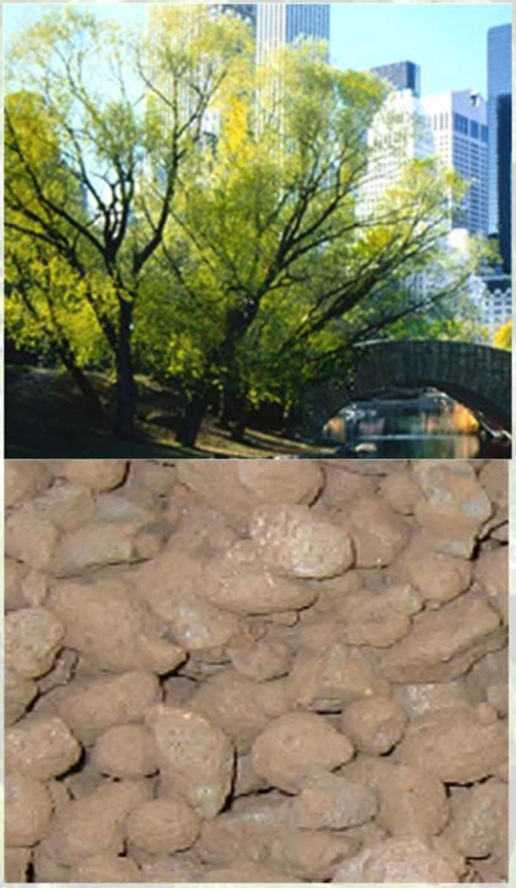
Urban Runoff Pollutants Removal of Three Engineered Soils



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Abstract

Urbanization converts largely pervious landscapes into buildings, roads, parking lots, and other impervious surfaces that increase storm runoff volume and contaminant loads. Urban storm runoff causes property damage, adds pollutants to receiving water bodies, increases the cost of infrastructure maintenance, and reduces groundwater recharge because of reduced infiltration.

Engineered soils are a type of soil that integrates soil and stones to support runoff storage, increase infiltration, and promote deep rooting that reduces the heaving of sidewalks, curbs and gutters by tree roots. They are highly porous, and have been used to expand the soil volume for trees in small tree wells in plazas and parking lots. In this study, pollutant removal rates of contaminated storm runoff and runoff storage capacities were tested for three different types of engineered soils. Surface runoff was collected from parking lots and streets in different types of land uses for a variety of storm sizes and seasons. The laboratory test results indicated that 29.0% to 84.0% of the nutrients in the storm runoff were removed by these engineered soils. The heavy metal removal rate ranged from 75.0 to 92.0%. Pollutant removal rates were strongly related to the type and size of rainfall event, runoff pollutants concentration, as well as the pollutants constituents and engineered soil types.

Introduction

Urban storm water runoff is a typical landscape and water resource management problem in cities around the world. It is especially relevant in fast-growing areas. Urbanization converts largely pervious landscapes into buildings, roads, parking lots, and other impervious surfaces that increase runoff volume and contaminant loads. Urban runoff is a key element in the urban ecosystem, and has been a crucial front in the fight for water resource protection. Rapid change in nutrient concentrations and temperatures of runoff flow is one of urban runoff's hydrological characteristics (Black, 1980; Gnecco et al., 2006; Gobel et al., 2007; McLeod et al., 2006). Urban runoff has been one of the leading causes and sources of impairment in rivers, lakes, and estuaries (Boller, 1997; USEPA, 2000). Studies have shown that urban runoff pollutant contributes to the deterioration of water quality (Crabill et al., 1999; Jeng et al., 2005; Lee and Bang, 2000; Li et al., 2007; Taebi and Droste, 2004). In the United States, billions of dollars have been invested in new wastewater treatment facilities to control water pollutions. Despite this effort, many of our lakes and streams are still plagued with pollution and not be used for swimming and fishing. Urban storm water runoff causes property damage, adds pollutants to receiving bodies of water, and increases the cost of infrastructure maintenance. Urbanization and the resulting increase in impervious surfaces are also associated with reduced groundwater recharge because of reduced infiltration.

Retention/detention ponds have been widely used for runoff control, providing storage for increased runoff and settling out of particulate pollutants (Hong et al., 2006). However, with the acceleration of substituting pervious landscape with concrete and the increasing cost of urban lands, retention /detention ponds have become the last resort for urban runoff control especially in developed metro areas. Instead, bio-retentions have been tested in laboratory and used for the removal of nutrient and heavy metals (Davis et al., 2001; Davis et al., 2006; Davis et al., 2003; Hsieh and Davis, 2005a; Hsieh and Davis, 2005b; Hunt et al., 2006; Kim et al., 2003; McIntyre, 2006). More recently, storm water treatment cells have been developed for the removal of storm water pollutants from parking lots, streets, and other pavement areas (Glass and Bissouma, 2005; Sonstrom et al., 2002). These systems use soil, sand, organic materials, microbes, and vegetation to remove pollutants from runoff or wastewater (Seelsaen et al., 2006). A replaceable surface mulch layer and filter soil layer performed well in removing pollutants from runoff (Coffman and Siviter, 2007; Hsieh and Davis, 2005b).

Engineered soil, a mixture of stones and soil, provide pore space for water and air that promotes deep rooting to reduce the heaving of sidewalks, curbs and gutters by tree roots (Grabosky and Bassuk, 1995; Grabosky and Bassuk, 1996; Smiley et al., 2006). Engineered soils are friendly to trees in urban environments and have higher porosity as compared with regular urban soil (Smiley et al., 2006). The larger volume of pore space provided by the highly porous engineered soil, can support larger growing trees and provide more space for temporarily storing surface runoff. Polluted urban soils have caused environmental problems, such as a growing risk for heavy metal uptake by human and livestock (Camobreco et al., 1996; Moller et al., 2005) and groundwater contamination (Mikkelsen et al., 1997). Vegetation has been used as one of the Best Management Practices (BMPs) to clean pollutants and thus improve water quality (Barrett et al., 1998; Cheng, 2003; Liu et al., 2007; Matteo et al., 2006; Vyslouzilova et al., 2003). Reducing surface runoff will reduce pollutants traveling downstream or into the receiving water body. However, it is unclear if engineered soils can effectively filter and trap pollutants despite relatively small amounts of soil. The goals of this study were to evaluate the effectiveness of three different types of engineered soils in removing pollutants from storm water runoff and their runoff water storage capacities.

Materials and Methods

Engineered Soil

Three different types of engineered soils were used in this study. These three type of soils were Cornell University soil (CU Soil) (Grabosky et al., 2002), Carolina Stalite soil (CS) (Costello and Jones, 2003), and Davis soil (DS) (Xiao et al., 2006). The CU soil consisted of 80% stone and 20% soil (by weight), as well as a small amount of hydrogel to thoroughly mix the stone and soil. The stone size ranged from 1.9 to 3.8 cm (0.75 to 1.5 inches). The CS soil was a mixture of 80% Stalite, a porous expanded slate rock, and 20% sandy clay loam soil (by volume). The rock (Stalite) size used in this study was 1.9 cm (0.75 inches). The Davis soil consisted 75% lava rock and 25% loam soil (by volume). The lava rock size was 1.9 cm (0.75 inches). The CU soil used in this study was donated by a commercial company (TMT Enterprises, Inc. San Jose, CA 95131) because this soil mix had been patented and licensed, while the CS and DS soils were mixed to specifications described by Costello and Jones (Costello et al., 2000) in a laboratory (Figure 1).

Figure 1. Engineered soils (a) CU soil. (b) CS soil. (c) DS soil. (d) Using soil mixer to make DS soil.

The physical properties (i.e., porosity, water holding capacity, and hydraulic conductivity) of these three types of engineered soil were tested to quantify the maximum water storage capacity and the available water for vegetation (Figure 2). The CU and CS soils were tested at University of Cornell (Grabosky et al., 2008). The Davis soil's physical properties test was conducted by a commercial soil engineering laboratory (Vector Engineering Inc., Grass Valley, CA 95945) and its water holding capacity test was conducted at the University of California Davis. Standard ASTM methods were used for these tests (Costello and Jones, 2003; Grabosky et al., 2008).

Figure 2. Laboratory testing soil physical properties (photo by Dr. Lumin Ma, Vector Engineering Inc., Grass Valley, CA).

Polluted Storm Runoff

Two types of polluted runoff (i.e., natural surface storm water runoff and synthetic runoff) were used in this study. Natural surface runoff was collected from four parking lots of three different types of land uses in Davis, CA. An older institutional (> 10 years) and a newly installed institutional (< 3 years) parking lot were located at the UC Davis campus. A commercial parking lot, which is shared by neighborhood retailers, was located at 1411 W. Covell Blvd., Davis, CA. The runoff from a residential area was collected from a small parking lot (total 16 spaces) in Orchard Park, a university-owned on-campus apartment complex. Surface runoff from each of these sites was collected during 2004 – 2006 rainy season.

To collect surface storm water runoff, a 19 gallon tub was placed at the bottom of a runoff drain (manhole). A Styrofoam (polystyrene foam) disk was placed in the tub so that once the tub was full, no more runoff flowed into the tub. The manhole cover plate was wrapped with sheet plastic that contained a drainage hole in the middle of the plate. Runoff was pumped from the tub into five gallon water containers and transported to the laboratory after the storm events (Figure 3).

Figure 3. Storm runoff collection (manhole, pump, and 5 gal bottles)

In addition to using the natural storm water surface runoff, synthetic runoff with different concentration of pollutants was used for this study. Water-soluble all-purpose plant food (20-20-20) (Scotts Mirache-Gro Products, Inc.) and soluble metals (Zn, Fe, and Cu) was added to the natural runoff (synthetic runoff I) to increase the pollutant concentration to test the pollutants removal rate of heavily contaminated water. This plant food was also added to de-ionized water to create the synthetic runoff (synthetic runoff II) with pollutants (i.e., nutrients) concentration at high, medium, and low level. The concentration of the high, medium, and low were determined based on the natural storm water runoff measurement of this study.

Laboratory Testing System

The laboratory testing system was constructed based on the traditional soil column test method (Camobreco et al., 1996; Gove et al., 2001; Thompson et al., 2008). The system included six soil storage columns, a water pump, a pressure regulator, and a water tub as illustrated in

Figure 4. Each soil storage column was made of a 30.5 cm (12 inches) diameter PVC (Polyvinyl Chloride) pipe with a height of 100.0 cm (39.4 inches). The bottom of the PVC pipe was sealed with 1.3 cm (0.5 inches) thick sheet plastic. A copper tubing (5.4 cm (2") long and 3/8" (OD) in diameter) was horizontally placed on the bottom of the soil container's well. Water only flowed out of the system via this copper tubing. A clear soft tube with a shutoff valve was connected to the copper tubing to control the outflow rate.

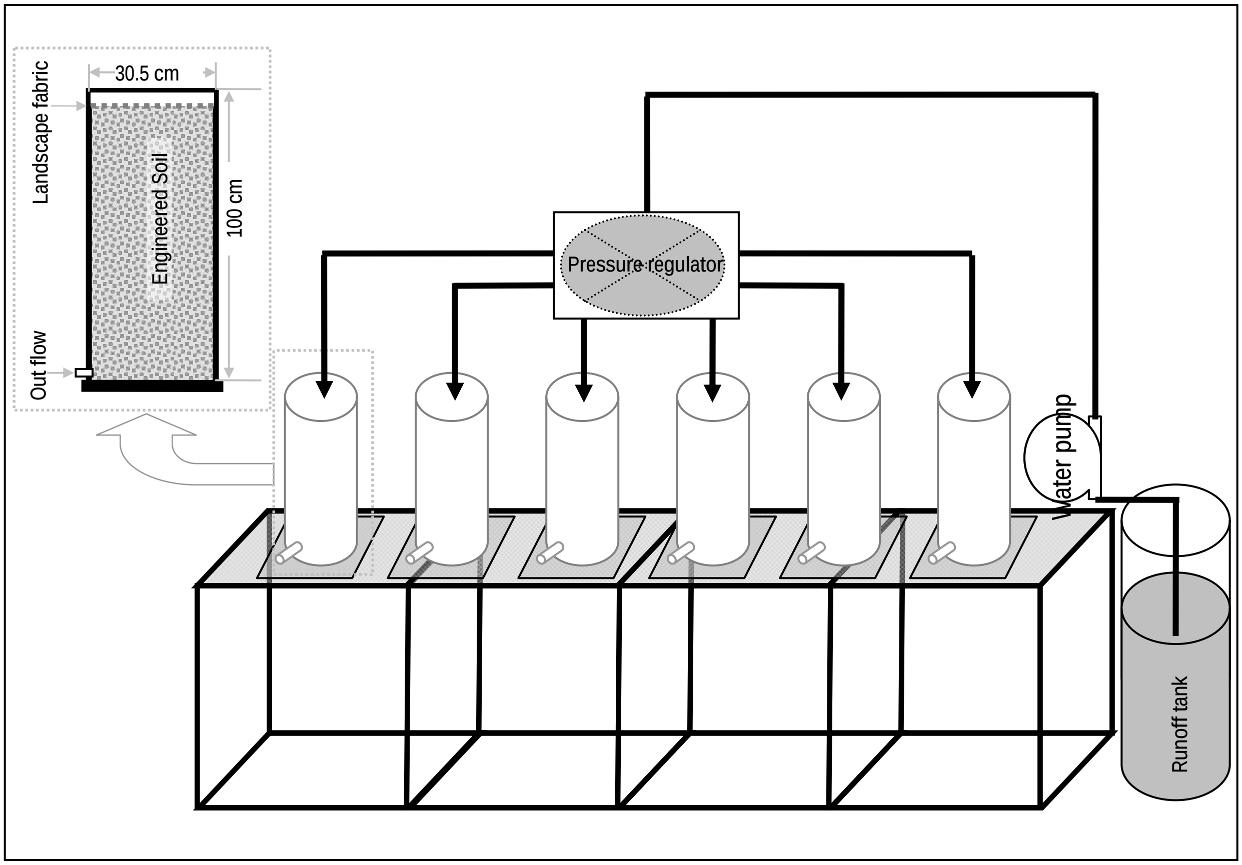

Figure 4: Laboratory testing system setup.

CU, CS, and DS soils were filled in each column and soil was gently packed during the filling. A single layer piece of landscape fabric was placed on the top of the engineered soil of each soil column to protect the soil from being washed off from the rock surface when adding runoff into the system. The top of the soil columns were covered (wrapped with an Aluminum foil sheet) after the runoff was added to the soil columns to prevent foreign substances from entering the soil columns and to reduce evaporation (Figure 5).

Figure 5: System setup (a) Columns were set on a wooden structure (b) The top of each column was wrapped with an Aluminum foil sheet to prevent contamination of the system and evaporation.

Runoff collected from each storm and at each location was separately mixed in a 72 liter (19 gal) water tub and from there it was pumped into these soil columns. A 500 ml water sample was taken from the water tub for analyzing water quality before runoff entered the system. For each test, the soil column was saturated with polluted runoff with a 24 hour detention time (equivalent to draining the soil profile to unsaturated if the soil columns were embedded in loam soil (saturated hydraulic conductivity: 1.32cm/h)) and then slowly gravity-drained to water container (i.e., five gal water bucket). During the drainage collection processes, each water container was placed inside a plastic bag to avoid water sample contamination. After draining from the soil columns ceased, a 500 ml sample was taken from each water container for water quality analysis. De-ionized water was used in the first test to obtain the chemical concentration background of each soil. Pollutant removal rates were calculated based on the runoff water's quality change before and after passing through the soil columns. Only pollutant concentrations of storm runoff greater than the chemical concentration of the background soil (i.e., soil and rocks of each soil) were used in the final analysis.

Single event and multiple event tests were conducted in the experiment. For single event tests, the soil was removed from the columns, the columns were cleaned, and engineered soils were repacked for each test. For multiple event tests, runoff was added to the soil column without any modification (i.e., repacking or replacement) of the soil column.

Water Quality Analysis

The water samples were analyzed at the Division of Agriculture and Natural Resources (ANR) Analytical Laboratory, University of California. The chemical constituents analyses focused on standard pollutants (US-EPA, 1983). The measured water quality parameters included nutrients (i.e., Total Kjehldahl Nitrogen (TKN), ammonia (NH4), nitrate (NO3), Phosphorus (P), and Potassium (K)), metals (zinc (Zn), copper (Cu), chromium (Cr), lead (Pb), iron (Fe), selenium (Se), nickel (Ni), mercury (Hg), and cadmium (Cd)), and conventional physical properties such as pH, Electrical Conductivity (EC), and Total Dissolved Solids (TDS), since they are of primary concern in runoff water quality. The ANR Analytical Laboratory performs water quality analyses for these selected chemical constituents with EPA recommended or standard analytical methods. The Method Detection Limits (MDL) for nutrients was 0.05 mg/L except TKN, for which the MDL was 0.1 mg/L. For metals, the MDL was 0.1 mg/L for copper, 0.02 mg/L for zinc, and 0.05 mg/L for both nickel and lead. For chromium and cadmium, the MDL was 0.005 mg/L, and selenium and mercury had an MDL of 1 µg/L. The nature of the water quality data sets were determined using standard statistical methods. The pH, EC, and TDS were measured immediately after the water samples arrived at the laboratory using the Ultra meter II (ULTRAMETER II, Models 6P, Myron L Company, 2450 Impala Drive, Carlsbad, CA 92010 USA). This instrument had a measurement resolution of 0.01% of both EC and TDS and 0.1 for pH. The instrument was calibrated with NIST traceable Standard Solutions having specific conductivity/ppm values before each measurement.

Results and Discussions

Soil Properties

All three engineered soils used in this study are well drain porous media. The drainage of these soils was restricted by their sub-layer's soils hydraulic conductivity. Figure 6 shows the dynamic of water content change of the DS soil. In less than two hours, the water content changed from saturation to field capacity. The porosity ranged from 31.0% (CU soil) to 45.3% (DS soil) (Table 1). Field capacity ranged from 11.6% to 20.0%. 19.4% to 25.3% of pore space was available to store storm water between storm events. As compared with clay loam soil's plant available water (PAW, a portion of the water holding capacity that can be absorbed by a

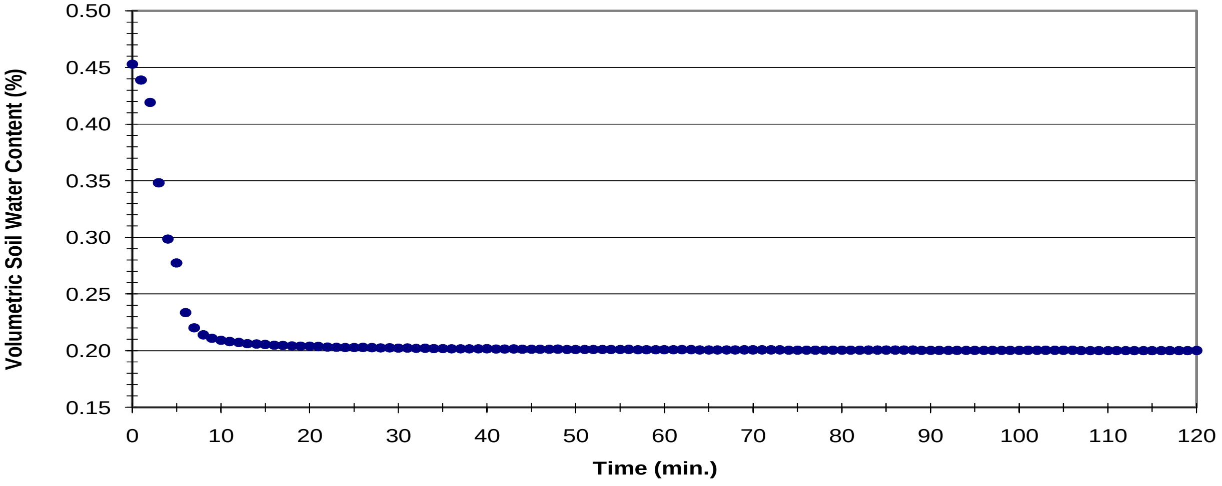

Figure 6: Dynamic change of volumetric soil water content (%) of DS soil.

plant) of 18%, the PAWs for engineered soils were 39%, 54%, and 63% for CU, CS, and DS, respectively.

Table 1. Physical Property of Different Soils

Soil	Porosity	Field capacity	Plant Available Water	Hydraulic Conductivity
Clay loam(1)	46.0%	36.0%	18.0%	0.2 cm/h(3)
CU(2)	31.0%	11.6%	7.0%	> 58.4 cm/h
CS(2)	39.0%	15.8%	9.8%	
DS	45.3%	20.0%	11.4%	> 58.4 cm/h

(1) (Ley et al., 1994); (2) (Day and Dickinson, 2008b); (3) (Maidment, 1993)

Runoff

In this study, storm runoff water was collected from 11 storms between February, 2005 and May, 2006. Based on 40 total runoff samples, the TKN ranged from 0.4 mg/L to 18.9 mg/L with a mean 3.3 mg/L (Table 2). The TKN was slightly higher and metal concentrations were lower than observed by EPA's urban runoff program in the west coast region (US-EPA, 1983). The synthetic runoff composed of collected runoff, plant food, and soluble meters had pollutant concentrations 60 times higher than natural runoff.

Table 2.Storm Runoff Quality

	Natural surface runoff				Synthetic Runoff			
	Mean	Max	Min	(1)No	Mean	Max	Min	No
TKN	3.32	18.90	0.40	40	194.41	553.40	59.60	6
NH4-N	1.05	5.91	0.06	24	113.64	342.12	30.86	6
NO3-N	1.16	2.85	0.06	25	143.33	428.10	38.58	6
(2)P_S	0.39	4.03	0.05	30	45.45	133.67	0.10	6
P_T	0.64	4.40	0.10	33	79.68	227.50	5.70	6
(2)K_S	7.60	41.28	0.46	40	181.63	508.29	38.41	6
K_T	4.17	24.00	0.60	15	199.88	549.10	54.00	6
(2)Zn_S	0.16	0.55	0.05	6	172.95	590.97	0.38	6
Zn_T	0.30	1.40	0.10	15	187.92	593.70	0.40	6
(2)Fe_S	0.87	1.10	0.50	3	24.52	108.90	0.10	6
Fe_T	1.37	3.00	0.50	5	66.28	230.50	1.70	6
Cr_T	0.01	0.02	0.01	9				
pH	7.30	7.60	7.10	4				
TSS	21.50	34.00	10.00	4				
Cu_S	0.20	0.20	0.20	1	103.55	328.20	0.70	6

(1): Number of samples above MDL.

(2): S stands for soluble.

Pollutant Removal Rate

For each single storm event, the pollutant removal rates ranged from zero to 100%. On average, all soils effectively removed nitrogen from storm runoff. CS and DS soil effectively removed P and K (Table 3). The P and K removal rate were not measured for CU soil because of the high P and K concentration in the CU soil – possibly because the soil used to mix CU soil was from agriculture land and contained fertilizer residue. All soils effectively reduced zinc concentration. Cr removal rate varied from zero to 100% in CU and CS soils while DS varied from 50% to 100% due to the low Cr concentration of the runoff water. Other parameters measured included Fe, Cu, Cd, Pb, Ni, and Hg. The concentrations of these pollutants in the runoff sample were below the laboratory's detectable level or the number of samples was not statistically large enough. At significance level of 0.05, there were no significant differences in on pollutant removal rates except the CU had a significantly greater NH removal rate than both DS and CU.

Table 3. Pollutants reduction of single storm event

	Pollutant reduction (percent)														
	Max			Min			Mean			STD			(1)No		
	CS	CU	DS	CS	CU	DS	CS	CU	DS	CS	CU	DS	CS	CU	DS
TKN	67	39	85	8	20	12	42	29	46	21	8	19	17	4	23
NH4-N	100	99	100	36	7	42	84	54	83	18	31	16	15	13	17
NO3-N	95	88	95	58	58	58	77	73	77	26	21	26	2	2	2
(2)P_S	96		95	13		11	62		59	26		25	16	0	19
P	82		78	0		0	58		52	23		25	16	0	19
(2)K_S	78		73	25		34	59		56	16		13	9	0	9
K			64			37			50			19	0	0	2
Zn	100	100	100	50	50	50	80	75	80	21	21	21	15	15	14
Cr	100	100	100	0	0	50	78	88	92	36	35	20	9	8	6

(1): Number of samples.

(2): S stands for soluble.

Soluble phosphorous removal rate by CS and DS soils are presented in Figure 7a for single events and Figure 7b for multiple storm events. Both CS and DS efficiently removed P from runoff. The phosphorous removal rate was not measured for CU soil because the concentrations in the runoff were lower than the soil's background phosphorous concentration. The multiple storm events test had a similar pollutant remove rates as those reported for single storm events (Table 4). This may accounts for the relatively lower pollutants concentration of the storm runoff collected from the study area.

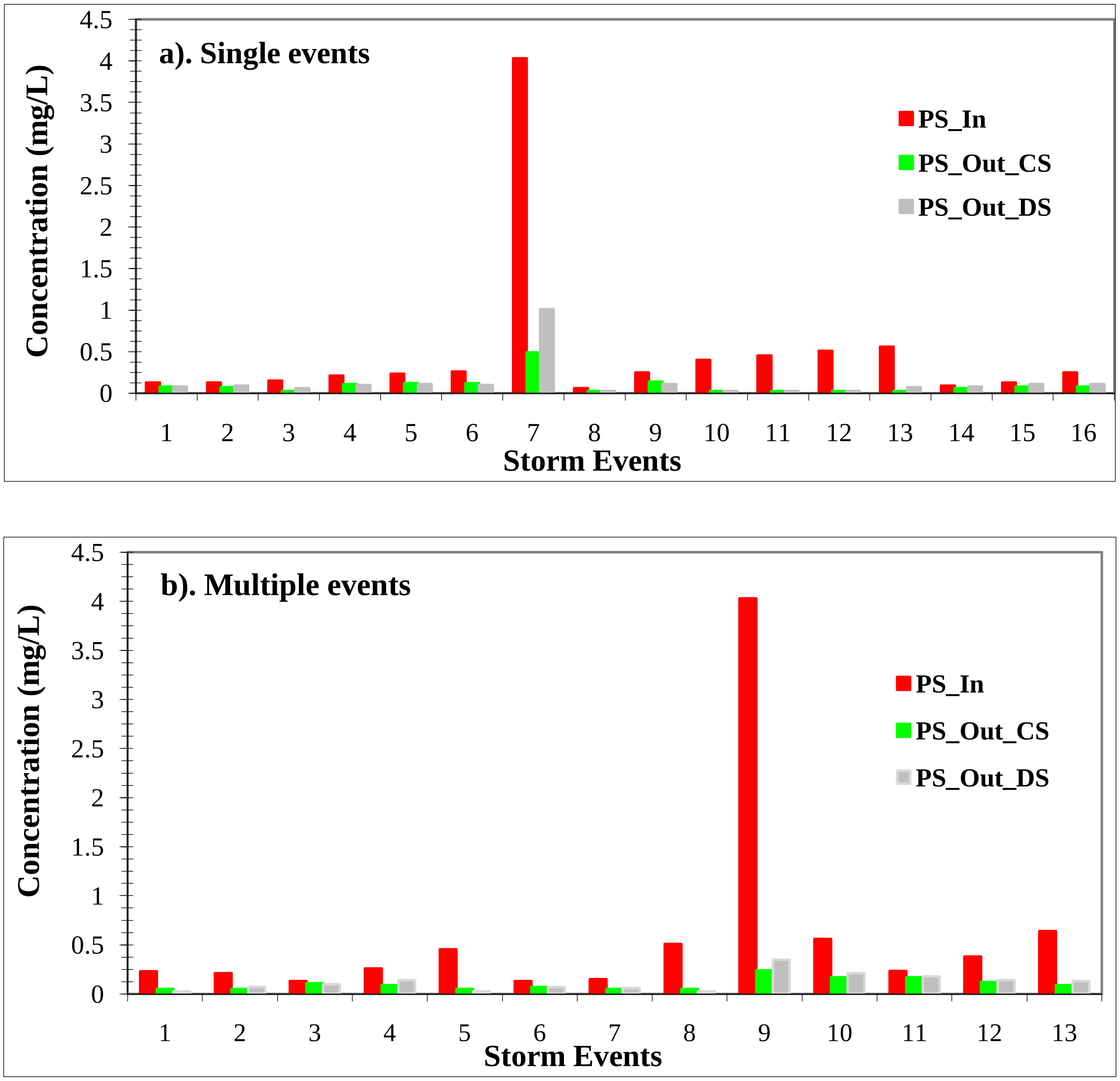

Figure 7: Soluble phosphorous removal by CS and DS soils. The x-axis is the storm event number. The PS_In is the runoff's phosphorous concentration before pass through the soil column. The PS_Out_CS and PS_Out_DS are phosphorous concentration after runoff pass through the CS and DS soil columns. At significance level of 0.05, there were no significant differences in pollutant removal rates among these three soils.

Table 4.Pollutants reduction of multiple storm events

	Pollutant reduction (percent)														
	Max			Min			Mean			STD			(1)No		
	CS	CU	DS	CS	CU	DS	CS	CU	DS	CS	CU	DS	CS	CU	DS
TKN	70	60	71	11	6	4	48	30	50	23	22	23	15	8	13
NH4-N	100	99	100	29	27	23	76	64	77	23	20	22	15	12	15
NO3-N	95	92	92	58	48	58	85	71	76	18	22	15	4	4	5
(2)P_S	94	48	95	15	48	23	65	48	65	24		25	14	1	13
P	89	0	86	0	0	0	55		55	29		25	15	0	13
(2)K_S	77	0	79	1	0	4	53		54	24		23	9	0	9
K	77	0	77	45	0	45	61		61	22		22	2	0	2
Zn	100	100	100	50	33	50	74	86	80	20	21	20	15	15	14

(1): Number of samples.

(2): S stands for soluble.

Test with Synthetic Runoff

Synthetic runoff I, mixed natural runoff with fertilizer and soluble metals, had a pollutants concentration tens time higher than the natural runoff had. The DS soil effectively reduced nutrient concentrations in both single event and multiple events test (Table 5). The majority of Zn, Fe, and Cu were removed from the runoff. The multiple events test results indicated that the system’s pollutant removal rate decreased as the number of storms with high pollutant concentrations increased. Figure 8 shows nitrogen removal by DS soil for a five storm tests. For the single event test, nitrogen removal rates ranged from 41% to 84%. However, the system eventually becomes nitrogen saturated in the multiple event tests because of accumulation in the system. This suggests that including vegetation in the system is needed for pollutants removing.

Table 5. Pollutants reduction from synthetic runoff I

	Pollutant reduction (percent)							
	Single event				Multiple events			
	Mean	Max	Min	STD	Mean	Max	Min	STD
TKN	58	93	0	26	39	91	0	36
NH4-N	81	100	59	12	51	92	0	36
NO3-N	4	16	0	6	10	34	0	14
P	71	100	0	35	59	100	0	49
K	47	87	0	36	32	87	0	36
Zn	86	100	39	18	57	100	0	41
Fe	48	100	0	42	68	100	0	39
Cu	62	100	34	24	53	100	5	33

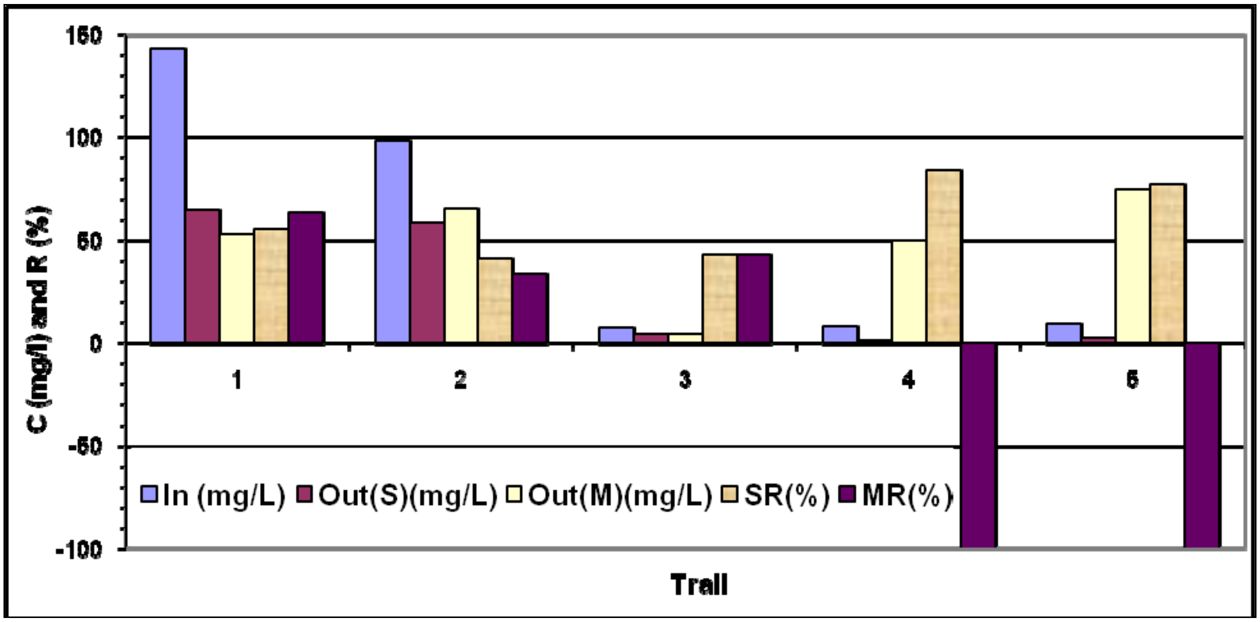

Figure 8: Nitrogen removal rate of single and multiple events by DS soil. The synthetic runoffs were composted natural storm water runoff and fertilizer. In (mg/L) is the nitrogen concentration of the runoffs before pass through the soil column. Out (mg/L) is the nitrogen concentration of the runoff passed through the system. S and M stands for single event and multiple events. SR and MR are the removal rate for single and multiple events.

The multiple storm event testing with lower pollution concentrations (synthetic runoff II) had similar results. With a constant synthetic runoff, the pollutant removal rates of DS soil decreased as trials increased (Table 6). The pollutant removal rate by DS soil decreased with trials for the highly concentrated synthetic runoff (TKN concentration at 43.2 mg/L) (Figure 9). The pollutants removal rates decreased slower for lower (TKN concentration at 5.3 mg/L) and medium (TKN concentration at 8.2 mg/L) concentrated runoff test (Table 6).

Table 6. Pollutants reduction (%) of synthetic runoff II by DS soil

Trial	TKN			NH4-N			PO4-P			P		
No	H	M	L	H	M	L	H	M	L	H	M	L
1	75	57	49	83	99	97	90	98	98	89	88	87
2	69	72	72	95	83	90	61	80	84	60	77	81
3	55	73	57	35	76	45	40	73	62	38	67	58
4	53	72	74	17	78	80	37	72	62	38	69	58
5	52	82	75	15	88	79	35	72	61	38	71	58
6	39	80	75	0	80	74	26	61	50	28	58	48
7	38	82	79	-4	86	73	26	73	50	30	71	48
8	32	78	75	-12	77	70	20	61	50	25	60	48
STD	15	8	11	40	7	15	23	12	18	21	10	15

H, M, and L stand for high (H), medium (M), and low (L) concentration. STD is standard derivation.

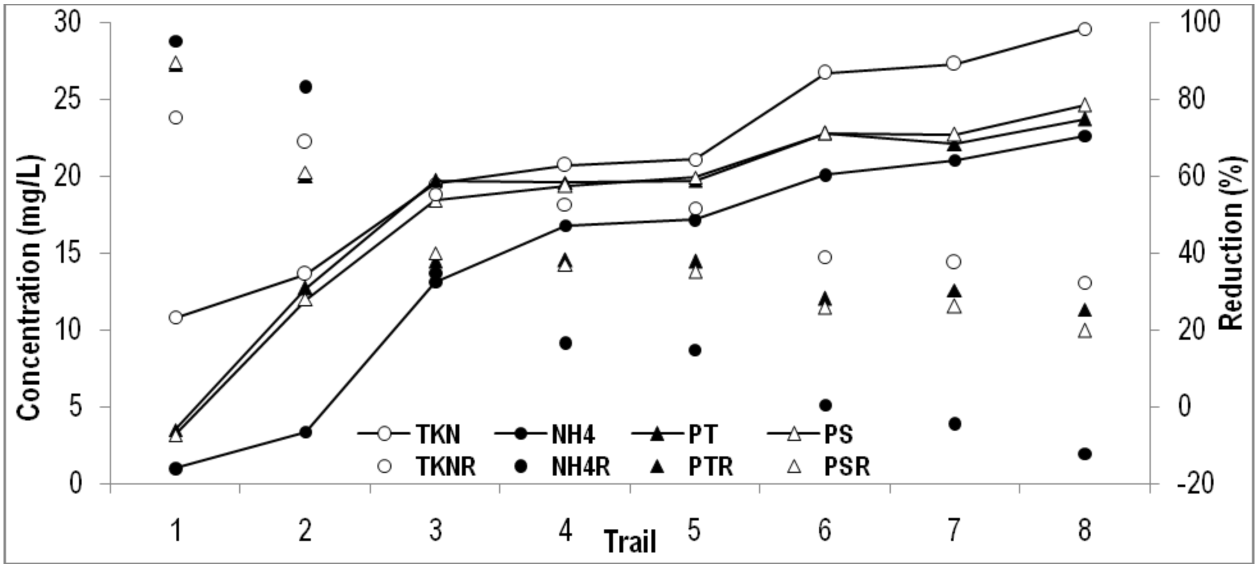

Figure 9: Pollutants reductions of multiple events by Davis Soil. The runoff was made of fertilizer and de-ionized. The concentration (TKN, mg/L) is equivalent to the highest TKN concentration found during the study period. PT and PS are total and soluble phosphorus. The R stands for % reduction.

All three types of engineered soil effectively removed pollutants from storm runoff. However, the engineered soil became saturated with pollutants in places where the runoff pollutant concentrations were high. These engineered soils should be integrated with other types of BMPs such as green vegetation to consume or break down the pollutants. The high porosity of these engineered soils provides large amount of space to store runoff. Several studies are exploring use of these soil media as storm runoff BMPs (Day and Dickinson, 2008a). However, micro-topographic and local drainage must be considered when using these porous materials. For example, these materials may not be sufficiently stable in hill-slope applications.

Table 7 shows the pH, EC, and TDS of runoff samples and water samples after different treatments (i.e., passing through different soils). All pH values increased in all treatments. In the single events testing, on average, pH increased 2.3%, 1.0%, and 2.3% when using CS, CU, and

DS soils, respectively. In the multiple events test, the smallest pH change was found from the CU soil which was 0.3% and the largest pH change was from the DS soil which was 1.0%. The pH change from the CS soil was 0.3%. This implied that pH changes were caused by the materials in the rock. The rate of pH change in the system slowed down as the amount of runoff passing through the engineered soil increased. Changes of pH should be considered when planting trees in these engineered soils because some tree species may be sensitive to these pH changes. Both EC and TDS values increased after runoff passed through the system and TDS and EC were linearly related (TDS = 0.638EC + 92.84, $R^2 = 0.869$, n = 111). A similar linear relationship between EC and total suspended solids was observed in surface runoff (Udeigwe et al., 2007). Observed TDS and EC were higher as compared with the runoff samples; one reason to cause this increase was from the experiment design. The outflow of the soil column was gravity drained through a quarter inch tubing. Although, the outflow head had been decreasing slowly, the excellent drainage characteristics of these engineered soils created a high water flow rate in the soil porous region that relocated the fine particle in the soil. A small amount of these fine particles were washed out as part of outflow. Increasing the amount of fine particles in the outflow caused the increase in both EC and TDS. Figure 10 shows water samples in the water sample bottle. The image in the right shows the runoff before (left) and after passing through the soil column (middle and left). The EC and TDS change will significantly decrease if this system were installed in real landscape because the materials surrounding the engineered soil had a much lower saturated hydraulic conductivity.

Table 7.Storm water runoff pH, EC, and TDS change on different treatments

		Runoff	Single Event			Multiple Events		
			CS	CU	DS	CS	CU	DS
pH	Max	7.84	7.96	7.60	7.78	7.55	7.52	7.63
	Min	5.68	6.60	6.65	6.66	6.83	6.85	6.91
	Mean	7.17	7.34	7.24	7.34	7.20	7.19	7.24
	STD	0.46	0.33	0.24	0.33	0.23	0.24	0.21
	Count	24	24	24	24	13	13	13

		Runoff	Single Event			Multiple Events		
			CS	CU	DS	CS	CU	DS
EC	Max	870.91	1,701.71	2,297.31	2,310.00	1,483.85	1,853.36	1,408.34
	Min	5.70	18.30	70.95	37.19	7.00	49.56	143.64
	Mean	197.53	452.42	927.80	561.79	717.69	851.46	594.23
	STD	260.37	411.09	634.13	588.33	506.13	590.86	372.28
	Count	24	24	24	24	13	13	13

		Runoff	Single Event			Multiple vents		
			CS	CU	DS	CS	CU	DS
TDS	Max	606.42	1,218.13	1,680.77	1,690.00	1,056.09	1,339.14	999.83
	Min	31.15	148.00	188.02	24.02	116.99	242.34	93.38
	Mean	206.42	401.71	787.01	393.38	505.47	738.21	410.77
	STD	177.89	252.70	394.26	429.14	276.24	393.02	265.53
	Count	24	24	24	24	13	13	13

Figure 10: Water quality testing, water samples from each test were stored in a 500 ml water bottle for water quality analysis. The green-blue water color in the left image is the synthetic runoff that was mixed with natural runoff and fertilizer. The image in the right shows the runoff before (left) and after passing through the soil column (middle and left).

Conclusions

The laboratory soil column test results indicated that CS, CU, and DS soil had effectively removed both nutrients and metals from polluted surface runoff. On average, for single storm event testing, the CS, CU, and DS soil removed 63%, 52%, and 60% of the nutrients, respectively. The metal removal rates were 79% for CS soil, 81% for CU soil, and 86% for DS soil. For multiple storm events, the CS, CU, and DS soil removed 63%, 53%, and 62% of the nutrients, and 74%, 86%, and 80% of the metals, respectively. Pollutants removal rates of engineered soil from synthetic runoff showed clear trend that the pollutant removal rate decreased with number of storms. The removal rates varied from 75% to 32% for TKN and 89%

to 25% for P. High porosity of these soils provides large amount space to store runoff. The drainage of these engineered soils was restricted by the materials underneath these porous materials. Pollutant removal rates were related to pollutant concentration. Pollutant removal rates decreased with the number of storm events as pollutants accumulated in the system. The decreased removal rates correlate to the runoff’s increased pollutant concentrations.

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