DEVELOPMENT OF A RAPID BIOFILTRATION MEDIA USING LOCAL MATERIALS

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ABSTRACT

Stormwater360, in collaboration with Callaghan Innovation, has undertaken a laboratory study to investigate innovative engineered soils for use with a flow controlled biofiltration /retention system.

Typically biofiltration/retention systems use the soil or substrate to control the hydraulic conductivity and corresponding contact time and performance. This study investigated media options with an external flow control. This allowed a coarser substrate with higher hydraulic conductivity to be developed.

Hence the primary aim of this study was to develop an engineered substrate made from locally available materials that had both high hydraulic conductivity and effective contaminant removal. Such a substrate allows the size and cost of the biofiltration device required for a given catchment area to be reduced.

Four engineered substrates with different active ingredients were tested. The active ingredients were as follows:

- Contech Engineered Solutions BioFilter Engineered Media;
- Compost and Zeolite;
- Biochar; and
- Biochar and Zeolite.

Column tests quantified maximum hydraulic conductivity, dissolved metal removal at deferring hydraulic conductivity and influent concentrations. Potential leaching of other potential contaminants from the substrate was also quantified.

The study also predicted the plant growth potential of the engineered substrates by examining the physical and chemical properties of the blends.

KEYWORDS

Stormwater treatment, Biofiltration, Rain gardens, Engineered Soils

1 INTRODUCTION

The primary aim of this study was to develop an engineered substrate for biofiltration that is made from locally available materials and has high hydraulic conductivity while retaining effective contaminant removal. A high hydraulic conductivity may allow the size and cost of the bio-filtration device required for a given catchment area to be reduced.

Three engineered substrates made from materials available in New Zealand were compared to a rapid filtration media sourced from the USA. The USA substrate has been successfully demonstrated as an effective rain garden mix, and particularly so with respect to the removal of dissolved metals (Contech, 2012).

Physical and chemical characterization was also undertaken to evaluate the suitablilty of the engineered soils for plant growth and health in a rain garden or tree pit application.

All four soils were designed to be used in the Urban Green BioFilter, which has a unique patented flow control system that regulates the flow through the media enhancing removal and limiting clogging.

2 BACKGROUND

2.1 ENGINEERED SOIL MEDIA

The filter substrate (or fill media) used in bioretention has a major influence on bioretention performance. The current design advice in Auckland for a fill media is to use a "sandy loam, loamy sand, loam, or a loam/sand mix (35–60% sand), with a maximum of 25% clay content" (Auckland Regional Council, 2003). This approach is also used in other older design guidelines in the United States and United Kingdom (Fassman, Simcock, & Wang, 2013; Carpenter & Hallam, 2010)

In areas with few natural, sandy-textured soils, the textural guideline is sometimes achieved by adding 30% to over 50% sand. In Auckland, addition of sand to local clay- and silt- textured soils has sometimes resulted in substrates that are vulnerable to compaction and slumping, inadequate permeability, inadequate aeration, and poor plant growth. Some sand-amended local soil mixes have also developed cracks upon drying, increasing the risk of stormwater bypassing this core filtering layer.

More recent international filter substrate guidelines recommend ranges of aggregate particle size distribution (PSD) to use as a screening process to achieve desired hydraulic conductivity, K_s (e.g. (FAWB, 2009; Seattle Public Utilities, 2008). This has increased the use of engineered substrates, as if the individual components of engineered media have high uniformity and known properties, a product with consistent performance can be created.

Guideline	Aggregate	Organic	Note
TP10 Auckland Regional Council (2003), Waitakere City Council (2004)	Sandy loam, loamy sand, loam, loam/sand mix (35–60% v/v sand)	Not specified	Clay content < 25% v/v
Prince George's County, Maryland (2007)	50–60% v/v sand	20–30% v/v well aged leaf compost, 20–30% v/v	Clay content < 5% v/v

Guideline	Aggregate	Organic	Note
		topsoil [B]	
The SuDS manual (Woods-Ballard, et al., 2007)	35–60% v/v sand, 30–50% v/v silt	0–4% v/v organic matter	10–25% v/v clay content
Facility for Advanced Water Bio filtration (FAWB, 2009)	Washed, well graded sand with specified PSD band	3% w/w organic material	Clay content < 3% w/w, top 100 mm to be ameliorated with organic matter and fertilizer
Seattle Public Utilities (2008)	60–65% v/v mineral aggregate, PSD limit ("clean sand" with 2–5% passing #200 sieve), U [C] ≥ 4	35–40% v/v fine compost which has > 40% w/w organic matter content	
North Carolina Cooperative Extension Service (Hunt & Lord, 2006)	85–88% v/v washed medium sand [D]	3–5% v/v organic matter	8–12% v/v silt and clay
City of Austin (2011)	70–80% v/v concrete sand [E]	20–30% v/v screened bulk topsoil [B]	70–90% sand content, 3–10% clay content, silt and clay content < 27% w/w. Sandy loam ("red death") is not permitted [F]

[A] % v/v is percent by volume; % w/w is percent by weight (mass).
[B] "Topsoil" is a non-technical term for the upper or outmost layer of soil, however there is no technical standard for topsoil.
[C] U, Coefficient of Uniformity = D_{60}/D_{10}, where D_{60} is particle diameter at 60% passing and D_{10} is particle diameter at 10% passing.
[D] A specific definition for "medium sand" was not identified. ASTM (2011a) D2487-10 classifies coarse-grained sands as those with $\geq$50% retained on a (USA) No. 200 sieve (75 um) and $\geq$ 50% of coarse fraction passing a No.4 sieve (4.76 mm). Clean sands contain <5% fines. Fine-grained soils are silts and clays whereby > 50% passes a No.200 sieve.
[E] Concrete sand is described by ASTMD2487-10 as coarse sand that is retained by a (USA) No. 10 sieve (2.00 mm)
[F] "Red death" is a commercially available fill material in Austin marketed as sandy loam.

Table 1 Recommendations for Bioretention Media Mixes worldwide

(Fassman, et al., 2013) [A]

2.2 THE URBAN GREEN BIOFILTER

The BioFilter is a flow through treatment device containing a vegetated biofiltration cell within a concrete vault. The biofiltration substrate (engineered soil mixture), has been optimized and standardized to consistently provide a high hydraulic conductivity while supporting plant growth Photograph 1 and a robust biological community as shown in Photograph 1. Stormwater runoff is filtered as it percolates through the media bed. The BioFilter contains an internal bypass which routes peak flows around treatment components and eliminates the need for an external bypass structure. The BioFilter is a compact, high flow alternative to conventional biofiltration designs that also provides excellent pollutant reduction.

The design filtration rate of the biofilter is controlled by the initial media permeability and a flow control orifice. Testing has shown that the engineered substrate has a maximum hydraulic conductivity greater than 9100mm/hr at a driving head of 305mm (CONTECH 2008), however the outlet flow control limits the rate to 2500mm/hr so pollutant loads can accumulate before the media hydraulic conductivity drops below the design rate and maintenance is required. Using an outlet control to control the hydraulic conductivity rather than the media itself allows soil with a higher void volume to be used. This substantially decreases clogging in the media and provides additional detention storage in the device. The flow control also improves pollutant removal performance by reducing velocities in the pore space within the media.

Photograph 1:

The Urban Green Biofilter® at Auckand Botanic Gardens Sustainable Water Trail

2.3 PROPOSED AUCKLAND UNITARY PLAN (PAUP)

The Auckland Council (2013) is planning to change the performance requirements of stormwater treatment from a percentage removal of Total Suspended Solids (TSS) to one based on specific design stormwater effluent concentrations of solids, metals and temperature. The change was made because the previous 75% removal of TSS was not always adequate to protect receiving environments, contaminants of concern were not always limited to sediment, and the percentage removal approach did not ensure an acceptable effluent quality was attained, i.e., it is relatively easy to achieve a high % removal when influent stormwater has high TSS concentrations, and difficult to reduce TSS concentrations from influent stormwater with very low TSS concentrations.

The new Design Effluent Quality Requirements (DEQR) proposed by the Auckland Council are shown in Table 2

Pollutant	Effluent quality requirement
Sediment	TSS < 20 mg/L

Metals	Total Copper (TCu) < 10 µg/L Total Zinc (TZn) < 30 µg/L
Temperature	Temp < 25 ^{o}C

Table 2 DEQRs in the proposed Auckland Unitary Plan (Auckland Council, 2013)

The DEQRs for TSS, TCu and TZn were based on a statistical analysis of field data from the International Stormwater Best Management Practices Database. In general, the DEQRs for TSS, TCu and TZn are based on the median effluent water quality of the BMP that performs the most poorly for the contaminant of concern.

In sensitive Auckland catchments, increases in stormwater flows are to be managed by detention and retention requirements to reduce peak flows and total runoff volumes. These areas have been classified as Stormwater Management Area: Flow (SMAF) areas.

2.4 FIELD TESTING OF A RAPID SOIL FILTRATION MEDIA

In 2012, Contech conducted laboratory vertical column tests to determine the dissolved metals and nutrient removal performance of a proprietary soil mixture. Results showed averaged dissolved Zinc and dissolved Copper removal rates of 96% and 76% respectively at moderate to high influent concentrations (Contech, 2012).

The substrate was subsequently tested in a nine month field test of the UrbanGreen™ BioFilter at the Port of Longview, Washington. The objective was to gain General Use Level Designation by the Washington State Department of Ecology. Over the 15 storm events, the BioFilter reduced suspended solids, total Zinc, total Copper and dissolved Zinc (Table 3). The engineered substrate maintained a high infiltration capacity and supported plant growth.

UrbanGreen BioFilter Performance Summary for 15 Storm Events Monitored at the Port of Longview Site in Longview, WA

Parameter	TSS		Total Zn		Dissolved Zn		Total Cu	
Units	(mg/L)		(µg/L)		(µg/L)		(µg/L)	
Analytical Method	EPA 160.2		EPA 200.8		EPA 200.8		EPA 200.8	
Sample Location	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
Minimum	10.0	1.0	33.6	4.5	179	5.1	1	1
Maximum	464	82	506	72	1070	291	34.6	8.1
Median	59	8	81.7	12.1	345	77	6.4	2.5
Mean	87.7	13	118	17.5	438	104	10	2.8
Removal Efficiency	85.2%		85.2%		76.3%		72.0%	

Table 3: Pollutant removal rates measured in Longview, WA for the UrbanGreen™ BioFilter field trial (Contech 2012)

Results indicate the Port of Longview field performance of the Bio Filter would meet the proposed Auckland Unitary Plan (PAUP). Median effluent concentrations for TSS, TZn where all below DEQR’s in the PAUP.

Of particular interest was the high rate of dissolved Zn removal by the system. Zn is one of Aucklands major contaminants of concern. Much of Auckland's Zinc contamination is attributed to dissolved zinc entrained in runoff from galavanised roofs (Kennedy & Sutherland, 2008).

The concentration of Cu in the stormwater events at Longview site were relatively low. All Cu influent concentrations where below the DEQR's set in the PAUP. Because of the low copper concentrations, the Cu removal capacity of the BioFilter at the Port of Longview field trial was not conclusively demonstrated, even though the effluent copper concentrations all satisfied the PAUP effluent concentration requirements during all 15 storms.

3 METHODOLOGY

3.1 THE ENGINEERED SOILS

Four engineered substrates were selected for testing. The three Stormwater360 mixtures where derived from materials sourced and blended in New Zealand.

Mix A: Rapid filtration media developed by Contech.

Mix B: A Stormwater360 proprietary mixture containing Compost and Zeolite

Mix C: A Stormwater360 Proprietary mixture containing Bio-Char

Mix D: A Stormwater360 proprietary mixture containing Bio-Char and Zeolite

3.2 PHYSICAL AND CHEMICAL CHARACTERISATION

Representative samples were collected from the four mixtures as blended or as they were delivered to Stormwater360. These were sent to the Landcare Research soils laboratory in Palmerston North for chemical and physical characterization.

3.3 COLUMN TESTING

Using the vertical test column and equipment setup used by Contech (2012) as a guide, a four column test setup was used (see Photograph 1). The specific research parameters described and chosen below were informed by research at the University of Canterbury (Good, 2011), Contech (2012), and Auckland Council documents such as the specification for Stormwater Bioretention Devices (Fassman, et al., 2013).The four column test setup was used to test the hydraulic conductivity, leaching characteristics, and dissolved metal removal capacity of each substrate.

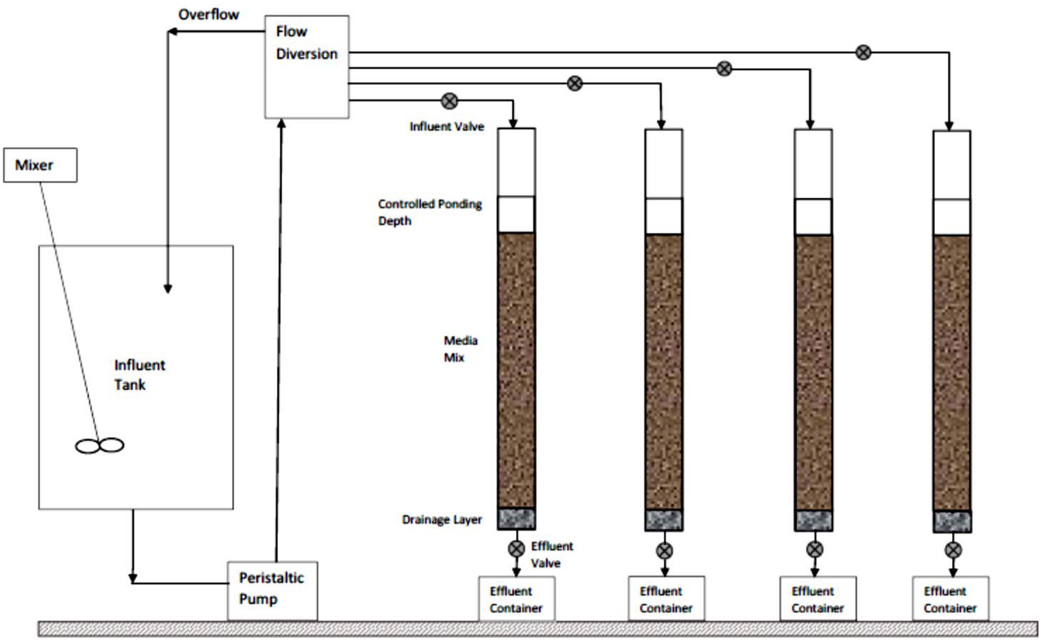

Figure 1: Four column test setup at Stormwater360

Photograph 2: Four column test setup at Stormwater360

3.3.1 COLUMN PREPARATION & TESTING PROCEDURE

The test columns were made and tested following the below procedure.

1. A drainage layer (100mm of 7-12 mm aggregate) was made,
2. Each substrate mix was wet compacted into testing columns in four 175mm lifts (700mm media depth total) using a ponding depth of 200mm for a period of 10mins per layer,
3. The reservoir was thoroughly flushed and cleaned if required,

4. Each column was flushed with tap water for a period of 15 minutes then allowed to drain,
5. The reservoir was filled with the required volume of tap water,
6. Metal salts were added to the reservoir as required to achieve specified concentrations,
7. The reservoir was mixed for 10 minutes (using recirculation),
8. The outflow orifice was set to the target hydraulic conductivity,
9. Flow of synthetic storm water through columns was started,
10. Stormwater was allowed to pond to required head; influent and effluent flow rates were adjusted as required,
11. Samples of both inflow and outflow were taken as required.
12. All Samples were analysed by Hills Laboratories following their recommended quality assurance procedures.

4 RESULTS & DISCUSSION

4.1 PHYSICAL CHARACTERISATION

The critical physical characteristics of the media being developed are:-

- permeability (mm/hr),
- volume of water detained (the pore volume that is emptied between saturation and 10kPa tension, i.e. 'field capacity'), and
- volume of water retained ('plant available water').

Plant available water is measured as the pore volume that is filled with air between 10 and 1500 kPa tension. The 10 kPa value is equivalent to the 'field capacity' in free-draining rain garden substrate. Once saturated and allowed to drain freely, the tension water is held in the media rapidly drops to this value. The detention capacity of a substrate along with the ponding depth above a rain garden reduce peak flow volumes. A portion of the pore volume does not contribute to water retention or plant uptake; in Figure 2 below this is referred to as 'bound water'. This water is held at high tension to the surface of soil particles. The volume of bound water is strongly correlated with the proportion of clay and organic matter in a soil. The higher the clay or organic matter content, the more of this bound water is present. If a substrate's water storage capacity is estimated by measuring its total moisture content (e.g. by putting it in an oven), retention can be grossly over-estimated. The water retention capacity for many Auckland non-volcanic soils is low, as shown by the 'Ultic Soils' bar on the far right in Figure 2 below. Nearly half the total pore volume is 'bound water' and therefore effectively not-contributing to stormwater attenuation.

Comparing detention and retention assists substrate selection, especially if there is confidence that the media is resilient to compaction. Compaction acts to decrease the detention volume, but may increase the retention volume (as large pores are squashed into smaller pores that retain water at lower tensions). Hence in Figure 2, SW360 Mix B is preferable to SW360 Mix D because it has similar detention capacity but a much larger retention capability. Plants will have a greater buffer of water to support growth between rain events.

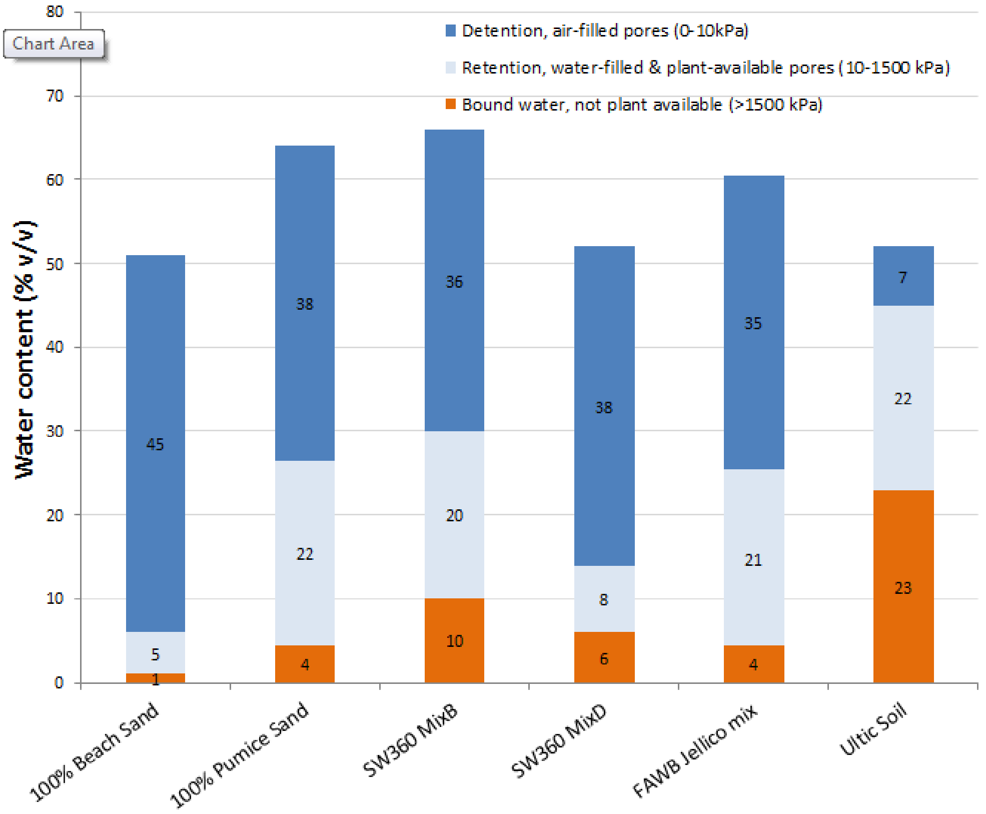

Figure 2: Water storage capacity of soil media

4.2 CHEMICAL CHARACTERISATION

The chemical properties of rain garden media must balance nutritional needs of the plants against potential leaching of the macro-nutrients nitrogen and phosphorus. Key chemical properties of rain garden growing media are given in Table 4 below. The media were either well-established rain gardens at least 2 years old, or '*as delivered*'. Four of the five established rain gardens sampled were designed to meet TP10 (ARC, 2003) guidelines. The last two were designed to approximate FAWB (Melbourne) guidelines. All five rain gardens were planted with perennial native New Zealand plants and had achieved near-complete vegetation cover at the time of sampling, i.e. they had demonstrated the substrate fertility was adequate for establishment.

Rain garden media description	pH	Total Carbon	Total Nitrogen	C:N ratio	Olsen Phosphate
Site,	(in water)	(% w/w)	(% w/w)	(calculation)	(µg/kg)
Corban Ave, Albany.	6.7	2.30	0.19	12	34
Davies Drive, Albany	7.0	8.70	0.73	12	115
Paul Matthews Road,	7.0	2.24	0.20	11	19
Portage Road, New Lynn.	5.9	3.95	0.17	23	15

Auckland version of an FAWB mix Jellico Street rain garden.	7.3	0.47	0.02	10	11
Auckland version 2 of FAWB mix, Jellico Street rain garden.	7.2	1.52	0.06	27	26
Stormwater 360 mix B.	7.0	7.63	0.11	72	12
Stormwater 360 mix D.	7.3	2.88	0.04	80	2
Rain garden media specifications	5.5-7.5[A]	2-10 [A]	varies	NA	varies [B]

[A] Auckland Council Draft rain garden specifications. However, the specification present organic matter on a volume basis, i.e. 10 to 30% v/v and Total Nitrogen as <1000 mg/kg (<0.1%), a very low value for natural soils (Simcock et al NZWater2014)

[B] Olsen P of 10-20 and >0.1% N is required for adequate growth of typical plants

Table 4: Key chemical properties of rain garden growing media. Some target levels depend on the contaminants being targeted and the predicted storm water inputs (especially for nitrogen and phosphorus) [1]

Rain garden media needs to be weakly acidic to weakly basic because the key metal contaminants such as Zinc can solubilise below 5.5. All five rain gardens sampled were in the target range. Leachate testing of the SW360 mixes indicated their pH levels were also within the target range. Total carbon contents can change significantly during rain garden establishment, typically decreasing as a result of organic matter mineralisation exceeding plant input and, in coarse mixes, physical washing of small organic particles from the mix. Losses are greatest for mixes with high organic matter, especially if adequate nitrogen content allows rapid microbial activity and the organic matter used in the mix is not mature. Rain garden guidelines specify a maximum organic matter content because rapid reductions in organic matter can cause slumping and elevated organic matter can be a contaminant in water ways (e.g. increasing Biological Oxygen Demand). Total carbon content of the established rain gardens are shown to have stabilised between 2.2 and 8.7% as indicated by Carbon to Nitrogen (N) ratios between 10 to 12 (with the exception of the Portage Road site), which would be expected of landscaped sites. The 'average' New Zealand pasture topsoil contains between 4 and 10% w/w organic carbon (Blakemore, et al., 1987). In the absence of long-term data from rain gardens, this range could be used to indicate the level that plant inputs can sustain in a rain garden, i.e. freely drained, deep, low to moderate fertility sites with permanent cover. Rain garden media with very low organic carbon contents (<2% w/w), such as the Jellico Street FAWB mix, are therefore likely to increase over time. The three 'as delivered' SW 360 mixes have low to moderate carbon contents. Using rain garden media with low to moderate carbon contents is a low-risk approach, particularly where nitrogen, phosphorus and copper are priority contaminants.

Moderate Nitrogen and Phophorus (P) levels are needed to meet landscape expectations and to quickly achieve a dense cover that can suppress weeds. Rain garden media can achieve these expectations with low concentrations of plant-available nitrogen and phosphorus if: first, organic mulches are selected to provide the short-term nutritional requirements to achieve canopy cover and provided shading for emergent weeds; second, the incoming stormwater supplies these macro-nutrients, and; third, plants are supplied in an unstressed condition. Short-term, plant-available P is indicated by Olsen

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[1] For NZ topsoils sampled mainly from perennial pasture before high-input dairying: medium levels for organic carbon are 4 to 10%, levels <2 are considered very low; medium levels for total nitrogen are 0.3 to 0.6% with level <0.1 regarded as very low, medium C:N ratios 12 to 16, medium Olsen P levels are 20 to 30 with levels

P. The Olsen P in the well-established rain gardens ranged from low to very high. If plant growth was judged adequate in the rain gardens with low Olsen P and Total N (Paul Matthews, Portage Road and Jellico Street) the conservative approach for rain gardens would be to adopt low N, P (and hence Carbon) values, and avoid the risks associated with high to very high N, P and C.

4.3 MAXIMUM HYDRAULIC CONDUCTIVITY

To determine the free draining maximum hydraulic conductivity (HC) of each mixture, water was passed through each soil media for three hours, left to dry for 24 hours, and then loaded with water for three hours again. Three days later, the test was repeated. Water was collected at the outflow orifice of each column for a period of one minute every hour to determine the flow rates. The HC of each soil was measured and is plotted in Figure 3.

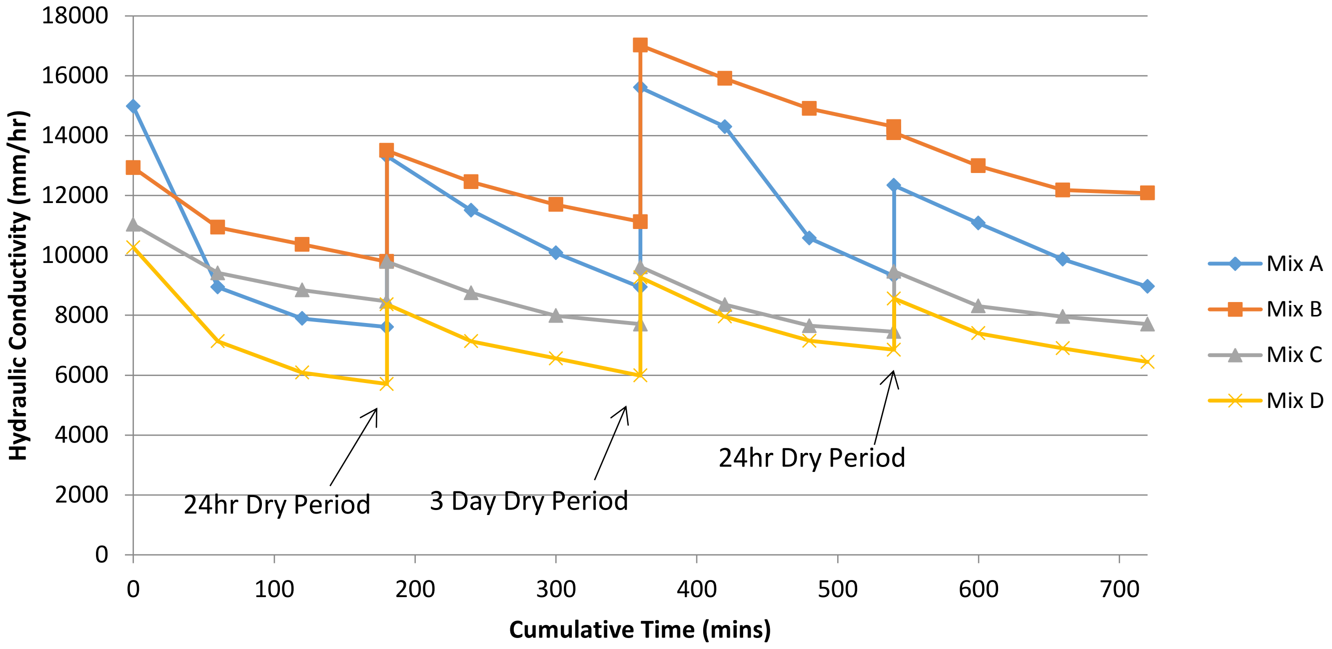

Figure 3: Hydraulic conductivity of the four soil mixes

The HCs of all four soil media decreased over time with continuous loading, but the flow rates recovered after a short dry period. Regardless of the decrease in flow rate over time, the HC values observed were very high; the lowest flow rate of 6000 mm/hr being measured for Mix D. For the purposes of the dissolved metal removal test, the flow rate was externally limited to flow rates of 500 mm/hr (low flow test), and 1000 mm/hr (high flow test) via a flow control at the effluent orifice.

4.4 LEACHATE TESTING

During the HC tests, the leachate from each soil media was quantified by measuring the change in water pH (see Figure 4) and suspended solids (see Figure 5). The pH measurements and test samples for suspended sediment concentration (SSC) tests were taken at the beginning and end of each period of continuous water flow and were analyzed according to standard test methods ASTM-D3977:2013R for SSC and NZS4402:1986–3.3.1 for pH.

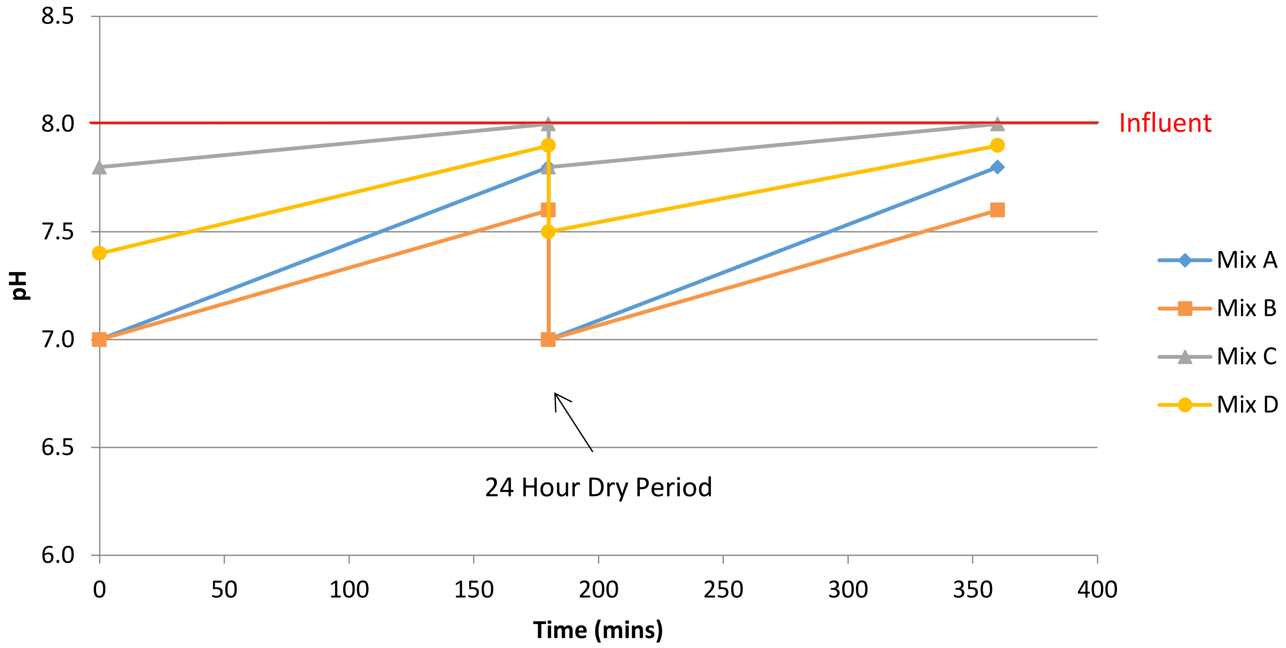

Figure 4: Influent and effluent pH during a two day test

The four substrates had different pHs but all were within the range of weakly acidic to weakly basic (ideal for rain gardens). The influence of substrate on pH weakened with flow duration but was restored following the 24 hour period of no flow. The influent water pH was 8.0.

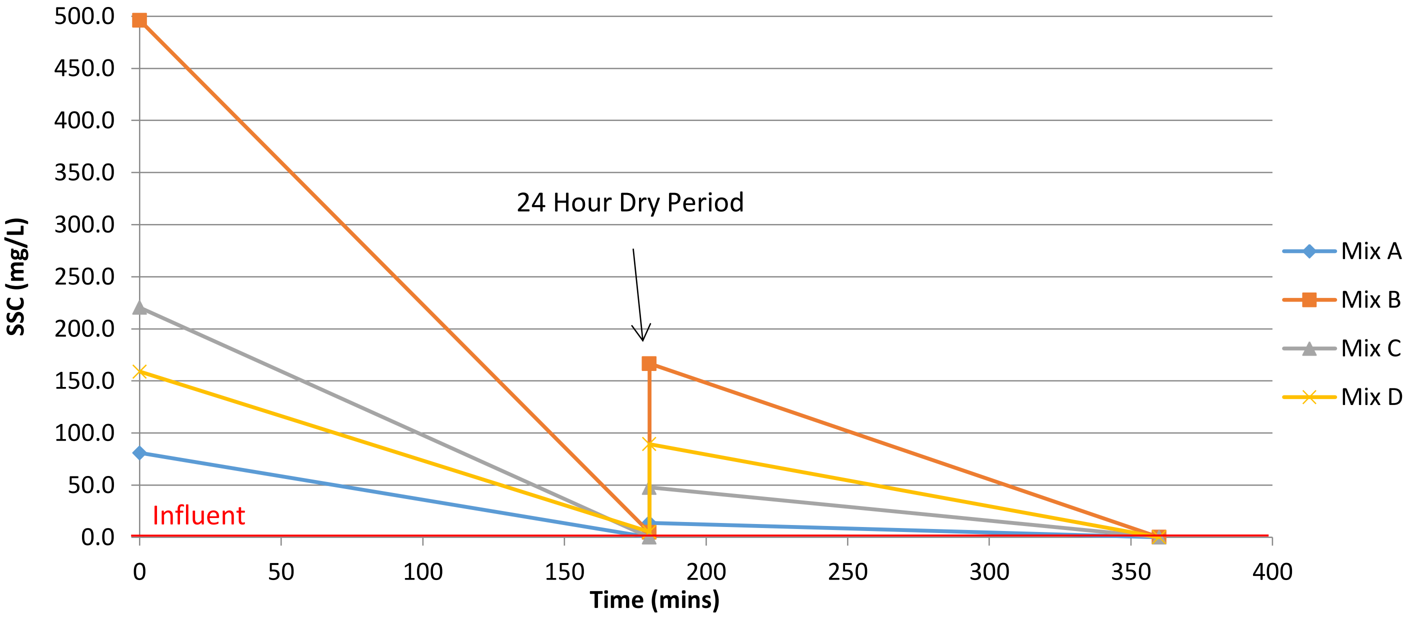

Figure 5: Influent and effluent suspended solid concentration during a two day test

Initial leaching of SSC was observed for all substrates. Mix B leached the highest concentration of suspended solids at 500 mg/L. After 180 minutes of continuous flow, leachate from all four substrates contained nomeasurable suspended solids. After 24 hour dry period, leaching again generated suspended solids, albeit at a lower initial concentration. After 180 minutes of continuous water flow SCC again decreased to zero.

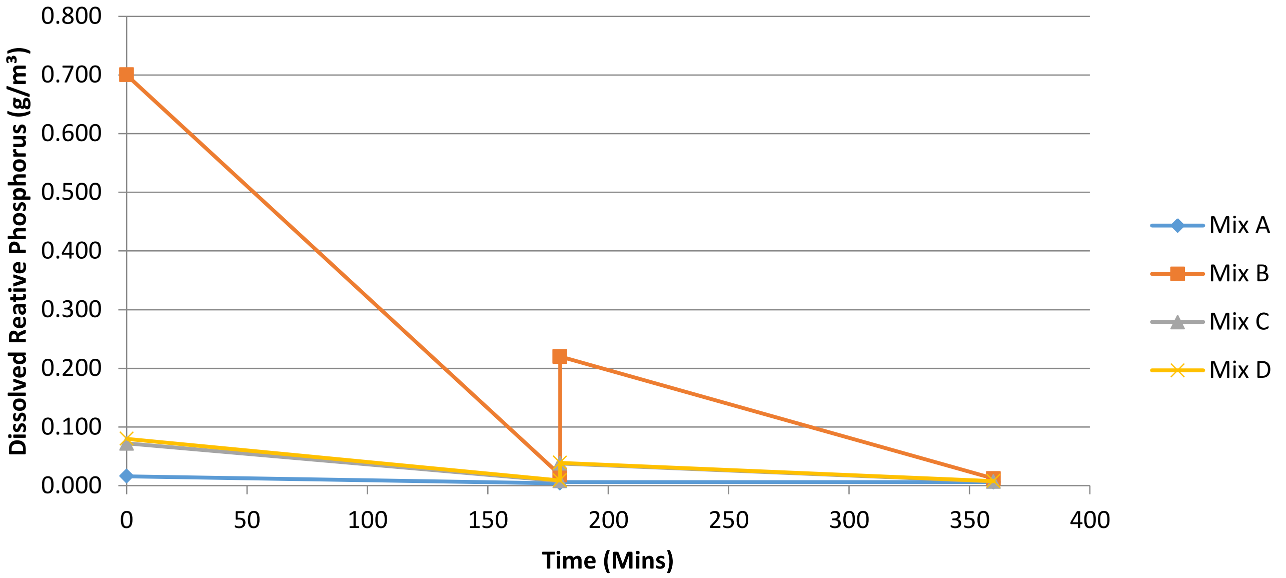

Figure 6: Influent and effluent dissolved reactive phosphorous during a two day test.

All four substrates showed significant decay in phosphorous export. However, the dissolved reactive Phosphorous (Orthophosphate) leached from Mix B is order of magnitudes higher than that of any of the other three mixes.

4.5 POLLUTANT REMOVAL

The results of the dissolved metals removal tests for the three test runs are shown in Table 5, Table 6 and Table 7. Both dissolved metal concentrations and total metal concentrations were measured, but only total metal results are shown because the dissolved and total metal removal results were similar. The dissolved metal removal rates for low HC (500 mm/hr) were within 1% for all measurements of total metal removal, and for high HC (1000 mm/hr) were within 2%.

Table 5: Test 1 influent, effluent and % removal of metals – Low HC (500 mm/hr), low metals concentration ([Cu] 0.024 mg/L, [Zn] 0.15 mg/L)

		Influent (mg/L)					Effluent (mg/L)			
Metal	Desired (mg/L)	0 mins	120 mins	240 mins	360 mins	Average	Mix A	Mix B	Mix C	Mix D
Total Cu	0.024	0.0529	0.0456	0.0424	0.0406	0.045	0.0020	0.0014	0.0014	0.0012
Total Zn	0.15	0.1617	0.1642	0.1577	0.1576	0.160	0.0017	0.0024	0.0014	0.0014
			Removal			**Total Cu**	**95.7 %**	**97.0 %**	**97.0 %**	**97.4 %**
						Total Zn	**99.0 %**	**98.5 %**	**99.2 %**	**99.1 %**

Table 6: Test 2 influent, effluent and % removal of metals – High HC (1000 mm/hr), low metals concentration ([Cu] 0.024 mg/L, [Zn] 0.15 mg/L)

		Influent (mg/L)					Effluent (mg/L)			
Metal	Desired (mg/L)	0 mins	120 mins	240 mins	360 mins	Average	Mix A	Mix B	Mix C	Mix D
Total Cu	0.024	0.0360	0.0351	0.0346	0.0337	0.035	0.0017	0.0012	0.0014	0.0013
Total Zn	0.15	0.1689	0.1702	0.1694	0.1714	0.170	0.0014	0.0019	0.0017	0.0012
			Removal			**Total Cu**	**95.1 %**	**96.4 %**	**95.9 %**	**96.3 %**
						Total Zn	**99.2 %**	**98.9 %**	**99.0 %**	**99.3 %**

Table 7: Test 3 influent, effluent and % removal of metals – High HC (1000 mm/hr), high metals concentration ([Cu] 0.24 mg/L, [Zn] 1.5 mg/L)

		Influent (mg/L)					Effluent (mg/L)			
Metal	Desired (mg/L)	0 mins	120 mins	240 mins	360 mins	Average	Mix A	Mix B	Mix C	Mix D
Total Cu	0.24	0.1219	0.1158	0.1182	0.1142	0.118	0.0086	0.0069	0.0080	0.0068
Total Zn	1.5	1.4475	1.4363	1.4538	1.4610	1.450	0.0036	0.0030	0.0071	0.0026
				Removal		**Total Cu**	**92.7 %**	**94.1 %**	**93.2 %**	**94.2 %**
						Total Zn	**99.7 %**	**99.8 %**	**99.5 %**	**99.8 %**

4.5.1 HIGH PERCENTAGE REMOVAL OF DISSOLVED METALS

A high removal rate of metals was observed for all soil mixes tested under all three test conditions at low and high metal concentrations. The metal removal rates were unexpectedly high. One explanation for these high results is the use of synthetic stormwater consisting of 100% dissolved metals (metals bound to sediment or organic matter may have reduced ability to chemically bind to substrates). Nevertheless, the results showed the three soil media (Mix B/C/D) performed just as well as the rapid filtration media developed by Contech (Mix A).

When the results were compared to the design effluent quality requirements proposed in the PAUP, the metal removal for all four soil mixes tested were found to be sufficient within the range of influent metal concentrations and HCs tested. The PAUP requires Total Copper in effluent to be reduced to less than 10 µg/L and Total Zinc to be less than 30 µg/L. In low HC conditions the Total Copper concentrations in effluent were reduced to a range between 1.2-2.0 µg/L across all four soil mixes. Total Zinc concentrations in effluent measured ranged between 1.2-2.4 µg/L. Under high HC conditions coupled with high dissolved metals concentration the four mixes also passed the PAUP requirements with Total Copper concentrations in effluent ranging between 6.8-8.6 µg/L and Total Zinc concentrations between 2.6-7.1 µg/L. Despite the high removal rates observed (93-95% removal) under high HC conditions (1000 mm/hr), the removal of Total Copper was not significantly below the PAUP effluent quality requirements.

4.5.2 EFFECT OF CHANGED HC AND DISSOLVED METAL CONCENTRATION ON METAL REMOVAL

Increasing the HC to 1000 mm/hr in Test 2 and 3 from 500 mm/hr in Test 1 resulted in a slight decrease in metal removal efficiency. The contact time between the soil media and water was reduced under a higher HC. The average metal removal rate of Cu for low HC conditions was 97% and for high HC conditions 95%. The removal efficiency of Zn was unchanged.

4.5.3 REPRESENTATIVENESS OF SYNTHETIC STORMWATER

The synthetic stormwater used for the laboratory tests did not contain any sediment or organic matter. The high dissolved metal removal rates observed across all four substrates and especially the significantly better performance of Mix A (the rapid filtration media developed by Contech) as compared to past field tests performed by Contech on the same media (76% Total Copper removal, 85% Total Zinc removal (Contech, 2012)) suggest that the metal removal rates of the column tests conducted were higher than in field practice. The organic content of stormwater, which is often absent in synthetic stormwater, has been identified as one reason better removal rates are generally found in laboratory tests compared to field studies (Minton, 2011).

Future experiments will repeat the column tests using either a synthetic stormwater blend with a solids component or to use collected stormwater spiked with target pollutants. The inclusion of solids into the influent water would provide a more realistic test and replicate some level of media clogging and other particle interactions that occur in practice.

5 FUTURE WORK

Research into filtration substrates is continuing at Stormwater360. In addition to the laboratory testing, the company is looking to conduct field tests of the BioFilter using local filtration substrates and to conduct plant growth trials. We plan to measure the effect of plants on stormwater volume reduction (via evapotranspiration) improved effluent quality via nutrient and metal uptake, and long-term HC.

6 CONCLUSION

The physical and chemical characterisation of the locally-developed bioretention substrates showed Mix B was the most suitable for plant health. Mix B would provide adequate water retention to support plants during prolonged dry periods. The chemical properties of Mix B are consistent with other rain garden mixture used in New Zealand.

Laboratory tests were conducted on four engineered substrates to determine their dissolved metal removal capabilites. A rapid filtration media developed by Contech, a US company providing stormwater solutions, was tested alongside three other soil mixes similarly.

Using a four column test setup the soil mixes were initially tested for hydraulic conductivity and leaching potential. The hydraulic conductivities of the soils ranged between 6000 – 17000 mm/hr and both HC and suspended sediment reduced over time. No solids were measureable in effluent sampled after three hours of continuous flow. The impact on pH ranged between 0 and 0.5 after a similar time period of three hours. A 24-hr 'dry' period allowed the substrates to recover a portion of their leaching potential.

The four substrates were tested in vertical columns using synthetic stormwater consisting of dissolved Copper and Zinc in either low concentrations ([Cu] 0.024 mg/L, [Zn] 0.15 mg/L) or high concentrations ([Cu] 0.24 mg/L, [Zn] 1.5 mg/L). Using an external flow control, the soil media were tested at two rates of hydraulic conductivity, 500 mm/hr and 1000 mm/hr.

All four substrates demonstrated high total metal removal rates for both Copper (92.7%-97.4%) and Zinc (98.5% – 99.8%). Minor decreases in metal removal efficiencies were observed at higher influent dissolved metal concentrations and when the test columns were subjected to a higher hydraulic conductivity.

The high metal removal rates of Zn and Cu in all four substrates tested suggest that the use of a synthetic stormwater consisting only of dissolved metals may have produced a better result than would be observed in the field. A more accurate assessment would have been attained by using synthetic stormwater that included some solids or organic matter. This being said all locally derived mixes performed as well as the Contech engineered substrate for pollutant removal in the experiments performed. The most promising substrates then need to be tested in New Zealand field installations, as has been done in the United States for the Contech substrate.

These New Zealand-designed bioretention substrates used with a flow-controlling device offer potential to achieve performance that meets new guidelines in a device with a smaller footprint. Such devices are targeted particularly at high volume discharges with little available land area, such as runoff from industrial sites.

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