AN OVERVIEW OF VERSION 2 OF THE CONTAMINANT LOAD MODEL

Mike Timperley, *Timperley Consultant;* ***Rajika Jayaratne,*** *Auckland Council*
Matthew D Davis, *Auckland Council and* ***Melanie Skeen****, Enviornmental Professional, United Kingdom*

ABSTRACT

The Contaminant Load Model (CLM) was first developed in 2006, and is now used within the Auckland regional and nationally. It is a spreadsheet tool to estimate the annual loads of total suspended solids (TSS), total zinc (TZn), total copper (TCu) and total petroleum hydrocarbons (TPH) discharged from stormwater networks serving areas of mixed urban land use and rural land. Version 2 is set for release, accompanied by two reports: a Model Development Report and a User Manual. The new version includes updated model parameters and the option for users to enter the load reduction factors, which were fixed at optimum values in the previous version of the model. The improved parameters include the source yields, which have been updated to take account of local and international studies published since May 2006. This paper discusses the model background, key features of the model, parameters, calibration, validation and model limitations.

KEYWORDS

Stormwater quality, modelling, total suspended solids, total copper, total zinc, total petroleum hydrocarbons, stormwater management

1. INTRODUCTION

The Contaminant Load Model (CLM) is an annual stormwater contaminant load spreadsheet model developed for the Auckland region of New Zealand. It is a simple mathematical model where source load is equal to the source area times the source yield. Where stormwater treatment and/or source control exist the source load is reduced by a load reduction factor (the treatment or control efficiency). The total load is simply the sum of individual source loads within a designated area. The model takes into account land use, materials and activity level. Strength of the model is the derivation of source yields. The yields are largely based on local monitoring, supplemented with international literature. A yield are available for nine land use classifications, nine types of roof materials (of particular concern due to zinc yields), six classes of motorways and roads, includes urban stream erosion, construction sites and rural land uses. The CLM was calibrated in three urban 'control catchments' of single land use where monitoring was undertaken and annual loads computed. In the Auckland urban stormwater context, the adverse effects of most concern are those resulting from the chemical contamination of bed sediments in the coastal marine area. Bed sediment contamination is directly related to the annual loads of dissolved and particulate chemicals draining from contributing catchments. Also of concern is sediment (total suspended solids), which also discharges from the stormwater system into the coastal marine area.

The CLM was developed to provide a simple tool for predicting these annual loads. Whereas the mathematics of the CLM is simple, the accuracy of the model depends almost entirely on two paired parameters: the contaminant yields for the various sources and the load reduction factors for different management options. This paper summarises the contents of the CLM Development Report prepared by Timperley et al. (2011a). It provides an overview of the yield parameters which are the key to understanding the strengths and weaknesses of the CLM. Also discussed are the model calibration, parameter validation and model limitations. The model includes the contaminants of most concern at the present time in the Auckland region: total suspended sediment (TSS), zinc (Zn), copper (Cu) and total petroleum hydrocarbons (TPH).

2. BACKGROUND

2.1 Modelled contaminants

TSS

Monitoring programmes carried out in last decade (eg: McHugh and Reed, 2006; Kingett Mitchel Ltd. and Diffuse Sources Ltd., 2004) identified accumulation of fine sediments in the receiving environment. From the perspective of benthic animals (animals that live in sediments), this is a very substantial habitat change. In general, biodiversity reduces as sediments become muddier. This makes fine sediment a serious contaminant and is included into the model.

Metals

A number of monitoring programmes carried out during 1998 -2010 have shown that the concentrations of zinc and copper in estuarine and coastal receiving environments are steadily increasing. Lead concentrations appear to have stabilised. On present trends zinc and copper will exceed international sediment quality guidelines in many locations, while it has already occurred in some estuaries, (ARC 2010).

The sediment concentrations of other heavy metals (arsenic, antimony, mercury, cadmium and tin) were highly variable. It appears that the concentrations of some of these metals are slowly increasing, but additional monitoring data will be required to confirm this. Therefore, zinc and copper are considered as the heavy metals of concern in the receiving environment at the present time and are included into the model.

Hydrocarbons

The main organic contaminants of interest in urban catchments are petroleum hydrocarbons and associated PAH (polycyclic aromatic hydrocarbons). The total amount of petroleum hydrocarbons is referred to as TPH (total petroleum hydrocarbons) and includes all petroleum-derived compounds. The concentration of hydrocarbons has been routinely determined in monitoring programmes. Results show that concentrations do not reflect a significant increasing trend. This may possibly due to analytical variability. However, the concentrations vary from a few hundreds to thousand micrograms per gram (McHugh and Reed, 2006, Kingett Mitchel Ltd. and Diffuse Sources Ltd., 2004). In Auckland urban areas, vehicle exhaust emissions, lubricating oil leaks and seal coat wear are considered to be the major sources of petroleum hydrocarbons. The concentration of TPH appears to be dependent on both traffic volume and catchment usage with high volumes and industrial catchments resulting in the highest concentrations. This makes considering TPH as contaminant of concern and included to the model.

2.2 Contaminant sources

There have been several investigations completed in the period between 2002 – 2010 (eg: Kingett Mitchel Ltd. and Diffuse Sources Ltd., 2003; Timperley et al., 2005; Kingett Mitchel Ltd. and Diffuse Sources Ltd., 2004; Kennedy and Gadd, 2003; Pennington and Webster-Brown, 2007; Pandey, 2007 and Reed, 2008). These studies increased understanding of the contaminant sources and loads, which enable to draw following conclusions.

1. decreasing sediment loads with increasing impervious area

Roads and roofs make up 70 to 80% of the impervious surface in a typical urbanised catchment. The data collected from the studies show that roads generate a very small proportion of the TSS carried in urban stormwater, while the proportion from roofs is close to zero. The studies provided some evidence that the major sources of sediment in urban catchments are open stream channel erosion and erosion of bare earth on construction sites.

2. Higher TSS from residential land uses

The relationship between sediment loads generation in different land use categories were found: industrial and commercial land use generate lower TSS loads than residential land use.

3. Increasing metal loads with industrial land uses and road usage

Table 1 provides results of annual loads and yields for urban catchments in the Auckland region. There is no direct relationship between metal loads and impervious surface area. However, there is a noticeable relationship with the land use type and road activity. In general, it was found that zinc roofing used in industrial zones as a main contribution of zinc in stormwater in urban areas, with road activity as another contributor. Therefore, the zinc contaminant loads are largely related to the area of galvanised roofs, which increase from residential to commercial to industrial. Copper contaminant load is related to the area of roads carrying high numbers of vehicles per day, which increased from residential to commercial and industrial.

Tables 1 and 2 show the yield and annual contaminant load estimated for three different land use categories. Annual loads estimated for a particular land use using a single yield parameter (loading rate) could generate a substantial error. In recent studies (Kingett Mitchel Ltd. and Diffuse Sources Ltd., 2004; Kennedy and Gadd, 2003; Pennington and Webster-Brown, 2007; Pandey, 2007), it was found that more accurate loads could be estimated, if yields are based on contaminant sources. The "yield" as used here is the amount of contaminant generated by a source per square metre per year.

Table 1: Auckland City stormwater quality control monitoring sites (Timperley et al., 2005)

Catchment	**Landuse**	**Catchment area (ha)**	**Percent impervious area**
Central Business District (CBD)	Commercial	30.1	85.3
Mission Bay	Residential	45.2	47.7 (MPD 69.3)
Mt Wellington	Industrial	34.0	56.2 (MPD 70.6)

Table 2: Yields and annual loads of metals and total suspended solids (Timperley et al., 2005)

Catchment	Yield				Annual loads			
	TZn [(a)]	TCu [(a)]	TPb [(a)]	TSS [(a)]	TZn	TCu	TPb	TSS
	g ha^{-1} a^{-1} [(b)]	g ha^{-1} a^{-1}	g ha^{-1} a^{-1}	kg ha^{-1} a^{-1} [(c)]	kg a^{-1} [(d)]	kg a^{-1}	kg a^{-1}	t a^{-1} [(e)]
CBD	1630	140	124	310	47.0	4.21	3.73	9.33
Mission Bay	573	79	60	620	26.0	3.57	2.71	28.0
Mt Wellington	5170	135	135	252	176	4.59	4.59	8.57

Notes: [(a)] TZn = total zinc; TCu = total copper; TPb = total lead and TSS = total suspended sediments.
[(b)] g ha^{-1} a^{-1} = gram per hectare per annum.
[(c)] kg ha^{-1} a^{-1} = kilogram per hectare per annum.
[(d)] kg a^{-1} = kilogram per annum.
[(e)] t a^{-1} = tonnes per annum.

3. MODEL OVERVIEW

2.1 General

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

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

1. total suspended solids (TSS)
2. total zinc
3. total copper
4. total petroleum hydrocarbons (TPH)

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

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

Five rural land uses are included in the model to enable the few catchments around the fringes of the Auckland urban area to be modelled. However, the CLM model is not designed for rural land and cannot be used reliably for catchments with more than about 20% of rural land. Harbour contaminant studies within the Auckland region with significant rural land have made use of the GLEAMs model to model the rural areas, for example (Timperley et al. 2010)

Each category is subdivided into further three categories in the CLM. The rural land uses are as follows.

1. Exotic production forest divided into three slope categories. In the Auckland region this forest is mostly pinus radiata
2. 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)
3. Farmed pasture divided into three slope categories
4. Retired pasture divided into three slope categories
5. Horticulture divided into three categories; two known soil types and one unknown soil type

2.2 Model Mathematics

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

Source Load = Source Area x Source Yield x Load Reduction Factor x Area Fraction Managed Eq (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 (m2)	=	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 wetted length 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, typical stormwater treatment devices like ponds etc.
Area fraction managed	=	The fraction of a source area draining to a stormwater treatment management option train. This must be a positive value less than or equal to one.

2.3 Model Parameters

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

1. Source areas: These are entered as areas in square metres by the model user, except that the length in metres is entered for roads.

2. Source yields: The yields are updated in Version 2 of the model to take account of data published since the release of the previous version. These cannot be altered by the model user.

3. Load reduction factors: These are chosen by the model from a list of default values when the model user selects a management option, eg, 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.

4. 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 option.

In summary, the model incorporates the yields for all known contaminant sources and LRFs for management options, even if these yields and LRFs are not accurately known. The model provides flexibility to replace the uncertain parameters with better values when these become available. On the basis of the present knowledge, the principal sources of the four contaminants are included in the model.

2.4 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 source management option trains, eg, stormwater treatment and source control, and the remaining yellow blocked columns, L, Q, V and AA are for user entry of load reduction factors (LRF) for selected load management option trains. In a separate section below the main body of the spreadsheet are the user input cells for management options at the bottom of the site and any alternative LRF for these options.

2.5 Contaminant yield parameters

The contaminant yields are the key parameter determining the accuracy of the model load predictions. These values were derived by different means for each of the source and contaminant combinations. The 2006 version values contained in the CLM were re-evaluated based on new information gathered since then and verified against additional national and international studies. Yields are available for nine land use classifications, nine types of roof materials, six classes of motorways and roads, urban stream erosion, construction sites and rural land use (Table 3).

2.5.1 Roofs

The TSS yields were derived mainly from Kingett Mitchel Ltd. and Diffuse Sources Ltd., (2004) 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}. Yield values are derived for nine different roof categories, and parameters were verified based on local and international literature.

The copper leaching rates from roof materials reported in Kingett Mitchel Ltd. and Diffuse Sources Ltd. (2004) were very low. Higher leaching rates would be expected from copper roof sheet, but this material was not included in the scope of roof materials examined in Kingett Mitchel Ltd. and Diffuse Sources Ltd. (2003). Therefore, the yield parameter for copper roof were derived mainly based on overseas studies (Dierkes et al., 2005; Göbel et al, 2006; Ludwig, 2007 and Arnold, 2005) and verified from local study carried by Pennington and Webster-Brown (2007).

Contaminant Load Model
Version 2.0 March 2011

Catchment name CATCHMENT NAME

A	B	C	D	E	F	G	H
Catchment area (m^2)				Source contaminant management train			
Source	Source type		Source Area (m^2)	1st manageme nt option	2nd managem ent option	3rd managem ent option	Fraction of area draining to train
Roofs	Galvanised steel unpainted						
	Galvanised steel poorly painted						
	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						
Roads	*Vehicles/day*	*Length (m)*					
	<1000		0				
	1000-5000		0				
	5000-20000		0				
	20000-50000		0				
	50000-100000		0				
	>100000		0				
Paved Surfaces other than roads	Residential						
	Industrial						
	Commercial						
Urban Grasslands and trees	Slope < 5						
	5 < Slope <10						
	Slope >10						
Urban Stream Channel	*length x width*						
	Urban area without construction sites		0				
Construction Site open for 12 months/year	Slope < 5						
	5 <Slope <10						
	Slope >10						
	Urban area with construction sites		0				
Exotic production forest	Slope <10						
	10 < Slope < 20						
	Slope >20						
Stable forest	Slope <10						
	10 < Slope < 20						
	Slope >20						
Farmed pasture	Slope <10						
	10 < Slope < 20						
	Slope >20						
Retired pasture	Slope <10						
	10 < Slope < 20						
	Slope >20						
Horticulture	*Soil type*	Volcanic					
		Sediment					
		Unknown					
	Total area of sources (m^2)		0				

Contaminant yields, loads, and load reduction factors

Source	Source type	I	J	K	L	M
		Total suspended solids (TSS)				
		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*					
	<1000	21	0	0.00		0
	1000-5000	28	0	0.00		0
	5000-20000	53	0	0.00		0
	20000-50000	96	0	0.00		0
	50000-100000	158	0	0.00		0
	>100000	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	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	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 (m^2)	Totals	0			0

Source	Source type	N	O	P	Q	R
		Zinc suspended particulate and dissolved (TZn)				
		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	2.2400	0.0	0.00		0.0
	Galvanised steel poorly painted	1.3400	0.0	0.00		0.0
	Galvanised steel well painted	0.2000	0.0	0.00		0.0
	Galvanised steel coated (Decramastic tiles)	0.2800	0.0	0.00		0.0
	Zinc/aluminium unpainted (Zincalume)	0.2000	0.0	0.00		0.0
	Zinc/aluminium coated (Colorsteel/Colorcote/new metal tiles)	0.0200	0.0	0.00		0.0
	Concrete	0.0200	0.0	0.00		0.0
	Copper	0.0000	0.0	0.00		0.0
	Other materials	0.0200	0.0	0.00		0.0
Roads	*Vehicles/day*					
	<1000	0.0044	0.0	0.00		0.0
	1000-5000	0.0266	0.0	0.00		0.0
	5000-20000	0.1108	0.0	0.00		0.0
	20000-50000	0.2574	0.0	0.00		0.0
	50000-100000	0.4711	0.0	0.00		0.0
	>100000	0.7294	0.0	0.00		0.0
Paved Surfaces other than roads	Residential	0.1950	0.0	0.00		0.0
	Industrial	0.5900	0.0	0.00		0.0
	Commercial	0.0000	0.0	0.00		0.0
Urban Grasslands and trees	Slope < 5	0.0016	0.0			0.0
	5 < Slope <10	0.0032	0.0			0.0
	Slope >10	0.0065	0.0			0.0
Urban Stream Channel	*length x width*	0.2100	0.0			0.0
	Urban area without construction sites	Totals	0.0	0.00		0.0
Construction Site open for 12 months/year	Slope < 5	0.0880	0.0			0.0
	5 <Slope <10	0.1980	0.0			0.0
	Slope >10	0.3710	0.0			0.0
	Urban area with construction sites	Totals	0.0	0.00		0.0
Exotic production forest	Slope <10	0.0012	0.0			0.0
	10 < Slope < 20	0.0036	0.0			0.0
	Slope >20	0.0073	0.0			0.0
Stable forest	Slope <10	0.0005	0.0			0.0
	10 < Slope < 20	0.0015	0.0			0.0
	Slope >20	0.0029	0.0			0.0
Farmed pasture	Slope <10	0.0053	0.0			0.0
	10 < Slope < 20	0.0160	0.0			0.0
	Slope >20	0.0320	0.0			0.0
Retired pasture	Slope <10	0.0007	0.0			0.0
	10 < Slope < 20	0.0022	0.0			0.0
	Slope >20	0.0044	0.0			0.0
Horticulture	Soil type: Volcanic	0.0018	0.0			0.0
	Sediment	0.0035	0.0			0.0
	Unknown	0.0035	0.0			0.0
	Total area of sources (m^2)	Totals	0.0			0.0

Source	Source type	S	T	U	V	W
		Copper suspended particulate and dissolved (Tcu)				
		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	0.0003	0.0	0.00		0.0
	Galvanised steel poorly painted	0.0003	0.0	0.00		0.0
	Galvanised steel well painted	0.0003	0.0	0.00		0.0
	Galvanised steel coated (Decramastic tiles)	0.0017	0.0	0.00		0.0
	Zinc/aluminium unpainted (Zincalume)	0.0009	0.0	0.00		0.0
	Zinc/aluminium coated (Colorsteel/Colorcote/new metal tiles)	0.0016	0.0	0.00		0.0
	Concrete	0.0033	0.0	0.00		0.0
	Copper	2.1200	0.0	0.00		0.0
	Other materials	0.0020	0.0	0.00		0.0
Roads	*Vehicles/day*					
	<1000	0.00148	0.0	0.00		0.0
	1000-5000	0.00887	0.0	0.00		0.0
	5000-20000	0.03695	0.0	0.00		0.0
	20000-50000	0.08579	0.0	0.00		0.0
	50000-100000	0.15703	0.0	0.00		0.0
	>100000	0.24314	0.0	0.00		0.0
Paved Surfaces other than roads	Residential	0.0360	0.0	0.00		0.0
	Industrial	0.1070	0.0	0.00		0.0
	Commercial	0.0294	0.0	0.00		0.0
Urban Grasslands and trees	Slope < 5	0.0003	0.0			0.0
	5 < Slope <10	0.0006	0.0			0.0
	Slope >10	0.0013	0.0			0.0
Urban Stream Channel	*length x width*	0.0420	0.0			0.0
	Urban area without construction sites	Totals	0.0	0.00		0.0
Construction Site open for 12 months/year	Slope < 5	0.0180	0.0			0.0
	5 <Slope <10	0.0390	0.0			0.0
	Slope >10	0.0740	0.0			0.0
	Urban area with construction sites	Totals	0.0	0.00		0.0
Exotic production forest	Slope <10	0.0002	0.0			0.0
	10 < Slope < 20	0.0007	0.0			0.0
	Slope >20	0.0015	0.0			0.0
Stable forest	Slope <10	0.0001	0.0			0.0
	10 < Slope < 20	0.0003	0.0			0.0
	Slope >20	0.0006	0.0			0.0
Farmed pasture	Slope <10	0.0011	0.0			0.0
	10 < Slope < 20	0.0032	0.0			0.0
	Slope >20	0.0065	0.0			0.0
Retired pasture	Slope <10	0.0001	0.0			0.0
	10 < Slope < 20	0.0004	0.0			0.0
	Slope >20	0.0009	0.0			0.0
Horticulture	Soil type: Volcanic	0.0004	0.0			0.0
	Sediment	0.0007	0.0			0.0
	Unknown	0.0007	0.0			0.0
	Total area of sources (m^2)	Totals	0.0			0.0

Source	Source type	X	Y	Z	AA	AB
		TPH suspended particulate and dissolved (TTPH)				
		Yield (g $m^{-2}a^{-1}$)	Initial load (g a^{-1})	Default load reduction factor	Manual load reduction factor	Reduced load (g a^{-1})
Roads	<1000	0.0335	0.0	0.0		0.0
	1000-5000	0.2013	0.0	0.0		0.0
	5000-20000	0.8387	0.0	0.0		0.0
	20000-50000	1.9474	0.0	0.0		0.0
	50000-100000	3.5645	0.0	0.0		0.0
	>100000	5.5192	0.0	0.0		0.0
	Urban area without construction sites	Totals	0.0	0.00		0.0
	Urban area with construction sites	Totals	0.0	0.00		0.0
	Total area of sources (m^2)	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 manageme nt option	Second managem ent option	Third manageme nt option	Fraction of area draining to train	Contamin ant	Default LRF	Manua l 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%				

Figure 1: The CLM Spreadsheet Model (Timperley et al., 2011a)

2.5.2 Roads

Yield parameters were derived mainly from Timperley et al. (2005). These values were determined in relation to distance travel by a single vehicle. For example Timperley et al. (2005) reported that a yield for TSS passing through catchpits on Richardson Road (a major arterial road in Auckland City) 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% (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:

Road surface TSS yield (g m-2 year-1) = 20 g veh-1 km-1 + 365 days year-1 x Y veh day^{-1} x Z g veh^{-1} km^{-1}/road width m x 1000 m km^{-1} Eq (2)

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

This equation (Eq 2) fits the measured runoff load for Richardson Road (Reed, 2007) 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.

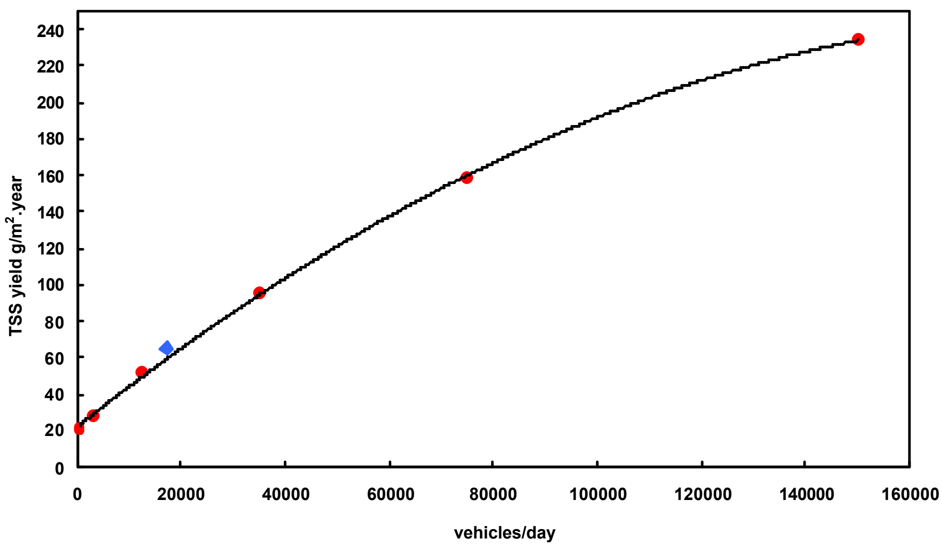

Figure 2: Assumed variation in the road surface yield of TSS (g m-2 year-1) with vehicles per day. The blue triangle is the point for Richardson Road (Timperley et al., 2011a)

Vehicle exhaust emissions, lubricating oil leaks and seal coat wear are considered to be the major sources of total petroleum hydrocarbons (TPH) in Auckland's urban areas. Fuel spills also occur. Over the period 2001 to 2003 the Auckland City/Metrowater stormwater monitoring programme obtained 302 stormwater samples from networks across the city.

During 2007, solids from the Grafton Gully motorway runoff treatment tank was analysed and TPH was measured (Reed, 2007). Results from those two studies were used to derive TPH yield parameters per single vehicle travel distance. In the CLM these parameters utilises in terms of the area of road surface and time i.e. g m-2 year-1. It was also noted that there is a strong co-relation of TPH and copper concentration. The median TPH to total copper concentration ratio was 22.7. Roof material survey reported that very few copper roofs in the Auckland city. This enable to establish vehicles are the major source of copper in Auckland city. The median TPH to copper concentration ratio used to calculate total TPH yield (Timperley et al., 2011a).

2.5.3 Urban streams (pervious surfaces)

The TSS yield for urban erodible stream channels is the most uncertain yield in the CLM due to lack of monitored data. 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) included in the model. The 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.

2.5.4 Construction sites (pervious surfaces)

The TSS yield for bare earth was determined by applying the sediment runoff model GLEAMS to the 34 stormwater catchments in Auckland City 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 assumed for use in the CLM for construction sites in the Auckland region.

2.5.5. Urban Grasslands and Trees (pervious surfaces)

Urban grasslands and trees (residential lawns, gardens, parks, reserves and school grounds etc) are the largest contributor to stormwater TSS in most urban catchments. The yield is somewhat uncertain for this source category. The median TSS yield for "urban" areas reported as 375 kg ha-1 year-1 (Williamson 1993). 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). However, this catchment is steeper and 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. Therefore, that a realistic stable pervious surface TSS yields for the city is between 400 and 500 kg ha-1 year-1 (40 and 50 g m-2 year-1). The yield parameters for this source category were determined through model calibration process (Timperley et al., 2011a).

2.5.5 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 variations of these yields with slope were 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 20% of rural land. It was assumed that no petroleum hydrocarbons (TPH) are generated from rural source areas.

2.6 Load Reduction Factors

The term "load reduction factor" (LRF) refers as the contaminant retention efficiencies expected from source control or stormwater treatment options. 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% (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 from the literature to 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.

The LRFs used in the CLM are given in Timperley et al. (2011a). If a LRF is considered to be incorrect for a specific device then the model user can enter an alternative LRF. In the previous version these parameters were fixed.

Table 3: Contaminant yields for the source areas used in the CLM (Timperley et al., 2011a in press)

	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	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	0.004	0.0015	0.033
	1k-5k vpd	28	0.026	0.0089	0.201
	5k-20k vpd	53	0.110	0.0369	0.838
	20K-50K	96	0.257	0.0858	1.947
	50k-100k vpd	158	0.471	0.1570	3.564
	>100K vpd	234	0.729	0.2431	5.519
Paved	Residential paved	32	0.195	0.0360	0
	Industrial paved	22	0.590	0.1070	0
	Commercial paved	32	0.000	0.0294	0
Perviou	Urban grasslands and trees	45	0.001	0.0003	0
		92	0.003	0.0006	0
		185	0.006	0.0013	0
	Urban stream channels (length x	6,000	0.210	0.0420	0
	Construction sites	2,500	0.088	0.0180	0
	Slope	5,600	0.196	0.0390	0
		106,0	0.371	0.0740	0
Rural	Exotic production forest	35	0.001	0.0002	0
	Slope	104	0.003	0.0007	0
		208	0.007	0.0015	0
	Stable forest	14	0.000	0.0001	0
	Slope	42	0.001	0.0003	0
		83	0.002	0.0006	0
	Farmed pasture	152	0.005	0.0011	0
	Slope	456	0.016	0.0032	0
		923	0.032	0.0065	0
	Retired pasture	21	0.000	0.0001	0
	Slope	63	0.002	0.0004	0
		125	0.004	0.0009	0
	Horticulture	50	0.001	0.0004	0
		100	0.003	0.0007	0
		100	0.003	0.0007	0

3 MODEL CALIBRATION

The CLM was calibrated for TSS, total zinc and total copper (there was no suitable data available for TPH), for three urban catchments in Auckland City for which stormwater monitoring flow and quality data had been collected in the Auckland City/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:

- 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.
- 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 loads for the three calibration catchments obtained by monitoring and from the calibrated CLM are compared in Table 4.

Table 4: Comparison of measured and modelled contaminant loads (kg year^{-1}) for the selected catchments (Timperley et al., 2011a in press)

	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

NOTE: * monitoring loads from Timperley et al. (2005)

4 PARAMETER VALIDATION

The yield parameters were validated with literature cited values (internationally and nationally), as there were no additional monitored data available for verification. The CLM yields were converted into annual mean concentrations by dividing the yields by the annual storm water discharge per square metre of surface.

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.

Some of the reported concentrations are not close to annual mean concentrations utilises in CLM. This may be because of annual mean concentrations are derived considering Auckland annual runoff volume, which cannot be credible. Therefore, only a general comparison of annual mean concentrations derived from the CLM for Auckland was made. The yield parameters derived for Auckland are matched well with other studies (Timperley et al., 2011a).

5 MODEL APPLICATION AND LIMITATIONS

5.1 INTENDED APPLICATION

The primary purpose of the CLM is to provide a basis for estimating stormwater contaminant loads discharged from a stormwater network serving catchments of urban land use. In general, the larger and more diverse the urban area, the more reliable are be the load estimates.

Complex catchments, for example, with multiple management options for different parts of the same source area, can be modelled by creating several virtual catchments so that each source area in each virtual catchment can limited to only one management option (but it also can have none). The sub catchments are "virtual" because they do not necessarily exist on the ground, although the sums of the virtual source areas equal the source areas in the original catchment. Each virtual sub catchment is modelled with a separate spreadsheet and the subcatchment loads are summed to produce the loads for the original catchment (Timperley et al., 2011b).

It should be noted that the CLM produces only the contaminant loads; it does not assess the effects of these loads on receiving environments. The CLM can be used to compare the contaminant loads with and without the designed treatment. This comparison is a sensible inclusion in an Integrated Catchment Management Plan (ICMP), for example. For assessing effects a separate procedure for estimating receiving environment bed sediment contaminant concentrations should be followed (Timperley and Reed 2008).

5.2 LIMITATIONS

5.2.1 Application to small catchments and default areas

The default area fractions are provided to estimate source areas when these areas are unknown. These values become unreliable as the catchment area decreases. For catchments smaller than 20 ha, the model user must confirm the validity of the default area fractions. If there is any doubt about the validity of the default area fractions, then the source areas should be estimated by other means, for example, aerial photography, development plans or a site survey. The success of applying the model to small catchments depends on the model user possessing a clear understanding of the sources of contaminants in the catchments and the CLM (Timperley et al., 2011b).

5.2.3 Application to rural land uses

The CLM has not been calibrated for catchments containing significant rural land due to lack of monitored data for rural catchments. Therefore, the TSS loads estimated by the CLM for such catchments will be more uncertain than will be the loads estimated for fully urban catchments. To minimise this error for catchments containing both urban and rural land, the CLM model should only be applied to areas where the total area of rural land is less than about 20% of the total catchment area.

5.2.4 Application as a design tool

The CLM does not provide any guidance for selecting suitable stormwater management options (treatment devices) for a particular catchment. The selection of the best management options must be made by applying sound stormwater engineering principles and best practice guidelines, considering the catchment characteristics – the hydrology and the sources, types and forms of the contaminants to be managed (eg: ARC 2003).

5.2.2 Application to places other than Auckland

The CLM model was developed based on monitored data for the Auckland region. It has also been used in other parts of New Zealand since the first release in 2006. The users must be aware that the yields for TSS are unlikely to be correct for rainfall and soils different from those in Auckland. The solution to this conundrum is to obtain TSS yield data from either monitoring or modelling for the intended area of application. However, the generation of chemical contaminants predicted in the CLM should be reasonably applicable to most urban areas of New Zealand.

Once management options have been selected, the CLM can be used to estimate the resulting catchment loads. This enables to compare the overall effectiveness of the management options selected.

6 CONCLUSIONS

The CLM spreadsheet model that was first introduced by the Auckland Regional Council in 2006 provided a more flexible and uniform method than the procedures previously available for estimating site sediment and chemical contaminant loads to aid the development of ICMPs and other studies in the Auckland region.

While acknowledging some 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. This has increased the Council's confidence in its regional approach to comparing the effects of stormwater on different marine receiving environments. Yield parameters were updated in Version 2 of the model based on information collected since 2006. The yields are largely based on local monitoring, supplemented with international literature. Version 2 the spreadsheet model will be made available soon, coupled with the release of two supporting reports: a Model Development Report and a User's Manual.

DISCLAIMER

Viewpoints expressed in this paper are those of the authors and do not reflect policy or otherwise of the Auckland Council.

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