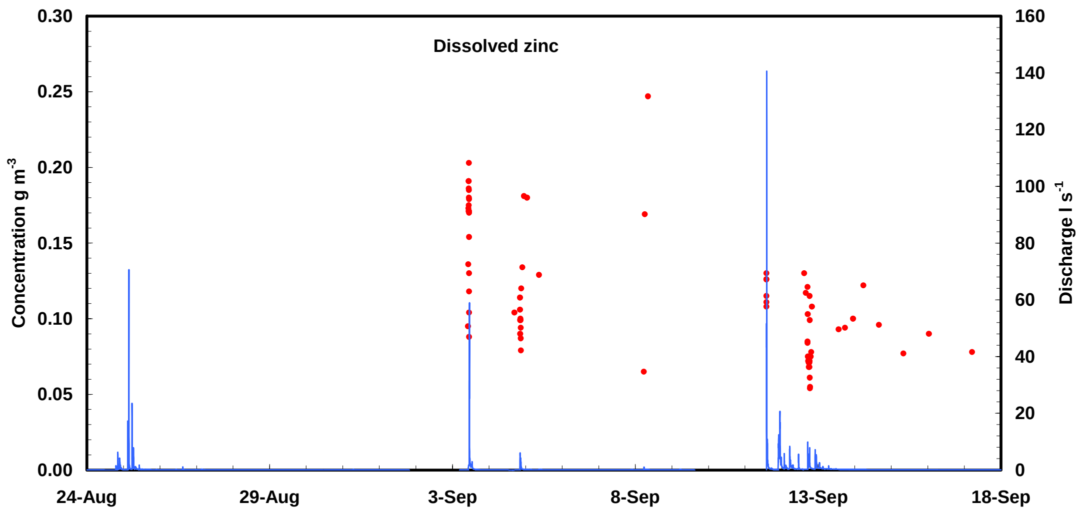

Figure 9. Dissolved zinc concentrations (dots) and run-off discharge (solid line).

6.4 Model results

Figure 10 shows the best fit of modelled to measured 1 minute run-off loads for particulate zinc. Note that both axes are logarithmic and that the model fit is dominated by the larger loads.

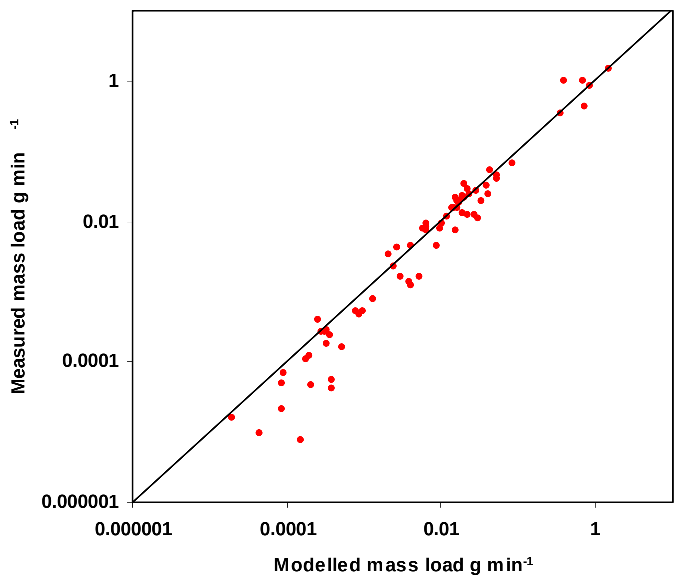

Figure 10. Model and measured 1 minute loads for particulate zinc. Note that both axes are logarithmic.

Figure 11 shows the predicted net accumulation of particulate zinc on Richardson Road during the monitoring period.

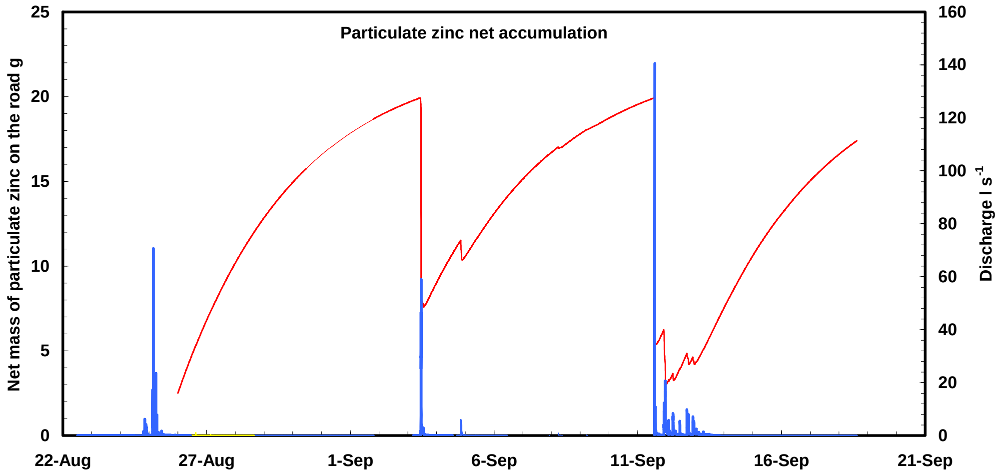

Figure 11. Net accumulation (red line) of particulate zinc on Richardson Road. The blue line is discharge.

It might be expected that with Auckland's frequent rain, there would be little opportunity for contaminants to be blown out of the road corridor. A good model fit could not be obtained, however, without assuming a reasonable non-wash-off loss. The extent of this loss is shown in Figure 11 by the way the net accumulation rate decreases with time during dry periods. Similar patterns of accumulation were required to obtain good fits for particulate copper and lead.

The best model fit gives a total of 37.0 g of particulate zinc (able to pass through the catchpits) generated over the 23.6 day monitoring period. There were an average of 17,354 vehicles per day passing along the 0.5km monitored section of Richardson Road. The road run-off ex-catchpit yield of particulate zinc was, therefore, 0.181 mg vehicle^{-1} km^{-1}. Best model fits for particulate copper and particulate lead gave estimates of 0.0414 mg vehicle^{-1} km^{-1} and 0.0463 mg vehicle^{-1} km^{-1} respectively.

Modelling dissolved metals required a different approach. It was readily apparent from the monitoring data that dissolved metals do not follow the accumulation/wash-off process followed by particulate metals. Simple chemistry also tells us this. Most of the adsorption/desorption processes that occur between dissolved and particulate metals are quite fast so it would be expected that dissolved concentrations would always reflect the concentrations of metal attached to nearby sediment, i.e., mg kg^{-1}, rather than the amount of particulate metal present, i.e., g m^{-3}. In other words, the dissolved metal concentration in contact with sediment containing, say, 1000 mg kg^{-1} of metal, would always be about the same irrespective of how much of the sediment was present. This is exactly what we found in the road run-off and it enabled a simple approach to predicting dissolved metal concentrations.

Figure 12 shows the relationship between the ratio of dissolved to particulate zinc concentrations and the concentration of particulate zinc. Note that both axes are logarithmic.

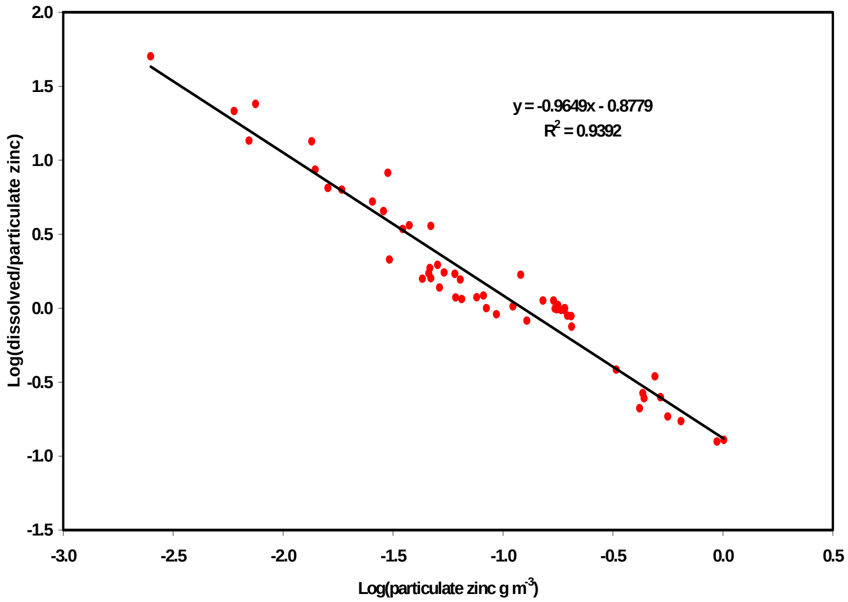

Figure 12. The dissolved/particulate zinc concentration ratio as a function of the particulate zinc concentration. Note that both axes are logarithmic.

This relationship shows that the dissolved zinc concentration varies only slightly and this can be seen from Figure 9. The best fit to this relationship enabled the dissolved zinc concentrations to be predicted from the modelled particulate zinc concentrations. The same procedure also worked well for copper. Figure 13 shows the match of modelled and measured dissolved zinc 1 minute loads (Note that this graph simply reflects the goodness of the fit shown in Figure 12).

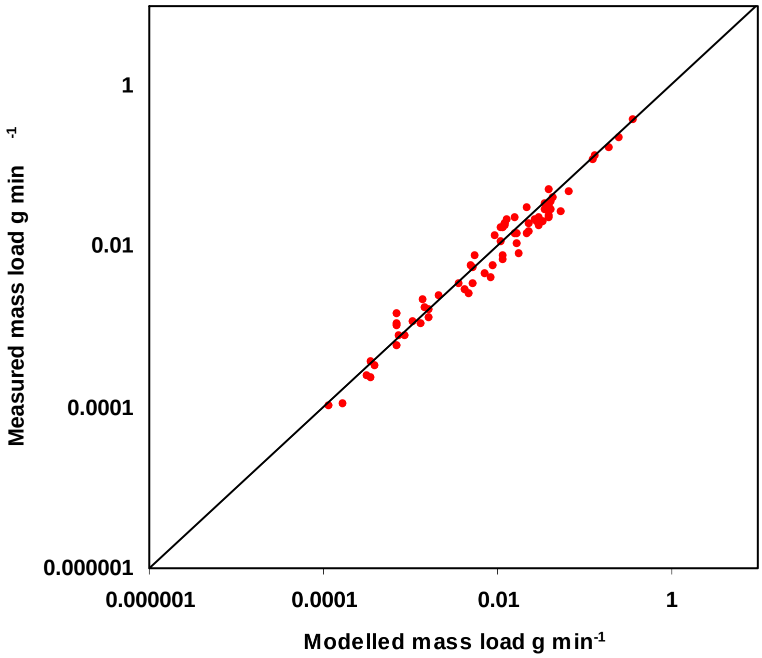

Figure 13. Measured and modelled 5 minute loads for dissolved zinc. Note that both axes are logarithmic.

Summing the 1 minute modelled dissolved zinc loads gives a total road run-off load of dissolved zinc of 38.5g over the 23.6 day period. This is 51% of the total zinc load; 75.5g.

The particulate copper load was 8.48g and the dissolved copper load was 2.83g which is 25% of the total copper load.

The load for particulate lead was 9.5g over the monitoring period. Dissolved lead concentrations in natural waters are usually very low and this was also the case for road run-off. The load for dissolved lead was only 0.21g which is 2% of the total lead load.

Table 4 shows the per vehicle loads reaching the stormwater sampling point for dissolved, particulate and total zinc, copper and lead.

The same modelling procedure produced an estimate for the total suspended solids load reaching the stormwater network of 30kg. This equates to 0.14 g $vehicle^{-1}$ km^{-1}. This value is used in the estimation of the natural soil loads (Section 8).

It is emphasised that these per vehicle loads are those reaching the stormwater network after passing through the road-side catchpits. Immediately prior to the monitoring survey the catchpits were cleaned (courtesy of Metrowater) so that loads in Table 4 are the lowest reasonably achievable and are undoubtedly lower than City-wide averages.

Table 4. Model results (mg vehicle^{-1} km^{-1}) for zinc, copper and lead reaching the stormwater network at the Richardson Rd site.

	Zinc	Copper	Lead
Particulate metal	0.180	0.041	0.046
Dissolved metal	0.188	0.014	0.001
Total metal	0.368	0.055	0.047

6.5 Uncertainties in the road run-off loads

Metal loads in run-off from roads are included explicitly in the mass balances although possibly not with the same level of resolution as for building roofs. For example, the road run-off metal loads were derived only from the vehicle counts for roads; metals generated from parking lots and driveways were not included. Given, however, that vehicles mostly travel slowly and only short distances (relative to roads) in parking areas and on driveways it is reasonable to assume that the metal loads from these areas are small relative to the loads in road run-off.

6.5.1 Catchpit retention efficiency for sediment

One of the major uncertainties in the road run-off loads is the average City-wide retention efficiency of the catchpits for metals. As noted above, the catchpits along Richardson Road were cleaned out immediately prior to the study thus maximising the catchpit retention efficiencies. Also, although rainfall of moderate intensity occurred during the study, more intense events are common in Auckland. The retention efficiencies of the catchpits measured during the study were, therefore, higher than the City-wide average and the City-wide road run-off loads reaching the stormwater network must be correspondingly greater.

There have been no direct measurements of retention efficiencies for *in-situ* catchpits in Auckland City but there are other date from which an *in situ* efficiency can be estimated. The Richardson Rd project produced a total sediment load escaping from the recently-cleaned catchments of 0.14 g vehicle^{-1} km^{-1}. By a combination of traffic counting and modelling and the 2001 census data, the total distance travelled by vehicles in Auckland City in 2001 has been estimated as 4.02 x 10^9 vehicle km. Combining these values gives a City-wide total suspended solids load of about 640 t a^{-1} escaping from catchpits.

The total suspended solids load in road run-off is not related solely to the numbers of vehicles so another approach is to express the load in terms of road area. The Richardson Rd total suspended solids load of 0.14 g vehicle^{-1} km^{-1} is equivalent to 90 g m^{-2} a^{-1}. Road surfaces cover approximately 1320 ha of the total land area of Auckland City. This gives a total suspended solids load escaping the City's catchpits of about 1200 t a^{-1}. The real load assuming clean catchpits, would be somewhere between these two values, say, about 900 t a^{-1}.

Approximately 2700 t a^{-1} of sediment is recovered from the City's catchpits (Auckland City Council data). Thus, based on these data, the catchpit retention efficiency for total suspended solids assuming clean catchpits would be about 75% [100 x (2700/(2700 + 900)]. This is a maximum estimate because 900 is a minimum value.

Another estimate of catchpit retention efficiency for total suspended solids was obtained from a laboratory study (Butler et al, 2004). Both synthetic sediment and road sediment collected from streets in the Oakley Creek catchment of Auckland City were tested with a model catchpit and water flows between 4 l s^{-1} and 20 l s^{-1} (For the Richardson Road site, a flow through each catchpit of 20 l s^{-1} is equivalent to rainfall of about 14mm in 10 minutes). For the synthetic sediment, all sediment greater than 500 µm (0.5 mm) was retained for all flows tested. Between 47% and 75%, depending on flow, ofsediment 100 to 500 µm was retained and for all flows only about 18% of sediment less than 100 µm was retained. At 4 l s^{-1} 58% of the road sediment was retained which implies that this sample consisted of very fine sediment in contrast to the findings of Ng et al (2003).

Ng et al, (2003) reported road sediment particle size for several streets in Auckland City. He found that an average of about 10% of the sediment was less than 100 µm and about 50% was less than 500 µm. Combining these data with the results of the Butler et al (2004) study implies that at least 50% of road sediment (i.e. all particles > 500 µm) is retained by clean catchpits. Of the 40% of road sediment from 100 to 500 µm, between 47% and 75%, depending on flow, is retained, say, an average of 65% (biased towards higher retention because of the predominance of low flows). Overall, therefore, the clean catchpit retention efficiency given by the Butler et al (2004) and Ng et al (2003) data is about 78%, (50% (100% x 0.5) for sediment > 500 µm plus 26% (65% x 0.4) for sediment 100 to 500 µm plus 1.8% (18% x 0.1) for sediment <100 µm). This value is in close agreement with the estimate of 75% from the Richardson Road study.

Accepting an estimate of 75% for the overall retention efficiency of total suspended solids in clean catchpits, the next step is to adjust this value to reflect the more realistic City-wide situation of catchpits partially full of sediment. In view of the Butler et al (2004) results, it is reasonable to assume that sediment < 100 µm will always escape the catchpits.

The next question is what proportion of sediment > 500 µm would be retained. The monitoring data obtained for Auckland City stormwater showed that, except during very heavy rain storms in the relatively steep Mission Bay catchment that has open sections of stream channel in the stormwater network, the particle size of suspended sediment in stormwater from a mixture of residential, commercial and industrial catchments seldom exceeded 500 µm. Thus, it would appear that even partially-full catchpits retain most sediment >500µm.

If it is assumed that sediment >500 µm will always be retained, then it follows that the reduction in retention efficiency resulting from a build-up of sediment in the catchpits affects only the 40% of road sediment particles between 100 and 500 µm.

The final assumption required is the efficiency with which partially-full catchpits trap road sediment 100 to 500 µm. There are no data on which to base this assumption so for the purposes of this study it is assumed that the partially filling of catchpits with sediment reduces the retention efficiency for these particles from about 65% in clean catchpits to 30%. This lower efficiency equates to a reduction in total sediment retention efficiency from about 75% to about 60%.

If 65% of the sediment 100 to 500 µm are retained in clean catchpits then the suspended sediment reaching the monitoring point in the stormwater network draining Richardson Rd would have included the remaining 35% of these sediment particles. It follows from the above assumptions that if the Richardson Rd catchpits had been partially full of sediment, 70% of the sediment particles 100 to 500 µm would have reached the monitoring point. That is, the load of sediment and attached zinc in this size range at the monitoring point would have doubled.

6.5.2 Catchpit retention efficiency for metals

To summarise the assumptions above:

1. The retention efficiency for sediment 100 to 500 µm is about 65% in clean catchpits.
2. The accumulation of sediment in catchpits reduces the retention efficiency only for sediment 100 to 500 µm.
3. The retention efficiency for sediment 100 to 500 µm reduces to 30% for catchpits partially full of sediment.

The next step is to convert these sediment retention efficiencies into efficiencies for zinc, copper and lead.

Ng et al (2003) found that, on average for zinc on the road surface, on average 24% was attached to sediment <100 µm, 56% was on sediment 100 to 500 µm, and 20% was on sediment >500 µm. These ratios do not persist into the stormwater network because some of the zinc (and also copper) dissolves when the sediment contacts rainwater. The dissolved fraction is not retained by catchpits. Assuming that dissolved zinc arises from all particles in proportion to the amount of particulate zinc, then from the Ng et al (2003) data, the ratio of the amount of zinc on sediment <100 µm to the amount of zinc on sediment 100 to 500 µm at the Richardson monitoring point would have been 24/19.6 (24/(0.35 x 56).

Of the total zinc potentially able to pass into the stormwater network at the Richardson Rd site over the 26 day monitoring period, 37 g was attached to sediment. Applying the ratio above implies that 20 g was on particles < 100 µm and 17 g was on particles 100 to 500 µm. The consequence of the catchpits being partially full of sediment would have been to double the 17 g of zinc carried by these larger particles to give a total particulate zinc load of 54 g. The particulate zinc yield would then have been 0.26 mg vehicle^{-1} km^{-1} increasing the total zinc yield to 0.45 mg vehicle^{-1} km^{-1}.

The yields calculated for copper and lead using the same assumptions for catchpits partially full of sediment are 0.061 mg vehicle^{-1} km^{-1}and 0.067 mg vehicle^{-1} km^{-1}

respectively for the particulate metals and 0.078 and 0.068 mg vehicle^{-1} km^{-1} respectively for total metals.

The actual *in situ* City-wide catchpit efficiencies estimated above for metals are obviously uncertain and because of the assumption that no sediment > 500 µm escapes from catchpits partially filed with sediment, the estimated efficencies are probably higher than the real City-wide average. It shoud be noted however, that because a proportion of the zinc reaching the stormwater network is dissolved, a reduction in the catchpit retention efficiency for sediment-bound zinc will produce a lesser reduction in the catchpit retention efficiency for total zinc. As will be seen in Section 10, however, for commercial and industrial catchments, reductions in catchpit efficiency to, say, 30% would make very little difference to the mass budgets for zinc. Even for the Mission Bay residential catchment the proportional increase in the road run-off contribution of zinc would be small. For copper and lead the situation could be somewhat different and this is discussed in Section 10.

6.6 Road run-off metal loads in the study catchments

The total road run-off metal loads reaching the stormwater network were calculated from the number of vehicles per day moving along each side of each road draining to the catchment stormwater monitoring point multiplied by the length of the road then by the values for the amount of metal reaching the stormwater network calculated in the section above for catchpits partially filled with sediment. The total catchment road run-off loads were then obtained by summing over all roads in the catchments. These loads are given in Tables 5, 6 and 7.

Table 5. Total metal loads in road run-off reaching the stormwater network in the catchment of the Central Business District assuming catchpits partially-full of sediment.

Road	Side 1		Side 2			Total suspended solids	Total Zinc	Total Copper	Total Lead
	Length	Vehicle count	Length	Vehicle count	Total distance travelled	Load	Load	Load	Load
	km	no day^{-1}	km	no day^{-1}	vehicle km day^{-1}	kg a^{-1}	g a^{-1}	g a^{-1}	g a^{-1}
Hobson St	0.205	31076	0	0	6371	372	1039	181	158
Greys Ave	0.365	2059	0.365	2477	1656	96.7	270	47.1	41.0
Vincent St	0.38	5901	0.38	4950	4123	241	673	117	102
Pitt St	0.45	10069	0.45	8551	8379	489	1367	239	208
Mayoral Dve	0.475	8131	0.475	7684	7512	439	1226	214	186
Karangahape Rd	0.1	13640	0	0	1364	79.7	223	38.8	33.9
Symond St*	0.165	17315	0	0	2857	167	466	81.3	70.9
Liverpool St	0.38	2096	0.38	1329	1302	76.0	212	37.1	32.3
City Rd	0.165	2011	0.165	1913	648	37.8	106	18.4	16.1
Turner St*	0.08	933	0.06	1682	209	12.2	34	6.0	5.2
Airdale St	0.25	716	0.25	471	297	17.3	48	8.5	7.4
White St	0.15	859	0.15	534	209	12.2	34	6.0	5.2
Marmion St**	0.04	933	0.04	1682	105	6.1	17	3.0	2.6
Waverley St**	0.065	933	0.065	1682	170	9.9	28	4.8	4.2
Payton Tce***	0.15	100	0.15	100	30	1.8	5	0.9	0.7
Total Annual load						2057	5748	1003	874

* Vehicle count from Auckland City website. ** Vehicle count assumed same as Turner Street. *** Cul-de-sac, vehicle count assumed 100.

Table 6. Total copper loads in road run-off reaching the stormwater network in the Mission Bay catchment assuming catchpits partially-full of sediment.

Road	Side 1		Side 2			Total suspended solids	Total Zinc	Total Copper	Total Lead	
	Length	Vehicle count	Length	Vehicle count	Total distance travelled	Load	Load	Load	Load	
	km	no day^{-1}	km	no day^{-1}	vehicle km day^{-1}	kg a^{-1}	g a^{-1}	g a^{-1}	g a^{-1}	
Te Arawa St	0.287	499	0.287	771	358	20.9	58.4	10.2	8.9	
Kurahaupo St	0.784	1032	0.784	653	1248	72.9	203.7	35.5	31.0	
Rukutai St	0.954	650	0.954	783	1362	79.5	222.2	38.8	33.8	
Aotea St	0.087	880	0.087	1325	192	11.2	31.3	5.5	4.8	
Atkin Ave	0.453	369	0.453	522	403	23.6	65.8	11.5	10.0	
Palmer Cres	0.087	156	0.087	176	29	1.7	4.7	0.8	0.7	
Godden Cres	0.784	663	0.784	388	825	48.2	134.5	23.5	20.5	
Patteson Ave	0.462	3235	0.462	3078	2922	171	476.7	83.2	72.5	
Kepa Rd	0.783	10600	0.783	10698	16676	974	2721	475	414	
Matatua St*	0.148	240	0.148	240	71	4.1	11.6	2.0	1.8	
Dudley Rd	0.174	625	0.174	548	204	11.9	33.3	5.8	5.1	
Total Annual load						1419	3963	692	603	

* Vehicle count assumed approximately half of Te Arawa

Table 7. Total metal loads in road run-off reaching the stormwater network in the Mt Wellington catchment assuming catchpits partially-full of sediment.

Road	Side 1		Side 2			Total suspended solids	Total Zinc	Total Copper	Total Lead
	Length	Vehicle count	Length	Vehicle count	Total distance travelled	Load	Load	Load	Load
	km	no day^{-1}	km	no day^{-1}	vehicle km day^{-1}	kg a^{-1}	g a^{-1}	g a^{-1}	g a^{-1}
Thomas Peacock Pl.	0.127	265	0.127	265	74.5	4.4	12.2	2.1	1.9
Homestead Dve.	0.462	585	0.462	585	533	31.1	86.9	15.2	13.4
Morrin Rd.	0.608	4559	0.608	4559	5461	319	891	155	138
Elizabeth Knox Pl.	0.506	1164	0.506	1164	1159	67.7	189	33.0	29.2
Eric Patton Pl. *	0.127	265	0.127	265	74.5	4.4	12.2	2.1	1.9
Total Annual load						426	1191	208	184