# 5 Metal Loads in catchment stormwater

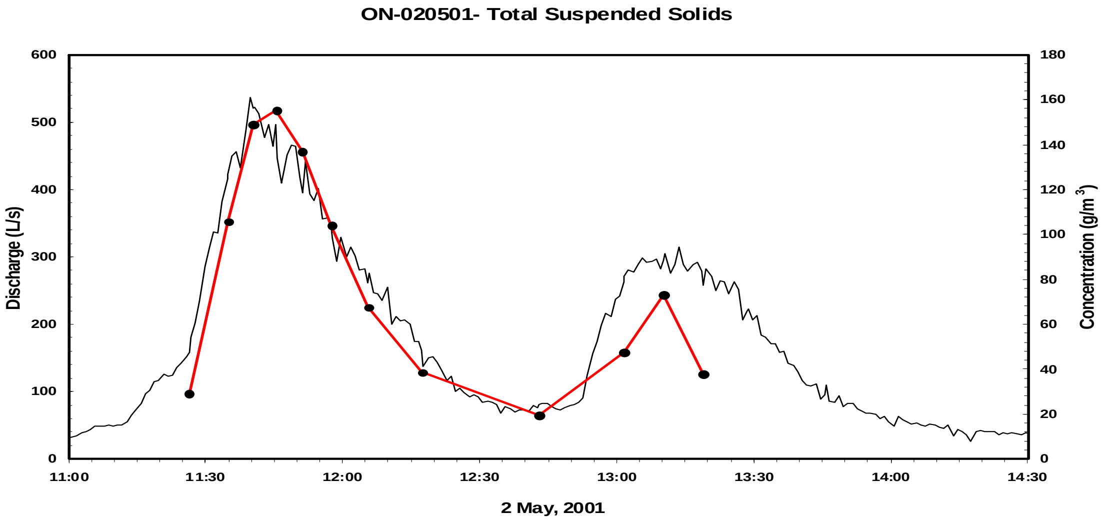
The stormwater monitoring programme and subsequent modelling have been described previously (Timperley and Reed, 2004, Timperley et al, 2004a, b). The following sections reproduce information from those earlier reports that is relevant to the project described in this report.

## 5.1 Monitoring programme

At each site, a flow recorder and water sampler capable of automatically collecting up to 24 samples were installed. At the CBD and Mission Bay sites the flow recorders measured both stage and velocity using pressure/ultrasonic transducers and from these measurements calculated discharge and logged the results. At the Mt Wellington site, the flow recorder measured stage only over a calibrated weir and transferred these measurements to the samplers. The samplers then calculated discharge from the programmed rating curves and logged the results. Flow measurements were made at either 1 or 5 minute intervals over the entire monitoring period. The flow data were downloaded at regular intervals either directly in the field or by telemetry.

The sample collection sequence was initiated either by discharge or stage and samples were subsequently collected on either a flow proportional or time basis. Between 150 and 200 samples were collected at each site over 10 to 15 rainfall events.

Figure 2 shows the typical form of the data obtained for a rainfall event. The event illustrated has a good coverage of samples extending almost to the end of the event. For many events, however, the samplers had collected their full trays of 24 single samples or 12 pairs of samples before the ends of the events. This occurred when the total run-off volumes of the events were too large for the programmed volume between samples.



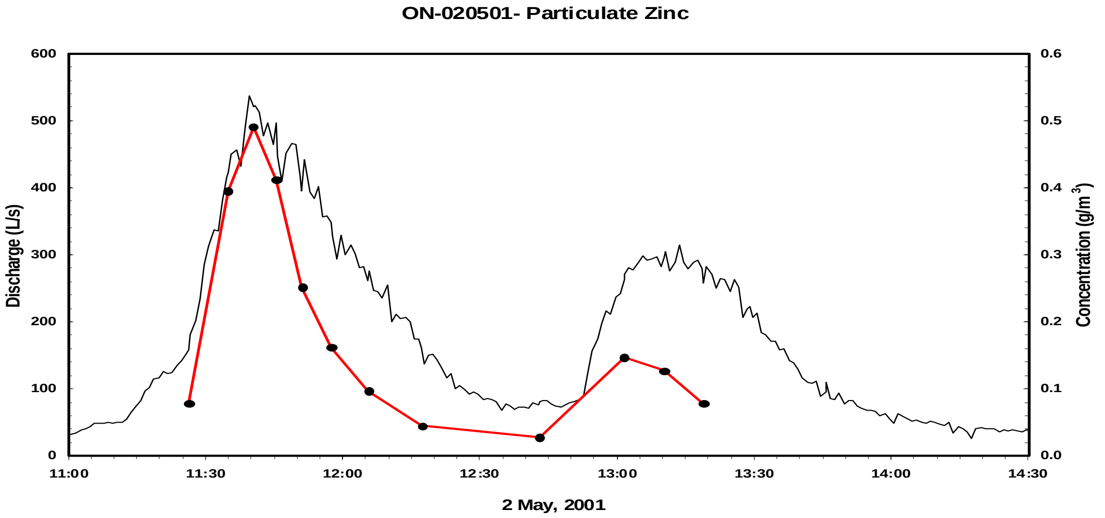


**Figure 2.** Total suspended. solids, particulate zinc concentrations and discharge for a rainfall event. The red line joins the measured contaminant concentrations and the black line is discharge.

## 5.2 Stormwater quality modelling

On average it rains in Auckland about once every three days, i.e., there are about 120 rainfall events each year. Over a 12 month period the monitoring programme sampled 10 to 15 of these events at each site. A stormwater quality model was required to extend the monitoring data for each site from the 10 to 15 monitored events to all the approximately 120 events in a year. Once this was done, the model results for the whole year were summed to obtain the annual contaminant loads passing the site.

The model described below was originally developed for the road run-off study described in Section 6 and was subsequently applied to Auckland City stormwater.

## 5.3 Modelling contaminant accumulation and wash-off processes

Zinc, copper, and lead originate from a variety of sources including vehicles and building materials (Table 1). Over extended periods of several days or more, it can be assumed that the contributions from these sources are relatively constant. The assumption that these metals accumulate on impervious surfaces at a linear rate is common to most models of stormwater quality but it is sometimes assumed, particularly for places that have strong winds and long dry periods between rainfall events, that portions of the chemicals deposited on impervious surfaces are removed by wind. This means that the rate of chemical accumulation per unit time, eg. mg day$^{-1}$, on an impervious surface decreases over time during dry periods. Modelling of road run-off (Section 6) and later modelling of Auckland City stormwater showed that the inclusion of non-wash-off processes in the model was necessary if good model fits to measured data were to be obtained.

Unlike the almost universal agreement about the contaminant accumulation process, there are different ideas about how the wash-off of accumulated contaminants from impervious surfaces is related to rainfall. Several of these different approaches were evaluated for modelling road run-off and it was found that good results could be obtained by equating the fraction of an accumulated contaminant washed-off over a particular time interval to a function of the rainfall intensity. For example, 2 mm of rain in a 5 minute period washes-off 95% of the contaminant on an impervious surface. The appropriateness of this relationship was subsequently confirmed for Auckland City stormwater.

An important requirement for the model was that the calibration parameters were directly related to some intrinsic, known characteristics of the catchments. One of the obvious characteristics is land use because the accumulation rates for many chemicals increase in the order residential < commercial < industrial.

The wash-off function was not expected to vary with catchment land use because contaminants on impervious surfaces would be expected to wash-off just as efficiently in an industrial catchment as they would in a residential catchment. The catchment slope was, however, expected to influence the wash-off efficiency with a small amount of rain in a steep catchment achieving the same wash-off fraction as a large amount of rain in a flat catchment, ie, the wash-off fraction would vary with average catchment slope.

The model has four calibration parameters, the accumulation rate, the "non-wash-off" removal coefficient (to allow for the removal of deposited contaminant by wind) and a "slope" coefficient. The fourth adjustable parameter is an exponent in the expression for the wash-off fraction.

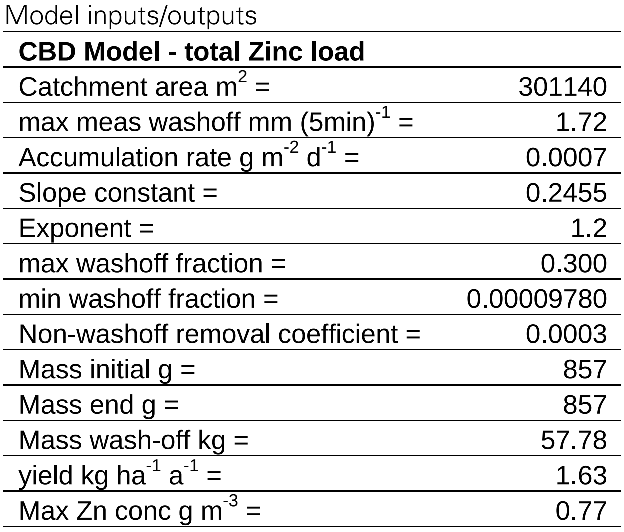
The other adjustable parameter in the model is the quantity of contaminant in the catchment at the start of the time series. This initial quantity is largely immaterial for chemical contaminants because it is small relative to the quantities accumulated at various stages through a 12 month time series. This is not generally the case for sediment which is usually available in unlimited quantities, particularly in residential catchments. Hence, the initial amount of sediment available in the catchment must be large enough so that wash-off does not substantially reduce the amount available. Even in catchments with very high impervious surface cover, such as the CBD, the almost continuous presence of exposed soil at construction sites means that the sediment available for wash-off at any time does not fit an accumulation model.

The simplicity of the model was conducive to a spreadsheet approach in Microsoft Excel. To span the monitoring period of 12 to 14 months with records at 5 minute intervals and to keep within the computational limits of Excel, 4 to 6 linked spreadsheets of monitoring data (one sheet for each 3 months of data), are required. The spreadsheets contain the date and time at 5 minute intervals, the average stormwater discharge for each interval (the average for the preceding 5 minute interval) and the measured concentrations of the variable being modelled for the intervals where measurements were made. In a 1 year time series there are 105,120 five minute intervals of which about 150 have quality measurements. The modelling task is to use the concentrations measured for the approximately 150 intervals to derive a relationship between contaminant concentration and stormwater discharge that can then be used to estimate the contaminant concentrations for the other 104,970 or so intervals.

The next section gives an example of the model outputs. The case shown is for total zinc in stormwater from the Central Business District catchment. The primary output is the yield given on the Model Inputs/Outputs sheet, 1630 g ha$^{-1}$ a$^{-1}$.

## 5.4 Example of model results: Total zinc in the Central Business District.

**Figure 3.** Model input/output sheet for the best model fit for total zinc loads in the CBD.



Model inputs/outputs

| **CBD Model - total Zinc load** | |
|---|---|
| Catchment area $m^2$ = | 301140 |
| max meas washoff mm $(5min)^{-1}$ = | 1.72 |
| Accumulation rate g $m^{-2}$ $d^{-1}$ = | 0.0007 |
| Slope constant = | 0.2455 |
| Exponent = | 1.2 |
| max washoff fraction = | 0.300 |
| min washoff fraction = | 0.00009780 |
| Non-washoff removal coefficient = | 0.0003 |
| Mass initial g = | 857 |
| Mass end g = | 857 |
| Mass wash-off kg = | 57.78 |
| yield kg $ha^{-1}$ $a^{-1}$ = | 1.63 |
| Max Zn conc g $m^{-3}$ = | 0.77 |

**Figure 4.** Comparisons of modelled and measured 5 minute loads

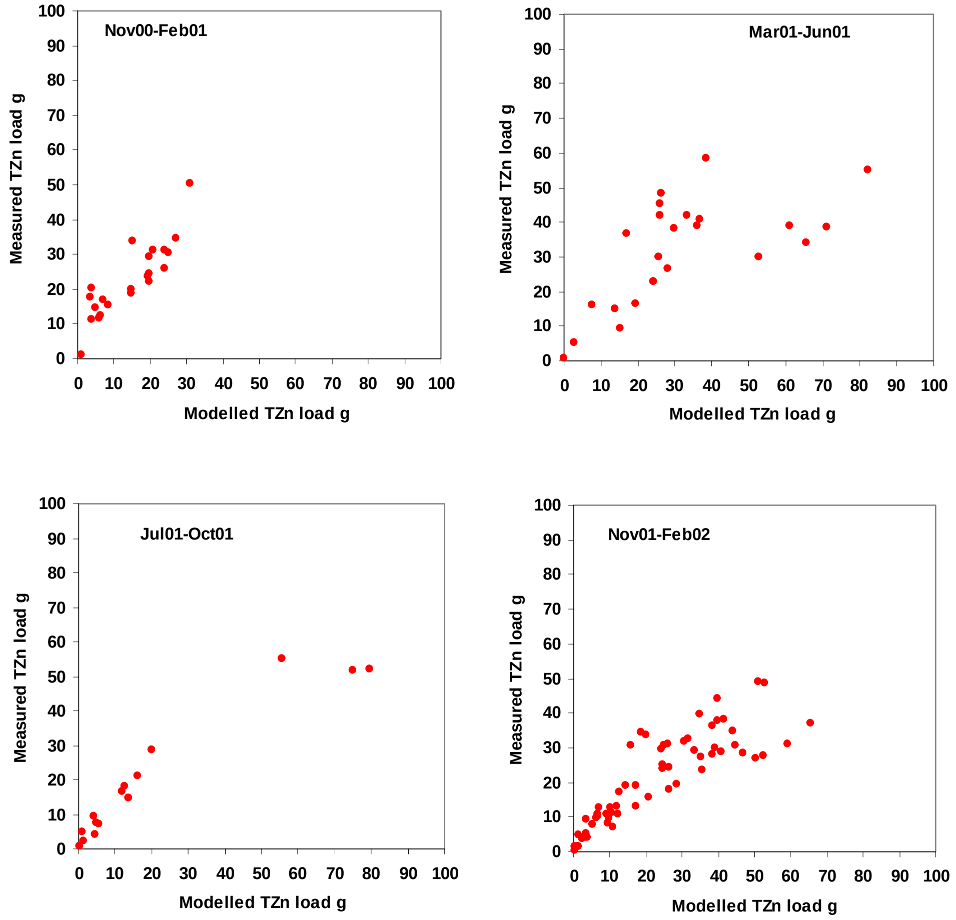


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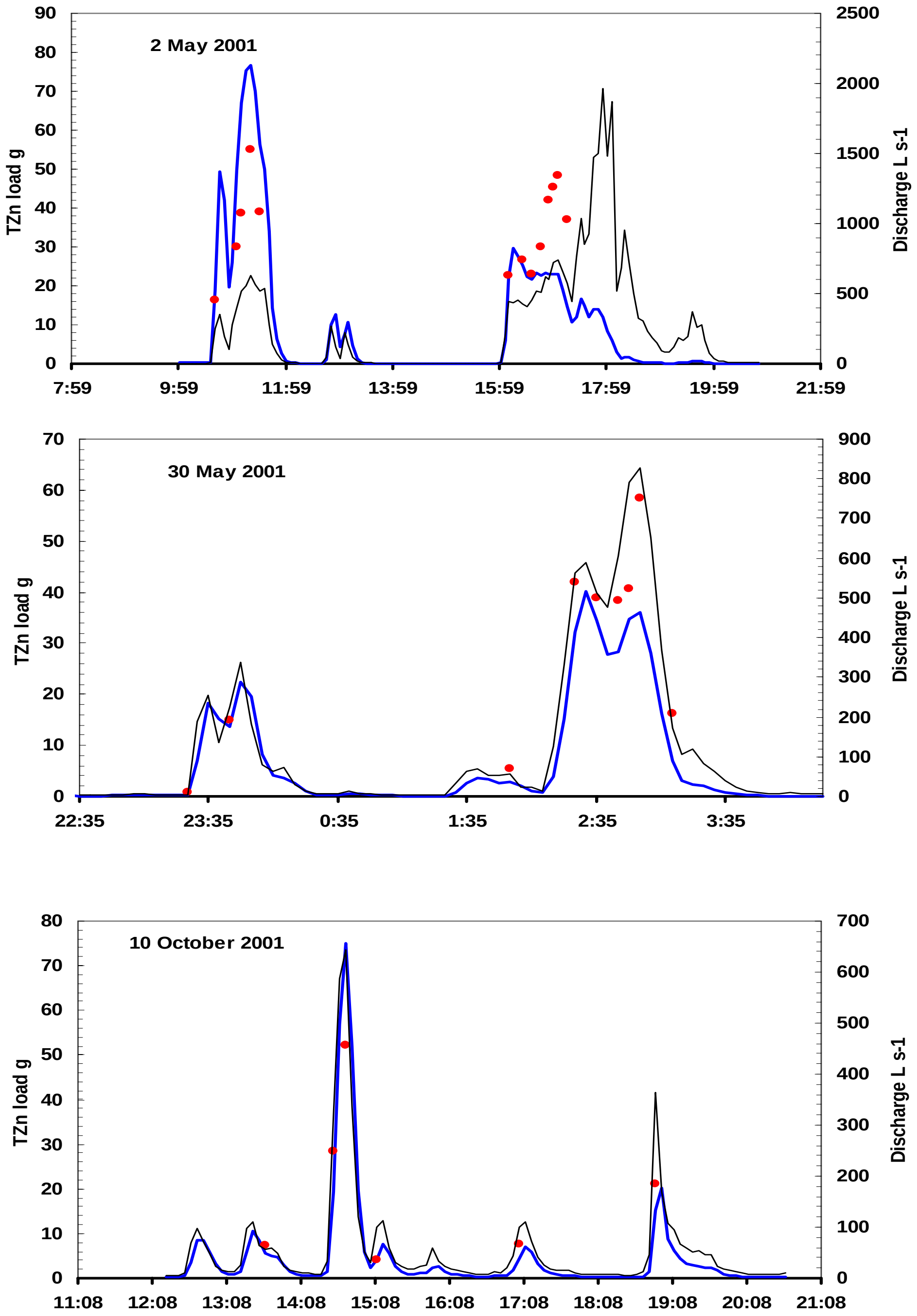
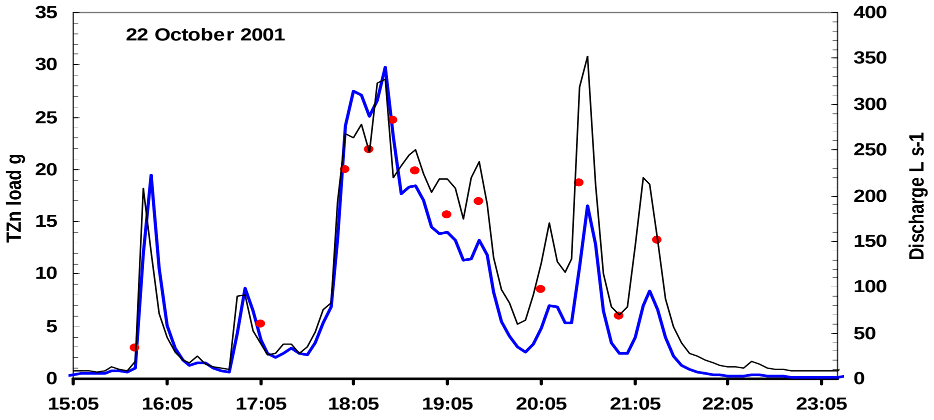
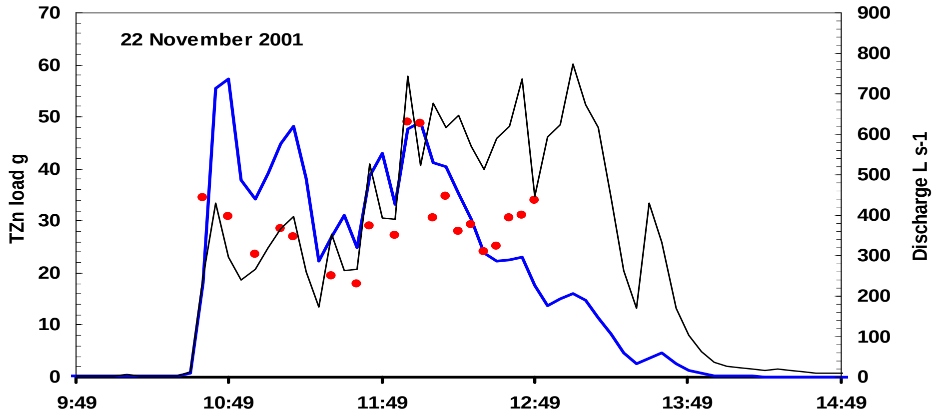
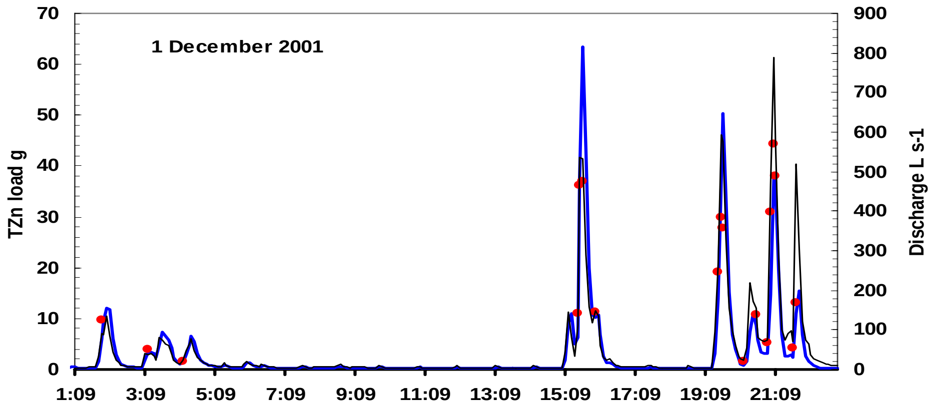
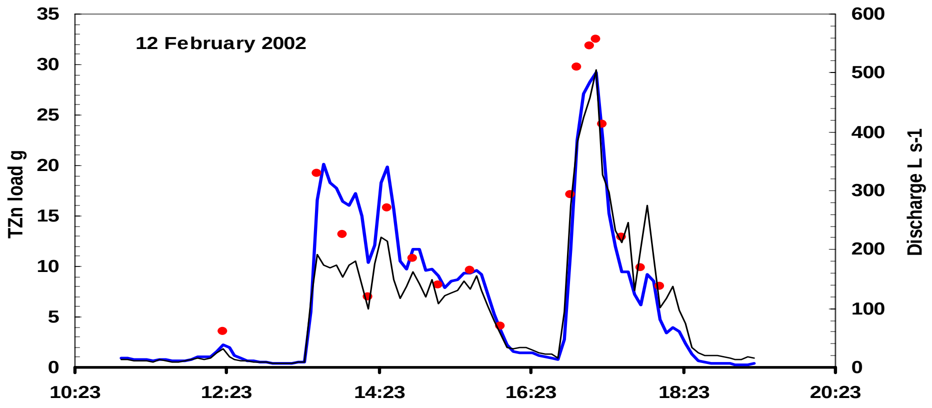
**Figure 5.** Comparisons of modelled and measured loads for individual rainfall events between May 2001 and March 2002. The dates of the events are shown on the figures. The black line is discharge, the blue line is the modelled total zinc load and the red dots are the measured loads..

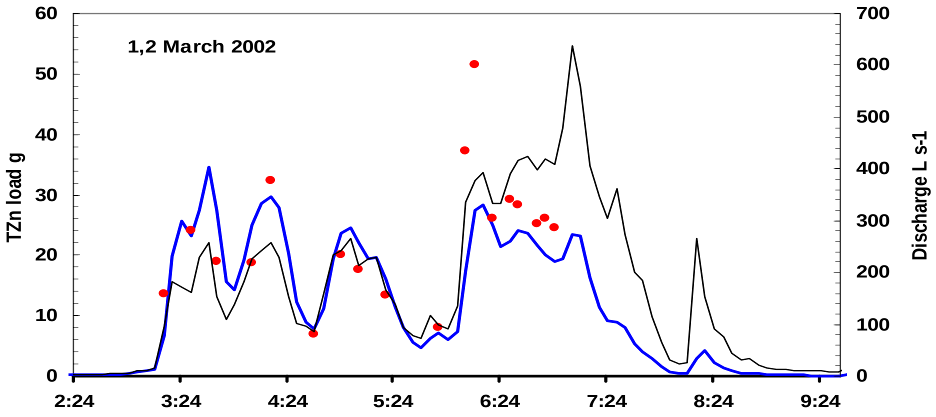



22 October 2001
TZn load g
Discharge L s-1
35
30
25
20
15
10
5
0
400
350
300
250
200
150
100
50
0
15:05
16:05
17:05
18:05
19:05
20:05
21:05
22:05
23:05


22 November 2001
TZn load g
Discharge L s-1
70
60
50
40
30
20
10
0
900
800
700
600
500
400
300
200
100
0
9:49
10:49
11:49
12:49
13:49
14:49


1 December 2001
TZn load g
Discharge L s-1
70
60
50
40
30
20
10
0
900
800
700
600
500
400
300
200
100
0
1:09
3:09
5:09
7:09
9:09
11:09
13:09
15:09
17:09
19:09
21:09


12 February 2002
TZn load g
Discharge L s-1
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
10:23
12:23
14:23
16:23
18:23
20:23


1,2 March 2002
TZn load g
Discharge L s-1
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
2:24
3:24
4:24
5:24
6:24
7:24
8:24
9:24

## 5.5 Metal and total suspended solids loads in catchment stormwater

The modelled total metal and suspended sediment yields from the study catchments are given in Table 2 and the annual loads are given in Table 3. In addition to metals from the sources listed in Table 1 and from any other unidentified discrete sources, these yields and loads include metals naturally in the catchment soils. These natural yields and loads are estimated in Section 8.

**Table 2.** Yields of metals and total suspended solids from the study catchments.

| **Catchment** | **Total Zinc** | **Total Copper** | **Total Lead** | **Total suspended solids** |
|---|---|---|---|---|
| | **g ha$^{-1}$ a$^{-1}$** | **g ha$^{-1}$ a$^{-1}$** | **g ha$^{-1}$ a$^{-1}$** | **kg ha$^{-1}$ a$^{-1}$** |
| **Central Business District** | **1630** | **140** | **124** | **310** |
| **Mission Bay** | **573** | **79** | **60** | **620** |
| **Mt Wellington** | **5170** | **135** | **135** | **252** |

**Table 3.** Annual loads of metals and total suspended solids from the study catchments.

| **Catchment** | **Catchment area** | **Total Zinc** | **Total Copper** | **Total Lead** | **Total suspended solids** |
|---|---|---|---|---|---|
| | **ha** | **kg a$^{-1}$** | **kg a$^{-1}$** | **kg a$^{-1}$** | **t a$^{-1}$** |
| **Central Business District** | **30.1** | **47.0** | **4.21** | **3.73** | **9.33** |
| **Mission Bay** | **45.2** | **26.0** | **3.57** | **2.71** | **28.0** |
| **Mt Wellington** | **34.0** | **176** | **4.59** | **4.59** | **8.57** |

## 5.6 Uncertainties in the catchment metal loads

### 5.6.1 Zinc

An average zinc yield for the whole of Auckland City can be calculated from the areas of residential, commercial and industrial landuse in the City (ARC, 1997) and the yield for each landuse given in Table 2. This average yield is 1200 g ha$^{-1}$ a$^{-1}$. Williamson (1993) derived an overall "urban" yield of 750 g ha$^{-1}$ a$^{-1}$ from mostly overseas literature data available up to about 1992. There have been no similarly rigorous updates of this yield since that time. It is possible that the modelled yield for Auckland City is in error but a more likely explanation is that the higher value for Auckland City is due to the more widespread use of galvanised roofing material in New Zealand than in most other countries. Also the zinc mass budgets for the CBD and Mt Wellington catchments show that the true total catchment loads for these catchments cannot be much less than the loads obtained using the modelled yields unless it is also assumed that the loads from roofs, roads and natural sources are too high.Thus, on the basis of existing knowledge about the sources of zinc in Auckland urban areas, the modelled yield is considered to be credible.

### 5.6.2 Copper

As explained above for zinc, error in the total catchment loads can be assessed by comparing the modelled yield for copper with the Williamson (1993) value. The Williamson (1993) urban yield for copper is 90 g ha$^{-1}$ a$^{-1}$. The yields obtained from modelling are 79 g ha$^{-1}$ a$^{-1}$ for the residential catchment (Mission Bay), 140 g ha$^{-1}$ a$^{-1}$ for the commercial (CBD) catchment and 135 g ha$^{-1}$ a$^{-1}$ for the Mt Wellington catchment (Table 2). The average Auckland City-wide yield, calculated as explained above for zinc, is 92 g ha$^{-1}$ a$^{-1}$, only a little higher than the Williamson (1993) urban value.

### 5.6.3 Lead

The Williamson (1993) urban yield for lead was derived from data collected during the period of leaded petrol use. The present-day yield is certainly lower than the Willamson (1993) value but a new post-leaded petrol estimate with which the result reported here could be compared, has yet to made.