C-CALM REVIEW OF REMOVAL EFFICIENCIES FOR STORMWATER TREATMENT OPTIONS IN NEW ZEALAND

NIWA Client Report: AKL2008-031

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Executive Summary

This report has been written as background work for the Catchment Contaminant Annual Loads Model (C-CALM) currently under development by NIWA for Landcare Research Ltd. It presents local and international research into the contaminant removal efficiencies of stormwater treatment options commonly used in New Zealand. Emphasis has been placed on the contaminants to be simulated in C-CALM (total suspended sediments - TSS, copper and zinc), though, with an eye to future model development, data on other contaminants have been reported where available. Background information about the water treatment including definitions and primary information sources are given in Section 0. Treatment options are discussed in Section 2 and include:

- Treatment comparisons (ensembles of information) – Section 2.1;
- Wet ponds and wetlands - Section 2.2;
- Filters – Section 2.3;
- Vegetative biofilters (raingardens / bioretention, swales and infiltration strips) – Section 2.4;
- Street sweeping – Section 2.5;
- Catch-pits and catch-pit inserts – Section 2.6
- Porous paving – Section 2.7; and
- Treatment trains – Section 2.8.

A phone survey of regional, unitary and selected territorial authorities in New Zealand was carried out (Section 3) to identify the main treatment options used around the country and the state of local knowledge about how well those options perform. As NIWA is familiar with stormwater treatment in the Auckland region and have had previous discussion with practitioners regarding the C-CALM project, authorities in the region were not contacted. No new treatment performance data were obtained from this survey. It was found that detention basins (ponds and wet lands), swales (especially along roads), catch-pits inserts and street sweeping are common around the country, however public porous paving, and raingardens are not found outside the main cities. Survey participants were sent a one-page description of C-CALM

(Appendix 1) and many showed great interest in its development. Few authorities are involved in water quality modelling and, where modelling is carried out, rely on consultancies. It was generally felt that models currently available are overly complex. The replies to the survey are given in Appendix 2.

Finally, generalised removal efficiencies to simulate treatment in C-CALM are given in Section 4. It is noted that information on environmental drivers which influence stormwater treatment such as rainfall dynamics and catchment characteristics is rarely reported in the literature so that relationships between these drivers and water treatment cannot be determined from the data. This means that the recommendations make broad assumption about treatment. Removal of sediments and associated particulate metals are to be pre-simulated for pond and wetlands and raingardens for a wide range of environmental conditions in order to develop a set of performance rules (see Semadeni-Davies, 2008). All other removal efficiencies have been derived from the literature. The removal efficiencies for dissolved metals from ponds, wetlands and raingardens were not simulated due to the complexity of the processes involved. Where possible (ponds, wetlands, street sweeping, catch-pits) sediment removal efficiencies are broken into sediment size classes, otherwise, removal is said to be for total suspended solids regardless of grain size. The literature derived recommendations for ponds, wetlands, raingardens, filters, swales, infiltration surfaces and porous paving have been broken into low, medium and high efficiency ratings. Users of C-CALM will be required to select the appropriate treatment rating on the basis of *a priori* knowledge (e.g., media for filters and flow path length for swales and infiltration strips).

1. Background

This report is intended to form the basis of generic performance ratings with respect to contaminant removal for the options covered within the Catchment Contaminant Annual Loads Model (C-CALM) being developed by NIWA. It presents a data and literature review of removal efficiencies for common stormwater management options used in New Zealand to improve stormwater quality. Street sweeping, and the use of structural devices for water treatment including so-called best management practices (BMPs) or sustainable urban drainage systems (SUDS) for low impact urban design and development (LIUDD) are covered. Devices included are ponds and wetlands, filters, vegetative bio-filters, catch-pits (with and without inserts) and porous paving. Treatment trains are also discussed. The report collates information available locally and internationally for the treatment options regarding their expected removal efficiencies. Where possible, reference has been made of environmental drivers and sediment particle size distributions (PSD).

The review has concentrated on studies which include removal efficiencies for total suspended solids (TSS), and particulate and dissolved zinc and copper which will be simulated in C-CALM, though with an eye to future model development, other common contaminants have been reported where available with the target contaminants.

Removal of contaminants borne in stormwater through water treatment is dependant on a myriad of different factors including:

- intensity and duration of stormwater delivery;
- antecedent hydrological conditions (e.g., depth of water table, storage capacity of local soils and the treatment device, accumulation and wash-off cycles of contaminants);
- topography (e.g., slope, aspect)
- contributing area to flow
- infiltration rate of treatment media including soil where applicable
- particle size distribution (PSD) of suspended sediment;

- chemistry of stormwater (e.g., pH, contaminants present and their concentration);
- hydraulic function of the treatment device (i.e., dimensions and configuration); and
- physical, biological and chemical conditions within the device (e.g., temperature, pH, presence of bonding sites for sorption, plantings, micro-flora and fauna).

Each of these factors is highly heterogeneous in both spatially and temporally so that there is no hard and fast constant for removal for a particular treatment device.

The original intention of C-CALM model development was to provide the GIS spatial decision support system (SDSS) with a set of performance rules that had been developed using continuously run conceptual simulation models of commonly used devices for water treatment. This approach would have enabled C-CALM to take some of the above factors into account by proxy without the need for explicit continuous simulation modelling of stormwater flow pathways and treatment within the GIS. Furthermore, it would give C-CALM a sound theoretical modelling basis without the complexity*;* data and user expertise required of operational urban drainage models. However*;* local data suitable for model development was only available to NIWA with a sufficient length of time for two ponds and a single raingarden (see Semadeni-Davies 2008). Thus out of necessity, the C-CALM project has had to make assumptions treatment efficiencies of stormwater treatment based on literature values for other treatment options.

1.1 Representing removal efficiency

By its nature as a simple water quality model for planning applications, C-CALM aims to represent average local removal efficiencies for water treatment. In this report, performance is presented in terms of percentage contaminant removal between influent and effluent. Percentage removal is both understood within the stormwater community and most stormwater studies report efficiency in terms of percentage removal. The choice was also guided by the ease of calculation. Thus, use of percentage removals will allow intuitive simulation of water treatment within C-CALM.

1.2 Primary sources of information

This review has given priority to local information on stormwater treatment options and efficiency ratings for treatment devices in New Zealand. The main local sources of information were websites, conference proceedings and a phone survey of regional and territorial authorities. However, such data has proved to be elusive with only a handful of reports available that have good quality data suitable for the assessment of device performance. Through necessity, this review has also had to consider international information including published reports, conference and journal articles. A recurring theme in the discussion below is the paucity of good quality stormwater treatment data both in New Zealand and internationally. What information is available shows a wide, and often conflicting, range of removal efficiencies. Taylor *et al*. (2005; and Taylor, M., personal communication 2008) carried out a similar review of local and international resources and expressed frustration at the lack of information on treatment efficiencies in general. They state that what data are available are often limited in value as they are presented without reference to environmental drivers such as local climate, hydrology, topography and geology that can affect treatment. Primary sources of information on removal efficiencies include:

- NZWERF online Stormwater Management Guideline - describes treatment devices commonly used in New Zealand and collates local and international information about those devices.
  (http://www.nzwerf.org.nz/publications/sw602/sw602.html)

- NZWWA Stormwater Directory of New Zealand - lists and summarises some 267 local and international reports on stormwater management, however, few of those reports include stormwater treatment studies.
  (http://www.nzwwa.org.nz/stormwaterdirectory.pdf)

- Auckland Regional Council (ARC) - a number of reports on removal efficiencies for specific devices have been commissioned and are available to the general public.
  (http://www.arc.govt.nz/albany/main/environment/water/stormwater/stormwater-publications.cfm)

- US EPA website - holds a wealth of publications online on stormwater management such as a series of stormwater fact sheets from 1999 (a-h) that have been cited in this report.
  http://www.epa.gov/ednnrmrl/

- Clark *et al*. (2006) - provides a comprehensive overview of peer review literature on stormwater management published between 1996 and 2006. The review has a chapter on low impact treatment technologies which includes infiltration and bio-filtration, detention and retention ponds, and wetlands. http://rpitt.eng.ua.edu/Publications/Publications.shtml.

- The International Stormwater Best Management Practices (BMP) Database holds reports and data for a range of treatment devices, predominantly from the USA. Data held in the database must meet quality protocols. http://www.bmpdatabase.org/

In order to augment the paucity of local information, a telephone survey was carried out of regional councils and selected city councils around the country. Participants where asked what treatment devices are used in their jurisdiction and whether any monitoring programmes of concurrent flow, and influent and effluent quality suitable for the derivation of removal efficiencies have been undertaken. However, no new data was located as a result of this survey.

2. Treatment options

The following literature review represents a selection of information that is available on removal efficiencies (focussing on Zn, Cu and TSS) for storm water treatment options commonly used in New Zealand. Background information such as local climate, topography, antecedent hydrological conditions in both the catchment and the treatment device and soil types is very rarely reported in the literature, which means that it is difficult to determine the extent to which external environmental drivers affect stormwater treatment. Despite its importance to water treatment, especially though settling, the sediment PSD is usually not reported. Similarly, removal efficiencies for metals are commonly reported in terms of total metal (i.e., TZn and TCu); information on metal portioning (dissolved vs., particulate) and fractionation (particulate metal split into sediment size class) is rare, and was not available for most of the treatment options cited below.

2.1 Performance summaries

Summaries of average stormwater contaminant removal efficiencies for common treatment devices have recently been prepared by the International BMP Database (2007 b; Table 1) and Taylor *et al*. (2005; see Table 2). The former was prepared by statistically analysing data lodged with the BMP database. The latter is the result of a literature review of which pooled published removal efficiencies from both local New Zealand and international sources (including an earlier International BMP database summary). The discussions provided for these summaries both have disclaimers which state that there is a wide range of reported removal efficiencies and that while there have been a number of monitoring programmes for ponds and wetlands, there is little data for less common treatment options such as porous paving. It should be noted that the tables represent ensembles of data rather than a specific treatment device, this means that they give an indication of average conditions and do not take differences in design and environmental drivers into account.

Table 1 includes removal efficiencies that have been calculated for the median influent and effluent event mean concentrations (EMCs) reported by the International BMP Database (2007 b). Removal efficiencies were also calculated for the minimum and maximum EMCs (Figure 1) and showed very similar percentages for TSS, however, removal of metals varied. Caution should be exercised in interpreting the percentage removals as it does not follow that the reported influent EMCs match those reported for the effluent.

Table 1 **Median of average influent and effluent concentrations (EMC over entire monitoring period) for selected contaminants and treatment devices (summarised from International BMP Database, 2007 b)**

			Wet Pond (n=25)	Wetland (n=19)	Bio-filters (n=57)	Media Filter (n=38)	Porous Pavement (n=6)
TSS (mg/l)	Influent		37.73	31.9	52.78	43.27	xx
			(27.61-51.55)	(18.10-53.39)	(44.12-63.15)	(33.52-55.84)	xx
	Effluent		9.74	13.38	17.84	10.85	16.96
			(7.03-13.49)	(7.25-25.81)	(12.26-25.98)	(7.57-15.57)	(5.90-48.72)
	Removal %		74	58	66	75	NA
Total Copper (µg/l)	Influent		9.84	5.65	31.93	14.57	xx
			(6.39-15.13)	(3.34-9.57)	(23.42-43.54)	(11.2-18.94)	xx
	Effluent		5.82	3.35	9.63	7.63	2.78
			(4.53-7.49)	(1.86-6.01)	(7.33-12.64)	(6.05-9.64)	(0.88-8.78
	Removal %		41	41	70	48	NA
Dissolved Copper (µg/l)	Influent		7.33	xx	14.14	7.75	xx
			(5.66-9.49)	xx	(9.64-20.75)	(5.53-10.87)	xx
	Effluent		4.35	xx	7.4	7	xx
			(3.55-5.33)	xx	(5.41-10.11)	(5.70-8.60)	xx
	Removal %		41	NA	48	10	NA
Total Zinc (µg/l)	Influent		60.75	47.06	176.71	92.34	xx
			(47.36-77.92)	(24.47-90.51)	(121.23-257.58)	(61.07-139.63)	xx
	Effluent		21.58	29.21	27.93	32.23	16.6
			(16.14-28.83)	(9.10-93.71)	(20.66-37.37)	(19.3-53.82)	(5.91-46.64)
	Removal %		64	38	84	65	NA
Dissolved Zinc (µg/l)	Influent		38.83	xx	58.1	69.27	xx
			(28.93-52.11)	xx	(36.35-92.86)	(47.03-102.03)	xx
	Effluent		29.17	xx	24.09	32.22	xx
			(17.81-47.78)	xx	(18.86-30.78)	(20.11-51.63)	xx
	Removal %		25	NA	59	53	NA

Notes:

n – number of devices included in summary statistical analysis.

xx – insufficient data for calculation.

Database contains data collected over the period 1999-2007, see website for details.

Values in parentheses are 95% confidence intervals around the median.

A difference in median concentration does necessarily indicate a significant difference between influent and effluent concentrations.

Bio-filtration includes bioretention cells, swales and vegetated infiltration strips.

Percentage removals calculated here from medians reported by the International BMP database.

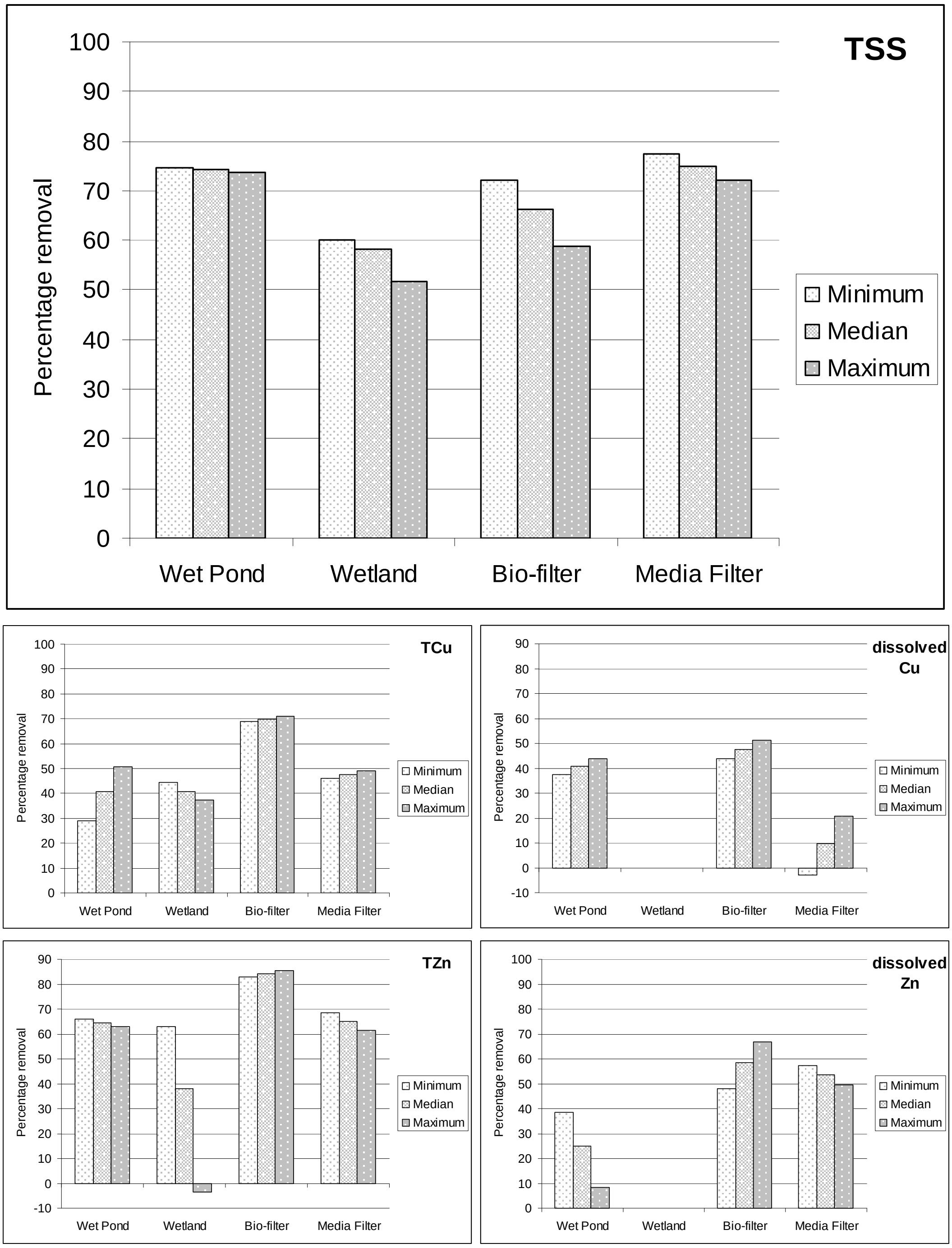


Figure 1 **Removal efficiencies for selected treatment devices and contaminants calculated from the maximum, median and minimum influent and effluent EMCs reported by the International BMP Database (2007 b).**

Table 2 Removal efficiencies for common stormwater treatment devices found in New Zealand (collated from local and international studies by Taylor *et al*., 2005)

	Sediment	Total Metals	Nutrients	Hydrocarbons
Vegetative Infiltration Devices	High	High	Mostly Moderate but some Contradictory Data	Moderate
Sand Filters	High	High for metals associated with particulates	Nitrate Increased	Low-Moderate
Alternative (to sand) Media Filters	High	High	Can be High depending on the type of media	Moderate
Ponds	Contradictory Data	Contradictory Data	Contradictory Data	Contradictory Data
Wetlands	Moderate	Moderate	Mostly Moderate but some Contradictory Data	No Data
Catch-pit filters	Low	Low	Low	Low
Hydrodynamic devices	Moderate	Moderate	Little Effect	Moderate
Treatment Trains	High	High	Moderate	High

High >75% removal with influent 10x background concentration
Moderate 20–75% removal with influent 10x background concentration
Low <20% removal with influent 10x background concentration

2.2 Wet ponds and wetlands

Wet ponds (also called retention ponds) and constructed wetlands consist of a permanent pool of water into which stormwater is directed. Water is retained until it is displaced by the next volume of stormwater. Wetlands differ from wet ponds in that they tend to be shallower (often marshy) and support plants adapted to saturated soil conditions. The purpose of both types of facility is to slow stormwater delivery to receiving waters for flow control and to improve water quality. While retained, natural physical, chemical and biological processes treat the stormwater. Settling of suspended sediments is the main form of water treatment in ponds and wetlands.

The depth, surface area, shape and location of inlet and outlet are important design factors affecting pond and wetland performance. Generally, the longer the retention time the better. The primary determinant of retention time in a pond or wetland is the live storage volume of the basin, the aim is to design facilities which are adequately sized to retain stormwater for effective sediment removal. Another aspect of pond and wetland design is the length-to-width ratio (Pettersson *et al*., 1999, Persson, 2000). The US EPA (1999 a) state that a ratio of 2:1 or more will decrease the possibility of short-circuiting and increase retention time allowing for greater settling. Baffles and islands can also be used to extend the flow pathway (Persson, 2000) assuming plug flow, though poor placement of these can introduce dead areas which reduce the active pond volume and retention time (e.g., Semadeni-Davies, 2006). Designing a pond or wetland basin to maximise flow lengths requires reliable information about the size of particles in stormwater reaching the facilities and their fall velocities. If the velocity used in design calculations is too high, the facility will be under-sized and ineffective, while a velocity that is too low can lead to over-sizing which introduces unnecessary costs. Long-term performance can be estimated on the ratio of the pond surface area to contributing source area. German (2003) found a relationship between the specific area (ratio pond surface area to contributing catchment area) and removal efficiency, however, the increase in efficiency with pond size plateaus after a specific area of 250 m^2 / ha impervious catchment surfaces.

Wetlands have their own set of removal processes related to the presence of vegetation. The choice of installing wetlands rather than ponds is often motivated by other, non-treatment related, factors such as habitat creation. There are two main design types recommended by the ARC (TP 10, 2003) that can be found in New Zealand: trapezoid (shallow basin with marginal planting); and banded (alternate pools and planted ridges). The US EPA (1999 b) list several other design types. According to the US EPA wetland plantings:

- Increase flow pathways and therefore retention times;
- Filter litter, debris and other floatables carried in stormwater though stems and foliage;
- Filter particulates as water flows through root masses;
- Provide surfaces for microbial growth therefore increasing biological uptake; and
- Provide surfaces for bonding of dissolved contaminants.

Additionally, vegetation can provide shading to keep water temperatures cool which is an important to maintain wetland dissolved oxygen. The conventional wisdom is that constructed wetlands increase water treatment over detention ponds due to the presence of vegetation, however, there are few studies which have compared treatment under similar environmental conditions. While there have been studies which show increased rates of removal for nutrients and bacteria (e.g., Bavor *et al*., 2001), sedimentation remains the primary treatment for particulate metals in wetlands (Somes *et al*., 2000; Walker and Hurl, 2002).

In a well maintained wet basin with an adequate retention time, settling removes up to 50-90% of the TSS and with it, the bulk of particulate contaminants (e.g., Schueler, 1992, cited in US EPA, 1999a). In addition to settling, between 40-80% of soluble nutrients in ponds and wetlands can be removed by biological uptake which means that these devices are often installed for treatment of organics rather than metals or other stormwater contaminants. Table 3 summarised removal efficiencies published from literature values by the US EPA (1999a and b) stormwater treatment fact sheets. It should be noted that ponds efficiencies are presented as a range of values while wetlands are presented as long-term averages. For the contaminants reported in both fact sheets, the wetland average removal efficiencies fit comfortably into the broad treatment ranges assigned to wet ponds for TSS, P and Pb but suggest lower removal of Zn. Table 1, which was prepared using data collated by the International BMP Database (2007 b), also suggests lower removal efficiencies for TSS, total Cu and total Zn than wet ponds (lack of data meant that removal efficiencies for the dissolved fractions could not be calculated for wetlands). However, there is evidence that increased TSS at the outlet in some cases is due to biogenic sources within the wetland rather than an indication of poor sediment removal (Kadlec and Knight, 1996).

The removal of metals in ponds and wetlands is complex and is highly dependant on the chemistry of both the influent stormwater and water stored in the basin. The US EPA (1999 a) states that the removal efficiencies for ponds due to settling of total Pb and Zn can range between 70-80% and 40-50% respectively. While particulate metals are able to settle with sediments, there can be changes in metal partitioning (i.e., dissolved vs. particulate metal) in the basin depending on water chemistry (notably pH). Consequent changes in metal mobility will have an impact on the total metal removal. There is also evidence of bio-accumulation of dissolved metals by basin vegetation and micro organisms.

Table 3 **US EPA (1999 a and b) percent removal efficiencies reported for wet ponds and wetlands.**

	Wet Ponds*	Wetlands**
TSS	50 - 90	67
TP	30 - 90	49
TN	-	28
Soluble nutrients	40 - 80	-
TCu	-	41
TPb	70 - 80	62
TZn	40 - 50	45
TCd	-	36

*derived from Schueler (1992)
**derived from CWP (1997)

Walker and Hurl (2002) analysed samples of settled bottom sediments from an Australian stormwater wetland. Water sampling of influent and effluent showed variable removal efficiencies (57, 71 and 48% for Zn, Pb and Cu respectively, Cr remained more or less constant and As increased by 150%) which led them to investigate possible removal mechanisms. They hypothesized that if settling is the only removal mechanism for metals that the quantity (and grain size) of settled sediment would reduce with distance from the inlet and that the relative concentration of particulate metals with grain size would be the same across the basin. The sampling found the first hypothesis was correct but that metal concentrations associated with settled sediments varied along the length of the flow path. This result suggests that other, biological and chemical, removal processes are involved.

Scholes *et al*., (1998) investigated total metal removal (Cd, Cu, Ni, Cr, Pb and Zn) for two wetlands near London. The facilities were of the same age but had different dimensions and design, and treated water from different land use types. They found similar removal efficiencies for Zn, Ni and Cr (13, 50 and 48% respectively) between the wetlands, however, one wetland had significantly lower efficiency than the other for Cd (53 and 25%), Pb (180 and 65%) and Cu (171 and 68%). The difference in removal efficiency was partly explained by differences in stormwater characteristics (i.e., inflow volumes, delivery rates and water quality) at the two sites. The better performing wetland was designed to have substrate as well as surface flows which increased the ability of dissolved metals to bond with soil particles. There was also evidence that the better performing wetland had higher biological uptake. Plant tissues too were analysed and it was found that reeds bio-accumulate trace metals and metal concentration is greatest in the roots.

Pontier *et al*. (2004) investigated treatment across different sections of a wetland treating road runoff. Water quality, sediment accumulation rates and metal concentrations and fractionation with respect to both TSS and settled solids were analysed. Their aim was to determine the fate of metals reaching the wetland. They found that the dissolved metal fraction could only be removed effectively if it were bonded onto particles which subsequently settled and that removal rates for the dissolved fraction varied with flow rates and water chemistry. The wetland they investigated received alkaline base-flow from chalky soils which was favourable to bonding with particles during retention and most metals in the basin were consequently in the particulate phase. Percentage removal efficiencies are not reported. In ponds or wetlands receiving acidic influent, the sorption rate would probably be less as there is a general increase in the dissolved metal fraction with lower pH (e.g., Dempsey *et al*., 1993; Sansalone *et al*., 1996; Sansalone and Buchberger, 1997).

2.2.1 New Zealand

Elliott (1996) found that the reduction in contaminant event mean concentrations were in the same range as reported by the US EPA (e.g., 64% for TSS, 42% for total Zn and 48% for Cu) at the Halswell Pond, Christchurch, however, the reduction in load was much greater due to significant water loss from the pond (i.e., bottom infiltration and evaporation). There was some evidence that dissolved metals were able bind to organic particles - unfortunately, pH was not reported.

Larcombe (2002) investigated the effect of vegetation on water treatment at the UNITEC constructed wetland in Auckland by comparing removal efficiencies before (1994; unpublished - taken in conjunction with the sand filter investigation described in ARC TP 48, McKergow, 1994) and after planting (2001-2). The wetland was constructed as two interconnected ponds but has since been planted and the vegetation has become well established. The results are summarised in Table 4. Both campaigns used automatic samplers to obtain composite flow weighted samples. In addition to the 1994 and 2001-2 sampling campaigns, Hickey *et al*. (1997) took a series of grab samples at both the inflow and outflow over a four storm events (one in 1995, three in 1997) to assess toxicity at the site. As flow data were not available, the event mean concentrations and contaminant loads cannot be calculated, this means that the results are not strictly comparable to the 1994 and 2001-2 field campaigns.

A total of 12 storms were monitored in the 2001-2 campaign, however, on several occasions, a storm occurred within 12 hours of the previous event which means that the stormwater entering the pond would presumably be relatively clean. Five of the events, all in 2002, were sampled over the entire duration allowing calculation of event mean concentrations and loads. The water samples were analysed for:: TSS; pH; COD; total and soluble Zn, Pb and Cu; TN and nitrate, nitrite and ammonia; and PAH (Polycyclic aromatic hydrocarbons).

Larcombe (2002) notes that the concentration of TSS in influent has been reduced since 1994 when the contributing area had some ongoing construction. Similarly, there were significant reductions in influent concentrations for the other contaminants with the exception of dissolved Cu which was only marginally higher in 1994. Hickey *et al*. (1997) recorded inflow concentrations (total and dissolved Zn, Cu and Pb) quite different to either the 1994 and 2002 values which suggests that the change in land use over the intervening period has been manifested in stormwater quality. For the contaminants analysed during both campaigns, removal improved for N, dissolved Cu and dissolved and total Zn. There was little change in removal of TCu and TPb. The removal efficiency worsened for TSS and COD. Despite the apparent reduction in removal efficiency for TSS, the colour of sediments in the influent and effluent sampled in 2002 changed from grey to brown. This suggests that the effluent sediments were organic and may have originated from the wetland vegetation which is consistent with the findings of Kadlec and Knight (1996). Biogenic sources of sediment would also explain why the total metal removal was greater than TSS removal in 2002. Thus Larcombe speculates that influent sediments were able to settle out. The reduction in COD is also probably due to increased biological activity in the wetland. It was speculated that the increased metal removal was due to the establishment of vegetation, particularly bio-uptake of dissolved metals.

Table 4 **Mean concentrations for the combined volumes of the five entire events sampled (Larcombe, 2002). compared with 1994 study average concentrations at the inflow and outflow. Units are g/m^3.**

Contaminants	Inflow		Outflow		% Removal	
	1994	2002	1994	2002	1994	2002
Suspended solids	81.2	27.6	13.5	15.2	83.3	44.9
COD	57.4	43.9	39.1	32.3	31.8	26.4
Ammonia nitrogen	0.021	0.046	0.058	0.050	-176	-8.6
Nitrate nitrogen	0.601	0.376	1.453	0.056	-141	85.1
Nitrite nitrogen	0.009	0.005	0.022	0.003	-144	40.0
Total nitrogen		0.994		0.668		32.7
Organic nitrogen		0.567		0.559		1.4
Copper total	0.0258	0.0155	0.0049	0.0032	81.0	79.3
Copper soluble	0.0056	0.0050	0.0032	0.0019	42.8	62.0
Lead total	0.0947	0.0204	0.0057	0.0005	93.9	97.5
Lead soluble	0.0024	0.0004	0.0011	0.0004	54.1	0*
Zinc total	0.225	0.161	0.071	0.023	68.4	85.7
Zinc soluble	0.097	0.089	0.052	0.012	46.3	86.5

* The zero percentage removal recorded for soluble lead occurred because soluble lead was below analytical detection limits in all samples.

Modelling to determine the long term removal efficiencies of ponds and wetlands for use in C-CALM is discussed fully in the project report by Semadeni-Davies (2008). The simulation routines have been tested against hydrological and water quality data collected at two stormwater ponds, Silverdale and Te Atatu, located in Auckland. The Silverdale pond had removal efficiencies calculated on load of 59%, 57% and 70% respectively for TSS, TCu and TZn. The efficiencies are within the range above (e.g., Table 1and Table 3) for the metals, but is fairly low with respect to TSS. The situation at the Te Atatu pond is problematic as influent and effluent samples were often not from the same events and as the long sampling interval meant that flow peaks and first flush phenomena may not have been captured. Trowsdale and Fletcher (2005), using the same data, reported maximum, minimum, mean and median concentrations of the influent and effluent (summarised in Table 5) and concluded that the pond is able to adequately treat stormwater though event based analyses of removal were not undertaken. There is some evidence that the pond is a source of total Cu.

Table 5 **Summary of sample concentrations for selected contaminants at the Te Atatu pond (collated from Trowsdale and Fletcher, 2005)**

	TSS (mg/l)		TCu (µg/l)		Dissolved Cu (µg/l)		Total Zn (µg/l)		Dissolved Zn (µg/l)	
	In	Out	In	Out	In	Out	In	Out	In	Out
Minimum	5	1	5	Na*	Na*	Na*	18	Na*	8	Na*
Mean	35	20	25	12	11	5	52	11	33	7
Median	23	9	20	9	11	4	48	10	30	5
Maximum	150	73	80	94	52	31	142	30	83	75

Na* below detection limit.

2.3 Filters

There are a number of different designs for stormwater filters including constructed sand filter chambers (see ARC TP 10 for descriptions and design criteria) and filter vaults fitted with filter cartridge units to smaller retrofit devices for manholes such as the Up-Flo^{TM} filter marketed in NZ by Hynds Environmental. Filters can also be found as part of other treatment devices such as underlying beds for porous paving and incorporated into catch-pit inserts. The type of filter fitted, its dimensions and filter medium will depend on the availability and cost of different media and local treatment needs including contributing impervious area (and therefore expected flow rates) and the type and concentration of contaminants to be treated.

There are two main treatment processes in filters: mechanical removal of sediments (i.e., settling and sieving - related to the size of the sediments relative to the pore spaces of the filter media); and chemical sorption of dissolved contaminants. A third removal process is precipitation as dissolved contaminants react with the filter medium to produce particles which can be trapped by the medium. Filter performance is dependant on the chemical and physical characteristics of the filter medium (e.g., total surface area, size of pore spaces) and water retention time in the filter (related to the inflow rate, the depth and hydraulic conductivity of the filter bed).

Filter media are many and varied with some filters designed to have mixtures or layers of media to treat different contaminants in stormwater. Sand continues to be very common in stormwater filters. Other media that have been used for stormwater treatment include: gravel, pumice (and synthetic perlite), compost and leaf litter, peat, zeolite, marine deposits (e.g., limestone and dolomite), activated carbon, soil, wood products, slag, fly ash (by-product of furnaces), porous concrete, wool pads and treated fabrics. There have been a number of studies into the use of different media in stormwater filters, some recent international and New Zealand examples are presented below. The most comprehensive studies have addressed filter hydraulics (i.e., hydraulic conductivity and risk of clogging) and breakthrough times for dissolved contaminants in order to assess the medium's suitability for long-term use in stormwater filters. The overriding conclusion of these studies is that contaminant removal processes are complex and related to the design of the filter and stormwater characteristics (i.e., flow and water chemistry). However, the choice of filter media is the single most important factor which influences the removal efficiency.

Wood products have been tested as filter media for stormwater treatment in a number of studies and include chips, shavings and bark. Jang *et al*. (2005) found high removal efficiencies for dissolved Zn, Cu, Pb and Cd in column experiments with commercially available hardwood bark mulches (upwards of 90%). They note that the removal capacity (i.e., how much of the contaminant can be retained in the material) must be assessed as well as efficiency in order to evaluate the media effectiveness over time and that bark could be a cost effective filter medium.

Färm (2002) compared combinations of peat, zeolite and both natural and synthetic opoka (a marine deposit) as filter media in a series of column experiments. Tests were carried out where the media were mixed or arranged in layers. Solutions of dissolved heavy metals (Zn, Cd, Cr, Cu, Pb) were applied to the columns and filtration was gravity fed. There was a negative relationship between metal removal efficiency and hydraulic load. Blends of opoka and zeolite were found have higher removal efficiencies than combinations with peat which was prone to wash-out and caused clogging of filter pore spaced. The synthetic opoka was less effective than natural opoka due to the presence of calcium oxide which caused pore spaces in the column to become clogged. Mixes were found to be marginally more effective than layering. Mean average removal efficiencies for ranged between 53 and 97% for Zn and 38 and 89 % for Cu with the lowest efficiencies associated with the highest hydraulic loads.

Hatt *et al*. (2007) carried out a set of seven laboratory column experiments using a 90 cm gravel bed over a 70 cm bed of sand or soil. Synthetic stormwater was applied with different flow rates to the filter. This study addressed hydraulic loading, breakthrough times and distribution by depth of contaminants captured by the gravel. Removal efficiencies were determined for TSS, nutrients (total and dissolved P, total N, ammonium and nitrate/nitrite) and dissolved metals (Zn, Cu, Pb). Removal efficiencies were greatest when flow rates were constant. For varied flow rates, which is more indicative of performance in the field, the average removal efficiencies were: 92% for TSS; 62% for Cu; 80% 38% for Zn; for Pb; and 53% for TP; 44% for TN.

Sansalone (1999) used column experiments to test plain silica sand and synthetic iron oxide coated sand (OCS) for suitability in partial exfiltration trenches. These trenches are similar in design to sand filters but are long and narrow for installation parallel to roads. The OCS breakthrough time was substantially greater than for plain sand. It was estimated that a full size trench filled with OCS could have an effective lifetime of 15 years. Removal efficiency was not reported.

Genç-Fuhrman *et al*. (2007) tested eleven sorbent materials that could be used in filters (alumina, activated bauxsol-coated sand, bark, bauxsol coated sand, fly ash, granulated activated carbon, granulated ferric hydroxide, iron oxide-coated sand, zeolite, sand and spinel) for the removal of dissolved metals found in stormwater (As, Cd, Cr, Cu, Ni and Zn). Both removal capacity and efficiency were assessed. Each material was found to have an affinity to different metals found in the stormwater test solutions. Bark and sand were found to the lowest removal capacity and were largely ineffective as sorbent materials for dissolved metals while alumina, bauxsol coated sand, granulated ferric hydroxide and granulated activated carbon (in that order) were found to be most effective for the range of metals tested.

Taylor (2006) carried out an evaluation of six different iron and steel slags to assess their suitability as stormwater filter media for the Australian (Iron and Steel) Slag Association. A literature search was also undertaken to identify and quantify the potential environmental impact of these media. Lab experiments were used to determine both removal efficiencies and hydraulic conductivity. Removal efficiency was determined using column experiments with application of artificial stormwater. Metals were in dissolved form. The hydraulic conductivity for all six slags was greater than the flow rate that could be supplied (100 000 mm h^{-1}) and no practical hydraulic restrictions are expected from the slag filters until and unless they become clogged. The slags were all able to reduce concentrations of dissolved As, Cd, Cu, Pb, Ni, Zn and N and P in artificial stormwater. Some of the slags were also able to remove Al, Cr, Mn and Mo. The removal efficiencies for the C-CALM target metals were 85-96% for Cu and 48-98% for Zn with four of the six slags having removal efficiencies > 90%. All the six slags tested have a potential as stormwater filter media as they reduced the concentrations of arsenic cadmium, copper, lead, nickel, zinc, phosphorus and nitrogen in the artificial stormwater. Some, but not all the slags also reduced the concentrations of aluminium, chromium, manganese and molybdenum.

Nanbakhsh *et al*. (2006) tested five combinations of artificial soil aggregate, sand and gravel arranged in layers within filtration units (height = 85 cm, length = 68 cm and width = 41 cm). The experiment was run over spring and summer 2004. One filter unit was planted with turf to assess whether planting can improve treatment (i.e., bioretention). Another unit was topped with paving blocks to test whether performance of filters is impaired when covered. The trial was a small scale study to determine which media combination would be most suitable for a full scale filter. A range of water quality indicators was assessed (e.g., BOD, turbidity, nutrient load, dissolved oxygen, pH, conductivity, TSS concentration), however metals were not included in the study. They found that there was no significant difference in the treatment of stormwater for the chosen water quality indicators despite the different set-ups. TSS removal was around 80% for the entire period for all the units, however, removal efficiency ranged between 66-70% in spring and > 90% in summer. This shows that while the filters behaved similarly, other seasonal environmental drivers affected the removal processes.

Up flow filters have recently been trailed by Hynds Environmental in New Zealand (Orakei Basin, Titirangi). The filter is configured so that water is forced hydraulically to flow up through a filter rather than being gravity fed. The main advantage of this approach is that the filter is able to drain and dry between events (increased filter-life, reduced risk of bacterial contamination). Additionally, as the filter gravity drains between events, backflow self-cleans the filter reducing the risk of clogging. Hence there is greater performance over time compared to conventional gravity-fed filters. Like other types of filter, the medium is a key consideration to removal efficiency. For instance, in a lab based pilot study, Pratap *et al*. (2005) found that mixes of sand with peat and compost gave better results with TSS removal averaging 50-80% for these blends compared to 40-50% for sand on its own. However, the latter media sometimes resulted in increased sediments loads as the compost was washed from the filter. In a related lab study, Clark *et al*. (2005) tested 12 combinations of filter media including zeolite, sand-peat and compost in column experiments with an up-flow configuration. These tests were followed up with full-scale tests in stormwater filters. It was noted that the media had different removal efficiencies for different metals and the degree of treatment differed for un-steady and steady state flow conditions. Overall, the peat and sand mix had the best metal removal efficiency but changed the pH detrimentally and caused some head loss. Results are reported graphically as ensembles for each medium and are not provided as percentage removals.

Dierkes *et al.*(2005) tested the suitability of porous concrete pipes as a medium to polish water that had sediments pre-treated by settling and separation. They found that removal of dissolved metals is enhanced if certain hydroxides are layered in the concrete. During a lab trial of nine different concrete pipes with and without hydroxides, they found a combination of an epoxy resin cement layered with an iron hydroxide material could remove over 98% of dissolved copper with little drop in efficiency over a 6 month trial period. This combination was tested in a full-scale prototype of an up-flow filter, stormwater in the filter sump was forced hydraulically into the pipes which are set in sand and gravel for further polishing. The influent to the filter was dosed (sediments, Cu, Zn, Pb and mineral oil) to give a similar water quality as local stormwater, and the system performance evaluated over a simulated 2 years of use (i.e., artificial flows where applied in "events" over a period of several weeks with a volume of water equivalent to 2 years in the field). The removal efficiency was 99 % for TSS and 99% and 84 % for total copper and zinc (removal of dissolved metals was very high) and 99% for mineral oils (representative of hydrocarbons in road runoff).

2.3.1 New Zealand

Sand filters continue to be common in New Zealand and their design often includes pre-settling either in a separate chamber connected with an overflow weir or in pooled water stored above the filter bed. A study of the UNITEC sand filter in Auckland, undertaken by the ARC (TP 48, McKergow, 1994) found that it exceeded the 75% target for reduction of event means concentrations and loads of TSS and total and dissolved metals (Pb, Zn and Cu). Removal of TSS and total metals was over 90% for the event mean concentrations and loads. The NZWERF online stormwater management guide (http://www.nzwerf.org.nz/publications/sw602/sw602.html) has collated the following expected contaminant removal rates (cited ARC TP10, US EPA, 1999 c) for sand filters:

- suspended solids > 75%
- total metals (copper, zinc, lead) > 75 %
- total phosphorus 33 %

- total nitrogen 21%
- biochemical oxygen demand 70%
- hydrocarbons >75%

Landcare Research has been involved in a number of studies to assess the performance of filter media available locally. These studies have involved both lab and field scale experiments with a range of filter configurations (e.g., treatment wall filters and filter beds below porous pavements). The ability of media to remove sediments, metals (total and dissolved), hydrocarbons and nutrients have been assessed.

Pandey *et al*. (2005) carried out lab experiments to test the ability of a number of natural filter media (*Sphagnum* moss; crushed limestone; waste wood pulp; wood ash and waste wool felt) at removing dissolved Cu, Zn and Pb as well as PAHs from artificial road runoff. Lime and wood ash were found to be very effective at removing both dissolved metals and PAHs. Two blends, each with 10% *Sphagnum* moss, were also tested (lime and wood ash). The best blend was the *Sphagnum*/wood ash mix which was able to remove >86% of PAHs and >94% of the heavy metals based on the relative concentrations of inflow and total leachate. This combination was further tested in the field using two "treatment wall" filters (located in Cambridge and Hamilton) and was found to be effective initially. Incidences of by-pass are not reported. Removal was determined from influent and effluent concentration, though it is not clear whether event means were compared. Initial removal rates (i.e., within one year of operation), the filters were able to remove between 60-80% of total Cu and 50-97% of total Zn. After 13 months in the field, Zn was no longer removed by the Hamilton filter, however, at the end of the monitoring period (39 months) the filter was still able to remove Cu (approx 80%) and PAHs. The Cambridge filter, which was located near heavy vehicle traffic and suffered truck spills including cream, started showing signs of deterioration after 22 months but was still able to remove the metals and PAH. It was noted that to increase filter life (i.e., prevent clogging), stormwater should be pre-treated to remove sediments particles.

A similar field test was carried out for the Tauranga District Council and the Bay of Plenty Regional Council (Taylor and Pandey, 2005) using a filter consisting of *Sphagnum* moss above a 30 cm bed of wood ash in a shallow rectangular tank (0.5 m deep by 1 m wide by 4 m long). Compared to stormwater in other parts of the country, the concentrations of TSS where found to be high while Zn, Cu and Pb were lower. Spills of fertilizer near the filter meant that P levels were very high. Flow and water quality was monitored for 14 events and EMCs were calculated for influent and effluent. The wall had a high by-pass rate (on average, only 16% of flow was treated) which was not considered in the calculations. The filter was able to remove most of the TSS (93%), total Cu (90%), and total and dissolved Zn (64% and 24% respectively), but could be a source of dissolved Cu for inflow concentrations < 3.5 µg l^{-1} (-17% average). Breakthrough of dissolved Zn occurred after 11 months, however the filter continued to remove half of the total Zn after breakthrough.

Trowsdale *et al*. (2006) carried out lab tests of six media available in Auckland: *Sphagnum* moss; smelter iron slag; a granular soil; zeolite; and a mixture of soil, compost and smelter iron slag. Contaminant retention capacity (Zn, Cu, N and P) and hydraulic conductivity were assessed in two sets of experiments. They found that all the media exceeded the minimum hydraulic conductivity required by the ARC (3 mm/h; TP 10, 2003). With the exception of the compost mix, the media were able to remove some 99% of both Zn and Cu. *Sphagnum* moss, iron slag, granular soil, and zeolite were able to retain P, but only the slag was able to remove N. The other media released N over time. Compost proved to be a source of P. The study recommended iron slag as the best overall filter media of the six.

2.4 Vegetative bio-filters

There are a large variety of stormwater treatment devices which utilise soil and vegetation to attenuate flows and remove stormwater contaminants. These devices, collectively called vegetative bio-filters, aim to restore natural physical and biological processes to urban areas by replacing impervious surfaces with permeable ones. They are usually small, serving a single source such as a roof or car park with a contributing area of < 1000 m^2. The variety of devices available means that it is often difficult to slot a particular device into a specific category and to do so can be subjective. Indeed, the International BMP Database recognises a single category bio-filtration treatment device (see Table 1). The US EPA (Clar *et al*., 2004) uses the collective term vegetative bio-filters and gives three broad categories: swales; bioretention units; and vegetated filter strips. Those categories are adopted here.

The basic design features of vegetative bio-filters are a permeable soil filter bed planted with hardy plants that are able to survive alternate wet and dry conditions. The devices should also have some form of by-pass and may include pre-settling basins. The devices are sometimes off-line so that stormwater is diverted away from the reticulated stormwater network - thus the ratio of treated to by-passed water is vital to treatment performance. Unfortunately, by-pass is not generally reported or taken into account when calculating removal efficiency. Where effluent can interact with soil and groundwater, caution should be exercised to prevent contamination. Indeed bio-filters are very often drained or lined with geo-textile to prevent contamination.

Aside from settling and local disposal via groundwater recharge, vegetative bio-filters allow mechanical, biological and chemical removal of contaminants in the filter bed. Biological uptake, particularly of nutrients, is both due to planting (i.e., with root water) and micro-organisms in the soil. In addition, there may be complexation by humic substances in organic particles (Walton *et al*., 1994). However, in common with filters, the main removal processes for dissolved metals seems to be absorption by mineral particles in the soil medium and precipitation reactions (see Section 2.3). This means that the success of bio-filters at treating dissolved metals is largely dictated by the choice of filter medium (i.e., hydraulic and chemical properties). While it is reasonable to assume that there is preferential removal of coarse sediments and associated particulate contaminants, no information about contaminant removal broken into PSD or metal fractionation was found.

Other related facilities include dry ponds, soak-holes and infiltration trenches where the aim is to provide temporary water detention for percolation into soil and groundwater between rain events. Green-roofs, where roof runoff is retained in roof top gardens can also be considered a type of vegetative bio-filter, albeit with limited storage capacity in the planting substrate and no potential for deep percolation (Villarreal and Bengtsson, 2005: Czemiel-Berndtsson *et al.*, 2006). While these facilities do provide water treatment, their primary purpose is usually for flow reduction. Hence they are not covered here. Where these structures are used for water treatment, it is assumed that the removal efficiency can be approximated by infiltration strips.

2.4.1 Raingardens and bioretention units

The US EPA (Clar *et al*., 2004) states that bioretention is a very versatile, highly flexible, multi-functional method of treating stormwater. The distinction between raingardens and bioretention units is largely subjective and the terms are often used interchangeably. In the literature, the latter term is often used to describe smaller housed units which may be isolated from surrounding soil while raingardens refer to larger devices constructed in situ. Both units and raingardens may include pre-treatment in a settling basin. Stormwater can be conveyed to raingardens via swales or infiltration strips. Unlike media filters, raingardens are often not lined allowing some interaction with local ground water, which means that there is a potential for deep percolation of contaminants reaching the base of the raingarden. Raingardens and bioretention units thus address the essential hydrological functions of natural drainage systems including interception, evapotranspiration, ground water recharge making them versatile for water quality treatment and runoff control.

The US EPA (Clar *et al*., 2004, 1999 d) notes that as bioretention is a fairly new method of treating stormwater, there are few studies available into water treatment efficiencies. The work by Davis and colleagues in Maryland is probably the most widely recognised internationally. Davis *et al*. (1998; 2003) found that upwards of 90% of TSS and total metals could be removed by bioretention. Davis *et al*. (2003) investigated bioretention of dissolved Pb, Cu and Zn both in the laboratory using two specially constructed cells and two existing raingardens, one new (around one year) and old (around 10 years). There were two lab bioretention units of differing dimensions (107 cm long x 76 cm wide, media depth 61 cm, and 305 cm x 152 cm, media depth 91 cm). Each box was filled with sandy loam and planted with creeping juniper. The field sites were different both in their planting and the filter media. In each case, artificial stormwater was applied to the surface of the bioretention units and effluent collected. They found that both the lab and field bioretention units were able to retain nearly all the dissolved metals and that the field raingardens can have an expected lifetime of at least 15 years. While influent pH, flow duration and density and water quality were varied, these factors had little impact on removal efficiency. On the other hand, the depth of the media bed influenced removal and the best removal rates were from deeper beds. However, the removal processes were not discussed; hence it is not possible to deduce the relative contribution of bio-uptake to removal. In a lab-scale test of bioretention units with a mixed medium of sand, mulch and soil, Sun and Davis (2006) found that uptake of metals by plants is relatively low compared to the retention in the medium. Retention in the medium is in turn related to both the physical and chemical properties of that medium.

Raingardens are increasingly being seen in New Zealand's urban landscape in the larger centres (see Section 2.8). In lab scale experiments carried out with local media, Zanders *et al*., (2003, cited in Taylor, 2005) and Taylor and Simcock (2006) tested a number of substrate mixes including sand, pumice, mulches, scoria and soil. For instance, Taylor and Simcock (2006) found a range of efficiencies for the different soil types summarised in

Table 6. Generally, natural sandy soils and pumice soil performed well whereas sand and a blend of pumice, granular soil and potting mix were not as effective and were source of sediment. The pumice blend and granular soils were also sources of total

Cu. The natural soils removed upwards of 80% of TSS, 70% dissolved Cu, 80% total Cu, and 98% each of dissolved Zn and total Zn.

Table 6 Summary of removal efficiencies for lab trials of raingarden planting media (after Taylor and Simcock, 2006).

	TSS	TCu	Dissolved Cu	TZn	Dissolved Zn
Sand (inert control sample)	-53	16	89	83	94
25 % Pumice + 25 % Granular Soil + 50 % Garden mix/soil	-181	-883	-6	46	85
Recent Soil (dune sand)	84	0	81	83	98
Pumice Soil	89	0	74	83	97
Anthropic Soil	3	-550	28	59	92

There have been two field studies of raingarden function in the Auckland region carried out in recent years in North Shore City (Landcare Research, Simcock *et al.*, 2007) and Waitakere City (NIWA, Reed and Pattinson, 2007). The findings of the NIWA / ARC study has not yet been published, although the data was used to develop the C-CALM raingarden / bioretention treatment module discussed in the accompanying paper (Semadeni-Davies, 2008).

2.4.2 Swales

Swales were originally used for stormwater conveyance and have only recently been adopted as a means of treating stormwater. According to the US EPA (Clar *et al.*, 2004, US EPA, 1999e) swales are dry open channels which are usually trapezoid in cross-section and are broad and shallow to maximise the wetted perimeter for infiltration. Treatment is through a combination of settling, bioretention, filtering and local disposal of infiltrate. Swale design ranges from traditional grassed ditches to engineered channels which have had infiltration enhanced by the addition of a filter bed and an under drain system. Swales are designed to store stormwater temporarily, allowing it to infiltrate into the base substrate. While retained in the swale channel, particulates are able to settle prior to filtration. Swales are usually grassed which aids water treatment by slowing flow rates (i.e. increasing the surface roughness) and filtering particulates, there may also be bio-uptake of nutrients. Planting also stabilises the soil to avoid channel erosion. Grassed swales need mowing as part of general maintenance so that flows are not unduly hindered, though this can lead to organics entering the stormwater system. Swales are often used as an early stage in treatment trains which convey stormwater from the source to larger site control devices. They are particularly common next to roads and sometimes form part of the roadside verge.

There have been very few studies about swale removal efficiencies reported in the literature. Those that are available suggest that swale length (and therefore storage capacity and retention time) and infiltration capacity are the most critical factors for treatment. Fletcher *et al*. (2002) carried out controlled experiments on swale removal efficiencies for TSS and nutrients. TSS removal ranged from 73 to 93%, removal for total N and total P ranged from 44 to 57% and 58 to 72 % respectively. Metal removal was not assessed. Removal efficiency decreased with increased flow rates. In a later study, Deletic and Fletcher (2006) assessed the performance of grassed infiltration surfaces including a section of lawn in Aberdeen where flow was directed down a channel formed by barriers set into the lawn and a swale in Brisbane. Water quality monitoring focussed on TSS; however, some nutrient analysis was also carried out. The data was collected to test a physically-based model for flow and removal of sediments under controlled flow conditions. At both sites, they found an exponential decay in the concentration of TSS as it moved down the channel. The rate of decay was related to the flow rate with lower flow rates associated with the highest sediment removal. The Brisbane swale showed removal efficiencies of around 90% with an inflow rate of 2 l/(s/m) down to 60 % for a low rate of 15 l/(s/m). In Aberdeen, removal ranged from 33-87 % with an inflow rate of 0.33 l/(s/m) and reduced to 15-25 % with an inflow rate of 1 l/(s/m). Model calibration showed that the saturated hydraulic conductivity of the underlying soil is critical for removal as it controls infiltration and therefore the volume of water reaching the outlet and the flow rate. At the Aberdeen site, they found that the parameter had to be recalibrated for each experiement as the soil became clogged with sediments which could have implications for the use of grassed surfaces for stormwater treatment. The value was measured in Brisbane. They conclude that longer swales can be expected to have greater removal efficiencies.

The US EPA (Clar *et al*., 2004) has collated removal efficiencies from a number of earlier reports (Barrett *et al*., 1993; Scheuler *et al*., 1991; Yu, 1993; and Yousef *et al*., 1985), their findings are summarised in Table 7.

Table 7 **Swale percentage removal efficiencies for a range of stormwater contaminants collated by the US EPA (Clar *et al*., 2004)**

Swale length (m)	Solids TSS	Nutrients		Total Metals			Oil and Grease
		TN	TP	Zn	Pb	Cu	
60	83	25*	29	63	67	46	75
30	60	-*	45	16	15	2	49

*Some swales, particularly the 30m systems show negligible or negative removal to TN

Bäckström (2003, 2002) investigated nine existing swales in northern Sweden during both rain and snowmelt events. Sediment removal was mainly though settling and was enhanced by trapping in grass. Removal efficiency was increased with swale length and the infiltration capacity of the substrate. While contaminant load removal was not consistently high, the first-flush was evened out. Water quality was monitored for four events at one of the swales and was found to have an average of 70% for suspended solids, 66% for both total and dissolved zinc and 34 % for total copper. It was speculated that particulate metals leaving the swale were probably bound to sediments <15µm. However, the swale was a source of dissolved copper (-27%). It was noted that trapped surface sediments are not permanently held in swales and could be flushed during high flows and that storm water with low contaminant concentrations could result in worsened water quality at the outlet. Bäckström (2003) notes that during cold winters, swales are useful as snow dumps, however, this can lead to by-pass of highly contaminated melt water, especially if the infiltration capacity is reduced due to ground frost.

New Zealand

In New Zealand, Larcombe (2003) investigated the flow hydraulics and removal efficiencies of a swale designed to the ARC criteria (TP 10, 2003). The objective of the study was to give recommendations to the ARC about optimum flow rates, slope and grass length in grassed swales.

The swale is located next to the Northern Motorway between Orewa and Albany about 1 km south of Silverdale. The swale consists of a shallow top-soil lined grassed basin divided every 150 m by a drainage grate. A 100m long section was isolated for the trial and v-notch weirs constructed at either end for monitoring. Road runoff from the motorway was diverted to the swale inflow weir. Flow was monitored from March to September 2002 (20 events) and rainfall recorded on site. The grass length was recorded throughout the trial period and it was noted that the grass was mowed on several occasions. Grass length varied between 4 and 20 cm. Flow proportional water quality samples were taken of both influent and effluent using ISCO automatic samples. Samples taken by each sampler were collected into event composites, thus the concentrations obtained can be considered representative of the event mean concentration.

It was found that flow behaviour and water treatment differed for high and low flow events. Unfortunately, during high flow events, water of unknown quality from surrounding grassed areas flowed into the swale so that the inflow exceeded outflow, this meant that removal efficiency could not be calculated reliably. Indeed, the contaminant concentrations often exceeded inflow during these events. For low flow events, there was very little water loss due to infiltration, and it was concluded that the percentage mass reduction for stormwater contaminants was essentially the same as the percentage concentration reduction. The removal efficiency for TSS ranged from 77% to -107%, the latter result is could be an artefact of the problem with isolating inflows rather than an indication of sediment flushing. Turbidity also showed differences in water quality treatment between high and low flow events. Removal for total metals ranged from 50-90% for Pb, 13-83% for Cu and 41-96% for Zn. While the efficiency was also least during high flows, the swale did not become a source of metals. A possibility, not addressed by Larcombe (2003), is that reductions in metal concentrations during high flow events were due to dilution from the water flowing from the swale side rather than water treatment. If this source of inflow did not originate from the road but from soil surrounding the swale, then it could be expected that this water could have high sediment concentrations but low metal concentrations. Removal efficiencies are also reported for bacteria and hydrocarbons.

2.4.3 Infiltration Strips or drain-fields

Infiltration strips differ from raingardens in that they are gently sloped and are not designed to pool water on the surface. These facilities are designed to infiltrate sheet wash from either adjacent upslope impervious surfaces or spread over the surface using a piped conveyance system. Infiltration strips often act as buffers between roads or car parks, and riparian strips and waterways (Clar *et al*. 2004, US EPA 1999f). They have also been used for conveyance to other treatment devices in treatment trains. They range from existing vegetated slopes to engineered systems consisting of a back-filled pit planted with dense vegetation. The vegetation acts to trap surface sediments and to attenuate flow. The overall removal efficiency is comparable to swales. In fact, in designs where flow is delivered as laterally sheet wash rather than to a discrete inlet, swale side slopes can be considered equivalent to infiltration strips.

Clark *et al*. (2007) cite a number of studies into the hydraulic performance of infiltration devices including strips and drain-fields. These show that infiltration capacity is affected by clogging and compaction. Clar *et al*. (2004) state that the efficiency of filter strips is inversely related to the flow rate and is maximised by high infiltration capacity. The rate of removal is a function of the filter medium, length, slope, soil permeability, size of contributing runoff area, particle size and settling velocity, and runoff velocity. Under moderate flow conditions, they can remove sediments, particulate contaminants and trace metals. Removal of dissolved contaminants is due to infiltration of polluted stormwater into the soil where it is retained by bio-uptake or sorption.

Gharabaghi *et al*. (2001, cited in Clark *et al*., 2007) monitored the removal of TSS from grassed filter strips. They found that a flow length of 2.44 m was able to remove 50% of the sediment but this jumped to 98% when the flow length was increased to 20 m. However, fines where not effectively removed. Removal of fines was increased when infiltrations was improved by installation of a drainage system.

New Zealand

In New Zealand, Zanders (2005) took samples of street dirt vacuumed from a length of gutter running next to a major intersection in Hamilton (Cobham Dr / Normandy Ave; 25000 vehicles per day). The site is subject to monthly street sweeping. Both PSD and heavy metal fractionation were analysed. While no testes were made with filter strips, the physical characteristics of the sediments and associated heavy metals were discussed in terms of the potential for road side vegetated strips to trap sediments of different sizes and therefore particulate metals.

Brough and Harrington (2007) presented the results of flow monitoring and modelling (MOUSE) through the Kirkwood infiltration basin in Christchurch which resembles a dry pond. Stormwater from the 4.2 ha subdivision is conveyed to the basin via swales which are at least 50 m in length. The basin consists of two facing slopes or lobes each taking stormwater from approximately half of the contributing catchment area. The system has been designed to retain runoff from the first 25 mm of rain and has under drains which lead effluent to buried soakage chambers below the basin. Excess runoff by-passes to the chambers. As part of consent compliance monitoring, grab samples were made of influent, effluent and groundwater which were analysed for hydrocarbons, Zn (total and dissolved), faecal coliforms and TSS. The samples were also tested for TN, Nitrates, Cu (total and dissolved) and E. Coli. While water quality monitoring for determination of removal efficiency requires more rigorous sampling routines, the results can give some indication of how the system is behaving. It was found that the concentration of contaminants in the influent and effluent was very low and that there was little difference between the two sets of grab samples. Given the low concentrations, it is possible that the implied poor removal efficiencies (e.g., 58%, 13 and 52% for TSS, TCu and TZn respectively) are an artefact of the relatively good water quality of the influent. That is, the concentration was at an irreducible level. Indeed, this is one of the reasons the International BMP Database warns against use of percentage removal to quantify treatment efficiency.

Ducker (2004) reported on removal of Zn from roof runoff in a vegetated infiltration strip located in Waitakere City. A down pipe conveys roof runoff from a 173 m^2 unpainted galvanised metal roof to the strip, flow is evened out over the surface using spreaders. The existing building is 15 years old with roofing material that appears extensively corroded; the strip was constructed in December 2001. The strip is about 3 by 6 m by width and length and the medium is a 50/50 blend of local topsoil and sand. The strip is lined with geo-textile with overlies a gravel filled drainage layer. Effluent from the strip drains to a pond.

Grab samples of roof runoff were made to gain reference concentrations of dissolved Zn. Effluent from a controlled constant application of artificial stormwater (1200L of 1 mg/L Zn was pumped into the raingarden flow distribution chamber at a constant rate of 7.29 L/min) was sampled to determine removal efficiency. Finally, soil was sampled and vegetation harvested to determine the fate of Zn retained in the strip. The flow experiment showed initially high concentrations of Zn in the effluent which could be due to flushing of roof runoff (which had a higher concentration of Zn than the artificial stormwater). Concentrations reduced to about 1/3 of the influent after 45 minutes and by the end of the 2 hour stormwater application period, effluent had concentrations very near the detection limit. Zn present in the harvested grass samples is significantly higher in the strip than in control samples from other parts of the lawn, and from Kikuyu grass collected from a rural area. This indicates some bio-uptake of

Zn with root water. Zn concentration in the soil was highest in the first two centimetres (approx. 800 mg/kg) and declined steadily with depth (100 mg/kg at 10 cm depth).

2.5 Street Sweeping

Street sweeping is a "good house-keeping" water treatment measure which aims at removing accumulated gross debris, litter and coarse sediments before entry to the reticulated stormwater network as wash-off and is an important first step in water treatment. Sweeping is widely practiced in New Zealand (see Section 2.8) using vacuum and regenerative sweeper truck technology. Sweepers typically scrub the road surface with water which is then sucked into a holding tank for disposal. Finer sediments and associated contaminants tend to remain on the road for subsequent entrainment following rain.

The US EPA (Fan, 2004) reviewed the sources and nature of sediments reaching combined sewers in stormwater and noted the impact of street sweeping on PSD which is summarised in Table 8. This report amalgamated PSDs and settling velocities for stormwater particles from a range of sources including the US EPA NURP study (Driscoll *et al.*, 1986 – US EPA presentation of the Nationwide Urban Runoff Program), the Construction Industry Research and Information Association (CIRIA) in the UK and Pisano and Brombach (1996). The latter presented the results of several hundred solids settling curves for a wide variety of waste types (dry weather flow, combined sewer overflow, stormwater, street solids, sediment scraping, pipe slime) collected across North America and Germany over the last two decades. Fan (2004) suggests that regular street sweeping (e.g., monthly) can reduce TSS by 15 to 20% depending on the PSD. Ashley and Crabtree (1992) found that larger particles have the highest removal rates. Liebans (2001) found that street sweeping is effective for removing sands but leaves fine sediments associated with the highest metal concentrations.

Table 8 **Potential reductions of sediments in urban stormwater due to street sweeping (after Fan, 2004)**

Particle Size (µm)	Effectiveness of street sweeping (% reduction)
>2000	80
>1000	70
>500	60
>250	55
>125	45
>62	30
>31	15

German and Svensson (2002) investigated the PSD and metal concentration of street sediments collected in Gothenburg, Sweden, prior to and after sweeping and sediments from the sweeper waste tank. As in the studies cited by Fan (2004), they found that sweeping removed coarse sediments leaving fines available for wash-off. The pre-sweeping fraction of sediments finer than 0.25 mm was 26%, this increased to 40% after sweeping. They note that the heavy metal concentration of the sediments was a function of the PSD with the highest concentrations associated with fines. However, the largest fraction of metals was associated with sand (0.125-0.5 mm) which made up the bulk of the pre-sweeping PSD at their site. This implies that even though street-sweeping does not effectively remove contaminated fines, the bulk of heavy particulate metals may still be removed depending on the local fractionation of the metals and PSD.

2.6 Catch-pits

Catch-pits are a standard component of most stormwater networks and are variously known as catch basins (especially in the United States), gully pots or gully pits, stormwater cesspits, kerb / curb inlets, and storm drain sumps. Their primary purpose is to convey road runoff from the gutter to the reticulated network. That is, they are the point to which stormwater s is concentrated and discharged to the reticulated pipe network. Catch-pits consist of a drain inlet covered with a safety grate leading to chamber or sump. A well designed catch-pit and maintained can retain up to 35-40%

of the annual sediment load in stormwater (Pitt and Field, 1998). However, sediments retained tend to be coarse grained – typically in the 250 – 2000 μm size range. Pitt and Field (2004) measured the solids removal effectiveness of 100 catch-pits and concluded that solids removal is principally a function of the rate of incoming gutter flow. Removal rates for TSS approach 45% when the inflow is discharging less than 0.005 m^3/s and is negligible for flow rates in excess of 0.139 m^3/s.

Fassman and Voyde (2007) found that the accumulation of sediment in a full size acrylic test catch-pit designed to Auckland City criteria reduced the storage capacity of the sump thereby reducing detention time and settling. Moreover, under heavy flows, turbulence in the sump caused scour and resuspension of accumulated sediments leading to high TSS concentrations in outflow water. The degree of scour increased with the depth of accumulation, that is, the depth of standing water, which protects the sediment surface from the stream of incoming water (and turbulence), is decreased.

2.6.1 Inserts

As catch-pits are the point of entry of stormwater to the reticulated network, installation of inserts to capture gross debris and sediments has become a popular first-line-of-defence for water treatment. While there are other types of catch-pit inserts available, filter bags are the main type of insert on the market in New Zealand and are becoming widely used, particularly in Auckland. For example, the North Shore City Council website (http://www.northshorecity.govt.nz/) states that more that 300 bags have been installed by the council since 1996. Part of their appeal is that they are cheap to install and require no catch-pit reconstruction for retrofitting. There are several brands available in New Zealand (e.g., Enviropods, ConstructionPods, Ecosol RFS 100).

The insert is designed to gravity filter sediments and gross debris entering the catch-pit and consists of a mesh cage or support frame suspended below the catch-pit grate which is fitted with a fine weave geo-textile filter bag. Typically, the frame can be adjusted in size to fit catch-pit dimensions. The purpose of the frame is to ensure that bags are not washed away during high flows. The bags come in a range of materials and mesh sizes and can be removed and changed. Rubber flanges extending from the catch-pit inlet direct flow into the frame and prevent leakage into the sump. The by-pass slots on the frame are designed to reduce the risk of wash-out or resuspension. Even so, the US Federal Highway administration fact sheet (website last visited on 11 Jan 2008) on catch-pit inserts states that due to the very short contact time and potential for flushing of previously trapped materials, treatment may be compromised at higher flow rates. There is also a potential for clogging, hence the bags must be adequately maintained and should be emptied and laundered regularly – between 3 and 6 months. Hynds Environmental recommends that Enviropod bags are changed when they are 1/3 full.

Several studies into removal efficiencies are cited below. The general consensus is that they are reasonably effective for the removal of gross pollutants (i.e., litter) and coarse sediments greater than 100 μm. Filter bags should therefore be installed as part of a treatment train rather than a stand-alone treatment option.

Enviropods seem to be the most common filter bag in New Zealand and are available from Stormwater360° (formerly Ingals), Hynds and Humes. They are widely used in the Auckland Region and several local field and lab testing programmes have been carried out. A lab evaluation of Enviropods, along with Flogard filter bags, for Auckland City Council (Butler *et al.*, 2004; McQuillan and Menzies, 2004) found that both types of filter bag were able to remove 78 to 98% of street sediments. Practically all particles >100 μm were removed, however, the efficiency was only 15 to 20 % for particles <100 μm. The testing was carried out at Auckland University using a full size model of a catch-pit with well defined stormwater sediment characteristics.

A comprehensive field investigation was carried out by the Enviropod NZ Ltd (2001) for North Shore City Council. A total of 294 Enviropods were installed around the city grouped into representative street sub-catchments (Takapuna Beach, Lake Pupuke, and Kaipatiki catchments, Browns Bay, Birkenhead and Milford). The sub-catchments have different traffic and organic loadings. Each area was supplied bags with mesh sizes selected for the local sediment characteristics – thus Takapuna (200 μm mesh) had a coarser mesh than Lake Pupuke (100 μm). At the end of the trial period which varied depending on the site and sediment characteristics, the bags were inspected to determine, amongst other factors, the remaining capacity, degree of clogging and evidence of overflow. Additionally, material collected in the filter bags from Takapuna Beach, Lake Pupuke and Kaipatiki was sampled and analysed for moisture content, metal concentration, sediment PSD and nutrients. The bags were found to be effective at removing coarse sediments as long as they were correctly maintained. The PSD of retained sediments showed that while the bulk of sediments were >2800 μm, the Takapuna and Kaipatiki filter bags had 22.5% and 26% respectively of sediments <63 μm. On the other hand, only 2.6 % of retained sediments at Browns Bay were <63 μm. Unfortunately, the incoming PSD for these catchments is not provided and there are no comparisons available between influent and effluent sediment or contaminant concentrations, hence removal efficiencies cannot be determined. Even so, the conclusion that particulate metals associated with coarser sediments were effectively removed seems reasonable.

The ARC commissioned an *in situ* evaluation of an Enviropod (100 µm mesh) installed in a catch-pit on Wairau Rd (Diffuse Sources Ltd, 2001). Flow through the catch-pit was monitored for 213 days and influent and effluent were sampled for sediment concentration during eight storm events. Metal removal was not investigated. The collected sediments were also analysed for PSD at the end of the field trial. The removal efficiency for sediments varied from event to event (between 49 and 95 %) with and average of 80% removal. The event with the lowest removal efficiency had high flows leading to by-pass. The bulk of sediments removed were coarse, >100 µm.

In addition to the Auckland evaluations cited above, the Stormwater360° website (http://www.stormwater360.co.nz/) has online reports on Enviropods from across Australasia showing similar results (registration required for downloads). Studies from other parts of New Zealand could not be found.

Ecosol (http://www.ecosol.com.au), an Australian company, market a filter bag with a 200 µm mesh similar to Enviropods, called the RSF 100 (Rapid Stormwater Filtration). Ecosol provide downloads of reports into the use and efficiency of their bags prepared by a number of local authorities in Australia and state that the bags have been installed at over 10 000 locations in Australia and internationally including New Zealand (e.g., Tauranga). Quoted directly on their website are the results of independent testing carried out by the University of South Australia (National Australian Testing Authority accredited). The bag was tested under lab conditions using a full size rig of a catch-pit. They state that the bag can capture 95 % of pollutants >1.5 mm and has a minimal hydraulic impact on flows entering the catch-pit. The results of the lab testing are summarised in Table 9.

Table 9 **Summary of lab evaluation of the Ecosol RFS 100 filter bag (evaluation by University of South Australia, cited on Ecosol website)**

Contaminant	Removal Efficiency- (%)	Description
Gross pollutants	95	Litter including cans, bottles, plastic bags etc. (generally >1.5 mm in diameter)
Vegetation	Up to 94	Organics including leaves and grass clippings (generally >200 μm)
Sediment	94	>200 μm
	65	> 100 μm
	53	> 50 μm
TSS	65	Inorganic solids suspended in water
Total phosphorous	40	Bound to suspended solids and organics
Total Nitrogen	21	Organic and inorganic forms
Hydrocarbons	Up to 20	Free floating oils that do not emulsify in aqueous solutions

2.7 Porous Paving

There are two broad categories of porous paving: paving blocks where water infiltrates a porous infill between blocks; and permeable asphalt or concrete. Porous paving is usually used as an alternative to normal paving for small areas such as car parks. There are two potential mechanisms for water treatment: loss of infiltrated stormwater to groundwater recharge (i.e., local disposal); and filtering of infiltrated water in the underlying substrate. Additionally, paving blocks can be planted with grass as a form of bioretention. The paving is underlain with a porous substrate such as layers or gravel or sand and may have under drains or a geo-textile lining (i.e., trapping of fines from percolating water) if potential groundwater contamination is an issue. The US EPA (1999g) issued a fact sheet on the installation and maintenance of porous paving using asphalt and concrete. The fact sheet notes that clogging can be an issue and paving needs regular maintenance (e.g., sweeping, suction, water blasting) to ensure continued removal. Clogging is a recurring theme in the studies cited below. Porous paving has largely been used as a runoff control measure, and as can be seen in Table 1, there are very few studies available about their potential for water treatment.

Abbott and Comino-Mateos (2003) examined the hydraulics of porous paving blocks overlying a layer of stone chips, both underlain by a geo-textile lining. The porous paving formed the outer edges of a tarmac covered car park. The system was found to both attenuate flow and reduce peak volumes of runoff, but was prone to clogging by oil and sediments. No water quality information is given.

Bäckström (2000) examined the ability of porous paving to function hydraulically during cold winters and measured *in situ* frost heave, ground temperature, groundwater levels and runoff between 1994 and 1997. Lab tests in a cold room were also carried out for a range of paving materials. He found that porous paving is still able to function when frozen though the infiltration capacity may be reduced. No water quality information is given.

Legret and Colandini (1998) carried out a long-term study of porous asphalt *in situ* in Rezé, France. They found the asphalt can be effective at trapping heavy metals (Pb, Cu, Cd and Zn). After eight years of operation, it was found that particulates were deposited in the upper 2 cm of the asphalt and that contamination of underlying soil was not significant and was confined to the first 20 cm of the soil. Approximately 10% of Pb, 60% of Cu and Zn and 85% of Cd infiltrated with stormwater to the geo-textile and soil layers. Effluent from the under drain had less than 3% of the influent metal load. Also in France, Baladès *et al*., (1995) found much lower removal efficiencies. Some 50-60% of heavy metals (Pb, Cd and Zn) and suspended solids were retained in porous paving. They did not find that the paving itself was able to trap metals. However, clogging can reduce inflow to 50% of the original rate after 2 or 3 years of operation. In a related study, Colandini *et al*., (1995) sampled the material clogging the pores of pervious asphalt which was analysed for PSD, heavy metal concentration and fractionation and potential metal mobility in order to gain an insight into the interaction between heavy metals and sediments in the paving. The sediments were mainly in the sand fraction and were contaminated with Pb, Cu, Zn and Cd. The concentration of the metals was linked to traffic intensity. Not surprisingly, the finer particles had the greatest metal concentrations.

Brattebo and Booth (2003) evaluated the long term performance of four commercially available porous paving products for both runoff control and water quality treatment. In their study nine parking stalls in a car park where used for the study, eight were paved in pairs with porous paving and the ninth covered with asphalt as a control. The stalls were isolated from each other to avoid subsurface horizontal flows and effluent was collected from separate drains. The paving used were two brands of plastic grids with intervening spaces filled with sand and two brands of concrete paving lattice paving. Of the concrete paving, the first was about 60% impermeable, filled with soil and planted with grass; the second was about 90% impermeable and filled with gravel. After six years in operation, the paving showed almost complete infiltration of runoff. Flow was monitored for a total of 15 rain events and composite samples were taken from the control and each paving trial for 9 events. Water quality was compared to the runoff from the impervious asphalt stall. The surface runoff from asphalt had significantly higher concentrations of motor oil, Cu and Zn. No sample had detectable diesel or Pb concentrations. The different brands of paving had comparable results. Water quality was compared to local quality criteria. The runoff over asphalt had toxic concentration of contaminants for 97% of the samples. In contrast, 31 of the 36 effluent samples from the parking stalls with porous paving fell below toxic levels and most samples had concentrations below detectable levels. They conclude that porous paving offers long term water treatment for contaminated stormwater.

2.7.1 New Zealand

In New Zealand, Taylor and Trowsdale (2005) assessed a number of filter media for use as substrates in combination with a commercial paving blocks consisting of artificial stone-chip aggregates. The work was undertaken for the Waitakere City Council using a series of lab tests (note that some of the tests had been carried out as part of earlier studies but the methodology was the same). The filter media tested were: *Sphagnum* moss; wood ash; *Sphagnum* moss blended with wood ash; iron slag; Patumahoe soil; zeolite; sand; and a mixture of soil, compost and iron slag. The hydraulic conductivity of the pavers and the filter media were assessed as were the removal efficiencies of the media for TSS and dissolved metals. The media were not tested in combination with the pavers so the study cannot give a true indication of potential treatment. Iron slag was recommended as the best substrate option on the basis of its hydraulic conductivity and removal efficiency (100% for Cu and Zn). The *Sphagnum* moss and wood ash blend was recommended as a second choice (97% of Cu and Zn).

There has been a recent study on the suitability of porous asphalt as a long-term roading surface (Herrington *et al.*, 2007) and was found to have potential in New Zealand. The focus on this report was on the structural integrity of the material, water quality was not addressed. Transit New Zealand is planning research into porous paving as part of the Long Term Pavement Performance Programme (LTPPP), but information on water quality is not yet available.
http://www.transit.govt.nz/content_files/technical/LTPP-Brochure-2007.pdf

2.8 Treatment trains

Treatment trains are conspicuous by their absence in stormwater removal performance literature. The idea behind treatment trains is to combine treatment facilities designed for different operational scales and target contaminants to optimise water treatment. A train combines two or more treatment facilities and could typically include swales and infiltration strips (source control) to convey and pre-treat stormwater for further treatment in larger facilities such as filters or wet ponds (i.e., site and catchment control). It has already been noted above that many treatment devices such as raingardens and sand filters are often designed with small pre-settling basins which can be considered part of a treatment train – however, the removal efficiencies for these facilities usually include the pre-treatment in the total so that the relative effect of each component cannot be separated.

It is important to realise that treatment trains have a profound effect on the hydraulic loading of individual structures in the train and that flow reaching downstream facilities will have reduced peak flows and total volumes, and attenuated flow. Villarreal *et al*., (2004) demonstrated this by modelling flow through a train of stormwater control facilities in Malmö, Sweden. The devices where arranged in both series and parallel and included open channels, green roofs, porous paving, a miniature wetland, dry ponds, and a shallow wet pond. The system was retrofitted for flow control to disconnect stormwater from a combined sewer in order to reduce incidences of combined sewer overflow and basement flooding. The study showed that linking stormwater control devices has the potential to balance out water delivery under even extreme rain events (e.g., the 10-year design rainfall) and it was estimated that the occurrence of combined sewer overflow could be reduced by up to 75%. While no water quality data were assessed as part of this study, other studies on the individual devices in the train have shown that they have the potential to improve stormwater (e.g., Czemiel-Berndtsson *et al*., 2006).

There has been some work on modular treatment units which resemble treatment trains in miniature. The US EPA (1999h) evaluated the StormTreat^{TM} system which is a 2.9m diameter drum 1.4 m high sectioned into a hub and outer rim. The inner hub contains a fabric filter bag and sedimentation chambers including surface skimmers for pre-treatment. Effluent from the hub flows to the rim which contains soil planted with wetland vegetation. The system is designed for small contributing areas but can be used for larger areas in parallel. Amongst other contaminants, the system is able to remove 99% of TSS, 77% Pb and 90% each of Zn and hydrocarbons. Pitt *et al*., (1999) describe a small scale treatment train unit consisting of a grit chamber for gross sediment removal, settling chambers and a peat moss / sand filter for polishing. A pilot-scale unit was tested at a car park with sampling over 13 events. The system removed 100% Pb, 91% Zn and 98% for SS and particulate associated contaminants.

In New Zealand, Simcock *et al*. (2006) carried out grab-sampling of the Landcare treatment train in Tamaki. This system is fairly unique in New Zealand and consists of a permeable car park draining to an engineered vegetated swale and a raingarden. The grab samples suggest high removal (90%) for TSS, moderate removal of dissolved Zn (67%) and low removal of dissolved Cu (11%). It was noted that proportionate sampling of stormwater quality over several inflow events is required to confirm these results.

It should be noted that the relative performance of a device in a train would depend on its position in the train configuration both due to the up-stream effect on water delivery (i.e., flow reduction and attenuations) and water quality of other devices in the train. Thus, even if treatment train information were more available, the results would be very site specific and not open to generalisation in a model such as C-CALM.

3. Phone Survey

A phone survey was undertaken to ascertain what treatment options are being used in New Zealand and the level of knowledge of how well these options perform. Participants were given a brief description of the C-CALM project and were asked which treatment options where used in their jurisdiction and whether any treatment efficiency monitoring had been carried out for those options. Finally, they were asked if they would be interested in using a model like C-CALM and what modelling tools (if any) they currently have access to. Each participant was then sent a copy of their survey replies and a one page description of C-CALM (reproduced in Appendix 1). Most participants were positive about the survey and showed interest in C-CALM as a product they would use. However, no new information on treatment efficiencies was uncovered. The reply sheets are presented in Appendix 2.

All the Regional and Unitary authorities were approached along with a selection of territorial authorities (TLAs) covering the main centres with the exception of Auckland. The situation in Auckland is well known to NIWA and stormwater practitioners in the region have been contacted earlier regarding the availability of data for C-CALM, hence neither the ARC nor TLAs were approached for the survey.

Generally, Auckland, Wellington and Christchurch seem to be leading the country in terms of take up of not only stormwater treatment in general but devices which can be considered low impact. Wet ponds, street sweeping and road side swales are found in most parts of the country while newer technologies such as raingardens seem to be restricted in their distribution to the main centres. Many of the ponds have not be en designed for stormwater treatment *per se* and were originally constructed as sediment basins during bulk earthworks. Some of the participants mentioned that LIUDD with respect to stormwater has been discussed favourably within their organisation and developers are being encouraged to take up sustainable water practices. Indeed, several participants noted that there are new developments planned in their area that will have some form of treatment device.

There is very little information on treatment efficiencies in New Zealand and most monitoring carried out is for consent compliance which tests effluent against set water quality standards (e.g., ANZECC). Some regions have adopted ARC stormwater design criteria without adaptation to local conditions.

3.1 Survey questionnaire

Contact Phone**:**
Contact person

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands		
Raingardens		
Bio-retention cells or planters		
Swales or infiltration trenches		
Street Sweeping		
Porous Paving		
Filters		
Catch-pit inserts		

Comments on water treatment in area.

Would your organisation be interested in using a GIS-based stormwater quality model?

Does your organisation already have access to stormwater modelling packages?

4. Recommendations for C-CALM treatment simulation

4.1 General assumptions

With the exception of sediment (and particulate Zn and Cu) removal from wet ponds, wetlands and raingardens, C-CALM will simulate stormwater treatment according to percentage removal efficiencies reported in the literature. The review above has revealed that removal efficiency of a particular stormwater treatment option is highly site and event specific and depends on the environmental drivers at the site (land use, geology, topology, topography hydrology and climate), water chemistry (e.g., pH) and the type and design of the treatment facility. However, most of the studies cited do not contain information on the wider environment; moreover, many of the studies were laboratory based, particularly for filters, which means they are not representative of field conditions. Developing a relationship specific to locations in New Zealand would require more information than is available. While it can be speculated that, for instance, regions with fine sediments (e.g., Christchurch loess soils) will have less successful treatment than areas with course sediments, there is not enough information to quantify the reduction in removal efficiency. Similarly, rainfalls around the country vary in frequency, intensity and duration – which will influence the design and function of stormwater treatment facilities. It should be noted that several studies provide data as an ensemble which means that performing statistical analyses of the efficiencies reported is open to possible bias. Hence, C-CALM can only give an indication of treatment.

In order to provide flexibility in the simulation of water treatment, C-CALM will offer users a range of treatment efficiencies for each contaminant and treatment option (i.e., optimal, average and poor) based on the efficiencies cited above. Users will be asked to select the appropriate level of treatment according to *a priori* knowledge.

4.1.1 Particle size distribution

The PSD of stormwater sediments and its impact on water treatment are detailed in Semadeni-Davies (2008). C-CALM will offer a choice of five PSDs to cover different ranges of sediment sizes, each with five sediment size bands initially containing 20% each of the sediment load (Table 10). These have been scaled up and down form the NURP (US EPA Nationwide Urban Runoff Program, Driscoll *et al.*, 1986) fall velocity classes. Sediment size was calculated using Stokes' Law or Rubey's equation assuming spherical particles and a water temperature of 20°C. However, due to the lack of data on sediment characteristics with respect to water treatment in the literature, removal efficiencies as a function of the sediment particle size distribution (PSD) will only be available in C-CALM for ponds and wetlands (where removal is modelled as a function of fall velocity and therefore PSD), street sweeping and catch-pits. All other treatment options will assume that sediment removal is even across the spectrum of sediment sizes. Similarly, the lack of information on metal fractionation with respect to water treatment means that it is assumed that the load of particulate metals is also split evenly across the five sediment bands.

Table 10 Fall velocities and PSD used to develop the performance rules (Semadeni-Davies, 2008)

Band	Particle mass in stormwater (%)	Density* (kg/m^3)	Medium Grain - NURP		Fine Grain		Medium Fine Grain		Medium Coarse Grain		Coarse Grain	
			Velocity (m/h)	Grain size (µm)	Velocity (m/h)	Grain size (µm)	Velocity (m/h)	Grain size (µm)	Velocity (m/h)	Grain size (µm)	Velocity (m/h)	Grain size (µm)
1	0-20	1300	0.009	4	0.001	1	0.005	3	0.014	5	0.09	5
2	20-40	1600	0.091	9	0.009	3	0.046	6	0.137	11	0.91	17
3	40-60	1900	0.457	16	0.046	5	0.229	11	0.686	20	4.57	37
4	60-80	2300	2.134	29	0.213	9	1.067	20	3.200	35	21.34	80
5	80-100	2650	19.812	78	1.981	25	9.906	55	29.718	96	198.12	380**

* Densities taken from CRCCH (2005)

** Calculated using Rubey's equation

4.1.2 Metal Partitioning

The concentration, partitioning and fractionation of metals are related to the metal source, accumulation time between events, particle concentration and PSD and rainfall intensity. This means that there is a high degree of variability in time and space.

Sansalone *et al.* (1995) investigated the hypothesis that heavy metal concentrations are significantly correlated to suspended solids concentrations in highway runoff. Runoff data from eight highway sites in the United States and Europe were analyzed to test this hypothesis and showed a strong positive correlation between heavy metals and suspended solids. This finding has implications for areas with busy roads as traffic is a major source of both sediments and metals in stormwater (e.g., particulate zinc form tyre wear and tear). Lin (2003) found that Cr, Cu, Zn, As, Cd and Pb in urban rainfall-runoff are primarily associated with particulates, but a significant proportion of As and Cd can be found in the dissolved fraction. The use of unpainted galvanised steel as a roofing material in New Zealand presents a problem for stormwater quality as it is the primary source of dissolved Zn (Timperley *et al.,* 2004 c).

Metal mobility (i.e., dissolved fraction) increases with stormwater acidity and varies from site to site and from event to event.. Dempsey *et al.* (1993) found that the pH of stormwater was a major consideration for metal mobility and that there is desorption of metals originally bound to particles in suspension over time. However, if the pH remains above 7 (neutral – alkaline) particulate metals are fairly stable and can be treated in stormwater devices which remove sediments. Sansalone *et al.* (1996) and Sansalone and Buchberger (1997) too found that metal mobility increases in acidic stormwater. They looked at the partitioning of metals and solids in highway runoff and found that metals partition into dissolved and particulate fractions as a function of pH, pavement residence time, and solids concentration. Results indicate that Zn, Cd and Cu are mainly in dissolved form while Pb, Fe and Al are mainly in particulate form (cf. Lin, 2003 cited above). The dissolved metals exhibit a strong first flush, the fraction of dissolved metals increased with decreasing rainfall, pH and increasing average pavement residence time.

NIWA has carried out a number of programmes in recent years which look at the sources, transport and toxicity of metals in Auckland stormwater (e.g., Timperley *et al.,* 2004 a, b and c). Samples from Richardson Rd showed that particulate Zn was 51 % of the total Zn load and the particulate Cu load was 25 % of the total copper load. Dissolved lead concentrations in natural waters are usually very low and this was also the case for stormwater. The load for dissolved Pb was only 2 % of the total lead load. The proportion of particulate Zn seems to drop initially as sediments are transported in stormwater before the metal is again absorbed on to particles. Generally, as stormwater moves away from the contaminant source, the particulate fraction was found to increase as metals became absorbed onto sediments. Furthermore, the concentrations of Cu and Zn bonded to fine particles increases during transport. However, this picture is complicated as metals bound to particles at the sediment source can be released into stormwater. Hence, at least initially, the dissolved fraction of metals can increase before decreasing. This kind of relationship seems to be fairly unique to Auckland (or has not been examined closely at other locations).

Metal partitioning has been invested at NIWA for various sites in Auckland city and detailed analysis of metal partitioning has been carried out for stormwater samples from Oakley Creek, Richardson Rd. (e.g., Timperley *et al.*, 2003; 2004; 2005). Timperley *et al.* (2004) explored the theoretical relationship between sediment size, SSA and metal sorption. The theoretical relationship of metal content and particle size was then tested for Zn with rather surprising results:

- there seems to be only a weak relationship between sediment size and Zn content, the form of this relationship changes as the sediment moves through the urban stormwater system from streams to estuaries

- the proportion of particulate Zn seems to drop initially as sediments are transported in stormwater before the metal is again sorbed on to particles.

Generally, as stormwater moves away from the contaminant source, the particulate fraction was found to increase as metals became absorbed onto sediments. Furthermore, the concentrations of Cu and Zn bonded to fine particles increases during transport. However, this picture is complicated as metals bound to particles at the sediment source can be released into stormwater. Hence, at least initially, the dissolved fraction of metals can increase before decreasing. Timperley *et al.* (2004) refer to this characteristic drop in the particulate fraction followed by a rise as stormwater flows through Auckland's stream network to estuaries as "U-shaped".

Timperley *et al.* (2005) examined sources of dissolved and particulate metals in Auckland stormwater in order to model metal loads. Primary sources were roads (increasing with traffic counts) and roofs (especially Zn); other sources listed include soils and building walls. The data accumulated for road runoff was used to develop high temporal resolution models for sediment and metal loads from this source. Particulate metal concentration was modelled using a simple accumulation wash-off model whereas dissolved metal content was found to be related to the mass concentration of particulate metals with respect to sediment (i.e., mg/kg) rather than the volume concentration (i.e., mg/l). Thus, the dissolved metal concentration in contact with sediment containing, say, 1000 mg kg^{-1} of metal, would always be about the same irrespective of how much of the sediment was present. This allowed them to use simple linear regression to determine the both dissolved Zn and Cu.

Timperley (personal communication, 2008) estimates that for road runoff in Auckland, the dissolved proportion makes up around half of the total Zn load and 75 % of the total Cu load. The load for dissolved Pb was only 2 % of the total lead load. On the basis of the ARC rooftop metal source study (TP 213, 2003), Timperley states that the dissolved fraction for both Zn and Cu is around 95% for roofs, which reflects the fact that sediment yields are low. Finally, Timperley estimates the dissolved fraction from permeable surfaces (i.e., soils) to be around 5 %, and the metal concentration from these surfaces are indicative of the environmental background signal.

Also in Auckland, Bibby and Webster-Brown (2005) compared the concentration and partitioning of Cu, Zn, Mn, Fe and Pb in urban and rural streams. Sediments from the different catchments were characterised by their size and physical properties into four groups: fine inorganic grains which make up a sediment matrix (<2 µm); angular crystals set in the matrix (1-20 µm), agglomerates (1-50 µm) and diatoms or other organic materials (5-50 µm). The type of sediment found in the different catchments was related to catchment size and geology rather than land use. Little difference was observed between the ability of the non-urban Waikato and Kaipara River sediments and urban catchment sediments to adsorb trace metals. However, the trace metal concentrations in the water column of the non-urban streams were significantly lower than in urban streams irrespective of flow or sediment class. Furthermore, they found no clear relationship between Zn, Cu and Pb content of the sediments and the sediment concentration which they suggest indicates that the metal content of the sediment is related to landuse. Within the urbanised catchments, the ratio of dissolved to particulate metal concentrations varied between sites. For instance, the East Tamaki site, which has higher pH compared to other sites, had higher binding rates and therefore particulate metal contents.

The uncertainty surrounding contaminant partitioning has great implications modelling within C-CALM given the requirement for a simple national model. Water chemistry is demonstrably complex with spatial and temporal variation and there is no clear guidance in the literature. The relationship between water pH and metal partitioning has already been discussed with reference to ponds and wetlands in Section 2.2. Other factors include the type (e.g., organic content and structure), PSD and concentration of sediment and the retention time of the contaminants in stormwater as well as stormwater salinity and redox conditions.

Bibbey and Webster-Brown (2006) demonstrate the complexity of physically-based modelling of partitioning. They used simulation as a tool to understanding binding of trace metals in Auckland urban streams compared to rural catchments in the region (see Bibbey and Webster-Brown, 2005, cited above). They used a diffuse-layer, surface complexion model to estimate the relative proportions of dissolved, absorbed and precipitated phases of Zn, Cu and Pb. The model allows for the electrostatic influences of charged surfaces in the surface complexing reactions between trace metals and amorphous metal oxides. Under the simplifying assumption that Fe-oxide was the only adsorbing surface they showed good agreement between observed and modelled adsorption for Pb, indicating the importance of Fe-oxide surfaces for Pb adsorption. However, the model did not predict Zn or Cu adsorption as well. The total organic carbon content of the sediment and presence of dissolved ligands and organic matter in the water column appeared to play an important role in Cu adsorption. For Zn, the presence of adsorbing surfaces other than Fe appeared to influence adsorption. They also found that pH has a great influence on binding. On the basis of earlier work (Bibbey and Webster-Brown, 2005, cited above), they postulated that changes in flow rate which change the composition of urban sediments could also change the partitioning of trace metals. Similarly, seasonal changes in pH and organic content could be a factor in partitioning.

More simply, Johansson *et al.* (2001) reviewed a number of studies which model the particulate fraction of various dissolved substances found in lakes according to statistical relationships between partitioning ratios and water chemistry and sediment variables such as pH and organic content. For practical purposes, the ratio of particulate to dissolved concentrations with respect to the sediment concentration can be used to derive a partition coefficient K such that:

$$K = \frac{C_p}{SPM\ C_d} \qquad \text{Equation 1}$$

where SPM is the suspended particulate matter concentration in mass dry weight per volume (kg/l), C_d is the dissolved concentration (kg/l) and C_p is the particulate concentration (kg/l). Physically, K describes particle affinity and represents the chemical equilibrium of numerous processes such as sorption onto particulate matter, precipitation and dissolution. K is not constant and varies with the factors given above.

Given the simplicity of the C-CALM model which will relate total annual metal yields empirically to the type of surface associated with landuse, it is suggested that a statistical relationship derived from stormwater flow and water quality data collected by NIWA in Auckland between 2001 and 2003 (data summarised in Table 11) be used. The catchments have a range of land uses including predominantly park (e.g., Motions), industrial (e.g., Onehunga), residential (e.g. Cox's Bay) and commercial (e.g., CBD). The data come from a variety of sources including stormwater and combined pipes and urbanised streams draining stormwater - this could lead to both higher sediment concentrations (e.g., channel and bed erosion) than may be expected from stormwater and dilution (i.e., mixing with stream baseflow) of the contaminant concentrations transported to the streams. There may also be desorption or absorption of metals in stream. None-the-less, the method can give an indication of the relationship between sediment and total metal loads and partioning with the caveat that other regions may have different relationships that can be used in C-CALM as data become available.

Table 11 **Summary of water quality data collected in Auckland catchments by NIWA between 2001-2003**

	Commercial	Residential				Mixed		
	CBD	Cox's Bay	Meola	Mission Bay	Remuera	Motions	Oakley Creek	Onehunga
Number of samples	162	60	71	177	72	110	182	138

A relationship was found using multiple linear regression with total metal and TSS loads (calculated as the product of concentration and instantaneous stream discharge, l/s) as predictors for the particulate metal load. The dissolved fraction is then the particulate metal load subtracted from the total load. Regression analysis was initially carried out for each catchment separately, and it was noted that the equations were very similar; hence the data was pooled into a single analysis. Some 972 samples were available for the regression. The intercept was set to zero. The coefficient of determination (R^2) was 0.97 for Cu and 0.96 for Zn. The recommended relationships are given in Equations 2 and 3. Figure 2 shows the degree of fit between the observed and predicted loads instantaneous particulate metal loads. The low coefficient for TSS in each equation is indicative of both the relative difference in the magnitude of TSS and metal concentrations (around 1000 times for Cu and 100 times for Zn) and the different sources of sediments with respect to the metals from the catchments. The scatter is due to the different environmental conditions both between catchments and events. According to equations, low TSS load with respect to the total metal load will result in a higher proportion of dissolved metal and vice versa.

$$PCu = 0.778TCu + 2.74x10^{-5}TSS$$ Equation 2

$$PZn = 0.554TZn + 0.004231TSS$$ Equation 3

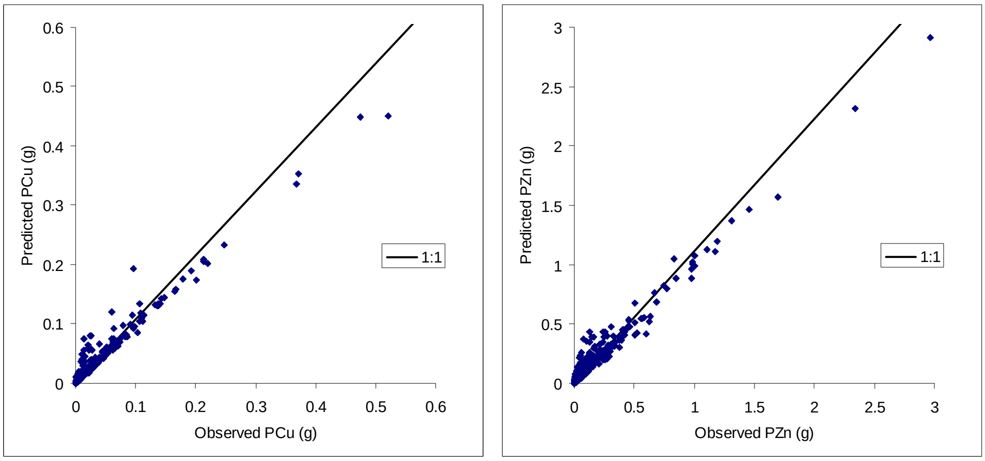


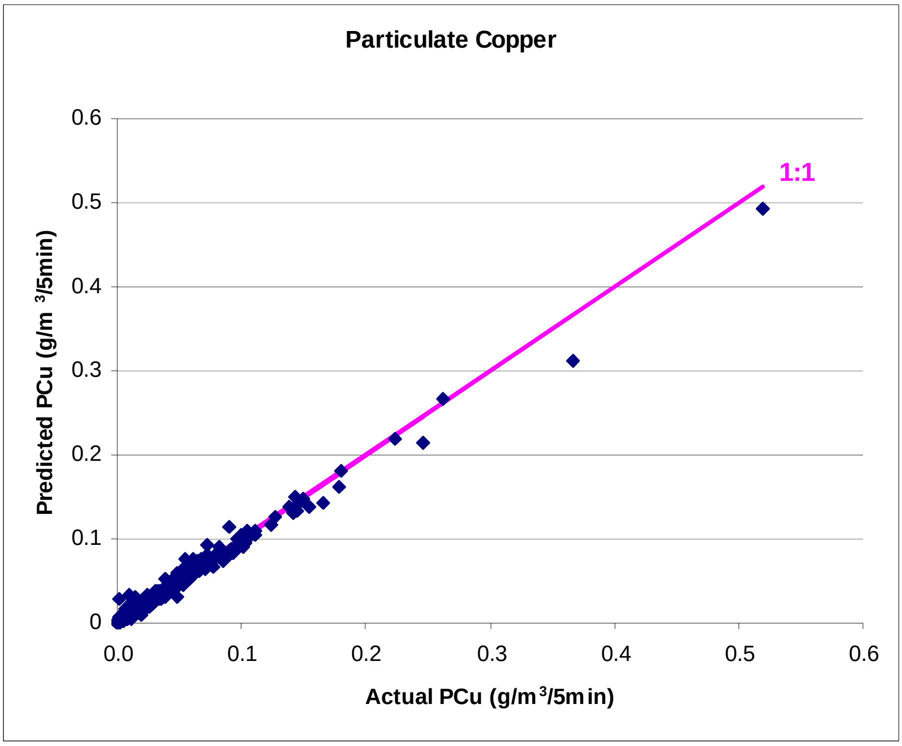
Figure 2 **Observed and predicted particulate instantaneous metal loads for Cu and Zn. Loads were predicted using a regression equation derived from Auckland stormwater quality data collected by NIWA. The one to one lines are given for comparison.**

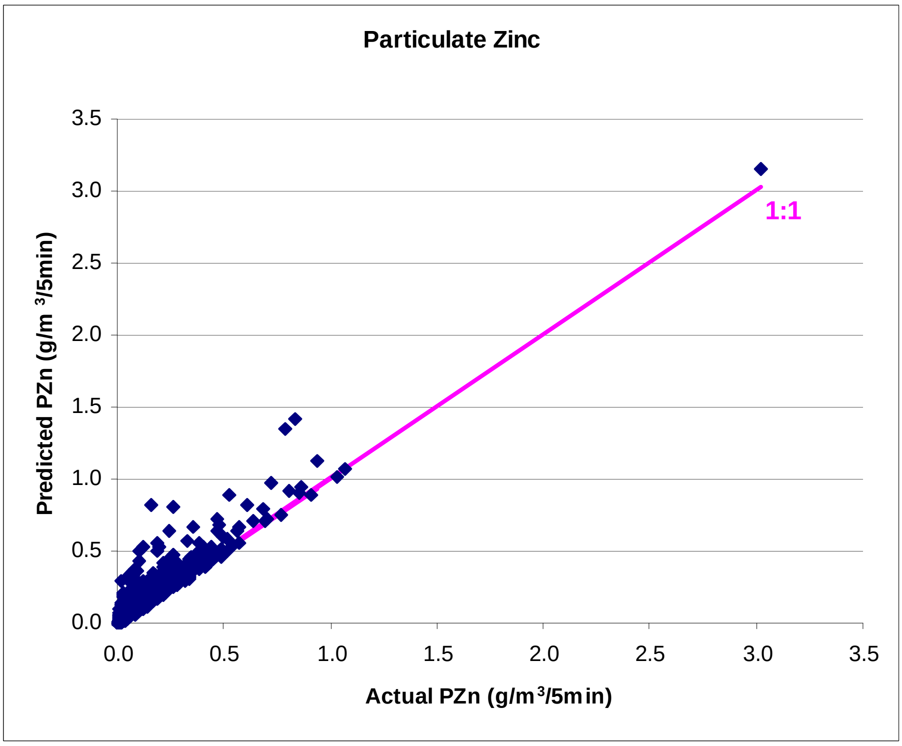
The problem with Equations 2 and 3 is that the statistical relationships do not fully capture the physical scenario. For instance, if 2.74×10^{-5} *TSS* > 0.222 *TCu*, then the particulate copper predicted by Equation 2 will exceed the total copper. Similarly for Equation 3; if 0.004231 *TSS* > 0.446 *TZn* then the particulate zinc exceeds the total zinc. To rectify the problem, the metals are now partitioned as follows. Conceptually, since particulate metals tend to bind to sediments, one would expect a correlation between TSS and the proportions of particulate metals (*PCu*/*TCu* and *PZn*/*TZn*). Plotting the proportions against the TSS concentration, both appear to have a hyperbolic relationship with asymptotes at *PCu*/*TCu* = 1, *PZn*/*TZn* = 1 and *TSS* = 0. Equations predicting *PCu* and *PZn* from *TCu*, *TZn* and *TSS* were determined by fitting hyperbole:

$$PCu = TCu\left(0.1384 + \frac{0.8461TSS}{a + TSS}\right)$$

$$PZn = TZn\left(\frac{TSS}{b + TSS}\right)$$

with constants a = 37.6131 g/m^3/5min and b = 21.5864 g/m^3/5min. Note that these constants must be scaled up or down accordingly to match the unit of *TSS*. Using these equations, the particulate metal content will not exceed the total metal content.


Particulate Copper
0.6
0.5
0.4
0.3
0.2
0.1
0
Predicted PCu (g/m 3/5min)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Actual PCu (g/m3/5min)
1:1


Particulate Zinc
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Predicted PZn (g/m 3/5min)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Actual PZn (g/m3/5min)
1:1

4.1.3 Metal fractionation

There is also much debate around the fractionation of particulate metals (i.e., the relative proportion of metals found in each particle size range). What is not disputed is that metal fractionation is theoretically related to the sediment surface area available for bonding. The conventional wisdom is that the smaller the particles, the greater the specific surface area (SSA, i.e., surface to mass ratio) and the potential for metals to bond to them. However, contaminant load also depends on the PSD which determines the mass and total surface area (SA) for each particle size fraction. Moreover, examination of particles under electron microscope (e.g., Lin, 2003) has revealed that coarse grains have a fractal dimension with internal pore spaces and surfaces for bonding. The metal load for a particle size fraction is the product of the suspended solids metal concentration and the corresponding sediment mass. Therefore, high particulate metal loads can result from either high metal concentrations and moderate sediment mass or moderate metal concentrations and high sediment mass. Thus, a PSD with a large proportion of coarse sediments could mean that the highest metal loads are associated with sands rather than silts and clays despite the greater SSA of fines.

Characklis and Wiesner (1997) and (Ding *et al.*, 1999) both found that the highest metal loads are associated with fine sediments. Lloyd and Wong (1999) compared literature values of Zn fractionation for Australia USA and Europe (Table 12). They conclude that even though the Zn concentration is highest for the smallest size fraction, the load is well distributed across the particle size range for the USA and Europe. However, in Australia, where the sediments are more finely graded, the greatest Zn loads are associated with the particles less than 40 μm.

Table 12 The mass of Zn related to the size distribution of particles (collated by Lloyd and Wong, 1999).

Particle size fraction	Australia		USA and Europe	
	% of solids in fraction	Zn mass (mg & %)	% of solids in fraction	Zn mass (mg & %)
<40 μm ~ 900 mg/kg	40	360 (65%)	10	135 (29%)
40-250 μm ~ 300 mg/kg	50	150 (27%)	50	150 (32%)
>250 μm ~ 450 mg/kg	10	45 (8%)	40	180 (39%)

Timperley *et al.* (2004) compared the theoretical relationship between sediment size, SSA and metal sorption with the fractionation of Zn found in sediment samples from Oakley Creek. They found only a weak relationship between sediment size and Zn content close to source, but the form of the relationship changes as the sediment moves through the urban stormwater system from streams to estuaries. That is, the metal content of the fine sediment classes increased as sediment is transported downstream. This is both due to sorption onto sediments during transport and settling of coarse particles.

Lin (2003) cites several studies which conclude that the relationship between metal content and sediment size is at best weak. Sansalone *et al.* (1998) presented a granulometry-based analysis where the total spectrum of particles in stormwater was collected. They found that higher proportions of contaminants bound to coarse sediments largely due to the relationship between SSA, SA and particle size fraction discussed above.

C-CALM SDSS will make the simplifying assumption that the fractionation of particulate metals is proportional to the PSD. That is, the total particulate metal load generated will be split proportional to the to the sediment size classes. This implies that a reduction of 20% in the mass load of fines sediments will be met with the same reduction in the mass load of particulate metals associated with that sediment band. Indeed, this is the assumption currently made by the ARC CLM.

4.2 Ponds and Wetlands

The removal of sediments and associated particulate metals in wet ponds and wetlands is simulated in C-CALM based on local flow rates, basin dimensions and PSD, and is discussed in Semadeni-Davies (2008). Removal processes for dissolved metals are more complex and, as well as detention time, depend on water chemistry of the stormwater and stored in the wet basin (especially pH), the degree and type of basin vegetation and the type of micro-flora and fauna present. This means that simple conceptual modelling is not possible for the dissolved fraction. Instead, it is recommended that the efficiencies be taken from the literature.

From the discussion above (Section 2.2) and Table 1 and Table 3, it seems reasonable to assume that stormwater treatment in ponds and wetlands is comparable. While there is some evidence that wetlands may offer increased removal of dissolved metals over wet ponds, the degree of difference is inconclusive, hence, the two treatment options are given the same efficiencies. Few of the studies cited provided removal efficiencies for dissolved metals *per se* with most reporting total metals - hence the efficiencies for C-CALM provided in Table 13 are open to interpretation. Generally, ponds and wetlands have higher removal efficiencies for Zn than Cu, though the range is greater.

Table 13 **Recommended C-CALM wet pond and wetland percentage removal efficiencies for dissolved Cu and Zn.**

	TSS and particulate metals	Dissolved Cu	Dissolved Zn
Low	Simulated	40	20
Medium	Simulated	50	40
High	Simulated	60	80

4.3 Filters

Section 2.3 showed that the removal efficiency of a filter depends on both the retention time and the type of medium in the filter bed. The retention time is determined by the inflow rate, the dimensions of the filter bed and the porosity (i.e., storage capacity and hydraulic conductivity) of the medium. Removal of sediments and associated contaminants is mechanical (sieving and settling within pore spaced) whereas removal of dissolved contaminants is chemical. While sand, which is cheap and readily available, continues to be a common medium, there has been a tendency to blend other materials such as compost, peat, moss or to coat the sand in a sorbent material. Other commonly used filter media include wood products, zeolite, pumice, fly ash and slag – all of which have different efficiencies. Most of the studies reported evaluated removal efficiency using laboratory column tests though there has been some *in situ* studies. The efficiencies for different media types are summarised in Table 14.

Table 15 gives the recommended removal efficiencies for use in C-CALM, the wide range is indicative of the choice of media. It is assumed that the filter is sized correctly for the inflow volume and flow rates.

Table 14 **Summary of removal efficiencies for filters – collated from studies cited in Section 2.3.**

	ARC TP10 (2003)	Färm (2002)	Hatt *et al.* (2007)	Taylor (2006)	Nanbakhsh *et al.* (2006)	Pandey *et al.* (2005)	Taylor and Pandey (2005)	Trowsdale *et al*. (2006)
Medium	Sand	Zeolite and opoka	Gravel	Slags	Soils	Sphagnum moss and wood ash (lab)	Sphagnum moss and wood ash (field)	Local materials
TSS	75	-	-	-	66-70	-	93	-
TCu	75	-	62	-	-	-	90	-
Dissolved Cu	-	38-89	-	85-96	-	>94	-17	>93
TZn	75	-	38	-	-	-	64	-
Dissolved Zn	-	53-97	-	48-98		>94	24	>93.

Table 15 **Recommended C-CALM removal efficiencies for filters.**

	TSS and particulate metals	Dissolved Cu	Dissolved Zn
Low	60	40	20
Medium	75	70	60
High	95	95	95

4.4 Vegetative Bio-filters

There are three broad categories of vegetative bio-filters: raingardens / bioretention, swales and infiltration strips. The removal processes of these facilities are a combination of local disposal of stormwater (i.e., deep percolation to groundwater), biological up-take via plant roots, and mechanical and chemical filtering in the soil bed. Thus removal efficiency depends on the flow characteristics of the site, including retention times, by-pass and under-drainage, the physical and chemical characteristics of the soil and the biological activity.

4.4.1 Raingardens and bioretention

The removal of sediments and associated particulate metals in raingardens and bioretention is simulated in C-CALM based on local flow rates, by-pass and raingarden dimensions, and is discussed in Semadeni-Davies (2008). Like the case for wet ponds and wetlands, removal processes for dissolved metals are more complex and cannot be adequately modelled given the lack of data available for model development and calibration. Instead, the recommended efficiencies in Table 16 have been taken from the literature. The studies reported in Section 2.4.1 show that depending on the planting medium, the facility can be a source of contaminants or remove nearly all dissolved metals.

Table 16 Recommended C-CALM removal efficiencies for raingardens and bioretention.

	TSS and particulate metals	Dissolved Cu	Dissolved Zn
Low	Simulated	20	30
Medium	Simulated	50	60
High	Simulated	95	95

4.4.2 Swales and Infiltration Strips

There are very few literature studies of swales and infiltration strip which assess removal efficiencies rather than concentrating of flow control and hydraulics. Given the similarity in the removal processes of the two types of bio-filter, especially when planted with grass, and the similar removal efficiencies reported, it is assumed here that they offer the same level of treatment; in general, the longer the flow path and the greater the infiltration capacity of the soil, the greater the removal efficiency. Recommended removal efficiencies or use in C-CALM are given in Table 17. Other bio-filter types such as infiltration trenches and green-roof are assumed to have the same removal processes and thus can treatment can be approximated in C-CALM using the efficiencies in Table 17.

Table 17 Recommended C-CALM removal efficiencies for swales and infiltration strips.

	TSS and particulate metals	Dissolved Cu	Dissolved Zn
Low flow path < 20m slow inflow rates	50	5	10
Medium	60	40	60
High (flow path > 50m) high inflow rates	90	90	90

4.5 Street sweeping

According to the phone survey, street sweeping is practiced in all the main centres around New Zealand. Table 18 gives removal efficiency for the C-CALM PSDs calculated using a logarithmic relationship between sediment size and removal efficiency determined from the data provided in Fan (2004, see Table 18). It is assumed that street sweeping is regular. Street sweeping is assumed not to remove dissolved metals.

4.6 Catch-pits

The location of catch-pits in gutters means that settling of coarse sediments in sumps is a first step in water treatment. Removal depends on the flow rate and the storage capacity (i.e., sump depth less settled accumulated sediments). There has been a move in some of the main centres around New Zealand to use catch-pit inserts (i.e., filter bags) to improve sediment trapping, though fines are not captured. Catch-pits and inserts are unable to treat dissolved metals. For catch-pits with no filter bag, C-CALM will only allow reduction of the coarsest sediment (i.e., 40% removal for sediments in the 380 μm size class). Recommended removal efficiencies separated into the C-CALM sediment size classes are given in Table 19.

Table 18 **Estimated removal efficiencies for TSS (and associated particulate Zn and Cu) for street sweeping as a function of PSD presented in Table 10 (based on data presented by Fan, 2004)**

Band	Medium Grain - NURP			Fine Grain			Medium Fine Grain			Medium Coarse Grain			Coarse Grain		
	Velocity (m/h)	Grain size (µm)	Removal (%)	Velocity (m/h)	Grain size (µm)	Removal (%)	Velocity (m/h)	Grain size (µm)	Removal (%)	Velocity (m/h)	Grain size (µm)	Removal (%)	Velocity (m/h)	Grain size (µm)	Removal (%)
1	0.009	4	0	0.001	1	0	0.005	3	0	0.014	5	0	0.091	5	0
2	0.091	9	0	0.009	3	0	0.046	6	0	0.137	11	5	0.914	17	10
3	0.457	16	10	0.046	5	0	0.229	11	5	0.686	20	15	4.572	37	20
4	2.134	29	20	0.213	9	0	1.067	20	10	3.200	35	20	21.336	80	35
5	19.812	78	30	1.981	25	15	9.906	55	30	29.718	96	40	198.120	380	60

Table 19 **Estimated removal efficiencies for TSS (and associated particulate Zn and Cu) for catch-pits with filter inserts as a function of PSD presented in Table 10**

Band	Medium Grain - NURP			Fine Grain			Medium Fine Grain			Medium Coarse Grain			Coarse Grain		
	Velocity (m/h)	Grain size (µm)	Removal (%)	Velocity (m/h)	Grain size (µm)	Removal (%)	Velocity (m/h)	Grain size (µm)	Removal (%)	Velocity (m/h)	Grain size (µm)	Removal (%)	Velocity (m/h)	Grain size (µm)	Removal (%)
1	0.009	4	0	0.001	1	0	0.005	3	0	0.014	5	0	0.091	5	0
2	0.091	9	0	0.009	3	0	0.046	6	0	0.137	11	0	0.914	17	0
3	0.457	16	0	0.046	5	0	0.229	11	0	0.686	20	0	4.572	37	0
4	2.134	29	0	0.213	9	0	1.067	20	0	3.200	35	0	21.336	80	60
5	19.812	78	30	1.981	25	0	9.906	55	20	29.718	96	60	198.120	380	90

4.7 Porous Paving

The phone survey found that porous paving is not common in New Zealand. Porous paving that does exist is primarily in car parks, often on private land. While there has been a study on filter media that can be used in conjunction with porous paving (Taylor and Trowsdale, 2005), no local *in situ* studies were found. The international literature has concentrated on use of porous paving for flow control and there are very few water quality studies. Water treatment is a combination of local disposal and filtering in the paving material and underlying substrate. Hence, removal efficiency is dependant on the rate of infiltration and is reduced over time by clogging which causes by-pass. The studies cited similar removal efficiencies for TSS, dissolved and total metals respectively but varied in their removal efficiencies. Recommended removal efficiencies or use in C-CALM are given in Table 20.

Table 20 Recommended C-CALM removal efficiencies for porous paving.

	TSS and particulate metals	Dissolved Cu	Dissolved Zn
Low (clogged)	25	25	25
Medium	60	60	60
High (new, high infiltration)	95	95	95

4.8 Treatment trains

Treatment trains cannot be represented explicitly within a generic model such as C-CALM as each element in the train influences the rate and volume of inflow delivery, and influent water quality of the next element. The pragmatic approach is to follow the same method as the ARC Contaminants Catchment Load (CLM) spreadsheet model where removal efficiencies for devices in the train are multiplied together. The caveat is added that this could lead to conservative estimates of removal efficiency.

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Appendix One: Description of C-CALM

C-CALM description

Contact:: Annette Semadeni-Davies, NIWA
Stormwater Engineer, NIWA
a.davies@niwa.co.nz
(09) 375 4532

NIWA is currently developing a spatial decision support system to estimate annual loads of suspended sediments, copper and zinc from urbanised catchments. The working name for the tool is C-CALM (Catchment Contaminant Annual Loads Model). The project is being carried out under subcontract to Landcare Research and is funded by the Foundation for Research Science and Technology in response to a need for a standard tool that can be used by Regional and Territorial governments to determine the impacts of urbanisation on local receiving waters. A workshop for stormwater managers held by NIWA in June 2006 established the need for such a tool. The delegates came from around the country and stated that operational urban drainage models currently used for stormwater and contaminant flows (e.g., MUSIC, SWMM, and MOUSE) are too demanding of data requirements, set-up and run times and user expertise for this purpose. They specified that the model should be simple and intuitive to use with minimal data needs (preferably in a format already used by the authority) and data handling requirements. Delegates also stated that the proposed model should be developed within a Geographical Information System (GIS) to enable geo-visualisation of contaminant sources and sinks both to aid decision making and to improve communication with other stakeholders.

C-CALM will use the Auckland Regional Councils spread sheet annual contaminant loads model as a basis for load estimation dependant on land use and surface type. This relates contaminant loads to the surfaces present in a model spatial unit and the relative areas of those surfaces. The current model is spatially lumped, must be run separately for each model unit (most often stormwater sub-catchments) and does not allow model units to be linked. C-CALM aims to be applicable across the country and will provide tools for the creation of future land use scenarios. We have decided to use ArcMAP as the platform as this package is widely used in New Zealand. One of the main innovations of C-CALM is that it will have variable stormwater treatment efficiencies to reflect the fact that contaminant removal is a function of treatment device size and design, sediment particle size distribution, metal partitioning and catchment characteristics. To do this requires as much local knowledge about treatment devices in use in NZ and their relative efficiencies as possible.

C-CALM is being developed as a planning tool for use in situations like the following:

- Consents put forward by developers for new sub-divisions, industrial parks or shopping precincts must be evaluated for possible impacts on local receiving waters.
- A pollution sink has been identified in a local estuary and the TLA is required to find the source and remedy the situation using appropriate stormwater treatment devices.
- The Regional Authority requires ICMPs to be updated for any new development.

In each case, users need to know the long-term impact of land use change and stormwater management on receiving environments. They need the information quickly and do not have the resources available for explicit modelling in an operational model. It is for this type of basic application that C-CALM is being developed.

Depending on data availability, treatment devices to be included in C-CALM are detention basins (i.e., wet ponds and wetlands), media filters, raingardens and bioretention units, swales, infiltration strips, catch-pit inserts and porous paving. C-CALM is planned for release in 2009.

Appendix 2: Survey replies

Northland Regional Council (Whangarei)

Contact Phone**:** (09) 438 4639 -Riaan Elliott (rianne@nrc.govt.nz)

	Do you use any of the following treatment options?	**Has you carried out any studies into the efficiencies of these options?**
Ponds or wetlands	Mostly sediment control ponds from construction phase that have been retained in new developments	N
Raingardens	1 (swimming pool carpark)	A comparative study with a shopping mall (Warehouse) carpark is planned.
Bio-retention or planters	N	N
Swales or infiltration trenches	Numerous sites such as Mangawai	N
Street Sweeping	Whangarei	N
Porous Paving	N	N
Filters	N	N
Catch-pit inserts	Filter bags are encouraged for temporary use	N

Comments on water treatment in area.

No reports yet but there has been some compliance monitoring of stormwater systems which have not been written up. The NRC relies heavily on information from the ARC.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes

Does your organisation already have access to stormwater modelling packages?

No but there has been some contract work by consultants

Environment Waikato (Hamilton)

Contact Phone H**:** 0800 800 401
Nick Kim direct: 07 859 0710 (nick.kim@ew.govt.nz)

It was noted that Hamilton is the primary urban area and much of the region's focus regarding water quality is agricultural runoff (e.g., Zn from facial eczema treatment and nutrients from dairying).

	Do you use any of the following treatment options?	**Has you carried out any studies into the efficiencies of these options?**
Ponds or wetlands	Many examples	N
Raingardens	One or two	N
Bio-retention cells or planters	Maybe	N
Swales or infiltration trenches	Rural roads rather than city streets	N
Street Sweeping	Probably	N
Porous Paving	Yes, some car parks	N
Filters	Some filters for industrial effluent, but not for stormwater	N
Catch-pit inserts	Maybe	N

Comments on water treatment in area.

Monitoring is for consent compliance where effluent water quality is checked against standards.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes, but Nick was unsure how C-CALM could be used by EW.

Does your organisation already have access to stormwater modelling packages?

No

Bay of Plenty Regional Council

Contact Phone**:** 0800 368 288 ext 9439
Paul Scholes (pauls@envbop.govt.nz)

	Do you use any of the following treatment options?	**Has you carried out any studies into the efficiencies of these options?**
Ponds or wetlands	Y	May be some reports archived
Raingardens	Y	
Bio-retention cells or planters	N	
Swales or infiltration trenches	Y	
Street Sweeping	Y	
Porous Paving	Y	
Filters	A woodbark filter was trialled	Report in NZWWA 2004
Catch-pit inserts	N	

Comments on water treatment in area.

Woodbark filter report is available in conference proceedings (see Section 2.3.1).

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes, particularly for consents.

Does your organisation already have access to stormwater modelling packages?

Consultants do most of the modelling. Paul has worked with Hydrocad, a free hydraulics package to check out whether swales could be good for water treatment in the region.

Gisborne District Council

Contact Phone**:** 06 867 2049
Jurgen Komp (jurgen@gdc.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Lagoon on foreshore takes stormwater	
Raingardens	N	
Bio-retention cells or planters	N	
Swales or infiltration trenches	Y	
Street Sweeping	Yes, but could be more often	
Porous Paving	N	
Filters	N	
Catch-pit inserts	N	

Comments on water treatment in area.

None available

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes

Does your organisation already have access to stormwater modelling packages?

No

Hawke’s Bay Regional Council (Napier)

Contact Phone**:** 06 835 9200 (DD 8338048)
Neil Daykin, Environmental Engineer

	Do you know of any of the following treatment options in your area?	**Has you carried out any studies into the efficiencies of these options?**
Ponds or wetlands	Wetlands are recommended for new developments?	N
Raingardens	N	N
Bio-retention cells or planters	N	N
Swales or infiltration trenches	Along roads, not usual in urban areas.	N
Street Sweeping	Napier and Hastings	N
Porous Paving	N (a project was planned for Hastings but did not go ahead)	N
Filters	N	N
Catch-pit inserts	Not sure (could be some examples of bags)	N

Comments on water treatment in area.

Compliance monitoring has been carried out for consents, but these are to check that effluent water quality is of the required standard.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes

Does your organisation already have access to stormwater modelling packages?

No

Taranaki Regional Council (Stratford)

Contact Phone: 06 765 7127

Bruce Pope (bruce.pope@trc.govt.nz)

It was noted that the TLAs would hold more information and stormwater is not the TRC mandate.

	Do you use any of the following treatment options?	**Has you carried out any studies into the efficiencies of these options?**
Ponds or wetlands	Yes, series of roadside ponds protect New Plymouth water supply from stormwater contamination.	N
Raingardens	N	N
Bio-retention cells or planters	N	N
Swales or infiltration trenches	Some near car parks	N
Street Sweeping	N	N
Porous Paving	Mainly car parks	N
Filters	N	N
Catch-pit inserts	Y, some in New Plymouth	N

Comments on water treatment in area.

Monitoring for consent compliance. The TLAs may have some studies.

Would your organisation be interested in using a GIS-based stormwater quality model?

Does your organisation already have access to stormwater modelling packages?

Horizons (Manuatu-Wanganui, Palmerston N.)

Contact Phone: 06 9522 800

Don’t deal with stormwater, were unable to help.

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands		
Raingardens		
Bio-retention cells or planters		
Swales or infiltration trenches		
Street Sweeping		
Porous Paving		
Filters		
Catch-pit inserts		

Comments on water treatment in area.

Would your organisation be interested in using a GIS-based stormwater quality model?

Does your organisation already have access to stormwater modelling packages?

Greater Wellingon Regional Council (Wellington)

Contact Phone**:** 04 384 5708
Juliet Milne (juliet.milne@gw.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Yes, these are often sediment control ponds from earthworks that have been left in place.	N
Raingardens	There is one known of	N
Bio-retention cells or planters	Maybe	N
Swales or infiltration trenches	Y	N
Street Sweeping	Y	N
Porous Paving	Maybe	N
Filters	There are several filters treating effluent from industrial sites	N
Catch-pit inserts	Y	N

Comments on water treatment in area.

There is little monitoring of stormwater treatment device performance in the Wellington region, what is done is checks on effluent quality for consent compliance. The GWRC is pushing for more monitoring of stormwater discharges and receiving environments in the region.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes, possibly.

Does your organisation already have access to stormwater modelling packages?

GWRC has been in contact with NIWA about modelling and has expressed some interest about modelling sediment in the Porirua Harbour from urban development. They have done some preliminary modelling of stormwater contaminants loads across the Wellington region using the ARC CLM model but though it may need tweaking for Wellington (e.g., soil types differ from Auckland's mainly volcanic soils and road widths may be narrower?). There was some confusion expressed about the number of models NIWA holds and how they can be used and in what situations. GWRC is currently doing a 'stock-take' of its stormwater investigations before deciding whether to recommence with modelling work.

Marlborough District Council (Blenheim)

Contact Phone**:** 03 520 7400
Brin Williman (brin.williman@marlborough.govt.nz)

	Do you use any of the following treatment options?	**Has you carried out any studies into the efficiencies of these options?**
Ponds or wetlands	N	
Raingardens	N	
Bio-retention cells or planters	N	
Swales or infiltration trenches	N	
Street Sweeping	Y	
Porous Paving	N	
Filters	Maybe	
Catch-pit inserts	Maybe	

Comments on water treatment in area.

Marlbrorough is a unitary authority and stormwater management is split between two sections of the council. There is currently a push for more LID in the region but there has been slow uptake with little or no treatment other than sumps in the reticulated network.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes

Does your organisation already have access to stormwater modelling packages?

Knowledge of packages like MOUSE

Tasman District Council

Contact Phone: 03 544 8176 (dd 5438577)
Kim Arnold (kim.arnold@tdc.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Only for waste water	
Raingardens	N, could be some privately owned	
Bio-retention cells or planters	N	
Swales or infiltration trenches	Swales along some roads, these are not engineered and are for conveyance.	
Street Sweeping	Y	
Porous Paving	Y	
Filters	N	
Catch-pit inserts	Only a couple	

Comments on water treatment in area.

No reports into efficiencies undertaken.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes, but application could be limited.

Does your organisation already have access to stormwater modelling packages?

Region is mostly rural and MIKE 11 is used for open channel flow. Wallingford software used to reticulated networks.

Environment Canterbury (Christchurch)

Contact Phone: 03 365 3828

Peter Savage (peter.savage@ecan.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Y	
Raingardens	Y	
Bio-retention cells or planters	N	
Swales or infiltration trenches	Y	
Street Sweeping	Y	
Porous Paving	N	
Filters	Y	
Catch-pit inserts	Y	

Comments on water treatment in area.

There have been a number of reports prepared for ECAN and the Christchurch City Council. A wet land study with some grab-sampling was recently carried out. Andrew Brough (03 363310), a consultant, presented a paper on the Kirkwood infiltration surfaces at Stormwater 07, but the work centred on hydrology rather than water quality (some grab tests were taken, see Section 2.4.3).

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes,

Does your organisation already have access to stormwater modelling packages?

Mostly carried out by consultants.

Otago Regional Council (Dunedin)

Contact Phone**:** 03 474 0827
Andrew Woodford (andrew.woodford@orc.govt.nz)

Was unable to help and suggested contact with the Dunedin City Council

	Do you use any of the following treatment options?	**Has you carried out any studies into the efficiencies of these options?**
Ponds or wetlands		
Raingardens		
Bio-retention cells or planters		
Swales or infiltration trenches		
Street Sweeping		
Porous Paving		
Filters		
Catch-pit inserts		

Comments on water treatment in area.

Would your organisation be interested in using a GIS-based stormwater quality model?

Does your organisation already have access to stormwater modelling packages?

Environment Southland (Invercargill)

Contact Phone**:** 03 211 5115
John Engel (john.engel@es.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Not yet, some new developments will have ponds	
Raingardens	N	
Bio-retention cells or planters	N	
Swales or infiltration trenches	Encouraged but limited take-up. Some examples in new development in Te Anau	
Street Sweeping	Y	
Porous Paving	N	
Filters	Maybe	
Catch-pit inserts	Maybe	

Comments on water treatment in area.

Stormwater is generally not treated in Southland and consents for stormwater are not needed. This means that take-up of treatment devices has been slow and is discretionary. There is a push in EW to improve stormwater quality in Invercargill and Gore.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes. Assessment of impacts of Invercargill stormwater is becoming an issue.

Does your organisation already have access to stormwater modelling packages?

Hamilton City Council

Contact Phone**:**
Kathy Tao (kathy.tao@hcc.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Y	
Raingardens	Some private raingardens	
Bio-retention cells or planters	N	
Swales or infiltration trenches	Y, very new	
Street Sweeping		
Porous Paving		
Filters		
Catch-pit inserts		

Comments on water treatment in area.

Not aware of any studies other than consents monitoring. HCC is encouraging take up of stormwater treatment facilities and is currently

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes, especially as there will be more stormwater control with the new by-law.

Does your organisation already have access to stormwater modelling packages?

Flow is modelled.

Palmerston North City Council

Contact Phone: 06 356 8199
Chris Pepper (chris.pepper@pncc.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Y	N
Raingardens	There are some new infiltration strips from pipe outlets. These were described in terms of landscaping.	N
Bio-retention cells or planters	N	N
Swales or infiltration trenches	Several swales.	N
Street Sweeping	Y	N
Porous Paving	N	N
Filters	N	N
Catch-pit inserts	Some Enviropods	N

Comments on water treatment in area.

PNCC has an annual monitoring programme of stormwater around the city as a snapshot of water quality to sources and sinks. The programme has not been running very long and no published material is available. Information about water treatment is by implication (i.e., if water quality in the area improves, it suggests that stormwater management has been successful).

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes.

Does your organisation already have access to stormwater modelling packages?

Flow modelling has been carried out by consultants using XP SWMM.

New Plymouth District Council

Contact Phone**:** 06 7596060
Tracey Mitchell (mitchellt@npdc.govt.nz)

	Do you use any of the following treatment options?	**Has you carried out any studies into the efficiencies of these options?**
Ponds or wetlands	Y	
Raingardens	N	
Bio-retention cells or planters	N	
Swales or infiltration trenches	Y	
Street Sweeping	Y	
Porous Paving	Some on private land	
Filters	There is a filter bag for removal of grit from a carpark.	
Catch-pit inserts	N	

Comments on water treatment in area.

All monitoring carried out by regional council. No efficiency monitoring known about.

Would your organisation be interested in using a GIS-based stormwater quality model?

Not sure, works with operation not planning

Does your organisation already have access to stormwater modelling packages?

Not for stormwater.

Kapiti Coast

Contact Phone: 04 9045700
Blair Murray (blair.murray@kapiticoast.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Yes including a new multi-basin wetland at Kotuku Park in Paraparaumu (designed by Truebridge Callender Beach, Ian Prentice)	N
Raingardens	Y	N
Bio-retention cells or planters	N	N
Swales or infiltration trenches	Y, some roadside swales	N
Street Sweeping	Y	N
Porous Paving	N	N
Filters	N	N
Catch-pit inserts	Approx. 35 enviropods	N

Comments on water treatment in area.

No monitoring apart from effluent for consent compliance.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes

Does your organisation already have access to stormwater modelling packages?

Flow modelling done by SKM consultants.

Wellington City Council

Contact Phone: 04 4994444
Iqbal Idris (iqbal.idris@capacity.net.nz, dd 04 9103809)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Y. There is a new wetland with UV treatment of influent.	Fortnightly monitoring of coliforms into wetland.
Raingardens	N	
Bio-retention cells or planters	N	
Swales or infiltration trenches	N	
Street Sweeping	Y	
Porous Paving	Not sure, maybe some car parks	
Filters	N	
Catch-pit inserts	N	

Comments on water treatment in area.

Not sure if there are any treatment efficiency studies.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes, identified a number of possible user groups including roading, erosion control and biodiversity

Does your organisation already have access to stormwater modelling packages?

MOUSE is used for flow modelling of reticulated network.

Christchurch City Council

Contact Phone**:** 03 9418999
Owen Southen (owen.southen@ccc.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	Y	Y
Raingardens	Y	
Bio-retention cells or planters	N	
Swales or infiltration trenches	Y	Y
Street Sweeping	Y	
Porous Paving	Trial	Not at monitoring stage
Filters	Y	
Catch-pit inserts	Y	

Comments on water treatment in area.

Halswell pond and Kirkwood infiltration basin studies have been cited in this report (Section 2.2 and 2.4.3). Effluent monitoring was carried out for the Aiden Field development a few years ago as part of a court action. This area has swales. However, no influent samples. EOS Ecology (Shelly McMurtrie, 03 3980538) took some grab samples from a wetland as part of a stormwater study, but this cannot be used to derive treatment efficiencies.

Would your organisation be interested in using a GIS-based stormwater quality model?

Y

Does your organisation already have access to stormwater modelling packages?

Dunedin City Council

Contact Phone**:** 03 4774000

Hugh Smirk (hsmirk@dcc.govt.nz)

	Do you use any of the following treatment options?	Has you carried out any studies into the efficiencies of these options?
Ponds or wetlands	There are a couple of ponds and more planned. Flow control is main objective	
Raingardens	No, but there has been some interest as planting in new developments	
Bio-retention cells or planters	N	
Swales or infiltration trenches	No, but there are plans in a new large subdivision.	
Street Sweeping	Y	
Porous Paving	N	
Filters	N	
Catch-pit inserts	Two models are under trial	

Comments on water treatment in area.

There has been interest in monitoring, but none to date. PAHs are a major concern and an old gas works may be contributing to the high levels in Dunedin stormwater.

Would your organisation be interested in using a GIS-based stormwater quality model?

Yes, but would like to know more information.

Does your organisation already have access to stormwater modelling packages?

Yes, InfoWorks (Wallingford) is being considered for use for a new modelling project to model waste and stormwater flows.