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Vegetative Swale for Treatment of Stormwater Runoff from Construction Site

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ABSTRACT

Land development, especially construction works, increase storm water volumes and pollution loads into rivers and lakes. The temporary drainage system at construction sites, particularly during the construction stage discharges a large amount of pollutants that can damage the aquatic system of the receiving water bodies. The potential of vegetative swale to alleviate this problem was evaluated. The size of the constructed vegetative swale was 7cm deep, 400cm long and 15cm wide at the bottom, and 17cm wide at the top. The experiment was conducted batch wise by filling the storage tank with the run-off water from the construction site. The water was allowed to flow through a pipe into the retention basin to maintain uniform flow before it entered the swale. The study showed that the run-off infiltrated through the soil at a rate of 489.6 mm/hr. Samples of surface run-off and infiltration water were collected at the end and the bottom of the swale. The results indicate that chemical oxygen demand (COD), total suspended solid (TSS), turbidity, iron and zinc were reduced by 85.4%, 80.8%, 36.4%, 52.8% and 96.0%, respectively, by surface flow and 91.1%, 98.8%, 58.2% 55.5% and 98.1%, respectively, by infiltration. Removal of nitrate and phosphorus by the planted vegetation was 69.4% and 21.1%, respectively, by infiltration. However, nutrient removal by surface flow was negligible. In conclusion, the vegetative swale was able to improve the water quality of the storm water run-off from the construction site from Class V to Class III, according to the Interim National Water Quality Standards for Malaysia.

Keywords: Construction site, Storm water run-off, Vegetative swale, Water quality

INTRODUCTION

The rapid rate of urban development in recent decades has led to significant changes in both the quantity and quality of storm water runoff (Line & White, 2007; Walsh *et al.*, 2004). Areas disturbed for construction activity have undergone soil erosion which carries

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pollutants (suspended solids, asphalt, sealants, oil, etc.) at rates from 2 to 40,000 times greater than the pre-construction conditions, and are important components of nonpoint source pollution that degrades surface water quality (Harbor, 1999). The pollutants found in storm water also cause ground water contamination with metals, suspended solids (SS) and oxygen depleting material (Pitt *et al*., 1996). Over the last 50 years the effects of SS on fish and aquatic life have been studied intensively throughout the world. It is now accepted that SS is an extremely important cause of water quality deterioration leading to aesthetic issues, higher cost of water treatment, decline in the fisheries resource and serious ecological degradation of the aquatic environment (Bilotta & Brazier, 2008).

According to the Malaysia Environmental Quality Report (DOE, 2006**)**, forty-two (42) of the rivers in Malaysia are categorised as being heavily polluted with suspended solids. Sediment deposition in river channesl also causes flash floods due to the reduction in the flow-carrying capacity of rivers (Zakaria *et al*., 2004). In order to protect surface and ground water quality, urban development must be guided by plans that limit run-off and reduce pollutant loading (EPA, 2008). Storm water quality is considered as improved when the quality status is at least Class IIB, based on the Interim National Water Quality Standards for Malaysia (Zulkifli, 2008). Class IIB is typically for water that is suitable for recreational use with body contact. According to the standard, Class V is the worst quality where the water is not suitable for any use (DOE, 2006).

Swales are often called grassed channels or biofilters. They are vegetated open channels for water management and have been designed specifically to treat storm water for a specified volume of run-off. Polluted storm water runs as a shallow overland flow through the grass which grows on porous soil; the water, together with dissolved pollutants, infiltrates into the soil while suspended particles settle in the grass, while the outflow from the grass is of much better quality and of lesser quantity than the incoming water (Deletic, 2005). Biofiltration is becoming widely used, due to its flexibility in terms of size, location, configuration and appearance. Biofilters may also be used as vegetated strips (Bratieres *et al*., 2008). They operate by filtering run-off through planted filtration media and provide treatment through fine filtration, extended detention and biological uptake (Melbourne Water, 2005). Most studies of biofilter performance have reported its potential for the removal of total Kjeldahl nitrogen (TKN) and ammonia (NH_3) (Henderson *et al*., 2007; Davis *et al*., 2006; Hseih & Davis, 2005a,b). However, in almost all studies (both laboratory and field), nitrate (NO_3^-) has been shown to leach out, often resulting in poor total nitrogen (TN) removal. The percolation through soil and gravel layers caused all constituents to be reduced except for nitrate (Walsh *et al*., 1997). Total phosphorus (TP) removal has generally been moderate to good (Henderson *et al*., 2007; Davis *et al*., 2006; Hseih & Davis, 2005b). Eventually, measured removal efficiencies for total suspended solids (TSS) were found to be consistently high (>90%) in all of the reviewed studies (Hatt *et al*., 2007; Hatt *et al*., 2006; Hseih & Davis, 2005a,b). Studies showed that vegetative swales are now widely employed in urban environments as an effective best management practice for controlling pollutants in storm water run-off (Kirby *et al*., 2005).

This paper presents the findings of a study on the performance of vegetative swale in removing pollutants from storm water runoff from a construction site. The main objective was to determine the efficiency of vegetative swale in removing sediment (TSS and turbidity), nutrient and metal.

MATERIALS AND METHOD

Study Site

This study was conducted using storm water run-off from a residential construction site in Batu Gajah, Perak. The study area is a typical construction site which is not only involved in construction work but also domestic activities in the workers' quarters. This study was done during the construction phase of the residential development project.

Field Water Sampling and Analysis

Initially, water samples from the construction site were collected for preliminary analysis. The samples were collected from the middle of the stream that was used as a temporary drainage. The sample bottle was lowered in the stream and rinsed three times with the run-off. The bottle was then filled by lowering to 60 percent depth of water column (making sure not to disturb the bottom sediment) while facing the current. One inch of air space was left in the bottle to allow for shaking or mixing before analysis, except for the samples for chemical oxygen demand (COD) and biochemical oxygen demand (BOD) analysis. The collected water samples were analysed in terms of TSS, turbidity, pH, COD, nitrate and metals according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1995). Table 1 summarizes the water quality from the construction site as compared to the water quality standard for Malaysia.

TABLE 1

Results for water quality at construction site as compared to the Interim Water Quality Standards for Malaysia

Parameters		Interim National Water Quality Standards for Malaysia						Construction site
		I	IIA	IIB	III	IV	V	
TSS, mg/L		25	50	50	150	300	300	652
Turbidity, NTU		5	50	50	N/A	N/A	N/A	2750
pH		6.5-8.5	6-9	6-9	5-9	5-9	N/A	7.96
COD, mg/L		10	25	25	50	100	>100	246
Nitrate, mg/L		Natural levels	7		N/A	5	Levels above IV	180
Metal, mg/L	Zinc	Natural levels	5		0.4*	2	Levels above IV	1.3411
	Iron		1		1	1(leaf) 5(others)		4.6143

The water quality shows high concentration of TSS, metals and also nutrients in the storm water run-off during the active construction activities. The average class of the discharged water is Class V. Water samples from the construction site were then used to test the effectiveness of vegetative swale in removing the pollutants.

Experimental Setup

A vegetative swale was constructed using galvanized iron, plywood and wooden planks. The size of the vegetated swale was 7cm deep, 400cm long, 15cm wide at the bottom and 17cm wide at the top with side projection of 3cm wall provided to allow run-off water containment during the experiment (Fig.1 and Fig.2). The empty-bed volume of the vegetated swale was approximately 39 200cm^3. The trench bottom and walls were lined with linen cloth to retain the soil inside the swale. A bottom slope of 0.44% was kept to maintain the hydraulic gradient.

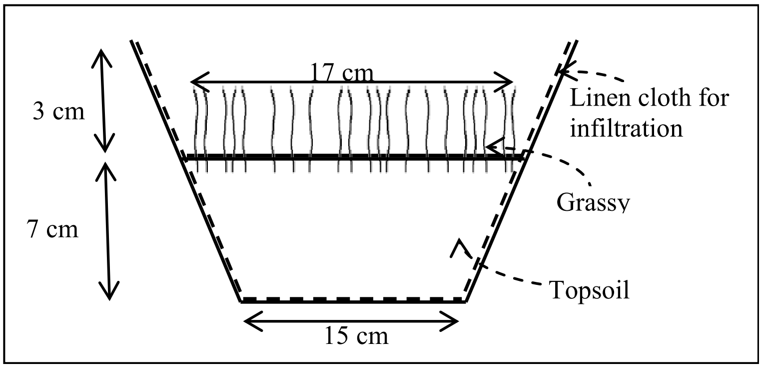

Fig.1. A cross section of vegetative swale

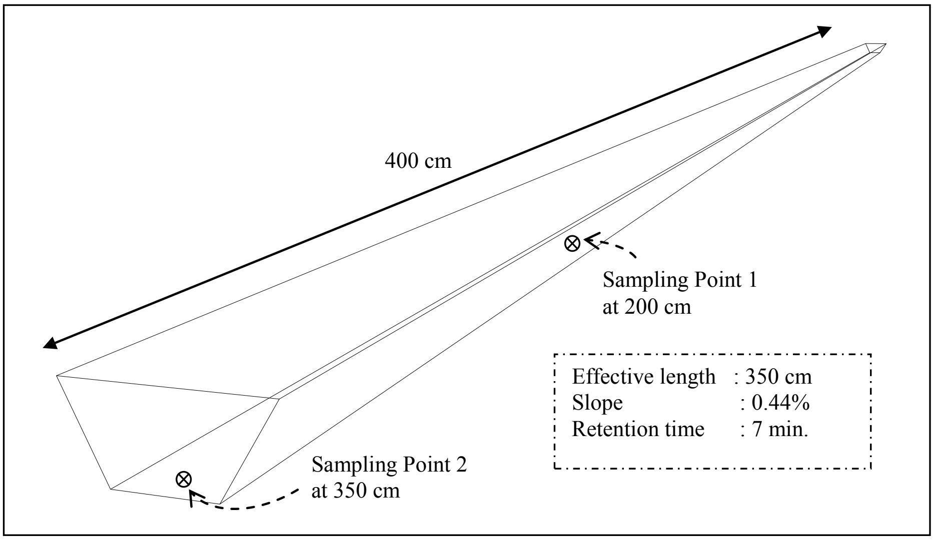

Fig.2: An overview of the infiltration points

The swale was provided with a feeding system which consisted of a storage tank and detention basin as shown in Fig.3. A detention basin was used to provide a constant inflow to the swale. A perforated PVC pipe was used to transfer the surface run-off from the storage tank to the swale. The grass species and the top soil used in this experiment were collected from Seri Iskandar wetland area.

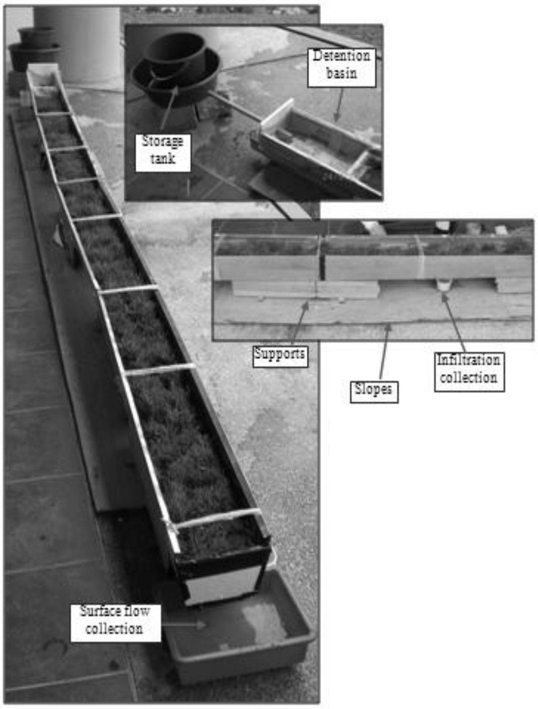

Fig.3: The constructed vegetative swale configuration

The experiment was conducted batch wise by filling the storage tank with 40 L run-off water from the construction site. The water was allowed to flow through the swale by gravity. On the other end of the swale, run-off water was allowed to overflow into a container and collected for water quality analysis. Water samples were also collected from two sampling points at the bottom of the swale, located at 200cm and 350cm from the influent point, respectively. This was done to measure the removal of pollutants through infiltration process.

The collected inflow and outflow samples were tested for total suspended solids (TSS), turbidity, pH, nitrate (NO_3^-), phosphorus (PO_4^{3-}), chemical oxygen demand (COD), and metals (zinc and iron). All samples were analysed according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1995).

RESULTS AND DISCUSSION

Infiltration Rate

The infiltration rate, *F*, is the velocity or speed at which water enters into the soil. It was measured by the depth of water (mm) that can enter the soil in one hour (Abdelhak, 2009). Out of 40 L of storm water run-off, only 6 L flowed through as surface flow. Thus, the infiltration rate for this swale system was calculated based on the 34 L infiltrated in 7 minutes run-off, as follows:

$$F = \frac{volume\ of\ \ water\ runoff}{surface\ area}$$

$$= \frac{\left(34 \times 10^3 \times 10^3\right) mm^3}{\left(170mm\ \times\ 3500mm\right) \times 7min}$$

$$= 8.16\ mm / min$$

$$= 489.6\ mm / hr$$

Sediment Removal

Storm water discharges from construction sites carry large sediment loads resulting in highly turbid water (Patil *et al*., 2011). Turbidity and TSS removal occur mainly by infiltration through the soil and deposition during surface flow. The infiltration reduced turbidity and TSS of the run-off by 96.6-98.8% and 50.9-58.2%, respectively (Fig.4). The surface flow showed lower removal efficiency for turbidity (80.8%) and TSS (36.4%), mainly because solid particles were carried to the outlet by the surface water.

Turbidity of the influent was reduced from 2750 NTU to 1750 NTU (surface flow), 1350 NTU (sampling point 1) and 1150 NTU (sampling point 2). Influent TSS of 652 mg/L was reduced to 125 mg/L (surface flow), 20 mg/L (sampling point 1) and 8 mg/ L (sampling point 2). Dillaha *et al*. (1986) assessed the pollutants' removal by vegetative filter strip and found that the sediment reduction was 81-91%.

Metal Removal

Infiltration reduced iron and zinc of the run-off by 54.2-55.5% and 87.2-98.1%, respectively (Fig.5). The surface flow showed lower removal efficiency for iron (52.8%) and zinc (96%). Iron in the influent was reduced from 4.614 mg/L to 2.178 mg/L (surface flow), 2.113 mg/L (sampling point 1) and 2.054 mg/ L (sampling point 2). Zinc in the influent was reduced from 1.341 mg/L to 0.054 mg/L (surface flow), 0.038 mg/L (sampling point 1) and 0.026 mg/ L (sampling point 2).

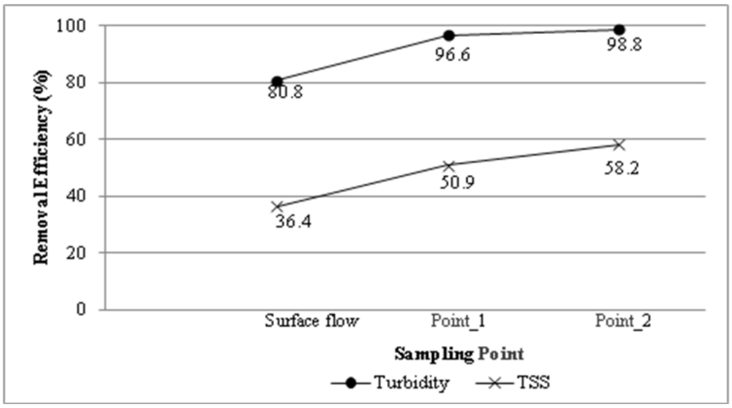

Fig.4: Turbidity and TSS removal efficiency by surface flow and infiltration through the swale

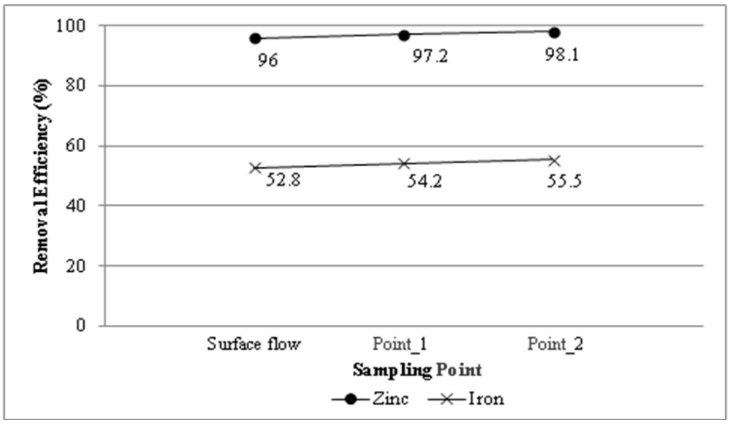

Fig.5: Metal removal efficiency by surface flow and infiltration through the swale

Similar results were obtained by Delgado *et al*. (1995), where the typical percentage reductions of zinc by vegetative filter strip was in the range of 75-84%. Yousef *et al*. (1987) deduced that the removal of metals will be greater for species present as charged ion, with the dominant removal mechanism being adsorption onto particles which are then removed by sedimentation.

Nutrient Removal

Results on the reduction of COD are presented in Fig.6. Significant COD reduction of more than 85% was achieved both by infiltration and surface flow. The COD in the influent was reduced from 246 mg/L to 36 mg/L (surface flow), 24 mg/L (sampling point 1) and 22 mg/L (sampling point 2). As expected, the results from surface flow indicated less reduction as compared to the results by infiltration. Removal of phosphorus and nitrate by the swale was observed in the water that infiltrated through the soil. The removal was within the range of 9.6-21.1% and 63.9-69.4% for phosphorus and nitrate. This could be due to plant uptake through the root system or by denitrification in the soil. Flow through the surface of the swale did not remove any nutrient.

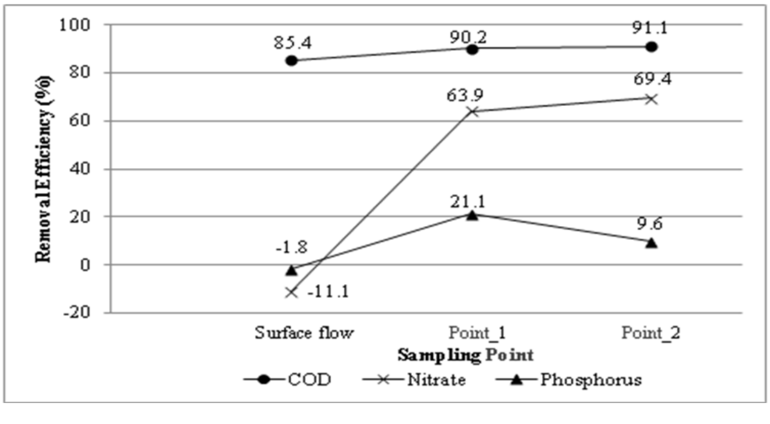

Fig.6: Nutrient removal efficiency by surface flow and infiltration through the swale

Higher value of nitrate in the surface flow (200 mg/L) as compared to the influent (180 mg/L) was probably due to nitrification of ammonia. Initial phosphorus value of 1.66 mg/L also increased to 1.69 mg/L in the surface flow and only reduced to 1.31-1.50 mg/L through infiltration. These results were similar to the findings by Dillaha *et al*. (1986), who found that soluble phosphorus was not successfully removed and in some cases, even increased as a result of solubilisation and leaching of previously accumulated phosphorus. Nutrient removal, however, can be optimised by selecting suitable species with higher capacities for assimilation of inorganic nitrogen and phosphorus and conversion into plant biomass (Vymazal, 2007; Greenway, 2003).

CONCLUSION

In conclusion, COD, turbidity, TSS, iron and zinc were reduced by 85.4%, 36.4%, 80.8%, 52.8% and 96%, respectively by surface flow. Infiltration through the swale provided higher removals than by the surface flow. Removal by infiltration for TSS, turbidity, iron, zinc and COD were 98.8%, 58.2%, 55.5%, 98.1% and 91.1%, respectively. Removal of nutrients by infiltration was 69.4% for nitrate and 21.1% for phosphorus. However, the surface flow did not remove any nutrient. It was found that vegetative swale could improve the water quality of the storm water run-off from Class V to Class III according to the Interim National Water Quality Standards for Malaysia.

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