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TE RAUHĪTANGA TAIAO

Development of the Contaminant Load Model

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Development of the Contaminant Load Model

Prepared for
Auckland Regional Council

Contents

Glossary

ACC – Auckland City Council

AEE – Assessment of Environmental Effects

CLM – Contaminant Load Model

TP10 – Technical Publication 10

ICMP – Integrated Catchment Management Plan

EMC – Event Mean Concentration

LRF – Load Reduction Factor (through stormwater treatment device)

TPH – Total Petroleum Hydrocarbon

TSS – Total Suspended Solids

vpd – Vehicle per day

VFM – Vehicle Fleet Model

VKT – Vehicle kilometre Travelled

1 Executive Summary

In order to assess the environmental effects of stormwater discharges, information about the nature and quantity of the contaminants that they contain is required. Stormwater quantity and quality can be highly variable and challenging and resource-intensive to monitor. A pragmatic solution is to model contaminant discharges based on information derived from observations of stormwater quality.

The Contaminant Load Model (CLM) is a spreadsheet-based model which has been developed to enable estimation of stormwater contaminant loads on an annual basis. The model is very simple in principle - the area of a particular land use (source) within the area being studied (the catchment) is multiplied by the quantity of contaminants discharged from that land use (source yield) to provide an annual load from that source. The loads from each source within the catchment are then added together to provide an annual contaminant load for the catchment of interest.

The CLM incorporates six urban land use types (sources), these being roofs (divided into nine different types of material); roads (divided into six different vehicles/day categories); paved surfaces, other than roads and roadside footpaths (divided into residential, commercial and industrial); urban grasslands and trees (divided into three different slope categories); urban streams; and construction sites (considered to be 100% bare earth for the purposes of estimating contaminant loads). Although it has been developed for urban stormwater discharges, the CLM also incorporates five rural land uses, each subdivided into three categories, to enable mixed land use catchments around the fringes of the Auckland urban area to be modelled.

Source yields from the different source areas are provided for Total Suspended Solids (TSS), zinc (Zn), copper (Cu) and Total Petroleum Hydrocarbons (TPH).

A further consideration in modelling contaminant loads is any stormwater management or treatment that is implemented to reduce the loads of contaminants discharged to receiving water bodies. These are generically represented in the model by load reduction factors (LRF), and can include a range of options from source control to stormwater treatment devices.

The first version of the CLM was made available for general use in January 2006 and a modified version currently in use was issued in May 2006. A new version, Version 2, has been made available with the release of this report (CLM Development Report) and the User Manual. The new version includes improved model parameter values and the option for users to enter their own load reduction factors (these were fixed at default values in the previous versions of the model).

This report describes: the principles, assumptions and limitations of the model; and the derivation of reference source area fractions, source yields and load reduction factors.

Acknowledgements

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The CLM and reports were subject to internal officer and international peer review. The international review was undertaken as part of the assessment of the Central Waitemata Harbour and Southeastern Manukau Harbour / Pahurehure Inlet contaminant studies.

Technical oversight and direction were provided by Dr Judy-Ann Ansen, Stormwater Technical Services Manager and Matthew Davis, Manager of Development and Technical Services of the Stormwater Unit.

2 Introduction

The purpose of the Contaminant Load Model (CLM) is to aid the estimation of annual contaminant loads discharged from stormwater networks serving large areas of mixed urban land use. These load estimates assist in assessing the effects of the discharges on receiving environments.

A requirement of the Resource Management Act (1991) is that applications for resource consents to discharge contaminants to natural waters must be accompanied by an Assessment of Environmental Effects (AEEs). This assessment must describe the contaminants in the discharge, the rates at which each contaminant is being, or will be discharged, and the adverse effects that each contaminant would or could cause in the receiving environment.

Most industrial effluents are discharged at near-constant rates and contain near-constant concentrations of the various contaminants. This means that the loads (e.g. kg day^{-1}) are also near-constant. Monitoring to determine these loads is relatively uncomplicated, requiring only a short period of monitoring to obtain representative loads. In contrast to industrial effluents, the quantity and quality of urban stormwater varies widely over short periods of time in response to rainfall.

The highly variable character of stormwater does not alter the legal requirement to describe the contaminants that are in the stormwater, the rates at which each of these contaminants is being, or will be, discharged and the effects of these contaminants in receiving environments.

As for industrial effluent, monitoring stormwater quantity and quality over a period of time is the most rigorous and scientifically defensible method of determining stormwater contaminant loads. The difference in monitoring requirements between industrial effuents and urban stormwater is that stormwater monitoring must span many rainfall events, because no two rainfall events ever produce the same loads. Even rainfall events of similar intensity and duration produce different loads because of different antecedent conditions, which determine how much of each contaminant is available to be washed off at the start of an event.

Faced with these constraints, resource consent applicants for stormwater network discharges have tried to estimate rather than measure stormwater contaminant loads for their AEEs. Early estimates involved multiplying the area of a particular land use, e.g. residential, by a single value derived from overseas data for the contaminant yield, e.g. 0.3 kg of zinc ha^{-1} $year^{-1}$ for residential land use.

It has now been identified that the primary sources of zinc are galvanised steel roofs and vehicle tyres, but the early procedure for estimating loads could not allow for the hugely different areas of galvanised steel roofs and numbers of vehicles that exist in different residential catchments.

Several projects commissioned by the ARC since 2002 have produced data from which yields for different urban sources could be calculated. A source load can now be estimated by multiplying the source area by its contaminant yield. Catchment or site loads are the sums of the individual source loads.

The CLM spreadsheet was produced to make these yields available to the wider stormwater community in a format that standardises and simplifies the estimation of catchment and site loads from individual source areas. It was also hoped that a tool such as this would go some way towards ensuring that loads for different parts of the region are calculated on the same basis. This was considered to be a useful step towards achieving a "regional" approach to stormwater management and avoiding spatial bias in the assessment of effects.

It should be emphasised that the CLM is of limited use for stormwater management purposes, other than for estimating stormwater contaminant loads for large urban areas, ie greater than about 20 ha (though this threshold is not fixed), with small or zero proportions of rural land. Application of the CLM to small urban areas is possible but only if the validity of the model parameters is confirmed for each small area. The CLM cannot be used for detailed design purposes. This can be done only by applying sound stormwater engineering principles to the contaminant, topographical, hydraulic and hydrologic characteristics of the areas. Nevertheless, the CLM does provide a means for assessing the relative contaminant load contribution of groups of catchments, allowing further stormwater management investigations to be prioritsed accordingly.

2.1 Report content

This report describes the CLM spreadsheet model, how the source areas, contaminant yields and load reduction factors were derived (i.e. the proportions by which loads are reduced by specific management interventions), and how they are used to calculate the stormwater contaminant loads.

Some of the source areas may be unknown for large urban areas, so the derivation of reference source area fractions suitable for these large areas is described.

The reasons why this model cannot be applied to small urban areas, without confirming that the model parameters are valid for those areas, are also explained in detail.

The source yields, the annual contaminant loads produced by the CLM for large urban catchments, and the annual average stormwater concentrations, are compared with international data. Annual average stormwater concentrations are obtained by taking into account the annual rainfall.

Finally, the uncertainty of model estimates are discussed in Appendix 2 for three different yield categories and reference source area fraction categories.

3 Model Overview

3.1 General

The CLM was developed and calibrated to estimate the annual loads, ie kg per year (kg yr^{-1}), for the following contaminants in stormwater from large, heterogeneous urban areas of the Auckland region.

The four contaminants for which loads are estimated by the CLM are:

- total suspended solids (TSS)
- total zinc
- total copper
- total petroleum hydrocarbons (TPH).

The CLM considers urban areas to comprise only the six sources listed below, although roofs, roads, paved surfaces and urban grasslands and trees are further subdivided as noted.

- roofs divided into nine different types of material
- roads divided into six different vehicles/day categories
- paved surfaces, other than roads and roadside footpaths, divided into residential, commercial and industrial
- urban grasslands and trees divided into three different slope categories
- urban streams
- construction sites, which are considered to be 100% bare earth for the purposes of estimating contaminant loads.

Five rural land uses, each subdivided into three categories, are included in the model, to enable mixed land use catchments around the fringes of the Auckland urban area to be modelled. The rural land uses are as follows.

- Exotic production forest divided into three slope categories. In the Auckland region this forest is mostly *pinus radiata*.
- Stable forest divided into three slope categories. This includes blocks of mostly indigenous forest that is not substantially disturbed (ie has a lower TSS yield than production forest).
- Farmed pasture divided into three slope categories.
- Retired pasture divided into three slope categories.
- Horticulture divided into three categories; two known soil types and one unknown soil type.

The CLM calculates annual contaminant loads in g yr^{-1} in the body of the spreadsheet and in kg yr^{-1} in the bottom-of-site summary at the bottom of the spreadsheet.

3.2 Model mathematics

The mathematics of the CLM are simple, with the same equation for all source/contaminant/management combinations. This equation is:

$$\text{Source Load} = \text{Source Area} \times \text{Source Yield} \times \text{Load Reduction Factor} \times \text{Area Fraction Managed} \quad (1)$$

Where:

Source load (g $year^{-1}$ or kg $year^{-1}$)	=	The quantity of a contaminant (g or kg) generated by the source over a one year period and available to be transported by runoff.
Source area (m^2)	=	The area of the source in m^2. For roads the road length is entered into the model and the area is calculated as described below. Stream channel area is the channel length times the effective width (defined as the wetted width of the average stream cross-section at mean flow).
Source yield	=	The quantity of a contaminant generated by 1 m^2 of a source over a period of one year.
Load reduction factor	=	The fraction by which a selection of management options reduces the contaminant load. The management options include stormwater treatment and source control, such as the painting of galvanised roofs, stream bank stabilisation with timber palings, etc.
Area fraction managed	=	The fraction of a source area draining to a management option train. This must be a positive value less than or equal to one.

3.3 Model spreadsheet

The model spreadsheet is shown in Figure 1. The sources of total suspended solids, zinc, copper and total petroleum hydrocarbons are listed in column A with the various subdivisions of the sources in column B. The yellow blocked cells are for user input. Within the main body of the spreadsheet Columns C and D are for entry of road lengths and the areas of the other sources respectively. The next four columns E to H are for selection of any source management options, e.g., stormwater treatment and source control, and the remaining green blocked columns, L, Q, V and AA are for user entry of load reduction factors (LRF) for selected load management options. In a separate section below the main body of the spreadsheet are the user input cells for management options at the bottom of the catchment and any alternative LRF for these options.

Figure 1: ARC CLM Spreadsheet

Contaminant Load Model
Version 2.0 March 2011

Catchment name CATCHMENT NAME

A	B	C	D	E	F	G	H	I	J	K	L	M
Catchment area (m²)				Source contaminant management train				Contaminant yields, loads, and load reduction factors				
								Total suspended solids (TSS)				
Source	Source type		Source Area (m²)	1st management option	2nd management option	3rd management option	Fraction of area draining to train	Yield (g m⁻² a⁻¹)	Initial load (g a⁻¹)	Default load reduction factor	Manual load reduction factor	Reduced load (g a⁻¹)
Roofs	Galvanised steel unpainted							5	0	0.00		0
	Galvanised steel poorly painted							5	0	0.00		0
	Galvanised steel well painted							5	0	0.00		0
	Galvanised steel coated (Decramastic tiles)							12	0	0.00		0
	Zinc/aluminium unpainted (Zincalume)							5	0	0.00		0
	Zinc/aluminium coated (Colorsteel/Colorcote/new metal tiles)							5	0	0.00		0
	Concrete							16	0	0.00		0
	Copper							5	0	0.00		0
	Other materials							10	0	0.00		0
Roads	*Vehicles/day*	*Length (m)*										
	<1000		0					21	0	0.00		0
	1000-5000		0					28	0	0.00		0
	5000-20000		0					53	0	0.00		0
	20000-50000		0					96	0	0.00		0
	50000-100000		0					158	0	0.00		0
	>100000		0					234	0	0.00		0
Paved Surfaces other than roads	Residential							32	0	0.00		0
	Industrial							22	0	0.00		0
	Commercial							32	0	0.00		0
Urban Grasslands and trees	Slope < 5							45	0	0.00		0
	5 < Slope <10							92	0	0.00		0
	Slope >10							185	0	0.00		0
Urban Stream Channel	*length x width*							6000	0	0.00		0
	Urban area without construction sites		0					Totals	0	0.00		0
Construction Site open for 12 months/year	Slope < 5							2500	0	0.00		0
	5 <Slope <10							5600	0	0.00		0
	Slope >10							10600	0	0.00		0
	Urban area with construction sites		0					Totals	0	0.00		0
Exotic production forest	Slope <10							35	0	0.00		0
	10 < Slope < 20							104	0	0.00		0
	Slope >20							208	0	0.00		0
Stable forest	Slope <10							14	0	0.00		0
	10 < Slope < 20							42	0	0.00		0
	Slope >20							83	0	0.00		0
Farmed pasture	Slope <10							152	0	0.00		0
	10 < Slope < 20							456	0	0.00		0
	Slope >20							923	0	0.00		0
Retired pasture	Slope <10							21	0	0.00		0
	10 < Slope < 20							63	0	0.00		0
	Slope >20							125	0	0.00		0
Horticulture	*Soil type*	Volcanic						50	0	0.00		0
		Sediment						100	0	0.00		0
		Unknown						100	0	0.00		0
	Total area of sources (m²)		0					Totals	0			0

B	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
	Zinc suspended particulate and dissolved (TZn)					Copper suspended particulate and dissolved (TCu)					TPH suspended particulate and dissolved (TTPH)				
Source type	Yield (g m⁻² a⁻¹)	Initial load (g a⁻¹)	Default load reduction factor	Manual load reduction factor	Reduced load (g a⁻¹)	Yield (g m⁻² a⁻¹)	Initial load (g a⁻¹)	Default load reduction factor	Manual load reduction factor	Reduced load (g a⁻¹)	Yield (g m⁻² a⁻¹)	Initial load (g a⁻¹)	Default load reduction factor	Manual load reduction factor	Reduced load (g a⁻¹)
Galvanised steel unpainted	2.2400	0.0	0.00		0.0	0.0003	0.0	0.00		0.0					
Galvanised steel poorly painted	1.3400	0.0	0.00		0.0	0.0003	0.0	0.00		0.0					
Galvanised steel well painted	0.2000	0.0	0.00		0.0	0.0003	0.0	0.00		0.0					
Galvanised steel coated (Decramastic tiles)	0.2800	0.0	0.00		0.0	0.0017	0.0	0.00		0.0					
Zinc/aluminium unpainted (Zincalume)	0.2000	0.0	0.00		0.0	0.0009	0.0	0.00		0.0					
Zinc/aluminium coated (Colorsteel/Colorcote/new metal tiles)	0.0200	0.0	0.00		0.0	0.0016	0.0	0.00		0.0					
Concrete	0.0200	0.0	0.00		0.0	0.0033	0.0	0.00		0.0					
Copper	0.0000	0.0	0.00		0.0	2.1200	0.0	0.00		0.0					
Other materials	0.0200	0.0	0.00		0.0	0.0020	0.0	0.00		0.0					
Vehicles/day															
<1000	0.0044	0.0	0.00		0.0	0.00148	0.0	0.00		0.0	0.0335	0.0	0.0		0.0
1000-5000	0.0266	0.0	0.00		0.0	0.00887	0.0	0.00		0.0	0.2013	0.0	0.0		0.0
5000-20000	0.1108	0.0	0.00		0.0	0.03695	0.0	0.00		0.0	0.8387	0.0	0.0		0.0
20000-50000	0.2574	0.0	0.00		0.0	0.08579	0.0	0.00		0.0	1.9474	0.0	0.0		0.0
50000-100000	0.4711	0.0	0.00		0.0	0.15703	0.0	0.00		0.0	3.5645	0.0	0.0		0.0
>100000	0.7294	0.0	0.00		0.0	0.24314	0.0	0.00		0.0	5.5192	0.0	0.0		0.0
Residential	0.1950	0.0	0.00		0.0	0.0360	0.0	0.00		0.0					
Industrial	0.5900	0.0	0.00		0.0	0.1070	0.0	0.00		0.0					
Commercial	0.0000	0.0	0.00		0.0	0.0294	0.0	0.00		0.0					
Slope < 5	0.0016	0.0			0.0	0.0003	0.0			0.0					
5 < Slope <10	0.0032	0.0			0.0	0.0006	0.0			0.0					
Slope >10	0.0065	0.0			0.0	0.0013	0.0			0.0					
length x width	0.2100	0.0			0.0	0.0420	0.0			0.0					
Urban area without construction sites	Totals	0.0	0.00		0.0	Totals	0.0	0.00		0.0	Totals	0.0	0.00		0.0
Slope < 5	0.0880	0.0			0.0	0.0180	0.0			0.0					
5 <Slope <10	0.1980	0.0			0.0	0.0390	0.0			0.0					
Slope >10	0.3710	0.0			0.0	0.0740	0.0			0.0					
Urban area with construction sites	Totals	0.0	0.00		0.0	Totals	0.0	0.00		0.0	Totals	0.0	0.00		0.0
Slope <10	0.0012	0.0			0.0	0.0002	0.0			0.0					
10 < Slope < 20	0.0036	0.0			0.0	0.0007	0.0			0.0					
Slope >20	0.0073	0.0			0.0	0.0015	0.0			0.0					
Slope <10	0.0005	0.0			0.0	0.0001	0.0			0.0					
10 < Slope < 20	0.0015	0.0			0.0	0.0003	0.0			0.0					
Slope >20	0.0029	0.0			0.0	0.0006	0.0			0.0					
Slope <10	0.0053	0.0			0.0	0.0011	0.0			0.0					
10 < Slope < 20	0.0160	0.0			0.0	0.0032	0.0			0.0					
Slope >20	0.0320	0.0			0.0	0.0065	0.0			0.0					
Slope <10	0.0007	0.0			0.0	0.0001	0.0			0.0					
10 < Slope < 20	0.0022	0.0			0.0	0.0004	0.0			0.0					
Slope >20	0.0044	0.0			0.0	0.0009	0.0			0.0					
Soil type: Volcanic	0.0018	0.0			0.0	0.0004	0.0			0.0					
Soil type: Sediment	0.0035	0.0			0.0	0.0007	0.0			0.0					
Soil type: Unknown	0.0035	0.0			0.0	0.0007	0.0			0.0					
Total area of sources (m²)	Totals	0.0			0.0	Totals	0.0			0.0	Totals	0.0			0.0

CATCHMENT AREA EQUALS SUM OF SOURCE AREAS
Difference - 0.000

Catchment overview of contaminant loads

Bottom of the catchment contaminant management train				Load reduction factors (LRF)			Bottom of catchment out-fall Loads (kg a⁻¹)				Average yields (kg ha⁻¹ a⁻¹)			
First management option	Second management option	Third management option	Fraction of area draining to train	Contaminant	Default LRF	Manual LRF	TSS	TZn	TCu	TPH	TSS	TZn	TCu	TPH
				TSS	0.00		0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
				TZn	0.00									
				TCu	0.00									
				TTPH	0.00									
				% Reduction with management			0.0%	0.0%	0.0%	0.0%				

3.4 Model parameters

The four parameters in the source load equation are derived by different methods as follows.

- Source areas. These are entered as areas in m^2 by the model user, except that the length in m is entered for roads.
- Source yields. These can not be altered by the model user. The yields are updated by the Council in new versions of the model to take account of data published since the release of the previous version.
- Load reduction factors. These are chosen by the model from a list of default values when the model user selects a management option, e.g. painting galvanised steel roofs, stabilising stream banks, or installing a sand filter to treat road runoff. The default values give the largest load reductions that could realistically be achieved by the chosen management option. The model user can enter alternative load reduction factors for management options if they are either known to, or expected to, produce sub-optimum load reductions.
- Area fraction managed. A value must be entered by the model user for all selected management option trains. If an entire source drains to a management option train then 1 must be entered as the area fraction managed. If a value, including 1, is not entered then the model ignores the selected management options. If no management options are selected than the area fraction managed is ignored.

The following sections describe the first three of these parameters in more detail. The area fraction managed requires no further explanation.

3.5 Model Applicability

While model limitations are discussed in detail in section 9 it is important at this point to emphasise that the CLM was developed for use in the Auckland region and its applicability to other parts of New Zealand is likely to vary considerably. In particular, source yields for TSS are unlikely to be correct for rainfall and soils different from those in Auckland and should be replaced with local data from either monitoring or modelling for the intended area of application. The generation of chemical contaminants predicted in the CLM should, however, be reasonably applicable to most urban areas of New Zealand.

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4 Source areas

Source areas are the minimum data required to use the CLM. Source areas should be calculated from the available GIS database information. However, for some catchments completed databases are not available. Therefore, the CLM has developed reference source area fractions for residential, commercial and industrial land uses. These provide a basis for dividing a catchment into its constituent source areas in the absence of any catchment-specific information. The following sections discuss the parameter derivation methodology.

4.1 Reference source area fractions

The reference source area fractions were derived from data collected within former (prior to 1 November 2010) Auckland City Council (ACC) boundaries between 2001 and 2008, and consequently are the most accurate for older urban areas. The fractions will continue to be valid for these urban areas until the redevelopment of these areas becomes sufficiently extensive for them to lose their original characteristics. The most obvious changes will be more intensive infill housing, more vehicles on the roads and different materials used for building roofs and cladding.

It is emphasised that the CLM does not use the reference source area fractions as a required model parameter. If the model user needs to use alternative fractions to estimate approximate source areas, then they should be entered into the model manually. The source areas required for the CLM will be a mixture of known areas and areas estimated using the reference source area fractions. It should be noted that these reference source area fractions are for the urban area, including motorways (see Table 4, 5 & 6). Any rural source areas must be entered separately into the model. While reference source area fractions are not defined for rural source area categories, reference fractions are given in relation to the proportion of each rural land use falling in each of three slope classes.

The following sections describe the derivation of the reference source area fractions.

4.1.1 Roofs, roads, paved and pervious surfaces

The former ACC area contained no rural land, so its source areas are entirely urban. A detailed GIS analysis has been undertaken for the 8,088 ha of ACC (about 52% of the whole of ACC based on 2009 local authority boundaries) draining to the Central Waitemata Harbour. This analysis showed that urban open space is 4.27% of this part of the City; the total motorway area is 1.50% and the urban built up area is the remaining 94.2%. According to aerial photographic data, the urban built up area is further divided into 84.2% residential, 5.14% commercial and 10.7% industrial land use. Hence these values are 79.3% residential, 48.4% commercial and 10.1% industrial respectively of the ACC total catchment area.

A GIS analysis of the whole of ACC was undertaken to determine the roof area (Kingett Mitchell and Diffuse Sources Ltd, 2003). The results are reproduced in Table 1. After excluding the predominantly commercial catchments of Stanley and the Central Business District (the grey shaded row in the Table 1), the impervious surfaces (roofs, roads and paved areas) cover 47.8% of the mostly residential part of the City. Of this 47.8%, roofs are 19.2% and roads and other paved areas make up the remaining 28.6%.

Table 1:

Total, impervious and roof areas for catchments in ACC in 2001 (Kingett Mitchell and Diffuse Sources, 2003).

Catchment	Total Area (m^2)	Total Impervious Area (m^2)	Roof Area (m^2)	% Roof Area of total impervious area (%)	% Roof area of total catchment
Avondale	6,847,357	3,365,604	1,423,218	42.3	20.78
Brentwood	790,802	431,458	184,931	42.9	23.39
Central Business	2,062,549	1,759,463	599,414	34.1	29.06
Ellerslie/Waitarua	8,199,195	3,867,801	1,494,490	38.6	18.23
Epsom	2,997,973	1,636,354	688,794	42.1	22.98
Freemans Bay/St	3,041,021	2,140,244	748,832	35.0	24.62
Glen Innes	7,344,985	2,417,270	928,786	38.4	12.65
Glendowie	4,273,056	1,597,948	637,833	39.9	14.93
Grey Lynn	4,479,270	2,512,744	1,090,240	43.4	24.34
Herne Bay	1,095,587	588,292	227,561	38.7	20.77
Hillsborough	4,018,552	1,154,693	442,850	38.4	11.02
Kinross/Lewis/Endea	2,195,808	805,756	335,258	41.6	15.26
Kohimarama	2,486,219	1,252,361	525,340	41.9	21.13
Meadowbank	3,368,399	1,393,143	588,305	42.2	17.47
Meola	15,101,708	7,386,467	3,169,905	42.9	20.99
Mission Bay	1,720,885	820,994	317,808	38.7	18.47
Motions/Westmere	4,234,972	2,228,356	816,092	36.6	19.27
Mt Wellington North	2,993,770	1,354,994	512,166	37.8	17.11
Mt Wellington South	1,549,078	849,681	367,844	43.3	23.75
Mt Wellington	9,469,025	5,356,322	2,200,523	41.1	23.24
Newmarket	4,572,942	2,553,450	1,007,639	39.5	22.04
Oakley	12,297,567	5,319,161	2,184,667	41.1	17.77
One Tree Hill	7,649,887	4,128,969	1,687,716	40.9	22.06
Onehunga	6,600,036	3,361,793	1,411,204	42.0	21.38
Orakei	2,038,160	743,783	241,721	32.5	11.86
Otahuhu East	4,587,942	2,178,215	882,008	40.5	19.22
Otahuhu West	1,588,100	1,023,496	414,843	40.5	26.12
Parnell	1,848,474	1,027,108	355,477	34.6	19.23
Point England	2,909,747	1217,629	365,002	30.0	12.54
Portland/Hapua	2,049,357	910,418	301,863	33.2	14.73
Pt Chevalier	1,746,635	802,974	459,395	57.2	26.26
Purewa	2,799,102	774,119	288,817	37.3	10.32
Royal Oak	4,081,447	1,798,215	779,711	43.6	19.10
St Heliers	1,856,075	912,452	352,246	38.6	18.98
Stanley	2,228,410	1,073,194	390,017	37.6	17.50
Waiata	1,010,522	463,721	175,271	37.8	17.34
Waterview/Fairland	646,234	285,471	117,039	41.0	18.11
Whau	6,097,367	2,592,073	1,086,889	41.9	17.83
Average					19.24

Data provided by ACC/Metrowater for 6,966 ha of the 8,088 ha of the City lying within the Waitemata Harbour catchment (excluding the commercial CBD and Stanley catchments and the three residential catchments of Brentwood, Epsom and Kinross), shows that local roads are 16.0% of the area. Assuming that this percentage applies to the residential area of the whole City, then 12.6% of the residential area is paved.

The proportions of impervious surface in the two adjacent commercial areas, the CBD and Stanley are quite different, i.e. 85% and 48.2% respectively. The CBD catchment is the most intensely developed commercial catchment in the Auckland region, as reflected by its high area fraction of impervious surface. In contrast, the Stanley catchment has an unusually low proportion of impervious area, because this catchment incorporates the Auckland Domain. This Domain is an almost 100 ha reserve of forest and grass, incorporating the Auckland Museum and extensive sports fields. Thus, the typical impervious area fraction for commercial developments lies between these two extremes. In the absence of further data, the typical area proportion of impervious surface in commercial catchments was assumed to be 66% (Refer Table 1).

The area fractions for roofs are similar in the built-up parts of both catchments, ie 34.1% in the CBD and 37.6% in Stanley. Vehicle parking in these catchments is mostly accommodated in parking buildings, which contribute roofs rather than paved surfaces to the catchments' impervious surfaces. This is not the case for most urban shopping centres, which have open parking areas. It seems likely, therefore, that the typical area fraction for roofs in commercial catchments would be a bit less than the fractions in the CBD and Stanley catchments. Accordingly, a roof area fraction of 30% is assumed as a reference source area fraction for commercial land use in the CLM.

This leaves an average fraction of 36% for roads and paved surfaces combined in commercial catchments. The area fraction of roads in commercial catchments would be expected to be a bit greater than in residential catchments, so in the absence of data to the contrary, a reference source area fraction for roads of 20% is assumed for commercial catchments, leaving a source area fraction of 16% for other paved surfaces.

The only measured source areas available for industrial land use are from the Tamaki catchment described in Timperley et al (2004), (this catchment is also called Mt Wellington). Building roofs are 20% of this catchment, paved surfaces are 25% and roads are 10%, giving a total impervious surface fraction of 55% (Timperley et al, 2004). Visual inspection of other industrial areas in South Auckland indicates that the Tamaki catchment is unusual for an industrial catchment, because it contains quite large areas of pervious grasslands between the industrial sites and Mt Wellington. Accordingly, for the CLM the typical industrial catchment was assumed to have a total impervious surface fraction of 65%, with roofs 20%, roads 20%, paved surfaces 25% and pervious surfaces 35%.

4.1.2 Roof materials

A total of almost 400,000 m^2 of building roofs in ACC has now been surveyed for area and type of material. The results are summarised in Table 2. The Mission Bay catchment is an old residential area, but it has been substantially redeveloped as land values have increased. Only 9.6% of the roof area is now galvanised steel (excluding coated galvanised steel tiles, e.g., Decramastic), whereas historically this proportion would have been much higher. The Whau catchment also has a low proportion of galvanised roofs (3.9%), with most of the roofs either coated galvanised steel tiles (e.g.Decramastic) or concrete tiles. The proportions of galvanised roofs in the other six residential areas surveyed ranged from 21% to 74%. The area weighted average (over the eight residential areas surveyed) was 27.8%.

The proportions of the different roof materials in Table 2 for the commercial and industrial areas in ACC were derived from data collected in CBD catchment (commercial) and Mt Wellington catchment (industrial).

These percentages were applied for the different materials to the roofs of ACC produced the overall area fractions for the different roof materials in each land use (residential, commercial and industrial) category are shown in Table 4, Table 5 and Table 6.

Table 2.

Roof materials and areas surveyed in ACC. Data for three catchments were supplied by ACC Council / Metrowater.

Data Source	Urban land use	Total roof area surveyed (m^2)	Galvanised steel unpainted (m^2)	Galvanised steel poorly painted (m^2)	Galvanised steel well painted (m^2)	Galvanised steel coated (m^2)	Zinc/aluminium surfaced steel unpainted (m^2)	Zinc/aluminium surfaced steel coated (m^2)	Copper (m^2)	Concrete (m^2)	Other Materials (m^2)
	Residential										
TP213	Epsom	29,954	966	6,262	839	4,603	684	2,683	-	12323	1594
TP213	Point Chevalier	15,370	845	3,634	1,528	417	96	2,008	-	4580	2262
TP213	Mt Roskill	18,922	789	4,752	1,476	3,572	523	2,211	-	5241	358
TP213	Westmere	26,293	2,101	11,677	5,687	3,562	31	1,650	-	860	725
TP318	Mission Bay	76,206	1,088	3,577	3,438	8,060	182	18,619	138	24137	16967
ACC/Metrowater	Point England	13,685	171	2,360	350	2,257	0	5,833	0	2714	0
ACC/Metrowater	Otahuhu	18,927	1,596	5,187	1,194	3,318	139	3,877	0	2358	1258
ACC/Metrowater	Whau	17,126	672	0	0	6,036	0	577	0	8919	922
	Total residential	216,483	8,228	37,449	14,512	31,825	1,655	37,458	138	61132	24086
	% of		3.80	17.30	6.70	14.70	0.76	17.30	0.06	28.24	11.13
	Commercial										
TP213	CBD	37,644	8,370	11,972	0	576	0	4,988	-	203	11535
TP318	CBD	66,112	4,493	13,275	5,594	2,490	3,927	11,922	0	15711	8700
	Total	103,756	12,863	25,247	5,594	3,066	3,927	16,910	0	15914	20235
	% of		12.40	24.33	5.39	2.96	3.78	16.30	0	15.34	19.50
	Industrial										
TP318	Tamaki (Mt Wellington)	74,214	64,502	3,096	1,383	0	0	2,788	0	0	2445
	% of industrial		86.91	4.17	1.86	0	0	3.76	0	0	3.29
	Total roof	394,453									

4.1.3 Road vehicles per day (vpd) categories

For the purposes of determining reference source area fractions, roads are categorised to two main groups based on vehicles carrying capacity.

- Roads > 50, 000 vpd – further two categories
- Roads < 50, 000 vpd – further four categories

In total there are six road categories in the CLM. The Vehicle kilometers travelled (VKT) predicted by the CLM for any road category, was calculated by dividing the road area by the respective road width (e.g. 24 m for 50,000-100,000 vpd, 31 m for >100,000 vpd) to get the length and then multiplying the length by the mean vehicle capacity for that road category.

For example, the annual VKT for 10,000 m^2 of a road carrying 50,000-100,000 vpd is given by

VKT = (10,000 m^2/24 m) x (1 km/1,000 m) x 365 day/year x 75,000 vehicles/day (2)

= 11,406,250 vehicle km/year

The following sections describe the reference source area fractions estimated for each category.

4.1.3.1 Roads >50,000 vehicles per day

Roads carrying more than 50,000 vehicles per day were assumed to be the motorways in the Ministry of Transport Vehicle Fleet Model (VFM, Metcalfe et al., 2006). The area of motorways in ACC divided into two categories, 50,000 – 100,000 vpd and >100,000 vpd, was derived by comparing the CLM predictions of annual vehicle km travelled (VKT) on roads in these two categories, with the predictions made for motorways using the VFM.

The VFM predictions (all VKT values are stated in millions) for motorways in the Auckland region in 1993 and 2004 were 3,150 VKT and 3, 940 VKT respectively. This is 35.63% and 34.56% of the total predicted VKT for all roads in the region. The mean value of the 1993 and 2004 values (35.10%) was assumed for estimating the VKT as follows. This percentage applied to the VKT of 4,020 predicted by the VFM for all roads in ACC, i.e. motorways and local roads, gives a VKT of 1,411 for ACC's motorways in that year.

When the areas of roads carrying 50,000-100,000 vpd and >100,000 vpd are equal to 1,156,883 m^2 and 60,889 m^2 respectively in the CLM, the total VKT calculated by the CLM for these two road categories is 1,427. This value is close to the VKT of 1,411 predicted by the VFM. These road areas give area fractions of the whole City for motorways of 0.751% for the 50,000 – 100,000 vpd category and 0.040% for the >100,000 vpd category.

4.1.3.2 Roads <50,000 vehicles per day

Four road categories are considered for roads carrying less than 50,000 vpd. The area fractions were calculated by the same procedure stated above. For these four categories were assumed to be the local roads of the Vehicle Fleet Model (VFM). Road widths of 17 m are assumed in the CLM for the three categories with <20,000 vpd, and a width of 21.5 m is assumed for the 20,000-50,000 vpd category.

Initial areas for each of these four road categories were assumed for residential, commercial and industrial land use. The areas for the road categories in residential land use only were then adjusted; until the annual vehicle kilometres travelled (VKT) calculated by the CLM for these road categories in the whole City matched that predicted by the VFM for local roads.

The total VKT predicted by the Vehicle Fleet Model for the entire Region's local roads (excluding motorways) in 1993 and 2004 were 64.37% and 65.44% respectively of the predicted total VKT for all local roads plus motorways. The mean of 64.91% applied to the ACC total VKT for all local roads plus motorways gives an annual ACC local road VKT of 2608.

The areas for local residential roads that gave the best match between the CLM and VFM predictions of VKT for local roads in ACC were:

1. 11,532,173 m^2 for the <1,000 vpd category
2. 5,972,018 m^2, for the 1,000-5,000 vpd category
3. 2,471,180 m^2, for the 5,000 – 20,000 vpd category
4. 617,795 m^2 , for the 20,000 – 50,000 vpd category

These areas give fractions of the total residential area for the four road categories of 8.96% (< 1,000 vpd), 4.64% (1,000-5,000 vpd), 1.92% (5,000 - 20,000 vpd) and 0.48% (20,000 - 50,000 vpd). The area fractions for these road categories in both commercial and industrial land use are 2% (< 1000 vpd), 6% (1,000-5,000 vpd), 10% (5,000 - 20,000 vpd) and 2% (20,000 - 50,000 vpd).

4.1.4 Paved surfaces

The area fractions for paved surfaces in ACC are the differences between the total impervious area proportions and the proportions of roads plus roofs given above. These paved area fractions are 12.6%, 16% and 25% for residential, commercial and industrial land uses respectively.

4.1.5 Pervious surfaces

<u>Stream length</u>

GIS analysis of the 8,088 ha of ACC within the Central Waitemata harbour catchment (52% of the City area), found that there are 34 km of open stream channel. Obviously the wetted cross section length at mean flow varies enormously among streams and also along the length of every stream. The value of 4 m used here to derive the reference source area fraction for urban streams, is an estimate based on the authors' visual inspections of the 15 streams in ACC. The total stream length of 34 km and the wetted cross section length of 4 m gives a total channel surface area of 136,000 m^2. This area is 0.17% of the City area and this is adopted as the reference source area fractions for all three land use types (residential, commercial and industrial).

<u>Construction site bare earth</u>

The reference source area fractions for construction site bare earth in ACC were calculated from the population increase for 2001; an increase in commercial area per head of new population;

the distribution of these people among new subdivisions; infill housing and apartments; and the area of bare earth that construction of each type of dwelling generates.

It should be noted that the reference source area fractions for construction site bare earth are very small. Consequently, the uncertainties in the parameters described below that were used to calculate these fractions have negligible influence on the accuracy of the total site TSS loads calculated by the CLM.

Population modelling for ACC produced a population increase for 2001 of 2.082% or 8,175 people. Seven percent of these additional people were accommodated in houses on vacant land, 49% in houses on infill land and 44% in apartments (Regional Growth Forum, 2003). Three persons on average were accommodated in each dwelling (Regional Growth Forum, 2003).

The typical area of a subdivision lot is 1,000 m^2 (Regional Growth Forum, 2003), and this whole area is usually bare earth at some stage during the development of a subdivision. Infill development generates 150 m^2 of bare earth for each lot, i.e.100 m^2 for the house (Regional Growth Forum, 2003), and an assumed 50 m^2 for other surfaces including the driveway and footpaths.

The area (m^2) of residential construction site bare earth in the City in 2001 was therefore calculated to be:

Residential construction site bare earth = (8,175 person/3 person/dwelling) x (0.07 vacant land dwelling/ dwelling x 1,000 m^2/vacant land dwelling) + (0.49 infill land dwelling/dwelling x 150 m^2/infill land dwelling)) (3)

= 391,038 m^2

This gives a construction site reference source area fraction of 0.304% for residential land use.

The contaminant generating potential of apartment buildings is the same as that of office buildings (source materials used are same in both building categories). Also, many apartment buildings are constructed within commercial areas. For these reasons, apartment buildings are included in commercial land use for the purposes of calculating contaminant loads using the CLM.

Apartment buildings range from single story to more than 20 stories and individual apartments range from studios of 30 m^2 to penthouses of more than 200 m^2. No readily accessible compilation appears to exist for the numbers of floors in apartment buildings and the areas of apartments in ACC. For the purposes of estimating the area of bare earth that resulted from apartment building construction in ACC in 2001, the average apartment area was assumed to be 80 m^2 and an apartment building was assumed to have 80 apartments and 10 floors, i.e. 10 apartments (30 persons) per 80 m^2 of ground area producing 8 m^2 of bare earth for each apartment.

Each new person generates a need for new commercial activity e.g. a supermarket. An area of 5 m^2 of new commercial land was assumed to be generated by each new person. New industrial development is unlikely within ACC (ARC growth model, 2006), so no additional industrial area was assumed to result from population growth.

The area (m^2) of commercial construction site bare earth in the city in 2001 (values estimated were based on 2001 land use information to be consistent with other models developed for the region) was therefore:

Commercial construction site bare earth = 8,175 person x (5 m^2/person + 0.44 apartment/dwelling x 8 m^2/apartment/3 person/dwelling) (4)

= 50,467 m^2

This gives a commercial construction site bare earth reference source area fraction of 0.60% in 2001[1].

Urban pervious areas can be further divided into three slope categories. Reference source area fractions for the various slope categories are given in Table 3. The values in the table are rounded approximations from GIS slope data for urban areas in the central Waitemata Harbour catchment.

Table 3

Reference source area fractions for slope categories in urban pervious surfaces.

	<5º	5º-10º	>10º
Urban grasslands and trees	0.750	0.250	0.000
Urban construction sites	0.750	0.250	0.000

4.1.6 Summary of reference source area fractions for urban land use

The reference source area fractions are shown in Table 4, Table 5 and Table 6 for application to known areas of residential, commercial and industrial land use.

Table 4

Area fractions of sources that can be assumed in residential land use if the total area of this land use is known

		Area Fractions
Roofs	Galvanised steel unpainted	0.0073
	Galvanised steel poorly painted	0.0333
	Galvanised steel well painted	0.0129
	Galvanised steel coated	0.0283
	Zinc/aluminium surfaced steel unpainted	0.0015
	Zinc/aluminium surfaced steel coated long run and tiles	0.0333
	Concrete	0.0544
	Copper	0.0001
	Other materials	0.0214

[1] values estimated were based on 2001 land use information to be consistent with other models developed for the region

	Total roofs			0.1924
Roads		<1000		0.0896
		1000-5000		0.0464
	Vehicles/day	5000-20000		0.0192
		20000-50000		0.0048
	Total roads			0.1600
Paved	Residential			0.1255
Pervious	Grasslands and trees		<5	0.3874
		Slope	5-10	0.1293
			>10	0.0000
	Stream Channel length x width			0.0017
	Construction Site		<5	0.0023
		Slope	5-10	0.0008
			>10	0.0000
	Total pervious			0.5221

Table 5

Area fractions that can be assumed for sources in commercial land use if the total area of this land use is known

			Area Fractions
Roofs	Galvanised steel unpainted		0.0372
	Galvanised steel poorly painted		0.0730
	Galvanised steel well painted		0.0162
	Galvanised steel coated		0.0089
	Zinc/aluminium surfaced steel unpainted		0.0113
	Zinc/aluminium surfaced steel coated long run and tiles		0.0489
	Concrete		0.0447
	Copper		0.0030
	Other materials		0.0568
	Total roofs		0.3000
Roads	Vehicles/day	<1000	0.0200
		1000-5000	0.0600
		5000-20000	0.1000
		20000-50000	0.0200
	Total roads		0.2000
Paved	Commercial		0.1584
Pervious	Grasslands and trees, Slope	<5	0.2504
		5-10	0.0835
		>10	0.0000
	Stream Channel length x width		0.0017
	Construction Site, Slope	<5	0.0045
		5-10	0.0015
		>10	0.0000
	Total urban pervious		0.3416

Table 6

Area fractions that can be assumed for sources in industrial land use if the total area of this land use is known

			Area
Roofs	Galvanised steel unpainted		0.1738
	Galvanised steel poorly painted		0.0083
	Galvanised steel well painted		0.0037
	Galvanised steel coated		0.0000
	Zinc/aluminium surface steel unpainted		0.0000
	Zinc/aluminium surfaced steel coated long run and tiles		0.0075
	Concrete		0.0000
	Copper		0.0000
	Other materials		0.0066
Total roofs			0.2000
Roads	Vehicles/day	<1000	0.0200
		1000-5000	0.0600
		5000-20000	0.1000
		20000-50000	0.0200
Total roads			0.2000
Paved	Industrial		0.2485
Pervious	Grasslands and trees Slope	<5	0.2625
		5-10	0.0875
		>10	0.0000
	Stream Channel length x width		0.0017
	Construction Site ……………………………..Slope	<5	0.0000
		5-10	0.0000
		>10	0.0000
Total urban pervious			0.3515

4.1.7 Reference slope fractions for rural land use

As noted above, areas of rural land uses must be obtained by the model user, but often the land slopes will not be readily available. Suitable reference land slopes have been estimated from topographical maps and from compiled data (e.g. Senior et al., 2003). The reference slopes are listed in Table 7.

Table 7.

Reference land slopes for rural land uses

	<10º	10º - 20º	20º - 30º
Exotic production forest	0.250	0.500	0.250
Stable forest	0.250	0.500	0.250
Farmed pasture	0.600	0.400	0.000
Retired pasture	0.600	0.400	0.000

5 Source yields

This section describes the derivation of default contaminant yields for each of the source area types in the CLM. Yields have been derived from a range of information sources including measurements of stormwater quality reported from several studies conducted in the Auckland region over the last decade. While this section focuses on yields (mass of a contaminant per unit area), the values described here have also been used to estimate annual mean concentrations of contaminants in order to allow comparison with stormwater quality measurements reported elsewhere. This comparison, which provided for the validation of the model, is described in Section 8.

5.1 Roofs

5.1.1 Roof materials

The roof runoff study (Kingett Mitchell Limited and Diffuse Sources Limited, 2003) measured contaminant concentrations in the runoff from a range of different roof materials, including galvanised steel in various states of surface finish from well painted, to poorly painted and unpainted. That report is the source of all of the yields for roof materials described below, except the yields for zinc from uncoated aluminium/zinc surfaced steel and for copper from copper roofs. The following roof materials are included in the model.

- galvanised steel unpainted
- galvanised steel poor paint
- galvanised steel well painted
- galvanised steel coated (Decramastic tiles)
- zinc/aluminium unpainted (Zincalume)
- zinc/aluminium coated (Colorsteel/Colorcote/new metal tiles)
- concrete
- copper
- other materials

5.1.2 Yield parameters derivation from contaminant concentrations

Kingett Mitchell Limited and Diffuse Sources Limited (2003) reported measured contaminant concentrations on a volume basis. These values are converted to yield parameters considering average annual runoff in urban areas.

The average annual rainfall over the Auckland region is 1,245 mm (see http://www.niwa.cri.nz/ncc/cs/annual/aclimsum_07).

The highest annual rainfall, in excess of 2,000 mm, occurs over the higher ground which is mostly in the west of the region. Nearer the coast where most of the urban area is located the rainfall is between 800 and 1,300 mm. To a reasonable approximation, therefore, annual average impervious surface runoff over the urban area is about 1,000 mm.

For 1,000 mm of annual runoff:

a runoff concentration of X g m^{-3} , equals a yield of X g m^{-2} $year^{-1}$.

The concentrations reported for roof runoff in Kingett Mitchell Limited and Diffuse Sources Limited (2003) is considered to have sufficient accuracy for the purposes of the CLM.

5.1.3 Total suspended solids (TSS)

The TSS yields were derived from the Kingett Mitchell and Diffuse Sorces Limited (2003) report. The TSS concentrations of different types of roofs in the region were generally low but highly variable, ranging from <3 g m^{-3} to 35 g m^{-3} for galvanised steel roofs, up to 26 g m^{-3} for roofs of Decramastic® tiles and up to 29 g m^{-3} for one roof of concrete tiles. For sheet metal roofs (number of results n=47, excluding roofs of Decramastic® tiles), many results were reported as <3 g m^{-3}. If a value of 1.5 g m^{-3} is assumed for all the concentrations < 3 g m^{-3} then the mean was 6.5 g m^{-3} and the median was 3 g m^{-3}. Accordingly, a TSS yield of 5 g m^{-2} $year^{-1}$ was assumed for all sheet metal roofs. The mean for Decramastic® tile roofs (n=3) was 12 g m^{-3} and the mean for concrete tiles (n=2) was 16 g m^{-3}. A TSS runoff load of 10 g m^{-2} $year^{-1}$ was assumed for the "other materials" category.

5.1.4 Total zinc

The results for galvanised steel produced the following median concentrations for the roof surface categories, as derived from Kingett Mitchell Limited and Diffuse Sources Limited, 2003:

- unpainted 2.24 g m^{-3} (n=12)
- poorly painted 1.34 g m^{-3} (n=20)
- well painted 0.20 g m^{-3} (n=12)

These results for galvanised steel are consistent with the results reported from overseas studies. For example, one study of roofs made of different materials in Sweden reported zinc runoff yields between 0.07 and 3.5 g m^{-2} $year^{-1}$ (Karlén et al 2001). The range reported by Kingett Mitchell Limited and Diffuse Sources Limited, (2003) was 0.12 to 2.25 g m^{-2} $year^{-1}$. The high yields in the Swedish study were for galvanised steel roofs but the highest yield was for zinc plate. Taking this into account, there is good agreement between the two studies. In another example, the yearly average runoff rate was about 3 g m^{-2} $year^{-1}$ for both new and naturally aged (1-40 years) zinc sheet roofs, at an urban site in Stockholm (Le, 2000).

The means for the other materials were 0.28 g m^{-3} (n=3) for coated galvanised steel tiles (Decramastic®), 0.43 g m^{-3} (n=5) for unpainted zinc-aluminium surfaced steel (Zincalume®), 0.04 g m^{-3} (n=3) for coated zinc-aluminium surfaced steel (Colorsteel®/Colorcote®), and 0.02 g m^{-3} (n=2) for concrete tiles (Kingett Mitchell Limited and Diffuse Sources Limited, 2003). The runoff concentrations for other materials were low and a concentration of 0.02 g m^{-3} was assumed for these materials.

The results for five roof runoff samples from unpainted zinc-aluminium surfaced steel ranged from 0.177 g m^{-3} to 1.87 g m^{-3} , with a mean of 0.43 g m^{-3} (Kingett Mitchell Limited and Diffuse Sources Limited, 2003). It was subsequently established that the highest concentration was obtained for unpainted zinc-aluminium surfaced steel contaminated with cement. The zinc-leaching rate of unpainted zinc-aluminium surfaced steel increases in alkaline conditions. Excluding this high concentration, the mean of the four remaining concentrations was 0.31 g m^{-3}. New Zealand Steel Ltd have been measuring the zinc-leaching rate from unpainted zinc-aluminium surfaced steel at a rural site in south Auckland. The rate obtained for the first period of the experiment was 0.17 g m^{-2} $year^{-1}$, but this reduced to 0.12 g m^{-2} $year^{-1}$ during 2006 (David Gifford, NZ Steel Ltd, pers comm).

Salt increases the leaching rate and it would therefore seem logical to expect an elevated leaching rate downwind of salt water. Given that a considerable proportion of the Auckland urban area is exposed to salt spray drift it seems reasonable to expect a region-wide leaching rate somewhere between the rural concentration of around 0.12 g m^{-2} $year^{-1}$ and the mean of 0.31 g m^{-2} $year^{-1}$ reported by Kingett Mitchell Limited and Diffuse Sources Limited, 2003. Accordingly, a yield of 0.2 g m^{-2} $year^{-1}$ is presently assumed to be a reasonable Auckland region-wide average.

The three values obtained for coated zinc-aluminium surfaced steel ranged from 0.02 g m^{-3} to 0.808 g m^{-3} (Kingett Mitchell Limited and Diffuse Sources Limited, 2003), a rather large range for this relatively new material. A yield of 0.02 g m^{-2} $year^{-1}$ was assumed to be representative of this material, as it seems unlikely that the baked paint surface would produce a yield greater than this.

5.1.5 Total copper

The copper leaching rates from all the roof materials reported by Kingett Mitchell Limited and Diffuse Sources Limited (2003) were very low. (Higher leaching rates would be expected from copper roof sheet, but this material was not included in this study). The medians for all categories of galvanised steel were <0.0005 g m^{-3} (Kingett Mitchell Limited and Diffuse Sources Limited, 2003). The means for the other materials were:

- coated galvanised steel tiles 0.0017 g m^{-3}
- unpainted zinc-aluminium surfaced steel 0.0009 g m^{-3}
- coated zinc-aluminium surfaced steel 0.0016 g m^{-3}
- concrete tiles 0.0033 g m^{-3}.

The copper runoff concentrations for materials other than those mentioned above were low (Kingett Mitchell Limited and Diffuse Sources Limited, 2003), and a value of 0.002 g m^{-2} $year^{-1}$ is assumed for these materials.

A recent review of calculated copper roof leaching rates for 1,179 sites in the USA produced a country-wide mean of 2.12 g m^{-2} $year^{-1}$ (Arnold, 2005). This review used the Odnevall Wallinder equation:

$$\text{Yield (g m}^{-2}\text{ year}^{-1}) = (1.04 + 0.96V \times 10^{-0.62pH}) \times (\cos\theta/\cos 45) \qquad (5)$$

whereby V is the annual rainfall in mm $year^{-1}$. This value is consistent with those produced by other studies. For example, Le (2000) measured a lower runoff rate of 1.3 g m^{-2} $year^{-1}$ for new copper sheet, but a similar rate of 2 g m^{-2} $year^{-1}$ for old (>40 years) copper sheet. The yield of 2.12 g m^{-2} $year^{-1}$ is used in the CLM.

5.2 Roads

Vehicle yields are usually reported as the mass of contaminant emitted by a single vehicle over a specified distance, i.e. mg $vehicle^{-1}$ km^{-1}. The CLM utilises these yields in terms of the area of road surface and time i.e. g m^{-2} $year^{-1}$. The following equation was used to convert vehicle yields to road surface yields:

$$\text{Road surface yield (g m}^{-2}\text{ year}^{-1}) = \text{vehicle yield mg vehicle}^{-1}\text{ km}^{-1} \times \text{number vehicles day}^{-1} \times 365 \text{ days year}^{-1} \times 10^{-3} \text{ g mg}^{-1} \times 10^{-3} \text{ km m}^{-1}/\text{road width m} \quad (6)$$

5.2.1 Total suspended solids

Timperley et al (2005) reported a yield for TSS passing through catchpits on Richardson Road, a major arterial road in ACC, of 0.14 g veh^{-1} km^{-1}. This is equivalent to 52.2 g m^{-2} $year^{-1}$ for that road (length 500 m, width 17 m, 17,354 veh day^{-1}). The TSS retention efficiency for roadside catchpits was estimated to be about 20% (Appendix One - note that this efficiency is for TSS **not** for total solids). Thus, the road surface TSS yield for Richardson Road was 52.2/0.8 = 65.2 g m^{-2} $year^{-1}$.

In addition to the TSS generated by the passage of vehicles, it is reasonable to assume that the yield of 65.2 g m^{-2} $year^{-1}$ includes an approximately constant yield from the natural erosion of the road surface. This erosion yield was assumed to be 20 g m^{-2} $year^{-1}$.

The road surface yield for roads with different numbers of vehicles per day is, therefore, given by the following expression:

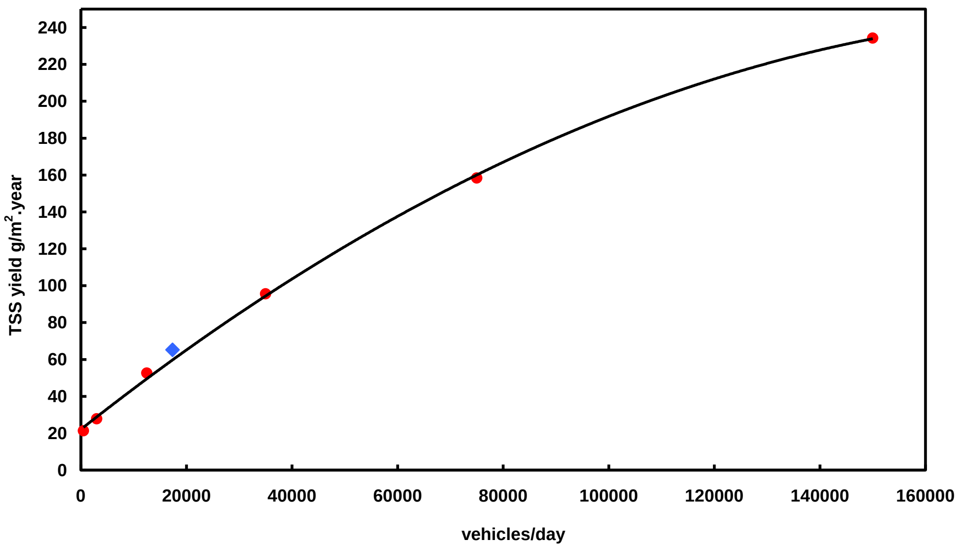
$$\text{Road surface TSS yield (g m}^{-2}\text{ year}^{-1}) = 20 \text{ g veh}^{-1}\text{ km}^{-1} + 365 \text{ days year}^{-1} \times \mathbf{Y} \text{ veh day}^{-1} \times \mathbf{Z} \text{ g veh}^{-1}\text{ km}^{-1}/\text{road width m} \times 1000 \text{ m km}^{-1} \quad (7)$$

whereby **Y** is the number of vehicles day^{-1} and **Z** is the vehicle TSS yield.

This equation fits the measured runoff load for Richardson Road with the vehicle yield **Z** = 0.1219 g veh^{-1} km^{-1}. The road surface TSS yield varies with vpd as shown in Figure 2. The blue diamond is the value for Richardson Road.

Figure 2

Assumed variation in the road surface yield of TSS (g m-2 year-1) with vehicles per day. The blue triangle is the point for Richardson Road



5.2.2 Total zinc

The vehicle yield of zinc is determined almost entirely by the product of the tyre wear rate and the zinc concentration in the tyre rubber. A compilation of tyre wear rates from the literature is available (see http://vergina.eng.auth.gr/mech0/lat/PM10/Tyre%20wear-wear%20rates.htm). These values are shown in Table 8, rearranged from the original compilation to match the dominant vehicle classes on New Zealand roads. The mean wear rates for mixed vehicles and passenger cars are almost identical, so these data were combined to produce a single rate for passenger cars.

The concentration of zinc oxide in tyre rubber is given as 1% (Rubber Manufacturer's Association http://www.rma.org), which is equivalent to 8,000 mg kg^{-1}.of zinc. This value applied to the tyre wear rates produced the vehicle road surface zinc yields shown in Table 8. These yields combined with the proportions of each vehicle class in the Auckland fleet (Metcalfe et al., 2006) produced the vehicle fleet-weighted road surface yields. Totalling these yields gives the <u>overall</u> zinc road surface yield for the Auckland fleet of 1.291 mg $vehicle^{-1}$ km^{-1}.

Table 8

Whole vehicle tyre wear rates and resulting zinc yields

	Mixed	Passenger	Light	Heavy	Motorbikes	Fleet
	mg km^{-1}	mg km^{-1}	mg km^{-1}	mg km^{-1}	mg km^{-1}	mg $vehicle^{-1}$ km^{-1}
	97	79	68	136	32	
	120	193	110	539	26.4	
	120	112	53	189		
	240	32	112	234		
	360	200		192		
	200	188		1403		
	64			798		
	40			769		
	53					
	120					
	80					
	163					
	64					
Mean tyre wear rates mg $vehicle^{-1}$ km^{-1}	132.4	134.0	85.8	532.4	29.2	
Vehicle zinc yields mg $vehicle^{-1}$ km^{-1}	1.059	1.072	0.686	4.529	0.234	
Auckland fleet proportions %		76.97	14.01	8.67	0.35	
Vehicle fleet-weighted zinc yields mg $vehicle^{-1}$ km^{-1}		0.825	0.0961	0.369	0.00082	1.291

Rather than the road surface yield for total zinc, the CLM requires the road surface yield for the zinc that is potentially available for transport as suspended and dissolved load, i.e. TSSZn + DZn. The Richardson Road project (Timperley et al., 2005) obtained ex-catchpit yields of 0.188 mg veh^{-1} km^{-1} for dissolved zinc and 0.180 mg veh^{-1} km^{-1} for particulate zinc (particulate zinc is referred to as TSS zinc in this report).

Using the estimated retention efficiency of 20% for TSS in catchpits (Appendix One), the on-road yield for TSS zinc would be 0.180/0.8 = 0.225 mg veh^{-1} km^{-1}. The small proportion of dissolved zinc that could be trapped in catchpits by adsorption to solids can be ignored for the purposes of this calculation. Thus, the road surface yield for zinc that is potentially available to be transported in both dissolved and particulate forms, i.e. TSSZn + DZn, is 0.188+0.225 = 0.413 mg veh^{-1} km^{-1}.

5.2.3 Total copper

Moores et al. (2010)) reported zinc and copper yields determined in earlier studies by monitoring runoff from four sections of roads in the Auckland region. They also provided a compilation from the New Zealand literature of other yields, some of which were calculated by Moores et al. (2010) from the literature data. The data that these yields were calculated from were obtained by four different methods: 1) analysis of road dust; 2) reviews of international literature; 3) modelling and 4) road runoff monitoring. The yields produced by modelling used data from international literature, so the model yields were not original and are ignored below in order to avoid duplication.

The yields reported by Moores et al. (2010) were highly variable, possibly because of the different driving conditions, e.g. free-flowing, congested, straight, curved, steep, flat etc, on the different roads studied. Contrary to the highly variable yields, however, the ratios of the zinc and copper yields and loads from which the yields were derived, were less variable. These ratios could be readily divided into three similar groups: 1) road dust; 2) motorway runoff (presumably without treatment); and 3) runoff from an urban arterial road after catchpit treatment (Moores et al., 2010).

The ratios of the zinc and copper yields for the 25^{th}, 50^{th} and 75^{th} percentiles of the yields derived from road dust collected in Waitakere City were 2.88, 1.13 and 2.00 respectively (Kennedy and Gadd, 2003). The ratios for the three motorway studies (yields were calculated by Moores et al. (2010) from reported EMCs) were 2.98 and 3.39 for two sites in Auckland (ARC unpublished data reported in Kennedy, 2003), and 0.88 for one site in Wellington (Sherriff, 1998).

The zinc/copper load ratio obtained in the single study that monitored runoff after catchpit treatment from an urban arterial road was 5.77 (Timperley et al., 2005). This higher ratio is probably due to the greater solubility of zinc and, therefore, the higher proportion of copper trapped in the catchpits.

New measurements made on roads in the Auckland region by Moores et al. (2010) produced ratios of 3.96 for the particulate fraction in runoff from a motorway site, 6.62 for runoff from a motorway off-ramp, 5.41 in runoff from a non-motorway state highway and 6.60 for runoff from a high-use urban road. The runoff at the latter site was probably collected after catchpit treatment but this is not likely for the motorway sites. It is possible, however, that the runoff at these motorway sites was treated in ponds or swales before sampling.

Moores et al., 2008 reported the metal and TPH concentrations in the solids collected from 30 road-side catchpits in Auckland. The median zinc/copper concentration ratios in three particle size fractions, <200 µm, 200-500 µm and 500-1000 µm were 3.37, 2.58 and 3.42, which are reasonably consistent with the particulates-only ratio of 3.96 for the runoff from the motorway site mentioned above.

The various zinc/copper ratios discussed above are listed in Table 9.

Table 9

Ratios of zinc to copper yields for road runoff in New Zealand (Moores et al., 2010)

Sample medium	Site	Comments	Zinc yield/copper	Reference
road dust	Waitakere City (Road Dust)	25th percentile	2.88	Kennedy and Gadd (2003)
road dust	Waitakere City (Road Dust)	50th percentile	1.13	Kennedy and Gadd (2003)
road dust	Waitakere City (Road Dust)	75th percentile	2.00	Kennedy and Gadd (2003)
runoff no prior treatment	Auckland southern motorway motorway at Otahuhu	calculated from Event Mean Concentration	2.98	ARC unpublished data quoted in Kennedy (2003)
	Auckland northern motorway at Silverdale	calculated from EMC	3.39	Larcombe (2003)
	Wellington motorway at Tawa	calculated from EMC	0.88	Sherriff (1998)
	Auckland northern motorway at Silverdale	calculated from first flush runoff loads of particulate fraction	3.96	Moores et al. (2010)
	Auckland motorway off-ramp at Silverdale	calculated from runoff monitoring	6.62	Moores et al. (2010)
	SH 17 Auckland rural road at Dairy Flat	calculated from runoff monitoring	5.41	Moores et al. (2010)
runoff after catchpit	Richardson Road, ACC	calculated from runoff loads	5.77	Timperley et al (2005)
	East Coast Road, North Shore City	calculated from runoff loads. Catchpit treatment probable but not confirmed	6.62	Moores et al. (2010)

catchpit solids	Auckland values from 30 catchpits)	50th percentile for <200 µm fraction	3.37	Moores et al, (2008)
		50th percentile for 200-500 µm fraction	2.58	Moores et al, (2008)
		50th percentile for 500-1000 µm fraction	3.42	Moores et al, (2008)

The greater solubility of zinc oxide from tyres, compared with copper metal from brake pads and linings, and the almost zero retention of dissolved metals by settling in catchpits, means that the total zinc/total copper concentration and loads ratio should increase in the order of road surface solids < untreated runoff < treated runoff. The ratios in Table 9 fit this order with the exception of the three ratios calculated from Event Mean Concentration (EMCs). Ignoring these three, the typical zinc/copper concentration or load ratios are approximately;

- two for solids on road surfaces:
- three for untreated runoff and
- six for treated runoff.

Accordingly, a ratio of three was applied to the road surface zinc yield, to produce the road surface copper yield of 0.138 mg veh^{-1} km^{-1} used in the CLM.

5.2.4 Total petroleum hydrocarbons (TPH)

Vehicle exhaust emissions and lubricating oil leaks are considered to be the major sources of total petroleum hydrocarbons (TPH) in Auckland's urban areas. Fuel spills also occur. As noted above, there are very few copper roofs in the city and vehicles are also the major source of copper. Given the same source for both TPH and copper, it is suggested that the TPH to copper load ratio in urban stormwater may be roughly constant.

The data from two studies support this postulate. Over the period 2001 to 2003 the ACC/Metrowater stormwater monitoring programme obtained 302 stormwater samples from networks across the city, for which concentrations of both TPH and copper were measured (data provided by ACC/Metrowater). The median TPH/total copper concentration ratio for these samples was 24.9.

The second study involves the analysis of solids from the Grafton Gully motorway runoff treatment tank in Auckland (Reed, 2007). The median TPH to total copper concentration ratio for five of the six sites sampled (one site produced an outlier TPH concentration) was 22.7. This ratio (22.7) used to calculate the total TPH yield. Accordingly, this ratio applied to the total copper yield (0.138 mg veh^{-1} km^{-1}) gives a total TPH yield of 3.13 mg veh^{-1} km^{-1}.

5.3 Paved surfaces

While data are available on the quality of stormwater discharged from roofs and roads in the Auckland region, this is not the case for other paved areas. Contaminant yields for these other paved areas were therefore derived from measurements of stormwater quality discharged from areas of mixed land use, once the contribution of other sources (roads and roofs) had been accounted for. This involved obtaining these yields by trial and error to achieve a good match between the loads predicted by the CLM and the loads obtained by monitoring the stormwater from the three study catchments of the Metal Sources and Load Study (Timperley et al, 2005). This exercise is described in more detail in Section 7 (Model calibration).

5.4 Pervious surfaces

5.4.1 Total suspended solids (TSS)

Urban streams

The TSS yield for urban erodible stream channels is the most uncertain yield in the CLM. An estimate of 6,000 g m^{-2} $year^{-1}$ was derived from the only comprehensive study undertaken in Auckland on urban stream erosion (Elliott et al., 2005). (Note: estimated value is applicable only for erodible channels, if banks are erosion protected, model user has the choice to select the appropriate treatment management method such as bank protection with rock /timber, concrete or piping).

Construction sites

The TSS yield for bare earth was determined by applying the sediment runoff model GLEAMS to the 34 stormwater catchments in ACC that drain to the Central Waitemata Harbour (Parshotam, 2008). The area-weighted yield for these 34 catchments was 2,542 g m^{-2} $year^{-1}$. Accordingly, a TSS yield of 2,500 g m^{-2} $year^{-1}$ is used in the CLM for construction sites anywhere in Auckland region.

The bare earth yields were adjusted for different slopes according to the relationship between slope and yield for bare earth derived using GLEAMS (Parshotam, NIWA, pers comm).

The relationship for bare earth is

$$\text{Yield} = 717.6 \text{ x slope in degrees} + 109.8 \qquad (8)$$

Urban Grasslands and Trees (Pervious surfaces)

The yield for urban grasslands and trees, ie stable pervious surfaces including residential lawns and gardens, parks, reserves and school grounds, is also somewhat uncertain. The median TSS yield for "urban" areas reported in the review of literature yields by Williamson's dated review (1993) is 375 kg ha^{-1} $year^{-1}$, whereas the yield calculated from more recent stormwater monitoring data for the Mission Bay residential catchment was 620 kg ha^{-1} $year^{-1}$ (Timperley et al, 2005). The part of this catchment above the monitoring point is steeper than the average for Auckland and the stormwater network apparently contains several short sections of open stream channel. Thus, the yield for this catchment might be higher than the typical yield for urban areas without open stream channels. It would seem, therefo re, that a realistic stable pervious surface TSS yield for the city is between 400 and 500 kg ha^{-1} $year^{-1}$ (40 and 50 g m^{-2} $year^{-1}$).

Urban grasslands and trees are the largest contributor to stormwater TSS in most urban catchments, so it was necessary to link the selection of this yield to calibration of the CLM as explained in Section 5. This produced the TSS yield of 45 g m^{-2} $year^{-1}$ that is used in the CLM for urban grasslands and trees.

The equation for urban grasslands and trees is

$$\text{Yield} = 12.33 \times \text{slope in degrees} \qquad (9)$$

5.4.2 Total zinc and total copper

The total zinc and total copper yields for pervious surfaces were determined based on marine sediment concentrations. There are two reasons for using these marine sediment concentrations as follows.

1. It is often difficult to obtain soils from urban catchments that have not been contaminated by urban activities and materials.
2. The contaminant loads produced by the CLM are for estimating contaminant accumulation in coastal marine areas. The loads should, therefore, reflect the materials that are actually transported to marine areas, rather than soils of the catchments which vary in composition and erodibility.

The total zinc and total copper yields are obtained by multiplying the TSS yields by the typical metal concentrations in pre-urban marine sediments, i.e. 35 mg kg^{-1} and 7 mg kg^{-1} respectively (Reed, 2008). These concentrations are approximate medians of those found in the lower sections of marine sediment core profiles, which were deposited before urban development occurred in the contributing catchments (Reed, 2008).

5.5 Rural sources

The yields (TSS, Zn, and Cu) for rural sources were selected from the ranges of values reported by others (Williamson, 1993, Senior et al., 2003, Parshotam, 2010). The variation of these yields with slope was derived from Senior et al., (2003) and Parshotam (2010). Although the rural TSS yields are among the least certain yields used in the CLM, the effects of this uncertainty on TSS loads is minor so long as the CLM is not applied to catchments with more than about 20% of rural land.

It was assumed that no petroleum hydrocarbons (TPH) is generated from rural source areas.

Table 10

Contaminant yields for the source areas used in the ARC CLM. The zinc and copper yields (cells shaded in gray colour) were derived by multiplying the TSS yield by 35 mg kg-1 and 7 mg kg-1 respectively. (Note: to convert units appropriately, the products divided by 1000)

	AREA	Contaminant yield g m^{-2} $year^{-1}$			
		TSS	Total zinc	Total copper	TPH
Roofs	galvanised steel unpainted	5	2.24	0.0003	0
	galvanised steel poor paint	5	1.34	0.0003	0
	galvanised steel well painted	5	0.20	0.0003	0
	galvanised steel coated	12	0.28	0.0017	0
	zinc/aluminium surfaced steel unpainted	5	0.20	0.0009	0
	zinc/aluminium surfaced steel coated long run and tiles	5	0.02	0.0016	0
	concrete	16	0.02	0.0033	0
	copper	5	0.00	2.1200	0
	other materials	10	0.02	0.0020	0
Roads	<1k vpd	21	0.0044	0.0015	0.0335
	1k-5k vpd	28	0.0266	0.0089	0.2013
	5k-20k vpd	53	0.1108	0.0369	0.8387
	20K-50K	96	0.2574	0.0858	1.9474
	50k-100k vpd	158	0.4711	0.1570	3.5645
	>100K vpd	234	0.7294	0.2431	5.5192
Paved	Residential paved	32	0.1950	0.0360	0
	Industrial paved	22	0.5900	0.1070	0
	Commercial paved	32	0.0000	0.0294	0
Pervious	Urban grasslands and trees <5^o	45	0.0016	0.0003	0
	Slope 5-10^o	92	0.0032	0.0006	0
	10^o	185	0.0065	0.0013	0
	Urban stream channels (length x width)	6,000	0.2100	0.0420	0
	Construction sites <5^o	2,500	0.0880	0.0180	0
	Slope 5-10^o	5,600	0.1960	0.0390	0
	>10^o	106,000	0.3710	0.0740	0
Rural	Exotic production forest <10^o	35	0.0012	0.0002	0
	Slope 10-20^o	104	0.0036	0.0007	0
	20-30^o	208	0.0073	0.0015	0
	Stable forest <10^o	14	0.0005	0.0001	0
	Slope 10-20^o	42	0.0015	0.0003	0
	20-30^o	83	0.0029	0.0006	0
	Farmed pasture <10^o	152	0.0053	0.0011	0
	Slope 10-20^o	456	0.0160	0.0032	0
	20-30^o	923	0.0320	0.0065	0
	Retired pasture <10^o	21	0.0007	0.0001	0
	Slope 10-20^o	63	0.0022	0.0004	0
	20-30^o	125	0.0044	0.0009	0
	Horticulture Volcanic soil	50	0.0018	0.0004	0
	Sedimentary soil	100	0.0035	0.0007	0
	Unknown soil	100	0.0035	0.0007	0

6 Load reduction factors

6.1 Source control and stormwater treatment

The term ”load reduction factor” (LRF) refers to the proportion by which contaminant loads can be reduced by management options that include source control measures such as roof painting and stream bank stabilisation, as well as stormwater treatment. For stormwater treatment devices the LRFs are the treatment or contaminant retention efficiencies.

The CLM requires a single LRF for each contaminant/management option whereas the efficiencies for stormwater treatment devices are usually quoted as wide ranges. For example, the treatment efficiency of wet ponds for TSS is given as 50 to 90% (ARC TP10, 2003). Much of this variation is a consequence of differences in catchment soil, vegetation and topographical characteristics, device design, hydraulic loading and so on.

The LRFs used in the CLM for treatment devices were selected on the basis of professional judgement after reviewing the literature. The LRFs represent the maximum degree of contaminant retention that could be expected for well designed, installed and maintained devices (note that TP10 provides ranges of treatment efficiencies).

The load reduction factors for source control are for 100% implementation of the measure to the specified proportion of the source area. For example, the painted proportion of a galvanised steel roof reduces the zinc runoff loads by 92%, from 2.24 g m^{-2} $year^{-1}$ for unpainted galvanised steel to 0.20 g m^{-2} $year^{-1}$ for well painted galvanised steel (no allowance is made for variations in the quality of the paint coating).

The LRFs used in the CLM are given in Table 11. If a LRF is considered to be incorrect for a specific device then the model user can enter an alternative LRF.

The LRFs fall into two categories:

- roof runoff; and
- all other sources.

The LRFs for management options dealing with roof runoff are different from the other LRFs because of the unusually fine TSS and the dissolved forms of metals that dominate in roof runoff. Devices such as ponds in which retention is based solely on settling have been given low LRFs for roof runoff in the CLM, because fine solids don’t settle fast enough to be efficiently retained and dissolved contaminants don’t settle at all.

6.2 Catchpits

There have been very few rigorous measurements of the retention efficiencies of catchpits either in New Zealand or overseas (Pennington 2008). Most of the monitoring programmes that have been undertaken have collected too few samples over too few rainfall events to enable a convincing efficiency to be derived.

In the absence of usable data for *in situ* catchpits, an estimate of catchpit TSS retention efficiency for use in the CLM was made from published New Zealand data on the particle size distribution of solids on road surfaces, and the retention efficiency for TSS of different particle sizes determined in the laboratory using a clean model catchpit. The data and procedure used for making this estimate are described in Appendix One.

These calculations together with an assumed adjustment of the efficiency from the clean model catchpit to *in situ* catchpits partly filled with solids, produced a catchpit TSS LRF of 20%. As will be apparent from Appendix One this LRF is very uncertain.

The catchpit LRF for total zinc and total copper are 11% and 16% respectively. The derivation of these values is explained in the Appendix.

6.3 Management option trains

The LRFs for the second and third options in a management train (columns F and G in the model spreadsheet) are only approximate at this stage for two reasons. Firstly, for most contaminant/train combinations there is no reliable monitoring data from which to derive LRFs. The current version of the CLM therefore uses the same LRF for a particular device irrespective of its position in a management train. The lack of data for management option trains is universal; it's not a problem unique to the CLM.

The second reason is that the current version of the CLM does not allow the LRFs for successive options to vary depending on the LRF for the preceding option. For example, the total zinc LRF for the second option, say 30% for a constructed wetland, remains the same irrespective of the LRF of the first option, say 11% for a catchpit or 60% for a biomedia filter.

Table 11

Load reduction factors used for the CLM management options (treatment device), irrespective of the device position in the management train. (NOTE: Rain tank is not considered as tretament device at this stage, as there are no reported information about device performances to derive LRF values)

Roofs

	Load reduction factor			
Treatment Option	TSS	Zn	Cu	TPH
Biomediafiltration	0.75	0.60	0.70	0.00
Constructed wetland	0.50	0.25	0.30	0.00
Dry pond	0.10	0.05	0.05	0.00
Painting	0.00	0.90	0.90	0.00
Rain garden	0.70	0.60	0.70	0.00
Sand-filter	0.50	0.10	0.15	0.00
Storm-filter	0.50	0.15	0.20	0.00
Swale	0.30	0.15	0.20	0.00
Vegetative filter strips	0.20	0.10	0.20	0.00
Wet extended pond	0.20	0.10	0.10	0.00
Wet pond	0.10	0.05	0.05	0.00
Wet pond with flocculation	0.80	0.40	0.60	0.00

Roads and other paved surfaces

	Load reduction factor			
Treatment Option	TSS	Zn	Cu	TPH
Biomediafiltration	0.75	0.60	0.70	0.70
Catchpit filter	0.40	0.20	0.25	0.30
Catchpits	0.20	0.11	0.15	0.15
Constructed wetland	0.80	0.60	0.70	0.60
Dry pond	0.60	0.20	0.30	0.10
Porous paving	0.50	0.30	0.40	0.50
Rain garden	0.75	0.70	0.75	0.80
Sand-filter	0.75	0.30	0.40	0.70
Storm-filter	0.75	0.40	0.65	0.75
Swale	0.75	0.40	0.50	0.40
Vegetative filter strips	0.30	0.10	0.20	0.30
Wet extended pond	0.80	0.40	0.50	0.20
Wet pond	0.75	0.30	0.40	0.15
Wet pond with flocculation	0.80	0.50	0.60	0.50

Urban grasslands and trees, construction sites and bottom-of-site

	Load reduction factor			
Treatment Option	TSS	Zn	Cu	TPH
Biomediafiltration	0.75			
Catchpit filter	0.40			
Catchpits	0.20			
Constructed wetland	0.80			
Dry pond	0.60			
Porous paving	0.50			
Rain garden	0.75			
Sand-filter	0.75			
Storm-filter	0.75			
Swale	0.75			
Vegetative filter strips	0.30			
Wet extended pond	0.80			
Wet pond	0.75			
Wet pond with flocculation	0.80			

Stream Channels

	Load reduction factor			
Treatment Option	TSS	Zn	Cu	TPH
Concrete Channel	1.00			
Enclose (pipe)	1.00			
Rock, timber bank protection	0.75			

7 Model calibration

7.1 Procedure

The CLM was calibrated for TSS, total zinc and total copper (there were no suitable data available for TPH), for three catchments in ACC for which stormwater monitoring flow and quality data had been collected in the ACC/Metrowater stormwater monitoring programme. These catchments were Mission Bay, Central Business District and Tamaki/Mt Wellington, which are 100% residential, commercial and industrial land use respectively. The annual stormwater loads from these catchments had been estimated by fitting an accumulation/washoff model to the monitoring data (Timperley et al, 2005).

The calibration of the CLM involved:

1. Entering the catchment source areas, selecting catchpits as the management options for all source areas except roofs and entering the proportions of the source areas draining to catchpits.
2. Adjusting the paved surface yields to achieve the best match between the annual contaminant loads calculated by the CLM and the annual loads determined from the monitoring programme.

The procedure is described in detail below.

7.2 Input data

7.2.1 Source areas

The areas of each roof material and the lengths and vehicles per day of all the roads were measured in each of the three catchments. The total areas of impervious surface were from a previous GIS analysis by ACC/Metrowater (reported here in Table 1), and the areas of paved surfaces were the differences between the total impervious surface areas and the sums of the road and roof areas.

The total pervious surface areas were the differences between the total catchment areas and the total impervious surface areas. The Mission Bay catchment was the only one of the three catchments to contain open sections of stream channel in the stormwater network. The lengths of these channels were estimated from drainage maps provided by Metrowater.

There was no population growth in the Mission Bay catchment between the 2001 and 2006 census, so there were no new construction sites. The population increase in the whole of the CBD between 2001 and 2006 was 13,214 or 2,643 per year (Auckland growth model, 2006). The Aotea Square catchment is 15.4% of the whole CBD, so the proportionate population increase in the Aotea Square catchment was 407 persons between 2001 and 2006. This number is equivalent to 136 apartments and a total construction site area of 1,088 m^2. In general, industrial areas in ACC are not expanding so the construction site area in the Tamaki/Mt Wellington industrial catchment was set to zero.

7.2.2 Source yields

The source yields for TSS, total zinc and total copper were determined as described in Section 4.3, from independent data for roof materials, roads, stream channels and construction site bare earth.

The yields for urban grasslands and trees (stable areas such as parks, sports fields, residential backyards, school grounds etc) were also determined from other independent data (see Section 4.3), but these yields were confirmed during the calibration process as explained below.

7.2.3 Management options

Catchpits were the only installed management option in any of the catchments. As far as could be ascertained from visual inspection, all roofs, roads, paved surfaces and almost all (100% was assumed for all catchments) urban grasslands and trees drained to catchpits either along the roads or in topographical depressions. The load reduction factors for catchpits are described in Section 4.

7.3 Calibration

The data entered into the CLM in terms of calibration are shown in Figure 3 below.

The yields for the paved surfaces were adjusted to calibrate the model as explained above. The main constraints on acceptable values for the yields were as follows:

1. The TSS yields for the different land uses should be broadly similar.
2. The yields for TSS, total zinc and total copper should be realistic, i.e. a total zinc yield of 10 g m^{-2} $year^{-1}$ (100 kg ha^{-1} $year^{-1}$) would be highly unlikely from a paved surface.

The paved surface TSS yields that gave the best match between the CLM loads and the monitoring programme loads for the residential, commercial and industrial catchments were 20, 31 and 32 g m^{-2} $year^{-1}$ respectively. These yields are similar and are within the range that would be intuitively expected for paved surfaces.

The paved surface zinc and copper yields were less consistent across the land uses. Because the paved surface yields were the adjustable calibration parameters, they include the true paved surface yields as well as all the errors in the other source yields. In addition to this, the source yields for zinc vary across a very wide range so the paved surface yields could simply reflect this wide range and the associated wide error range.

As noted above, the TSS yield for urban grasslands and trees was confirmed during the calibration process. Urban grasslands and trees are the largest contributor to catchment TSS loads, so small variations in the TSS yields for urban grasslands and trees required large changes to be made to the paved surface TSS yields in order to achieve satisfactory calibration.

For example, TSS yields for the urban grasslands and trees of 40 g m^{-2} $year^{-1}$ for slopes of <5^{o} and 82 g m^{-2} $year^{-1}$ for slopes of 5-10^{o}, required a paved surface TSS yield of 60 g m^{-2} $year^{-1}$ for a good match of loads to be obtained. If the urban grasslands and trees TSS yield were increased to 50 g m^{-2} $year^{-1}$ and 102 g m^{-2} $year^{-1}$ for the two slopes respectively, then a good match of loads could not be obtained with a paved surface TSS yield of 0 g m^{-2} $year^{-1}$. The TSS yield for urban grasslands and trees of 45 g m^{-2} $year^{-1}$ was considered to produce the most realistic paved surface TSS yields.

7.4 Calibrated CLM annual loads

The loads for the three calibration catchments obtained by monitoring and from the calibrated CLM are compared in Table 12.

Table 12

Comparison of measured and modelled contaminant loads (kg year-1) for the selected catchments (monitoring loads from Timperley et al, 2005)

	Residential (Mission Bay)		Commercial (Central Business District)		Industrial (Mt Wellington)	
	CLM	Monitoring	CLM	Monitoring	CLM	Monitoring
TSS	28,011	28,000	9,381	9,330	8,575	8,570
Total zinc	26.0	26.0	50.5	47.0	176	176
Total copper	3.60	3.6	4.20	4.2	4.6	4.6

Figure 3 Parameters used for model calibration. A LRF of 0.5 was entered for the Aotea Square (CBD) construction site wet pond because this pond overflowed in most rainfall events

Catchment name			Mission Bay					Aotea Square					Tamaki / Mt Wellington				
Catchment area (m^2)				Source contaminant management train					Source contaminant management train					Source contaminant management train			
Source	Source type		Source Area (m^2)	1st management option	2nd management option	3rd management option	Fraction of area draining to train	Source Area (m^2)	1st management option	2nd management option	3rd management option	Fraction of area draining to train	Source Area (m^2)	1st management option	2nd management option	3rd management option	Fraction of area draining to train
Roofs	Galvanised steel unpainted		1209					6791					64996				
	Galvanised steel poorly painted		3975					20063					3120				
	Galvanised steel well painted		3821					8455					1394				
	Galvanised steel coated (Decramastic ti		8957					3763					0				
	Zinc/aluminium unpainted (Zincalume)		202					5935					0				
	Zinc/aluminium coated (Colorsteel/Colord		20691					18019					2809				
	Concrete		26824					23745					2463				
	Copper		153					0					0				
	Other materials		18855					13149					0				
Roads	*Vehicles/day*	*Length (m)*															
	<1000	2020	34340	Catchpits			1	2550	Catchpits			1	12172	Catchpits			1
	1000-5000	1825	31025	Catchpits			1	19210	Catchpits			1	18938	Catchpits			1
	5000-20000	462	7854	Catchpits			1	27931	Catchpits			1	0				
	20000-50000	783	16052	Catchpits			1	0					0				
	50000-100000	0	0					0					0				
	>100000	0	0					0					0				
Paved Surfaces other than roads	Residential		41681	Catchpits			1	0					0				
	Industrial		0					0					47994	Catchpits			1
	Commercial		0					121557	Catchpits			1	0				
Urban Grasslands and trees	Slope < 5		175696	Catchpits			1	34218	Catchpits			1	186114	Catchpits			1
	5 < Slope <10		58565	Catchpits			1	11406	Catchpits			1	0				
	Slope >10		0					0					0				
Urban Stream Channel	*length x width*		2100					0					0				
	Urban area without construction sites		452000					316792					340000				
Construction Site open for 12 months/year	Slope < 5		0					1088	Wet pond			0.5	0				
	5 <Slope <10		0					0					0				
	Slope >10		0					0					0				
	Urban area with construction sites		452000					317880					340000				

8 Model validation

8.1 Procedures for model validation

There are two possible procedures for model validation. One is to compare the loads produced by the CLM with the loads determined from measurements of stormwater quality discharged from catchments which were not used in the development or calibration of the model. Ideally, these would be large urban catchments typical of those for which ICMP are being developed. Not surprisingly perhaps, there are no such data for New Zealand urban catchments of this size.

The other less rigorous but more convenient procedure for validation is to compare the annual mean concentrations produced by the CLM for stormwater from specific urban land uses with stormwater contaminant concentrations in the literature. In the absence of the type of data described above, this procedure was used for the CLM and is described below.

8.2 Comparison of concentrations

Whereas the CLM produces annual contaminant loads, most studies reported in the literature did not measure discharge and so report only measured concentrations. As is readily apparent from any set of short interval stormwater monitoring data, both discharge and concentrations vary substantially, often by an order of magnitude or more, during a single runoff event. It is a meaningless exercise, therefore, to compare individual sample concentrations.

Given the highly variable discharge quantity and quality of stormwater over short intervals of time, the only meaningful comparison is between loads determined over an extended period. Annual loads which span the usual variation in runoff over the four seasons provide the most valid comparisons but require intensive monitoring over at least a twelve month period, as was done for ACC catchments including those used for model calibation.

Event mean concentrations (EMCs) which are calculated as the event loads obtained by summing the individual sample loads, divided by the total event discharges, also vary substantially (there is zero probability of two EMCs being identical). Never-the-less, EMCs provide a more rigorous basis for comparison than do sample loads or concentrations. In Auckland, one rainfall event occurs on average each three days so the annual load is comprised of roughly 120 event loads. Subsets of about 20 of these event loads spread in time over a twelve month period would be about the minimum number that would provide a reasonable basis for comparing the stormwater loads from two sites. As the number of event loads decreases the extent of bias would increase and the comparisons would become much less reliable.

For the comparisons described here, data for total suspended solids (TSS), total zinc, total copper and total petroleum hydrocarbons (TPHs) were compiled from international and local literature. Most of the international data are from Germany, USA, Sweden and the UK whereas the local data are mostly from Auckland with some from other parts of New Zealand. The contaminant sources in the literature studies were matched with the appropriate source categories in the CLM. For some studies, however, the reported sources did not fit any of the CLM categories and hence new categories of “unknown” and “other” are used.

For the purposes of this comparison the lowest of all concentrations found in the literature for a particular source is recorded as the “low value” and the highest found as the “high value”. The value recorded as the “median” is the median of all the means, medians, etc, from the different studies.

It should be noted that these literature data were compiled without a clear procedural objective for comparing the data with CLM loads. As a result, no critical evaluation of the data quality and relevance was undertaken and the compilations comprise mixtures of single, mean, and median sample concentrations, composite sample concentrations, EMCs, and for the CLM concentrations were derived from loads as described below.

Furthermore, many of the reported data are not original, ie, they are quoted from other sources and publications some of which are included in the compilations. Some original data are, therefore, duplicated and probably replicated in the compilations. It is also apparent from examining the compilations, that some of the reported concentrations cannot possibly be even close to annual mean concentrations because the implied annual loads assuming the Auckland annual runoff volume, are not credible.

At best, therefore, only a general comparison of annual mean concentrations derived from the CLM for Auckland with the broad ranges of concentrations in the following tables is possible.

Table 13 give some relevant details about the studies from which data were extracted for comparison with the loads produced by the CLM.

Table 13

Some relevant sampling details from the literature studies

Reference	Local	No. Events	No. Samples	Units	Measurement type	Comments
1	N	na	na	na	na	Values compiled from other studies
2	N	na	na	mg/L	EMC	Values compiled from other studies
3	N	na	na	mg/L	Standard	Values compiled from other studies
4	N	na	na	mg/L	na	Values used in the model StormTac
5	N	na	na	mg/L	EMC	Values compiled from other studies
6	N	3765	3765	mg/L	na	Values compiled from other studies
7	N	na	na	mg/L	na	
8	N	10	73-123	mg/L	EMC	Values compiled from this study
9	N	na	na	mg/L	median EMC	Values compiled from other studies
10	N	na	na	mg/L	na	Values compiled from this and other studies
11	N	na	158	mg/L	na	Values compiled from this study
12	N	na	na	mg/L	na	Values from a technical guideline
13	N	na	na	mg/L	na	Values complied from other studies
14	N	na	na	na	na	Values compiled from other studies
15	N	1-33	varying	mg/L	EMC	Values compiled from this and other studies
16	N	na	na	mg/L	EMC	Values compiled from other studies
17	N	na	na	mg/L	EMC	Values compiled from other studies
18	N	na	na	mg/L	EMC	Values compiled from other studies
19	N	na	15-148	mg/L	Mean	Values compiled from this study
20	N	32	384	mg/L	EMC	Values compiled from this study
21	N	31	31	mg/L	na	Values compiled from this study
22	N	na	na	mg/L	na	Modelled values based on 177 locations
23	N	2	multiple	mg/L	3 time based composites	Values compiled from this study
A	Y	5	na	mg/m^3	na	Values compiled from this study
B	Y	4	74	mg/veh/km	na	Values compiled from this study
C	Y	na	na	mg/veh/km	na	Values compiled from this and other studies
D	Y	na	na	mg/m^3	na	Values compiled from other studies
E	Y	2-5	na	mg/L	Mean	Values compiled from this study
F	Y	6	na	mg/L	Mean per rainfall event size	Values compiled from this study
G	Y	na	na	mg/L	na	Values compiled from this study
H	Y	na	na	kg/ha/a	na	Values compiled from this study
I	Y	20	na	g/m^3	EMC	Values compiled from this study

8.2.1 Conversion of CLM annual loads to annual mean concentrations

For comparison of the yields (g m^{-2} $year^{-1}$) used in the CLM with the compiled sets of international and local concentrations, the CLM yields were converted into annual mean concentrations by dividing the yields by the annual stormwater discharge per m^2 of surface.

Stormwater networks in Auckland, in common with those elsewhere, drain predominantly impervious surfaces, ie roofs, roads, parking lots, etc. They also drain variable proportions of pervious surfaces depending on the catchment.

The average annual rainfall over the Auckland region is 1,245mm (http://www.niwa.cri.nz/ncc/cs/annual/aclimsum_07). Average runoff in Auckland thus ranges from about 1,180 mm (95%) to perhaps 700 mm (56%). Assuming that most of the network stormwater arises from impervious surfaces, and for convenience in converting loads to concentrations, an average runoff of 1,000 mm was assumed.

Given the many other inaccuracies in this comparison as explained above, an error of a 100 mm or so in the assumed runoff is immaterial. This assumption means that 1 m^2 of surface produces 1 m^3 of runoff and that a yield of X g m^{-2} $year^{-1}$ is equivalent to an annual mean concentration of X g m^{-3}.

Some studies from the Auckland region report contaminant loads from roads in mg $vehicle^{-1}$ km^{-1}. These were converted here into concentrations of g m^{-3} assuming the road widths for each vehicle day^{-1} (vpd) category given in Table 14.

Table 14.

Conversion of road categories to areas. 1

Vehicle count vpd	Midpoint vpd	Road width m	Area/km m^2/km
<1,000	500	17	17,000
1,000-5,000	3,000	17	17,000
5,000-20,000	12,500	17	17,000
20,000-50,000	35,000	20.5	20,500
50,000-100,000	75,000	24	24,000
>100,000	150,000	31	31,000

The CLM zinc and copper annual mean concentrations for pervious surfaces, ie, urban grassland and trees, etc, in the comparison tables were calculated from the zinc and copper concentrations assumed in the CLM for pervious surface TSS , ie, 35 mg kg^{-1} and 7 mg kg^{-1} respectively.

8.2.2 Total suspended solids

The reported TSS concentrations for roof runoff range from 13 g m^{-3} to 840 g m^{-3} (Table 15). The “average” house in Auckland has a roof area of about 100 m^2 producing an annual runoff of about 100 m^3. A runoff TSS concentration of 840 g m^{-3} equals an annual TSS runoff load of 100 kg. Obviously this could arise only from a roof made of massively bulky material with a high erosion rate or from a roof with a very high atmospheric load of solids. Neither situation is found in Auckland.

Most roofs in Auckland are either sheet metal with a negligible erosion rates (in total mass terms) or clay or concrete tiles or metal tiles coated with chips. Of these, concrete would be expected to have the highest erosion rate but this could not be more than a few kilograms per year otherwise the long lifetime of concrete roofs could not be explained. The lowest reported concentration from the literature (Table 15) is within the range of roof runoff monitoring data for Auckland.

Unlike the roof runoff concentrations, TSS concentrations in road runoff are of the same order of magnitude as those found for Auckland roads (Table 15).

The comparison of concentrations for paved surfaces is complicated by the fact that the yields for paved surfaces are used for calibrating the CLM. Despite this the concentrations are not too dissimilar.

The literature concentrations for pervious surfaces range from 8 g m^{-3} to 340 g m^{-3} for forest, pasture and horticulture land. This range is similar to that for the CLM for these landuse categories. There are no literature data for urban streams or construction site bare earth.

Table 15.

Comparison of TSS annual mean concentrations from the CLM with data from international and local studies.

			International TSS (mg/l)				Local TSS (mg/l)					yeild (g/m2/yr)	
Source	**Criteri**	**Category**	**Low value**	**High value**	**Mediar**	**Liturature source**	**Low value**	**High value**	**Median**	**Literature source**	**Chosen value**	**Chosen value**	**Comments**
Roofs	materi al	Galvanised steel unpainted					1.50	8.20	3.00	A	4.2	**5**	
		Galvanised steel poorly painted					2.20	29.00	4.87	A	4.2	**5**	
		Galvanised stell well painted					3.00	9.00	2.60	A	4.2	**5**	
		Galvanised steel coated					5.00	26.00	6.00	A	10.0	**12**	
		Zinc/ aluminium unpainted	43	43	**43**	17	6.00	17.00	12.00	A	4.2	**5**	
		Zinc/ aluminium coated					3.00	18.00	7.00	A	4.2	**5**	
		Concrete	43	43	**43**	17	3.00	29.00	16.00	A	13.4	**16**	
		Copper	43	43	**43**	17					4.2	**5**	
		other materials									8.4	**10**	
	not specifi ed		13	840	**113**	2, 5, 10, 12, 13, 15							
Roads	vehicle s per day	< 1000	12	232	**102**	2, 5, 10, 14, 17	18	18	18	J	17.5	**21**	
		1000-5000	11	400	**111**	, 5, 10, 13, 14, 17, 20	23	23	23	J	23.4	**28**	
		5000-20000	41	468	**182**	, 5, 10, 13, 14, 17, 20	44	44	44	J	44.2	**53**	
		20000-50000	19	468	**228**	, 5, 10, 13, 14, 17, 20	81	81	81	J,I	80.0	**96**	
		50000-100000	64	501	**179**	2, 5, 10, 12, 13, 14, 15, 16, 17, 20	134	134	134	J	131.7	**158**	
		> 100000	8	501	**151**	2, 5, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17	198	198	198	H	195.0	**234**	
	not specifi ed		64	468	**308**	2, 15							
Areas	utilisation	Residential	21	1104	**65**	, 4, 5, 6, 9, 15, 16, 19							
		commercial	18	2582	**86**	2, 4, 5, 6, 9, 19							
		industrial	45	375	**72**	2, 4, 5, 6, 9							
		open space	11	22	**15**	6, 9, 16							
		agricultural	43	43	**43**	16							
Paved surfaces other than roads	utilisati on	Residential	7	75	**41**	13, 17	28	28	28	H	26.7	**32**	Derived by trial and error during the calibration process
		Industrial	60	87	**74**	13, 16	27	27	27	H	18.3	**22**	Derived by trial and error during the calibration process
		Commercial	40	300	**118**	4, 12, 13, 16, 17	17	17	17	H	26.7	**32**	Derived by trial and error during the calibration process
Urban grassland and trees	slope	< 10	11	602	**307**	2, 16	21.08	50	27.875	Williamson (1993)	37.5	**45**	
		10 - 20					21.08	50	27.875	Williamson (1993)	76.7	**92**	38mg/L gives a good calabration fit to catchments with slope 0-5°, from there on the yield = 12.33 x slope (degrees)
		> 20					21.08	50	27.875	Williamson (1993)	154.2	**185**	
Urban Stream Channel	idthxlength								6000	Elliot et al 2005	5000.0	**6000**	Best guess value based on monitored data
Construction Site open for 12	slope	< 10					2083	2083	2083	GLEAMS	2083.3	**2500**	Area weighted yeild from GLEAMS
		10 - 20					4667	4667	4667	GLEAMS	4666.7	**5600**	used a relationship of 717.6 x slope degrees + 109.8
		> 20					8833	8833	8833	GLEAMS	8833.3	**10600**	used a relationship of 717.6 x slope degrees + 109.8
Exotic production forest	slope	< 10								GLEAMS	29.2	**35**	Area weighted yeild from GLEAMS for this slope category
		10 - 20								GLEAMS	86.7	**104**	Area weighted yeild from GLEAMS for this slope category
		20<					0.5	250	125.5	Senior et al (2003)	173.3	**208**	Area weighted yeild from GLEAMS for this slope category
Stable forest	slope	< 10								GLEAMS	11.7	**14**	Area weighted yeild from GLEAMS for this slope category
		10 - 20								GLEAMS	35.0	**42**	Area weighted yeild from GLEAMS for this slope category
		20<					0.5	100	50.25	Senior et al (2003)	69.2	**83**	Area weighted yeild from GLEAMS for this slope category
	unknown		8	71	**113**	4, 15, 16							
Farmed pasture	slope	< 10	40	340	**174**	4, 9				GLEAMS	126.7	**152**	Area weighted yeild from GLEAMS for this slope category
		10 - 20								GLEAMS	380.0	**456**	Area weighted yeild from GLEAMS for this slope category
		20<					6.5	1100	553.25	Senior et al (2003)	769.2	**923**	Area weighted yeild from GLEAMS for this slope category
Retired pasture	slope	< 10								GLEAMS	17.5	**21**	Area weighted yeild from GLEAMS for this slope category
		10 - 20								GLEAMS	52.5	**63**	Area weighted yeild from GLEAMS for this slope category
		20<					0.5	150	75.25	Senior et al (2003)	104.2	**125**	Area weighted yeild from GLEAMS for this slope category
Horticulture	Soil type	Volcanic								GLEAMS	41.7	**50**	Area weighted yeild from GLEAMS for this slope category
		Sediment								GLEAMS	83.3	**100**	Area weighted yeild from GLEAMS for this slope category
		Unknown	12	83	**44**	2, 17, 19				GLEAMS	83.3	**100**	Area weighted yeild from GLEAMS for this slope category

8.2.3 Zinc

The range of zinc concentrations reported in Table 16 for galvanised steel roofs is at the upper end of the literature concentrations reported in Kingett Mitchell Ltd and Diffuse Sources Ltd (2003). The most likely reason for this is that the data in Table 16 are mostly from large urban centres in the northern hemisphere where erosion rates are known to be high because of acidic or otherwise aggressive rainfall. Runoff concentrations in Auckland and in other relatively small urban centres are generally in the range of 1 g m-3 to 6 g m-3. The reported runoff concentrations for other roof materials are low but still about an order of magnitude higher than those measured in Auckland. Acidic rainfall as explained above could also be the reason for this difference.

As for TSS, the literature zinc runoff concentrations for roads are very similar to those measured in Auckland and used in the CLM. The literature concentrations for paved surfaces are also similar to those used in the CLM.

The literature zinc runoff concentrations for pervious surfaces are low but as for the other roof materials, they are about an order of magnitude higher than those used in the CLM. This is almost certainly because the yields (concentrations) assumed for the CLM are for uncontaminated surfaces so as to avoid counting sources twice. In contrast, the literature data will be mostly as measured and will, therefore, include contributions from anthropogenic sources.

Table 16.

Comparison of zinc annual mean concentrations from the CLM with data from international and local studies.

			International Zinc (mg/L)				Local Zinc (mg/L)				
Source	**Criteria**	**Category**	**Low value**	**High value**	**Median**	**Literature study**	**Low value**	**High value**	**Median**	**Literature study**	**Chosen value**
Roofs	material	Galvanised steel unpainted	4.940	12.200	**9.110**	7, 10, 19, 21	0.10	3.10	2.50	A	**2.240**
		Galvanised steel poorly painted					0.60	3.30	1.61	A	**1.340**
		Galvanised stell well painted					0.05	2.90	0.53	A	**0.200**
		Galvanised steel coated					0.02	0.29	0.28	A	**0.280**
		Zinc/ aluminium unpainted	0.370	6.000	**3.275**	10, 15, 17, 21	0.18	1.87	0.43	A	**0.200**
		Zinc/ aluminium coated	0.100	85.000	**21.501**	7, 11	0.02	0.81	0.04	A	**0.020**
		Concrete	0.030	0.900	**0.418**	7, 10, 17, 19	0.02	0.02	0.02	A	**0.020**
		Copper	0.370	0.370	**0.370**	10, 17					**0.000**
		other materials	0.240	1.020	**0.496**	7, 17					**0.020**
	not specified		0.100	16.320	**2.927**	1, 2, 3, 12, 15, 21	0.14	1.9	0.4	D	
Roads	vehicles per day	< 1000	0.035	0.400	**0.222**	2, 5, 10, 14, 17	0.0019	0.0247	0.0057	B, C,	**0.004**
		1000-5000	0.015	0.960	**0.347**	2, 4, 5, 10, 14, 17	0.012	0.195	0.088	B, C, G	**0.027**
		5000-20000	0.024	1.420	**0.169**	4, 10, 14, 17, 20	0.048	0.617	0.190	B, C, G	**0.111**
		20000-50000	0.068	1.420	**0.334**	4, 10, 14, 17, 20	0.112	0.718	0.353	B, C, G, I	**0.257**
		50000-100000	0.170	2.000	**0.660**	2, 4, 5, 10, 12, 14, 16, 17, 20	0.030	2.623	0.441	B, C	**0.471**
		> 100000	0.050	2.000	**0.635**	2, 5, 8, 9, 10, 11,12, 14, 16, 17	0.318	4.062	0.943	B, C	**0.729**
	not specified		0.270	0.370	**0.323**	3, 15	0.0014	3.44	1.16	F	
Areas	utilisation	Residential	0.012	0.585	**0.133**	2, 4, 6, 9, 10, 11, 15, 16, 19, 23					
		commercial	0.060	0.400	**0.186**	2, 4, 6, 9, 10, 15, 16, 19					
		industrial	0.028	0.600	**0.174**	2, 4, 6, 9, 11, 13, 16, 23					
		open space	0.006	0.740	**0.020**	6, 9, 11, 16					
		agricultural	0.017	0.017	**0.017**	16					
Paved surfaces other than roads	utilisation	Residential	0.130	0.585	**0.438**	3, 17					**0.140**
		Industrial	0.450	0.450	**0.450**	3					**0.330**
		Commercial	0.050	0.400	**0.310**	3, 4, 12, 17					**0.000**
Urban grassland and trees	slope	< 10	0.020	0.080	**0.050**	2, 3, 10					**0.002**
		10 - 20									**0.003**
		> 20									**0.006**
		not specified	0.004	0.020	**0.012**	3, 16					
Urban Stream Channel	Widthxlength										**0.210**
Construction Site open for 12 months	slope	< 10									**0.088**
		10 - 20									**0.196**
		> 20									**0.371**
Exotic production	slope	< 10									**0.000**
		10 - 20									**0.002**
		20<									**0.007**
Stable forest	slope	< 10	0.020	0.020	**0.020**	3					**0.000**
		10 - 20									**0.001**
		20<									**0.004**
	unknown		0.010	0.060	**0.015**	4					
Farmed pasture	slope	< 10	0.015	0.040	**0.030**	4					**0.002**
		10 - 20									**0.004**
		20<									**0.018**
Retired pasture	slope	< 10									**0.001**
		10 - 20									**0.002**
		20<									**0.007**
Horticulture	Soil type	Volcanic									**0.002**
		Sediment									**0.004**
		Unknown	0.080	0.263	**0.161**	2, 17, 19					**0.004**

8.2.4 Copper

The literature reported copper concentrations for roof runoff (including galvanised steel roofs) are higher than were those measured in Auckland. The literature reported copper values for galvanised roofs may be sourced from material deposited on the roofs due to industrial emissions or some other urban sources. Other than that, the copper concentrations compare well.

Unlike the road runoff concentrations of TSS and zinc, the concentrations for copper reported in the literature are generally higher than are those measured in Auckland and those used in the CLM. The lowest values reported are similar but the high literature values are an order of magnitude higher than both the values determined from local studies and the values assumed for the CLM.

This difference has been a matter of considerable interest over the last decade but studies commissioned by the ARC and other research have failed to provide a convincing explanation. Further studies are in progress and these are expected to confirm the general range of road runoff loads used in the CLM.

Table 17.

Comparison of copper annual mean concentrations from the CLM with data from international and local studies.

			International Copper (mg/l)				Local Copper (mg/l)				
Source	Criteria	Category	Low value	High value	Median	Liturature source	Low value	High value	Median	Liturature source	Chosen value
Roofs	material	Galvanised steel unpainted	0.004	0.153	**0.051**	7, 10, 19, 21	<0.0005	<0.0005	<0.0005	A	**0.0003**
		Galvanised steel poorly painted					<0.0005	0.0024	0.0008	A	**0.0003**
		Galvanised stell well painted					<0.0005	0.0021	0.0006	A	**0.0003**
		Galvanised steel coated					0.0013	0.0019	0.0017	A	**0.0017**
		Zinc/ aluminium unpainted	0.153	0.153	**0.111**	10, 17, 21	0.0006	0.0013	0.0008	A	**0.0009**
		Zinc/ aluminium coated	0.016	0.250	**0.071**	7, 11	0.0028	0.5930	0.1174	A	**0.0016**
		Concrete	0.005	0.153	**0.104**	10, 17, 19	0.0280	0.5930	0.1174	A, E	**0.0033**
		Copper	0.500	33.000	**7.150**	10, 11, 17	0.8750	4.0417	1.7667	E	**2.1200**
		other materials	0.058	0.090	**0.054**	2, 7, 17					**0.0020**
	not specified		0.030	0.500	**0.131**	3, 12, 13, 15, 21, 22	0.0100	1.1700	0.0600	D	
Roads	vehicles per day	< 1000	0.025	0.086	**0.055**	2, 10, 14, 17	0.0006	0.0017	0.0009	B, C	**0.0007**
		1000-5000	0.007	0.086	**0.217**	2, 4, 10, 13, 14, 17, 20	0.0035	0.0000	0.0035	B, C, G	**0.0042**
		5000-20000	0.007	0.440	**0.113**	2, 4, 10, 13, 14, 17, 20	0.0148	0.0429	0.0247	B, C, G	**0.0175**
		20000-50000	0.012	0.630	**0.151**	2, 4, 10, 13, 14, 17,20	0.0343	1.4333	0.0557	B, C, G, I	**0.0407**
		50000-100000	0.200	0.940	**0.245**	2, 4, 10, 12, 13, 14, 16, 17, 20	0.0100	0.1825	0.0765	B, C	**0.0744**
		> 100000	0.010	0.560	**0.161**	2, 8, 10, 11, 12, 13, 14	0.0971	0.2826	0.1545	B, C	**0.1152**
	not specified		0.070	1.250	**0.194**	1, 3, 14, 15, 16	0.0080	0.1780	0.0620	F	
Areas	utilisation	Residential	0.008	0.109	**0.025**	2, 4, 6, 10, 11, 15, 16, 19, 22					
		commercial	0.008	0.060	**0.064**	2, 4, 6, 10, 15, 16, 19, 22					
		industrial	0.024	0.130	**0.096**	2, 4, 6, 11, 15, 16, 22					
		open space	0.001	0.004	**0.003**	6, 11, 16					
		agricultural	0.041	0.041	**0.041**	16					
Paved surfaces		Residential	0.023	0.380	**0.202**	13, 17					**0.0440**
		Industrial	0.100	0.600	**0.350**	3, 13					**0.0620**
		Commercial	0.030	0.560	**0.160**	3, 4, 12, 13, 17					**0.0800**
Urban grassland	slope	< 10	0.011	0.020	**0.016**	2, 3, 10					**0.0003**
		10 - 20									**0.0006**
		> 20									**0.0013**
		unknown	0.041	0.020	**0.031**	16, 22					
Urban Stream Channel	Widthxlength										**0.0420**
Construction Site	slope	< 10									**0.0175**
		10 - 20									**0.0392**
		> 20									**0.0742**
Exotic production	slope	< 10									**0.0001**
		10 - 20									**0.0004**
		20<									**0.0014**
Stable forest	slope	< 10	0.010	0.010	**0.010**	3					**0.0000**
		10 - 20									**0.0002**
		20<									**0.0007**
	unknown		0.004	0.020	**0.008**	4, 22					
Farmed pasture	slope	< 10	0.010	0.030	**0.015**	4					**0.0004**
		10 - 20									**0.0007**
		20<									**0.0035**
Retired pasture	slope	< 10									**0.0001**
		10 - 20									**0.0004**
		20<									**0.0014**
Horticulture	Soil type	Volcanic									**0.0004**
		Sediment									**0.0007**
		Unknown	0.011	0.094	**0.042**	2, 17, 19					**0.0007**

8.2.5 Total petroleum hydrocarbons

There have been few reported investigations of total petroleum hydrocarbons (TPH) in road runoff. One reason for this could be the relatively benign environmental image of TPH in small quantities but a more likely reason is the great difficulty of collecting representative samples of water containing TPH. TPH is a mixture of hydrophobic chemicals that concentrate at the water-atmosphere interface and adhere to solid surfaces including the plastics used in water sampler components.

The reported literature concentrations of TPH in stormwater range from 0.02 g m^{-3} to 400 g m^{-3}. Obviously, the large concentration is very much greater then an annual mean concentration. The low concentrations are reasonable, however, and are similar to those estimated from Auckland survey and monitoring data.

Table 18.

Comparison of TPH annual mean concentrations from the CLM with data from international and local studies.

			International TPH(mg/L)				Local TPH (mg/L)				
Source	**Criteria**	**Category**	**Low value**	**High value**	**Median**	**Literature study**	**Low value**	**High value**	**Median**	**Literature study**	**Chosen value**
Roads	vehicles per day	< 1000			**0.160**	10					**0.02**
		1000-5000	0.160	400.000	**101.955**	5, 10					**0.10**
		5000-20000	0.080	0.550	**0.320**	5					**0.41**
		20000-50000	0.080	0.550	**0.320**	5	0.0160	7.4000	0.6301	I	**0.96**
		50000-100000	0.510	400.000	**71.473**	5, 10, 12					**1.76**
		> 100000	0.020	400.000	**53.618**	5, 10, 11, 12					**2.73**
	not specified			1.402		1					

8.2.6 Summary of concentrations comparison

8.2.6.1 TSS

The TSS concentrations reported in the literature for roof runoff range from low values that are similar to those obtained by monitoring roof runoff in Auckland, up to high values that are not credible for Auckland roofs. Literature concentrations for road runoff are of the same order of magnitude as those produced by the CLM for Auckland roads.

Allowing for the fact that the yields for paved surfaces in the CLM were derived from calibrating the CLM, there is adequate agreement between the literature concentrations for paved surfaces and the concentrations from the CLM. The literature concentrations for pervious surfaces span a similar range to the range produced by the CLM. There are no literature data for urban streams or construction site bare earth.

8.2.6.2 Zinc

The range of zinc concentrations reported in literature for roof runoff are either at the upper end of, or up to an order of magnitude above, the range obtained by monitoring roof runoff in Auckland. Most of the literature data are from large urban centres in the northern hemisphere where erosion rates are known to be high because of acidic or otherwise aggressive rainfall. The most likely reason for the lower concentrations in Auckland roof runoff is Auckland's much less corrosive rainfall.

The literature zinc runoff concentrations for roads are very similar to those measured in Auckland and used in the CLM. The literature concentrations for paved surfaces are also similar to those used in the CLM. .

The literature zinc runoff concentrations for pervious surfaces are about an order of magnitude higher than those used in the CLM. This is almost certainly because the yields (concentrations) assumed for the CLM are for uncontaminated surfaces so as to avoid counting sources twice. In contrast, the literature data will be mostly as measured and will, therefore, include contributions from anthropogenic sources.

8.2.6.3 Copper

For all the source areas for which concentrations can be compared, the lowest copper concentrations reported in the literature are similar to those produced by the CLM but the high literature values are an order of magnitude higher than both the values determined from New Zealand studies and the values produced by the CLM.

For roofs and pervious surfaces the reasons for the differences are probably the same as the reasons given above for zinc. The differences between the literature and CLM copper concentrations in the runoff from paved surfaces and roads cannot be explained.

8.2.6.4 TPH

The low TPH concentrations reported in the literature are credible in terms of loads and are similar to those estimated from Auckland data. The highest concentrations in the literature cannot be representative of annual mean loads.

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9 Model limitations

This section describes the principal limitations of the CLM. It is important that users are familiar with these limitations in order that the model is not used for purposes for which it was not developed. In particular, model users are reminded that the CLM is intended to be a catchment-scale planning or screening tool and should not be used for the selection or design of specific storwmater treatment devices.

The limitations of the CLM include:

- model accuracy is influenced by differences between reference source area fractions and actual source areas in a given study area;
- model accuracy is also influenced by uncertainty in source yields;
- model accuracy is also influenced by uncertainty in LRFs for different treatment devices and the inability of LRFs to reflect the sequencing of treatment devices in a treatment train;
- the model is unlikely to be accurate for small sites;
- the model may not be transferable to locations outside of the Auckland region;
- the model is of only limited applicability to rural areas; and
- as noted above, the CLM is not a design tool.

Each of these limitations is described in further detail below.

9.1 Source areas

If source areas are known then the CLM will produce loads with accuracy limited only by the uncertainties in the source yields and load reduction factors. The largest errors in the loads occur when some source areas are not known and the reference source area fractions are inappropriate for the particular catchment.

As will be apparent from the procedures described above for deriving the reference source area fractions, they are unlikely to be exact for any catchment, so uncertain loads will always be produced by use of the reference fractions. In general, the larger the catchment and more similar it is in character to the urban areas of ACC, then the more accurate will be the calculated loads. The limitations of these reference source area fractions must be recognised by the model user and it is his/her responsibility to decide from knowledge of the urban area to be modelled if the reference source area fractions are to be valid. Where this is not the case, consideration should be given to accurately measuring source areas for the study area in question, for instance from GIS analysis of aerial photographs and other relevant shapefiles.

The most common situations that lead to excessively erroneous loads from the use of the reference source area fractions are described in the following sections.

9.1.1 Roof materials

Galvanised steel is by far the largest contributor to roof runoff zinc loads, and copper sheet is the only significant contributor to roof runoff copper loads. Substantial deviations of the actual areas of these materials from those determined using the reference source area fractions lead to highly erroneous zinc and copper loads.

The most rapid change in roof materials that has already occurred in many older urban areas is the replacement, subsequent to 1995, of galvanised steel roofing with aluminium/zinc coated steel (this new material was introduced in 1994). The use of galvanised steel for roofing had declined substantially by about the year 2000, so applying the reference source area fractions for roof materials to catchments developed after this time will produce excessively large zinc loads.

If the model user knows that extensive replacement of galvanised steel has taken place, or that most development occurred after 2000, then the reference source area fractions for roof materials should be altered to reduce the fraction of galvanised steel and increase the fraction of aluminium/zinc coated steel (remember the calculation of source areas using the reference source area fractions is done outside the CLM). Apart from this, a rough rule-of-thumb is that for large urban areas developed before 2000 that have not undergone extensive redevelopment, the reference source area fractions will be sufficiently reliable through to about 2020.

The situation for copper sheet roofs is less problematic. Copper sheet is not widely used on residential building roofs, mainly because of its high cost. This situation is unlikely to change in the foreseeable future. The situation where the reference source area fraction for copper roofs might not be valid is where a small catchment has, or will have, one or more substantial commercial or public buildings with copper roofs. This situation should be readily apparent from either the development plans for a new catchment or from visual inspection of an existing catchment.

9.1.2 Roads

Large lengths of motorways in particular, but also arterial roads, invalidate the reference source area fractions for the road vpd categories. This situation is easily recognised and the area fractions can be altered accordingly. The motorway area can usually be obtained from GIS.

9.1.3 Paved surfaces

The areas of paved surface are not directly a major issue for the intended application of the CLM to large urban catchments. Care was taken to ensure that model calibration produced credible paved surface loads (this was successful for TSS but less successful for the metals, see Section 5), but the paved surface yields include the true paved surface yields which are unknown, together with the errors in all the other source yields. This uncertainty on the calculated loads is minimised by ensuring that the catchment area is large and that the area of paved surfaces is a small fraction of the total catchment area.

The problem with paved surface areas arises where they are a large proportion of the catchment area. This can be a feature of smaller catchments; particularly industrial catchments which frequently have high area proportions of paved surface.

The problems with small sites are explained in more detail below.

9.1.4 Construction sites and streams

Construction sites and urban streams have high yields for TSS, although for large urban catchments the areas of both construction sites and urban streams are usually quite small. If catchment has no active construction or no streams, then the areas of these can be set to zero. Conversely, if a catchment has a large amount of bare earth on construction sites, e.g. a new subdivision, or a substantial stream, then the areas of these sources should be increased. The area of urban grasslands and trees should be either increased or decreased to balance the changes made to the areas of construction sites and streams. These changes would improve the accuracy of the TSS loads but would have little effect on the total zinc and total copper loads.

9.2 Reference source area fractions

The errors that can arise in the calculated loads from inappropriate application of the reference source area fractions are suggested in the Contaminant Load Model User Manual. The following example illustrates these errors.

Of the eight stormwater catchments included in the ACC/Metrowater stormwater monitoring programme, coincident quality and discharge data were successfully captured for only four catchments. Three of these catchments were used for calibrating the CLM (Chapter 7). The annual stormwater contaminant loads for the Orakei catchment were determined from the stormwater monitoring data using the same accumulation/washoff model that was used for the Mission Bay catchment (Timperley and Reed 2008).

The Orakei catchment is very close to the Mission Bay catchment. Both of these catchments are 100% residential, but the character of their stormwater networks appears to differ in that the network in the Orakei catchment has no obvious sections of exposed stream channel above the sampling site.

The source areas, e.g., roofs and roads, have not been measured for the Orakei catchment, so the only option for obtaining the source areas is to use the residential reference source area fractions stated in Table 4.

The results obtained (without any adjustments to the reference source area fractions to allow for known characteristics of the Orakei catchment), are compared to the stormwater loads determined from monitoring data in Table 19 below. The loads compare well for copper but the loads calculated with the CLM for TSS and total zinc are about twice the loads determined from the catchment stormwater monitoring data. These differences reflect the extent to which the source areas of the Orakei catchment differ from the areas calculated using the reference source area fractions for residential land use.

As noted above, the Orakei catchment stormwater network has no apparent open stream channel above the sampling site. The population increase between 2001 and 2006 was 38 people or about 7.6 persons per year. This is equivalent to 2.5 dwellings or about 380 m^2 of construction site bare earth (Section 4.1.5).

The Orakei catchment is a high value residential area similar in character to Mission Bay, with many of the original galvanised steel roofs now replaced with other materials. Consequently, the proportion of galvanised steel roofs in the Orakei catchment is possibly similar to that in the Mission Bay catchment and certainly much lower than the default fraction for residential galvanised steel roofs.

The area fractions can, therefore, be changed as follows for the Orakei catchment:

1. the stream area set to zero;

2. the construction site area set to 380 m^3; and
3. the total area proportion of galvanised steel roofs reduced to 10.6% (of total roof area) as in the Mission Bay catchment but with the same distribution of surface condition, i.e. unpainted, poorly painted and well painted (Chapter 4).

The CLM calculated loads with adjusted area fractions shown in Table 19.

The CLM TSS load is now closer to, but still about 30% higher than, the load determined from the monitoring data. A ground-level inspection of the Orakei catchment would be the only way to identify other adjustments to the area fractions that would deduce this difference. Ideally, of course, this inspection would be done as a normal pre-cursor to applying the CLM.

The zinc load is also higher than the load determined from the monitoring data. It is probable that this is due to smaller areas of galvanised steel roofs than the 10.6% of roof area that was measured for Mission Bay. There is no method of confirming this other than a survey of roof areas and materials in the Orakei catchment. The copper load remains effectively the same as the load determined from the monitoring data.

The differences shown in Table 19 highlight the potential errors that can arise from application of the reference source area fractions to urban areas that differ substantially in character from the assumed "average" urban area. It should be noted that the Orakei catchment of 54.7 ha is small relative to most of the urban areas for which ICMP are prepared. As an urban area increases in size, it is likely to become more heterogeneous and the reference source area fractions are more likely to reflect the actual catchment source areas.

Table 19

Annual stormwater contaminant loads (kg year-1) for the Orakei residential catchment determined from stormwater monitoring data and using the CLM, with and without adjusting the reference source area fractions for residential source areas

	Stormwater monitoring	CLM without adjusting the reference source area fractions	CLM with adjusted source area fractions
TSS	14,700	26,766	18,777
Total zinc	24.6	55.6	34.2
Total copper	3.56	3.30	3.27

9.3 Source yields

The yields for roof materials, roads and pervious surfaces have been derived from the most reliable data available to the authors. Nevertheless, some yields still have considerable uncertainty. In particular, the TSS yield for urban streams is very uncertain and will be highly variable across streams depending on the stream morphology, e.g. slope of the channel, bank structure, type of riparian vegetation, and catchment soil type. If a stream is a substantial component of a catchment (this can be assessed by comparing the stream TSS loads with the total catchment TSS loads in the CLM spreadsheet), then the model user should be aware that the catchment TSS loads will have higher than usual uncertainty. This would be relevant to the design of an in-line pond, for example.

The other relatively uncertain yields are those for copper and TPH in road runoff, although both of these yields are more reliable than were those in the earlier versions of the CLM. Further improvement in the accuracy of these yields can be expected when new road runoff monitoring data become available.

9.4 Selection of management option trains

The CLM restricts, to a limited extent, the selection of management options for roof runoff, but there is no restriction for any source on the order in which options can be selected. For example, a biomedia filter can be selected for option one and a wet pond for option two. Although such unrealistic trains can be selected in the CLM, the resulting errors in the catchment loads are negligible. As explained below, the CLM cannot be used as a design tool, so an inappropriate selection of management options is irrelevant in that respect.

In the example mentioned above, the biomedia filter will trap all TSS and particulate forms of contaminants and almost all of the dissolved forms, assuming no bypass. There will, therefore, be nothing left for the pond to trap (it could be installed for quantity control but this is not relevant to contaminant loads). If the devices were installed in the reverse sequence (a very logical sequence), then the pond would trap the heavier solids and thus reduce the maintenance required for the biomedia filter.

9.5 Load reduction factors

The most uncertain LRF in the CLM is that for catchpits (Appendix One), but there is plenty of evidence that catchpits are relatively inefficient for fine TSS and dissolved contaminants. Substantial errors in the catchpit LRF will, therefore, make only minor contributions to the errors in the catchment loads.

The LRF for the second and third options in a management train (columns F and G in the CLM spreadsheet), are only approximate at this stage for two reasons.

1. For most contaminant/train combinations there are no reliable monitoring data from which to derive the LRF. The current version of the CLM uses the same LRF for a particular device irrespective of its position in a management train. The lack of data for the retention efficiencies of management option trains is universal; it’s not a problem unique to the CLM.

   The errors this lack of data causes are illustrated by two stormwater treatment ponds in series. It is commonly assumed that the retention efficiencies of the ponds for TSS will be the same. This is not so, because the particle size distribution of the stormwater TSS will decrease with passage through the first pond, so the proportion of the TSS retained by settling in the second pond will be less than that of the first pond.

2. CLM model developed in Excel spreadsheet following simple computational steps. No sophisticated computational algorithm has developed in this version to change the LRF for a device 2^{nd} or 3^{rd} in a management option train according to the LRF of the preceding device. For example, the total zinc LRF for the second option, say 30% for a constructed wetland, remains the same irrespective of the LRF of the first option, say 11% for a catchpit or 60% for a biomedia filter.

The situation is most likely to be encountered where an unusual sequence of stormwater treatment devices has been installed in an existing catchment. In this case the model user should alter the combined LRF for the train (columns L, Q, V and AA in the CLM spreadsheet) to more accurately reflect the performance of the train.

9.6 Application of the CLM to small sites

The primary purpose of the CLM is to aid the estimation of stormwater contaminant loads discharged from a stormwater network serving a large area of mixed urban land use. In general, the larger and more heterogeneous the urban area, the more reliable will be the model load estimates.

The model is applicable to small sites but caution is required to ensure that the model assumptions apply. The model predicts loads for total suspended solids (TSS), total zinc, total copper and total petroleum hydrocarbons, derived from the sums of the loads from roofs, roads, paved surfaces (other than roads and roadside footpaths) and pervious surfaces. Within an urban area of mixed land use, galvanised steel roofs and vehicle tyres are the dominant sources of zinc and vehicle brake pads and discs are the dominant sources of copper. So long as these are the dominant sources in a small site then the model load predictions for these contaminants are likely to be reasonably valid.

For example, each m^2 of unpainted galvanised steel roof will produce the same amount of zinc irrespective of whether the site is small with only one house or large with 10,000 houses. Similarly, an "average" vehicle will leave the same average amount of zinc on the road from tyre wear irrespective of whether the site is small with 0.5 km of road or large with 100 km of road. The amounts of TSS produced by pervious surfaces in the model are also reasonably independent of the size of the site.

Paved surfaces are the major problem for small sites. If it is known that the activities undertaken on the paved surfaces of a small site could generate unusually large amounts of a CLM contaminant then obviously the load predictions are likely to be wrong. This is a common problem with small industrial sites.

As industrial catchments decrease in size, the composition of the stormwater from the paved surfaces becomes increasingly influenced by the particular industrial activities in the catchment. For example, one small industrial catchment might contain a timber yard and a particle board manufacturer and another might contain a vehicle dismantler and a concrete products manufacturer. The composition of the stormwater from the paved surfaces of these two catchments will be substantially different and the paved surface yields used in the CLM will not be valid for either catchment.

At the end of the day, the success of applying the model to a small site depends on the model user having a clear understanding of both the sources of contaminants on the site and the limitations of the CLM.

9.7 Application of the CLM to places other than Auckland

The model was first made generally available in January 2006 to help with the development of ICMPs throughout the Auckland region. It has also been used in other parts of New Zealand but with limited success, mainly because the yields for TSS are unlikely to be correct for rainfall and soils different from those in Auckland. The only solution to this is to obtain TSS yield data from either monitoring or modelling for the intended area of application. The generation of chemical contaminants predicted in the CLM should, however, be reasonably applicable to most urban areas of New Zealand. Where local data on stormwater quality are available, the applicability of the CLM can be assessed by comparison of those data with the annual mean concentrations presented in Section 8.2 of this report.

9.8 Application of the CLM to rural land uses

Relative to the same areas of urban land, rural land generates negligible quantities of zinc, copper and TPH but can contribute substantial quantities of TSS. The CLM has not been calibrated for catchments containing rural land. This means that the TSS loads estimated by the CLM for such catchments will be more uncertain than will be the loads estimated for fully urban catchments. In order to minimise this error, the model should not be applied to catchments with more than 20% of total catchment area with rural land.

9.9 CLM as a design tool

Some users have assumed that the CLM is a design tool able to replace relevant stormwater engineering education and experience. This is certainly not the case and it should be apparent from this report that the CLM does not provide any guidance for selecting suitable options for a particular site. The selection of the best management options must be made by applying sound stormwater engineering principles to the site characteristics, including the hydrology and the sources, types and forms of the contaminants to be managed. As a first point of reference, readers are directed to Auckland Council's TP10 Guidelines for the design of stormwater management devices (ARC, 2003).

Once management options that are appropriate for the site have been selected on the basis of these principles, then the CLM can be used to estimate the resulting site loads for evaluating the overall effectiveness of the management options selected, and for providing load data for input to the receiving environment assessment.

The temptation for model users inexperienced in the principles of stormwater management to use the model as the sole means of selecting management options can lead to inappropriate or impractical outcomes. Adequate user expertise is required to avoid this.

10 Conclusions

The CLM spreadsheet first introduced by the ARC in January 2006 provided a more flexible method than the procedures previously available for estimating site sediment and chemical contaminant loads to aid the development of ICMPs.

Irrespective of the uncertainties in the model results, the model's widespread use throughout the Auckland region has achieved the primary objective of achieving regionally consistent contaminant loads for effects assessments in ICMPs. This has increased the Council's confidence in its regional approach to comparing the effects of stormwater on different marine receiving environments.

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12 Appendix One: Derivation of Catchpit LRF

12.1 Total suspended solids

12.1.1 Procedure

The procedure used for estimating the TSS retention efficiency for catchpits involved the following steps.

1. Determining the typical particle size distribution (PSD) for:
    a. solids on road surfaces;
    b. TSS in road runoff; and
    c. TSS in catchpit discharge.
2. Estimating the TSS retained in catchpits.

12.1.2 Particle Size Distribution (PSD) of road surface solids

Kingett Mitchell Ltd (2004) summarise New Zealand data for the PSD of solids on road surfaces. Two data sources provide remarkably similar PSD as shown in Table 20 below. The mean % represents surveys of road dust on 15 roads. This mean PSD produces the mass distribution across particle size ranges shown in Table 21.

12.1.3 PSD of TSS in road runoff and catchpit discharge

Measurements of the PSD in 302 stormwater samples collected during the ACC/ Metrowater stormwater monitoring programme produced a median PSD with d_{90} of 117 µm, d_{95} of 133 µm and d_{99} of 160 µm. Thus, 200 µm is about the maximum size of solids suspended (i.e. TSS) in stormwater flowing in the ACC network. Although the PSD of TSS in the stormwater might be different in the absence of catchpits, there is no convenient method of investigating this.

12.1.4 TSS retained in catchpits

Butler et al (2005) studied the retention of solids of different sizes in a clean model catchpit for a range of water flows. For flows greater than about 3 l s^{-1} the solids retention was 100% for solids greater than 500 µm, 50% for solids 100 to 500 µm and 15% for solids <100 µm (Figure 4 in Butler et al, 2005). It is important to note that these results were for a catchpit completely free of accumulated solids and so the solids retained would have been at its maximum.

The next step was to distribute the experimental solids retention from Butler et al (2005) across the PSD of road surface solids and this raised the first major problem. If particle settling is the primary mechanism of solids retention in catchpits, then it is apparent that the retentions reported by Butler et al (2005) could have been achieved only if their 0-100 µm fraction was dominated by large particles and their 100-500 µm fraction was dominated by small particles. Unfortunately the PSD for their two fractions was not reported.

This problem was circumvented by making the following assumptions for the Butler et al (2005) results:

- 65% of road surface particles <500 μm were retained
- Within the particle size range 0-500 μm the retention efficiency varied in direct proportion of the ideal particle volume.

Applying these assumptions to the road surface PSD produced the catchpit retention efficiencies shown in Table 22 and the mass balance shown in Table 23. As explained above, for the purposes of these calculations TSS is considered to be solids within the size range 0-200 μm. The mass balance in Table 23 shows that 265 kg (26.5%) of road surface solids are potentially transportable as TSS in the stormwater network. Of this quantity, 56 kg is retained in the model catchpit, giving a TSS retention of 21%.

The extent to which catchpit TSS retention efficiency is reduced by solids accumulated in the catchpits is unknown, but it could be less than the efficiency for a clean catchpit with no accumulated solids. In the absence of relevant data, a TSS retention efficiency of 20% is assumed.

An approximate check on these calculations can be made by comparing the PSD for the TSS discharged from this model catchpit, with the median PSD for TSS in the Auckland stormwater network derived from the PSD for 302 samples collected during the ACC/Metrowater stormwater monitoring programme. This comparison is shown in Table 23. The clean catchpit TSS PSD is slightly finer than the network TSS PSD, but the similarity confirms the credibility of the calculations and the reasonable validity of the 20% TSS retention efficiency for clean catchpits.

12.2 Total zinc and total copper

The Richardson Road project (Timperley et al, 2005) obtained ex-catchpit yields of 0.188 mg veh^{-1} km^{-1} for dissolved zinc and 0.180 mg veh^{-1} km^{-1} for particulate zinc (particulate zinc is referred to as TSS zinc in this report). TSS zinc and TSS copper are retained to the same extent as TSS, ie 20%, but the proportions of dissolved zinc and copper retained are negligible.

The amount of total zinc potentially available on the road surface and available for transport with TSS and in dissolved forms is, therefore, 0.188 + 0.180/0.8 = 0.413 mg veh^{-1} km^{-1}. The amount retained is 0.225 – 0.180 = 0.045 giving a retention efficiency for total zinc of 11%.

For copper the amount potentially available for transport is 0.138 mg veh^{-1} km^{-1} (Section 4.2.2.3). The ex-catchpit yields obtained in the Richardson Road project were 0.014 mg veh^{-1} km^{-1} for dissolved copper and 0.041 mg veh^{-1} km^{-1} for TSS copper. Applying the 20% retention efficiency as above gives a road surface TSS of 0.410/0.8 = 0.513 mg veh^{-1} km^{-1}. Thus, dissolved copper was 21.5% and TSS copper was 78.5% of the total road surface copper potentially available for transport. Applying these percentages to the road surface yield of 0.138 mg veh^{-1} km^{-1} gives road surface dissolved copper of 0.030 mg veh^{-1} km^{-1} and road surface TSS copper of 0.108 mg veh^{-1} km^{-1}, of which 20% or 0.022 mg veh^{-1} km^{-1} is retained in catchpits. The retention efficiency is, therefore, 0.022/0.138 = 0.157 or 16%.

Table 20

Typical particle size distributions of road surface solids. (References and data taken from Kingett Mitchell, 2003)

	Particle size distribution µm												
	50	100	150	200	250	300	350	400	450	500	2000	no. of roads averaged	Reference
% finer	3.0	10	15	25	30	35	42	45	50	55	100	6	Ng et al (2003)
% finer	5.0	10	20	28	35	40	48	55	60	65	100	9	Kennedy unpublished data, Chou (1982)
mean % finer	4.0	10	18	27	33	38	45	50	55	60	100	15	

Table 21

Mass distribution of road surface solids across particle size ranges

	particle size ranges µm										
	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-2000
mass distribution %	4.0	6.0	7.5	9.0	6.0	5.0	7.5	5.0	5.0	5.0	4.0

Table 22

Catchpit TSS retention efficiencies as a function of particle size determined in laboratory studies with a clean model catchpit (Butler et al 2005)

	Particle size ranges µm										
	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-2000
Laboratory % retention in clean model catchpit (Butler et al, 2005)	15		50								100
Cumulative % retention for road surface solids (see text)	0.134	3.63	16.8	46.1	98.0	100	100	100	100	100	100

Table 23

Mass balance for 1000 kg of road surface solids transported in runoff through clean catchpits. "% finer network TSS" is the median determined from 302 samples collected during the ACC/Metrowater stormwater monitoring programme

	particle size ranges µm											
	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-2000	Cumulative mass kg
Distribution on road surface kg	40	60	75	90	60	50	75	50	50	50	400	1000
Mass retained in catchpits kg	0.054	2.18	12.6	41.5	58.8	50	75	50	50	50	400	790
Mass	39.9	57.8	62.4	48.5	1.23	0	0	0	0	0	0	210

discharged from catchpit kg												
% finer on road surface	4.0	10	18	27	33	38	45	50	55	60	100	
% finer in catchpit	0.007	0.282	1.88	7.13	14.6	20.9	30.4	36.7	43.0	49.4	100	
% finer discharged from catchpit	19.0	46.6	76.3	99.4	100	100	100	100	100	100	100	
% finer network TSS*	11	67	92	100	100	100	100	100	100	100	100	

13 Appendix Two: Uncertainty analysis of yield parameters and source areas

The yield parameters and reference source area fractions derived in the CLM were based on information collected by ACC between 2001 and 2008. The influence of uncertainty in these parameters was tested by varying model input parameters within specified ranges. The CLM was applied to the entire Waitemata Harbour catchment, which consists of 34 stormwater management units (SMUs). These 34 sub catchments fall into three different land use groups (residential, commercial and industrial). The model was run for each combination of selected model parameters. The source areas used in this assessment were based on 2001 land use categories.

13.1 Source areas

The reference source area fractions for each of the three catchment land use groups are given in Table 24.

The following sub section provides an overview about parameter selection.

<u>Roofs and roof materials</u>

The area proportions used in the uncertainty analysis for different roof materials were derived from surveys of building roofs in 11 urban areas of Auckland City, 8 residential, 2 commercial and one industrial. The 20th, 50th and 80th percentiles for 7 of the 8 different materials on roofs in the 8 residential areas were used as the low, best and high values for sensitivity testing. The values for the "other materials" category were determined by the difference.

For commercial areas the uncertainty range was assumed to be ±20% of the best value. The proportion of galvanised steel roofs in the single industrial catchment surveyed, 86.9%, is probably near the top of the range for Auckland's industrial areas. Accordingly the high area proportions for roof materials were assumed to be the same as the best values and the low values were assumed to be 50% of the best values.

<u>Roads</u>

The local road area proportion for 92.4% (30 of the 34 SMU) of the area of Auckland City that drains into the central Waitemata Harbour is 17.46%. It was assumed that this is the proportion for residential areas. This value was determined from GIS and so is assumed to have negligible error. A slightly higher proportion of 20% is assumed for both commercial and industrial land use and the range of uncertainty was assumed to be 15% to 30%.

<u>Paved surfaces</u>

Residential paved areas are the difference between the total impervious surface area (GIS) and the sum of the roof and road areas. The proportion of residential paved surfaces is 10.72%, i.e., 47.32-19.13-17.46 = 10.72. The estimate for commercial land use is 16%, i.e., 66 – 30 - 20 = 16%. A total impervious area proportion of 65% is assumed for industrial land use. This gives a paved area proportion of 25%, i.e., 65 – 20 – 20 = 25% for industrial land use.

The estimate for residential areas is assumed to have no error. The ranges of uncertainty for the commercial and industrial paved areas are assumed to be 13% to 19% and 20% to 30% respectively.

Pervious areas

Pervious area proportions are the differences between the total land use areas and the total impervious surface areas, i.e., roofs, roads and paved surfaces.

The area proportion for stream channels was derived from GIS data for Auckland City. Although this is probably quite accurate for the Auckland City part of the catchment, the areas of North Shore and Waitakere Cities within the central Waitemata Harbour catchment have higher proportions of streams. Thus, the low proportion was assumed to be the same as the best proportion, ie. 0.4% and the high proportion was assumed to be 0.6%.

The area of construction site bare earth was estimated from the population growth projections and several parameters related to dwellings.

Auckland City road areas: Motorway and local road categories

Assuming uncertainty in the 2001 area proportions for the two motorway and four local road categories implies uncertainty in the VFM predictions for that year. This is reasonable and these uncertainties are shown below when the uncertainties in the future trends for roads are discussed.

Motorway categories

An uncertainty in the area proportion for the >100,000vpd motorway category of ±20% is assumed.

Local road categories

The low and high area proportions for local road categories 1000-5000vpd, 5000-20,000vpd and 20,000-50,000vpd were set at ±20% of the best proportions for residential areas and ±10% of the best proportions for commercial and industrial areas. The area proportions for the remaining category, <1000vpd, is determined by difference.

13. 2 Yields parameters

Three different yield categories were selected considering the uncertainties of the data used to derive them. The selected values are shown in Table 25.

Table24: Source area proportions for 2001 with ranges for uncertainty testing.

Source	Source area	2001 area proportions								
Rural trees (of total SMU)		0.1109								
Rural pasture (of total SMU)		0.1555								
Total motorways (of total SMU)		0.008301								
Total urban(of total SMU)		0.7253								
Urban landuse (of total urban)	Residential	0.8776								
	Commercial	0.0415								
	Industrial	0.0810								
		low			best			high		
Motorways vpd categories (of total	50k-100k vpd	0.6116			0.5145			0.4174		
	>100K vpd	0.3884			0.4855			0.5826		
		Residential			Commercial			Industrial		
		low	best	high	low	best	high	low	best	high
Urban roofs (of urban landuse)		0.1913	0.1913	0.1913	0.2000	0.3000	0.4000	0.2000	0.2000	0.4000
Roof materials (of urban landuse roofs)	galvanised steel unpainted	0.02106	0.0405	0.0649	0.0992	0.1240	0.1488	0.4346	0.8691	0.8691
	galvanised steel poor paint	0.1222	0.2227	0.2603	0.1946	0.2433	0.2920	0.0209	0.0417	0.0417
	galvanised steel well painted	0.0270	0.0541	0.0866	0.0431	0.0539	0.0647	0.0093	0.0186	0.0186
	galvanised steel coated tiles	0.1236	0.1593	0.1807	0.0237	0.0296	0.0355	0.0000	0.0000	0.0000
	zinc/aluminium surfaced steel unpainted	0.0007	0.0043	0.0137	0.0302	0.0378	0.0454	0.0000	0.0000	0.0000
	zinc/aluminium surfaced steel coated (Longrun,	0.0788	0.1238	0.2206	0.1304	0.1630	0.1956	0.0188	0.0376	0.0376
	copper	0.0003	0.0006	0.0003	0.0080	0.0100	0.0120	0.0000	0.0000	0.0000
	other materials (by difference)	0.6223	0.3948	0.1729	0.4708	0.3384	0.2061	0.5164	0.0330	0.0330
Urban local roads (of urban landuse)		0.1746	0.1746	0.1746	0.1500	0.2000	0.3000	0.1500	0.2000	0.3000
Road vpd categories (of urban local roads)	<1k vpd (by difference)	0.5400	0.4200	0.3000	0.1900	0.1000	0.0100	0.1900	0.1000	0.0100
	1k-5k vpd	0.2800	0.3500	0.4200	0.2700	0.3000	0.3300	0.2700	0.3000	0.3300
	5k-20k vpd	0.1400	0.1800	0.2200	0.4500	0.5000	0.5500	0.4500	0.5000	0.5500
	20K-50K	0.0400	0.0500	0.0600	0.0900	0.1000	0.1100	0.0900	0.1000	0.1100
Urban paved (of urban landuse)		0.1072	0.1072	0.1072	0.1300	0.1600	0.1900	0.2000	0.2500	0.3000
Urban pervious (of urban landuse)		0.5268	0.5268	0.5268	0.5200	0.3400	0.1100	0.4500	0.3500	0.0000
Pervious surfaces (of urban pervious)	grasslands and trees	0.5105	0.5105	0.5085	0.4955	0.3155	0.0855	0.4500	0.3500	0.0000
	stream channels (length x width)	0.0040	0.0040	0.0060	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	construction sites	0.0123	0.01230	0.0123	0.0245	0.0245	0.0245	0.0000	0.0000	0.0000

Table25: Ranges of uncertainties in source yields used for uncertainty testing. Grey boxes indicate values with negligible effects on total loads and, therefore, not tested. Paved yields were derived from the combination of yields used for uncertainty testing (see text).

Source	AREA	TSS (g m^{-2} yr^{-1})			Total zinc (g m^{-2} yr^{-1})			Total copper (g m^{-2} yr^{-1})		
		low	best	high	low	best	high	low	best	high
Roofs	galvanised steel unpainted	5	5	5	1.680	2.240	3.190	0.0003	0.0003	0.0003
	galvanised steel poor paint	5	5	5	0.894	1.135	1.624	0.0003	0.0003	0.0003
	galvanised steel well painted	5	5	5	0.078	0.146	0.1970	0.0003	0.0003	0.0003
	galvanised steel coated tiles	12	12	12	0.140.	0.28	0.5600	0.0017	0.0017	0.0017
	zinc/aluminium surfaced steel unpainted	5	5	5	0.140	0.20	0.4400	0.0009	0.0009	0.0009
	zinc/aluminium surfaced steel coated (Longrun, tiles)	5	5	5	0.0180	0.0180	0.0180	0.0016	0.0016	0.0016
	copper	5	5	5	0.0000	0.0000	0.0180	1.38	2.12	2.44
	other materials	10	10	5	0.0180	0.0180	0.0180	0.0020	0.002	0.002
Roads	<1k vpd	21.10	21.30	21.93	0.0022	0.0041	0.0066	0.0410	0.0014	0.0025
	1k-5k vpd	26.59	27.81	31.55	0.0130	0.0243	0.0397	0.0025	0.0081	0.0149
	5k-20k vpd	47.46	52.56	68.13	0.0541	0.1014	0.1655	0.0102	0.0338	0.0621
	20K-50K	83.75	95.60	131.8	0.1256	0.2355	0.3842	0.0238	0.0785	0.1441
	50k-100k vpd	136.7	158.4	224.5	0.2298	0.4310	0.7032	0.0435	0.1437	0.2637
	>100K vpd	200.7	234.3	336.7	0.3561	0.6674	1.0889	0.0674	0.2225	0.4083
Paved	Residential paved		34			0.1400			0.0440	
	Industrial paved		32			0.3300			0.0620	
	Commercial paved		20			0.0000			0.0550	
Pervious	Urban grasslands and trees	36	45	54	0.0013	0.0016	0.0019	0.0003	0.0003	0.0004
	Urban stream channels (length x width)	3000	6000	9000	0.1050	0.2100	0.3150	0.0210	0.0420	0.0630
	Construction sites	2909	3636	4363	0.1018	0.1273	0.1527	0.0204	0.0255	0.0305
Rural	Trees	18	35	53	0.0006	0.0012	0.0019	0.0001	0.0003	0.0004
	Pasture	50	100	150	0.0018	0.0035	0.0053	0.0004	0.0007	0.0011

13.3 Results analysis

The maximum estimated uncertainties were estimated as the products of low areas and low yields and the products of high areas and high yields (grey shaded cells in Tables 26, 27 and 28). These combinations produce extreme estimates of the uncertainties in the loads of ± 33% for TSS, -51% + 54% for total zinc and -31% + 42% for copper reference to the medium value.

Such extreme combinations are unlikely because the combinations of areas must be consistent with the total area of the catchment of the central Waitemata Harbour and the combinations of yields must be consistent with the original calibration of the contaminant load model. For example, the combination of low yields for all sources produces loads well below any realistic estimate of uncertainty in the measured loads for the calibration catchments.

Therefore, a more reasonable range of estimated values is that produced by combined mixtures of low, medium and high areas and yields. These combinations produce uncertainties lower than those given above and about ± 20% for TSS, ±35% for total zinc and ± 25% for copper.

13.3.1 TSS

The TSS loads produced using the various possible combinations of yields and areas are shown in Table 26. Most of the TSS is produced from pervious surfaces and despite the uncertainties in the roof, road and paved areas, the total area of pervious surface remains close to that given by GIS. Uncertainties in the TSS yields make by far the greatest contribution to the range of catchment TSS loads.

Table26: TSS loads (t/year) for various combinations of yields and source areas.

	Yield		
Source area	**low**	**medium**	**high**
low	6614	9938	13178
medium	6628	9935	13224
high	6647	10586	13273

13.3.2 Total zinc

As was found for TSS, uncertainty in the zinc yields contributes most to the range of catchment zinc loads shown in Table 27. Different roof areas make a substantial difference to the catchment zinc load, however, because galvanised steel roofs were the largest single source of zinc.

Table 27: Zinc loads (kg/year) for various combinations of yields and source areas.

	Yield		
Source area	**low**	**medium**	**high**
low	10091	13363	18345
medium	14832	20787	16938
high	16938	29236	31982

13.3.3 Total copper

The areas of roads and the total VKT are known with reasonable certainty and the areas of sheet copper roofs at that time were small. Consequently the copper loads are not much different between the low and high combinations of areas as shown in Table 28. On the other hand, uncertainties in the yields, particularly for road runoff, are large and contribute to an almost 2-fold difference between the lowest and highest loads.

Table28: Copper loads (kg/year) for various combinations of yields and source areas.

	Yield		
Source area	**low**	**medium**	**high**
low	948	1244	1746
medium	972	1381	1869
high	977	1522	1955