Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.781109

51 (2013) 4129–4137
May

Taylor & Francis
Taylor & Francis Group

Application of a gravel wetland system for treatment of parking lot runoff

Jiyeon Choi, Marla C. Maniquiz-Redillas, Soyoung Lee, Jean Margaret R. Mercado, Lee-Hyung Kim*

Department of Civil & Environmental Engineering, Kongju National University, 275 Budaedong, Seobukgu,
Cheonan, Chungnamdo 331-717, Korea
Tel. +82 41 521 9312; Fax: +82 41 568 0287; email: leehyung@kongju.ac.kr

Received 15 May 2012; Accepted 31 December 2012

ABSTRACT

In this study, the applicability of a gravel wetland system, a best management practice similar to horizontal subsurface flow constructed wetland was investigated for the treatment of parking lot runoff. Monitoring of storm events was performed between July 2010 and November 2011 to estimate the pollutant event mean concentration (EMC) at the inflow and outflow of the gravel wetland system. The ratio of the discharge EMC to the inflow EMC (EMC_{out}/EMC_{in}) was assessed by treatment-affecting factors such as rainfall, rainfall intensity, volume, average flow and peak flow ratios. Based on the results, the system showed satisfactory treatment efficiency for total suspended solids (more than 70%) and total Zinc (almost 60%). Average treatment efficiency for chemical oxygen demand was 50%; while 35 to 45% for nutrient such as total nitrogen and phosphorus. Among the factors, the volume ratio (Vol_{out}/Vol_{in}) and average flow ratio ($Avg.\ flow_{in}/Avg.\ flow_{out}$) showed greater influence in the EMC ratio. Rainfall also influenced the EMC ratio but not very significantly. Overall, the system was able to treat 30–60% of inflow and improved the water quality standard of outflow to one or two levels higher than the inflow, even if the inflow was highly polluted.

Keywords: Best management practice; Gravel wetland system; Parking lot; Stormwater runoff

1. Introduction

Rapid urban expansion is the conversion of vegetation areas, which provide stormwater runoff interception, storage, and infiltration functions, to impervious surfaces that often results in an increase in the rate and volume of surface stormwater runoff [1,2]. Significant increase in urban stormwater runoff can negatively impact receiving waters resulting in water quality problems including direct pollution of receiving waters, impairment of water treatment processes due to extreme fluctuations in runoff water quality, and reduction of sewer system efficiency [3].

---

*Corresponding author.

Presented at the Nonpoint Source (NPS) Workshops
at the Third International Conference on Rainwater Harvesting & Management, Goseong, Korea, 20–24 May 2012
and the Korea-China World Expo Exhibition Plan, Beijing Normal University, Beijing, China, 4–7 July 2012

1944-3994/1944-3986

Stormwater best management practices (BMPs) are widely used techniques for handling stormwater runoff. Recently, more attention has been given to construct BMPs that remove pollutants since most BMPs focus only to control the water flow in order to alleviate peak flows and flood prevention [4]. The most common BMPs are constructed wetlands (CWs), infiltration, swales, and bioretention systems.

CWs are effective treatment systems and simple technologies that involve low energy and operational costs. They are designed to performed same processes that occur in natural wetlands, but do so within a more controlled environment [5]. Refs. [6,7] initiated the horizontal sub-surface flow (HSSF) CWs in the early 1960s and was improved more by the addition of porous media such as gravel in late 1980s in the UK. This feature is still used in the conventional HSSF CWs design. The use of HSSF for wastewater treatment (e.g. domestic, surface runoff, industrial, and leachate from sanitary landfills) has received increasing attention in the last decade [8]. The HSSF CW can provide a reliable secondary level of treatment with regard to biochemical oxygen demand (COD) and total suspended solids (TSS). However, it is frequently less effective for nitrogen removal, since this removal mechanism requires a longer hydraulic retention time and enough oxygenation [9].

BMP facilities including CWs are commonly designed considering the water quality volume (WQV) that could be determined by several methods. In Korea, this WQV is the first flush design runoff volume expressed in depth per drainage area multiplied by the area that is draining into the BMP [10,11]. However, treatment of first flush capture volume alone could hardly achieve the high level of water quality standard in Korea. For the economic and efficient operation of the BMP, determination of affecting factors like rainfall variables, pollutant event mean concentration (EMC), antecedent number of dry days (ADD), traffic volume, land use, geographic and geologic characteristics of the region, maintenance practices, and drainage system configuration in the treatment performance is important. Therefore, this study investigated the applicability of a gravel wetland system for the treatment of stormwater runoff in a highly impervious parking lot. The study aims to determine the factors affecting treatment performance of gravel wetland system in terms of EMC discharge. The effluent was also compared to the water quality standard in rivers in Korea. Based on the findings, suggestions were provided to improve the design of gravel wetland system.

2. Materials and methods

2.1. Site description and gravel wetland system design

The gravel wetland system was installed in an asphalt-paved parking lot (100% impervious), which drains from a 460 m^2 catchment area. The schematic of the gravel wetland system designed for this study was presented in Fig. 1. The gravel wetland system is

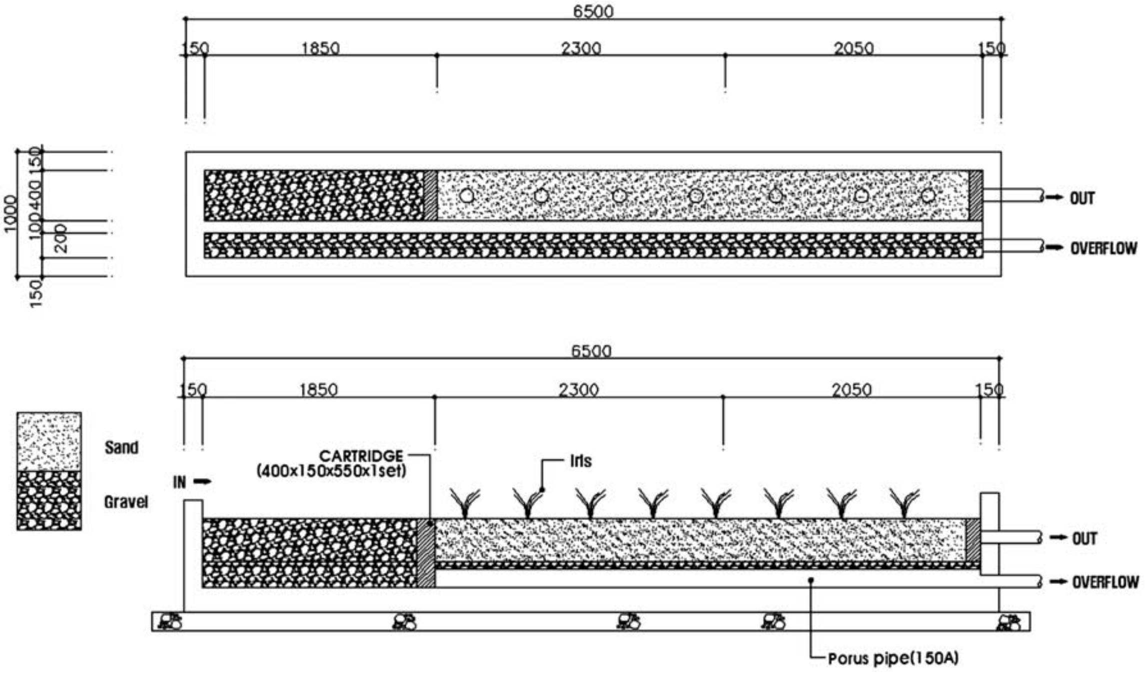

Fig. 1. Schematic of the gravel wetland system.

a type of HSSF CW wherein the water is fed in the influent and continues its way under the surface of the bed in a more or less horizontal path until it reaches the effluent zone. The system was consisted of three main parts that include the sedimentation tank, media/plant area and overflow channel. The sedimentation tank captures and allows the large particles to settle while the media/plant further enhances the treatment process by means of the mechanisms of filtration, adsorption, and plant uptake. In case of excessive runoff due to heavy flow and loading, an overflow channel with gravel media was also included in the system. The vertical media layer containing woodchip was installed after the sedimentation tank to minimize the clogging in the media/plant area. Iris (*Acorus calamus*), a short plant that has flowers and is also common plant species in wetland was planted at the landscape area. The population density of the plants was 13 plants/m^2.

2.2. Storm event monitoring and data analyses

A total of 11 storm events were monitored from July 2010 to November 2011 to estimate the pollutant EMC at the inflow and outflow of the gravel wetland system. Continuous flow measurements were performed at the inflow and outflow of the gravel wetland system every 5- or 10 min interval. Rainfall data were also collected including the rainfall intensity, rainfall duration, ADD, etc. The total sampling time was adjusted to approximate the time during which the "first flush" was processed [12]. Generally, at least 12 samples were manually collected at both the inflow and outflow. Typical water quality parameters were measured, including TSS, COD, total nitrogen (TN), total phosphorus (TP), and total zinc (Zn). Analyses of these parameters were performed in accordance with standard methods [13].

EMC was calculated by the summation of loadings during each sampling period using the volume (or flow rate) for that period. The equation below was used for the determination of EMC.

$$\mathrm{EMC} = \frac{\sum_{i=1}^{n} (C_i \times q_i)}{\sum_{i=1}^{n} (q_i)} \tag{1}$$

where EMC = event mean concentration, mg/L; C_i = pollutant concentration at time i, mg/L; q_i = flow in the ith sample; n = total number of samples for the time period.

The pollutant removal efficiency (RE) was calculated based on the "efficiency ratio (ER) method" defined in terms of average RE of pollutants for the time period [14].

$$\mathrm{RE}\ (\%) = \frac{\mathrm{EMC_{in}} - \mathrm{EMC_{out}}}{\mathrm{EMC_{in}}} \tag{2}$$

where $\mathrm{EMC_{in}}$ = average inflow EMC, $\mathrm{EMC_{out}}$ = average outflow EMC.

3. Results and discussion

3.1. Storm event and runoff characteristics

The summary of the monitored event data is provided in Table 1. The first monitoring was conducted on 16 July, 2010 where 3.5 mm of rainfall was recorded and lasted for 4 h. During the storm event, no outflow occurred due to the low average rainfall intensity of 0.875 mm/h and the media inside the system was hypothesized to be incompletely saturated. The non-outflow occurrence at the first storm event monitoring resulted to zero value for the following ratios: ratio of outflow volume to inflow volume ($\mathrm{Vol_{out}/Vol_{in}}$), ratio of outflow average flow rate to inflow average flow rate (Avg. $\mathrm{flow_{out}}$/Avg. $\mathrm{flow_{in}}$) and ratio of outflow peak flow rate to inflow peak flow rate (Peak $\mathrm{flow_{out}}$/Peak $\mathrm{flow_{in}}$). The volume discharged in the system was approximately 60 to 70% at 9.73 mm mean rainfall and 4.24 mm/h mean rainfall intensity.

The maximum rainfall observed in this study was 32 mm that occurred during 10 h duration on November 30, 2011. During that time, all inflow volume was completely discharged ($\mathrm{Vol_{out}/Vol_{in}} = 1$). Moreover, the Avg. $\mathrm{flow_{out}}$ exceeded the Avg. $\mathrm{flow_{in}}$ (Avg. $\mathrm{flow_{out}}$/Avg. $\mathrm{flow_{in}} > 1$) and the Peak $\mathrm{flow_{out}}$ exceeded the Peak $\mathrm{flow_{in}}$ (Peak $\mathrm{flow_{out}}$/Peak $\mathrm{flow_{in}} > 1$).

The pollutant concentrations of typical water quality parameters in urban runoff studies are generally quantified by means of EMC. A statistical summary of the inflow EMC is shown in Table 2. The average inflow EMC (mean ± standard deviation) are 163.8 ± 118.0 mg/L for TSS, 191.3 ± 234.6 mg/L for COD, 8.74 ± 4.87 mg/L for TN, 0.67 ± 0.45 mg/L for TP and 644.8 ± 646.5 µg/L for total Zn. In comparison to other urban sites in Korea [15], the mean EMC of most pollutants except TP was three times higher in magnitude due to the successive road maintenance and construction activities during the monitoring period.

Table 3 shows the correlations between hydrologic and hydraulic variables and inflow EMC. As can be seen, the total rainfall was highly correlated to total runoff ($R = 0.992$). Moreover, total rainfall was correlated with rainfall duration ($R = 0.662$) and average rainfall intensity ($R = 0.558$). ADD was positively correlated with rainfall duration ($R = 0.716$) but negatively correlated with Peak $\mathrm{flow_{out}}$/Peak $\mathrm{flow_{in}}$ ($R = -0.704$).

Table 1
Summary of monitored rainfall events ($n = 11$)

Parameter	Unit	Minimum	Maximum	Median	Mean	SD**
ADD*	Day	0.2	20.7	4.53	6.08	6.27
Total rainfall	mm	1.5	32.00	5.00	9.73	10.66
Rainfall duration	h	0.82	9.95	1.85	2.98	2.69
Avg. rainfall intensity	mm/h	0.86	15.52	2.04	4.24	4.96
Total runoff	m^3	0.05	11.79	0.52	2.64	4.06
Vol_{out}/Vol_{in}	–	0.00	1.00	0.76	0.69	0.29
Avg. $flow_{out}$/Avg. $flow_{in}$	–	0.00	1.13	0.83	0.78	0.31
Peak $flow_{out}$/Peak $flow_{in}$	–	0.00	2.94	0.75	0.89	0.77

*Antecedent dry day.
**Standard deviation.

Table 2
Stormwater runoff (inflow) pollutant EMC ($n = 11$)

Parameter	Unit	Minimum	Maximum	Median	Mean	SD*	CV**
TSS	mg/L	12.3	344.1	141.9	163.8	118	0.7
COD	mg/L	22.3	793	117.7	191.3	234.6	1.2
TN	mg/L	2.24	19.91	8.76	8.74	4.87	0.56
TP	mg/L	0.21	1.59	0.57	0.67	0.45	0.66
Total Zn	μg/L	55.2	2275.1	380.1	644.8	646.5	1.0

*Standard deviation.
**Coefficient of variation.

High correlation was observed between Vol_{out}/Vol_{in} and Avg. $flow_{out}$/Avg. $flow_{in}$ ($R = 0.989$). Also, Vol_{out}/Vol_{in} and Peak $flow_{out}$/Peak $flow_{in}$ was found to be correlated to each other ($R = 0.557$). On the other hand, most of the pollutant parameters were negatively correlated with hydrologic and hydraulic variables. TSS EMC appeared to be negatively correlated to those variables except for Peak $flow_{out}$/Peak $flow_{in}$ ($R = 0.279$) as shown in the table. COD EMC also showed high negative correlation with Vol_{out}/Vol_{in} ($R = -0.942$) and Avg. $flow_{out}$/Avg. $flow_{in}$ ($R = -0.957$). TN EMC was also negatively correlated with average rainfall intensity ($R = -0.940$), total runoff ($R = -0.825$) and total rainfall ($R = -0.756$). TP EMC also have negative correlations with total rainfall ($R = -0.710$), average rainfall intensity ($R = -0.630$), total runoff ($R = -0.775$), Vol_{out}/Vol_{in} ($R = -0.764$) and Avg. $flow_{out}$/Avg. $flow_{in}$ ($R = -0.762$). In the case of Total Zn, only average rainfall intensity ($R = 0.853$) showed positive correlation.

According to [16], urban runoff quantity and quality depend on several factors which determine flow rate magnitude and time distribution, as well as pollutant concentrations. These factors include rainfall patterns, volume, intensity, and ADD, traffic volume, landuse, geographic and geologic characteristics of the region, maintenance practices, and drainage system configuration. Average rainfall intensity and flow rate have often been used to represent the energy input from the storm event [17,18] since a higher EMC may be expected in a more intense storm if maximum values are a good descriptor of the process. ADD and Peak $flow_{out}$/Peak $flow_{in}$ showed weak correlations to pollutant EMC due to the fact that these parameters are a function of flow rate and catchment area which could be dependent on rainfall and runoff in particular [15]. For this reason, the low correlations also suggest that not only monitoring parameters contribute to stormwater pollutants EMC, but other factors should also be considered.

3.2. Pollutant RE

The pollutant RE of the gravel wetland system is shown in Figure 2. Apparently, the maximum RE was 100% due to the absence of outflow during the first monitoring event. The mean RE ranges from 36 to 72%, while median RE was between 42 and 68%. The

Table 3
Pearson correlations (*R* value) of monitored parameters and inflow EMC

Parameter	ADD	Total rainfall	Total rainfall duration	Ave. rainfall intensity	Total Runoff	$\mathrm{Vol_{out}}$/ $\mathrm{Vol_{in}}$	Avg. $\mathrm{flow_{out}}$/ Avg. $\mathrm{flow_{in}}$	Peak $\mathrm{flow_{out}}$/ Peak $\mathrm{flow_{in}}$
ADD	1.000							
Total rainfall	0.322	1.000						
Total rainfall duration	0.716	0.662	1.000					
Ave. rainfall intensity	−0.253	0.558	−0.232	1.000				
Total runoff	0.206	0.992	0.572	0.635	1.000			
$\mathrm{Vol_{out}}$/$\mathrm{Vol_{in}}$	−0.034	0.440	0.230	0.155	0.453	1.000		
Avg. $\mathrm{flow_{out}}$/ Avg. $\mathrm{flow_{in}}$	−0.168	0.343	0.118	0.136	0.370	0.989	1.000	
Peak $\mathrm{flow_{out}}$/ Peak $\mathrm{flow_{in}}$	−0.704	−0.177	−0.241	−0.173	−0.113	0.557	0.664	1.000
TSS	−0.465	−0.845	−0.471	−0.582	−0.827	−0.595	−0.487	0.279
COD	0.072	−0.497	−0.092	−0.408	−0.528	−0.957	−0.942	−0.428
TN	0.220	−0.756	−0.029	−0.940	−0.825	−0.242	−0.213	0.075
TP	0.321	−0.710	−0.141	−0.630	−0.775	−0.764	−0.762	−0.468
Total Zn	−0.338	0.199	−0.460	0.853	0.277	−0.365	−0.357	−0.358

highest mean *RE* was achieved by TSS with 72% removal followed by total Zn, COD, TP, and TN with 58, 49, 43, and 36% removal, respectively.

Among all parameters, TN has the lowest RE (−2%), which was observed during the last monitored event on 30 November 2011. During that time, a heavy rainfall of 32 mm occurred which exceeded the design rainfall of the facility. This occurrence has resulted in a complete discharge of runoff from the system. Difficulties of achieving high RE were also attributed to the design of the facility. Occurrence of rainfall exceeding the design capacity of the facility fails to effective treatment of stormwater runoff. Efficient treatment of stormwater runoff usually employs first flush. Therefore, treatment of all or a larger volume of runoff is ineffective, impractical, and uneconomical. Treating the whole rainfall duration is still difficult to achieve (e.g. 90–100% pollutant removal).

According to [5], most of the particulate matters are filtered out and settled within the first few meters beyond the inflow zone. Particulate matters that are not removed in pretreatment system are effectively removed by filtration and settlement. However, the accumulation of trapped solids is a major threat for good performance of HSSF systems as the solids may clog the bed. Therefore, the effective pretreatment is necessary for HSSF systems. Also, organic compounds are degraded aerobically as well as anaerobically by bacteria attached to plant underground organs (i.e.

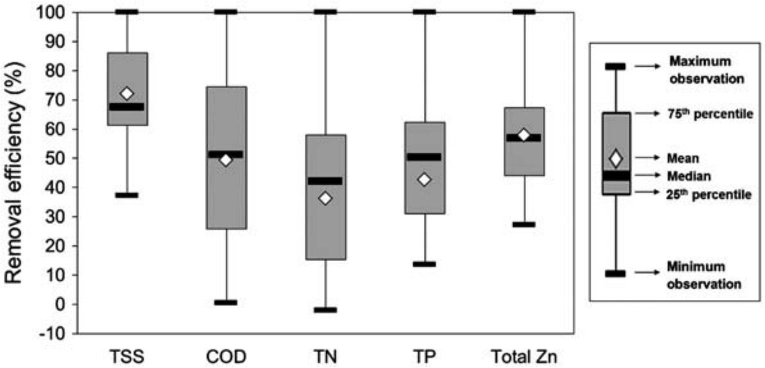

Fig. 2. Pollutant RE.

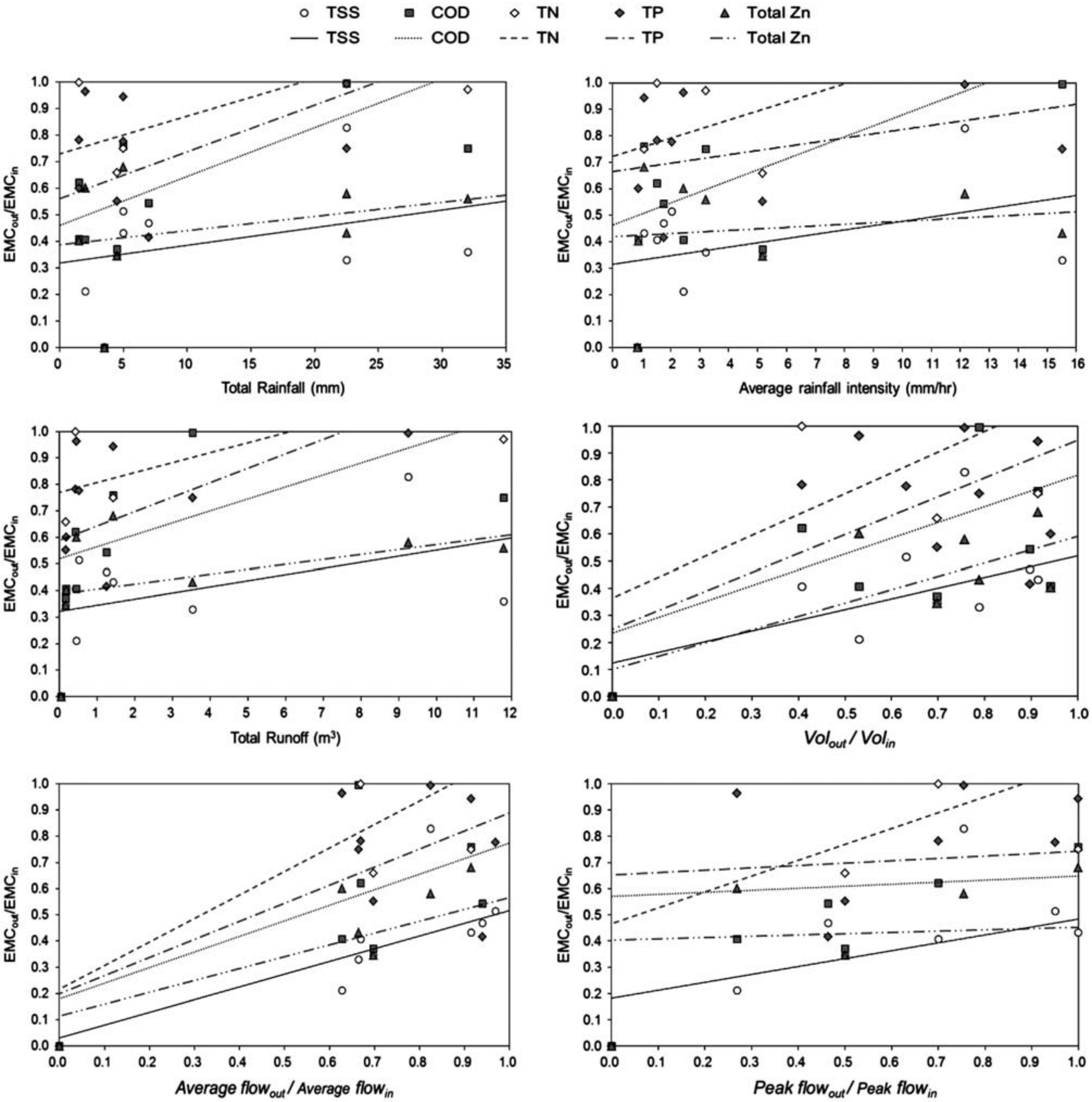

Fig. 3. Plots of EMC ratio (EMC_{out}/EMC_{in}) vs. affecting factors.

roots and rhizomes) and media surface; and the removal of organics is generally very high in HSSF CWs.

Despite the high RE values for TSS and COD, high RE for TN and TP was still difficult to achieve. The major removal mechanism of nitrogen in HSSF-CWs is nitrification/denitrification [19]. Nitrogen removal becomes effective if a longer hydraulic retention time and enough oxygenation are provided. The gravel wetland system however has limitations to perform those functions. Higher cation exchange capacity of the fine-grained soils attributes to higher elimination rate of TP. However, the fine-grained soils were not used for HSSF system. The adsorption capacity of sand and gravel is very limited. Moreover, phosphorus is primarily removed by ligand exchange reactions, where phosphate displaces water or hydroxyls from the surface of iron and aluminum hydrous

Table 4
Comparison of inflow and outflow EMC with Korea's water quality standard

Parameter	Inflow		Percent EMC discharge (mean ± SD*)	Outflow	
	EMC (mg/L)	Standard level		EMC (mg/L)	Standard level
TSS	141.9	VI (>100 mg/L)	38.2 ± 4.6	54.3	IV (<100 mg/L)
COD	117.7	VI (>11 mg/L)	60.4 ± 6.4	71.1	VI (>1 mg/L)
TP	0.57	VI (>0.5 mg/L)	70.6 ± 6.5	0.4	V (<0.5 mg/L)

*Standard deviation.

oxides. The media used (i.e. sand and gravel) at the gravel wetland system in this study do not contain great quantities of iron, aluminum, or calcium thus, removal of phosphorus is generally low. As a comparison to other studies [20–24], similar removal efficiencies were obtained for TSS (70–79%), COD (40–90%), TN (21–58%) and TP (40–82%).

3.3. Factors affecting performance

Fig. 3 shows the regression plots of EMC ratio (EMC_{out}/EMC_{in}) with respect to selected hydrologic and hydraulic variables to identify the factors affecting the treatment performance of the system. Similar trends in regression lines were apparent between total rainfall and total runoff as well as Vol_{out}/Vol_{in} and Avg. $flow_{out}$/Avg. $flow_{in}$. Despite the low values of the coefficients of determination (R^2) in the regression plots, strong correlations were observed between hydrologic and hydraulic variables and inflow EMC (see Table 3) which therefore affected the EMC ratio (i.e. ratio of discharge EMC to inflow EMC). Among all the hydrologic and hydraulic variables, total rainfall and Vol_{out}/Vol_{in} greatly influenced the discharge EMC.

The EMC ratio against Vol_{out}/Vol_{in} and Avg. $flow_{out}$/Avg. $flow_{in}$ shows the steepest slope of trend lines that were about 45–89% and 39–83%, for Vol_{out}/Vol_{in} and Avg. $flow_{out}$/Avg. $flow_{in}$, respectively conversely, total rainfall, average rainfall intensity and total runoff have the mildest slopes approximately ranging from 0.23 to 5.5% with respect to the EMC ratio. The steep sloping trend lines indicate that the change on the x-axis (i.e. affecting variables) corresponds to a substantial change in the EMC ratio. On the contrary, low-sloped trend lines correspond to a minor change in the EMC ratio. For example, a 10 mm unit increase in total rainfall would yield a 7% increase in TSS EMC ratio; while only a 0.3 unit increase in Vol_{out}/Vol_{in} could yield a 12% increase in TSS EMC ratio.

When the maximum volume ratio was reached ($Vol_{out} = Vol_{in}$), the TSS and total Zn discharge EMC were 52 and 59% of inflow EMC, respectively. COD and TP on the other hand discharged higher inflow EMC of 82 and 95%, respectively. Moreover, maximum TN EMC ratio was achieved before reaching the maximum volume ratio.

Typically, the design rainfall criteria selected in BMPs were 5, 10, and 20 mm since in Korea almost 70–80% of the total number of storm events per year was mostly below 10–20 mm [25–27]. Considering the design rainfall of 5 mm, the lowest discharge EMC was 35% of TSS inflow and ranked from the least to greatest in the following order: total Zn (41%) < COD (55%) < TP (65%) < TN (80%). Based on 10 and 20 mm design rainfall, the rank in pollutant discharge EMC was the same as the 5 mm design rainfall 39 and 45% for TSS, 44 and 49% for total Zn, 65 and 83% for COD, 74 and 91% for TP and 87 and 100% for TN. The difference in discharge EMC between 5 and 10 mm was 6% while a slightly higher difference of 12% between 10 and 20 mm. When total rainfall increased from 5 to 20 mm, the difference in discharge EMC appeared to be not considerably high.

The mean and median standard deviations of the EMC ratio for all pollutants were 19.3 and 18.9%, respectively, and not statistically different. Hence, the use of median EMC ratio was preferred in the analysis since median values often give a better estimate of the central location of the distribution when the data have a small number of high or low observations.

3.4. Water quality of discharge pollutant EMC

Table 4 shows the estimated outflow EMC calculated using the percentage of median discharge EMC from the analysis of the gravel wetland system. The inflow EMC values were taken from the median values reported in Table 2. The inflow TSS, COD, and TP EMCs fall in level VI in Korea's water quality standard in rivers and streams, the category polluted water with dissolved oxygen concentration of less than 0.2 mg/L. The high inflow pollutant concentrations in this study were attributed to a nearby road maintenance construction during the monitoring period. Using the gravel wetland system, the 54.3 mg/L of TSS was effectively removed thereby increasing the water quality level of the outflow to level IV. Effective reduction of 0.4 mg/L TP concentration was also observed raising the outflow TP level to level V. However, the level of the COD concentration at the outflow was retained even after 71.1 mg/L of COD was removed by the system. This was regarded to the inflow EMC that was considerably highly polluted even though 38–70% of COD inflow EMC was treated by the system. The gravel wetland system's main treatment mechanisms are filtration and sedimentation, which limit the treatment of organic matters and nutrients. Therefore, in order to achieve the level I_a water quality standard, only at least 20% of TSS inflow concentration and less than 5% of COD and TP inflow concentration should be discharged.

4. Conclusions and recommendations

In this study, the applicability of a gravel wetland system in the treatment of parking lot runoff was investigated based on the pollutant EMC reduction. The pollutant EMC ratio (EMC_{out}/EMC_{in}) was also regressed with several factors such as rainfall, rainfall intensity, volume, average flow, and peak flow ratios to determine the effect of these factors in discharge EMC. Based on the results, the gravel wetland system showed satisfactory treatment of typical pollutants comparable to other studies. The RE was ranked from greatest to least for the following pollutants: TSS > total Zn > COD > TP > TN. Since the gravel wetland system's main removal mechanism was filtration and sedimentation, high removal efficiencies for TN and TP were limited. However, it was observed that when the system reached the maximum volume ratio ($Vol_{out} = Vol_{in}$), the system was still effective in treating solids and particulate metal. Because even the entire runoff just passed by the system, the TSS and total Zn discharge only 52 and 59% of inflow TSS and total Zn EMC, respectively. The total rainfall does not greatly affect the BMP performance but the pollutant discharge EMC still depends on rainfall depth. Therefore, a target pollutant is recommended to determine first when designing similar BMP.

Overall, the gravel wetland system seems to improve the water quality level of the inflow though the outflow water quality level was not very high. The gravel wetland system was able to treat 30–60% of inflow but achieving the highest water quality level of level I_a was ambitious. This was attributed to high inflow EMC and the limitation in pollutant removal mechanisms such as filtration and sedimentation occurring in the system. Based on the experiences and knowledge obtained from this study, the following recommendations were provided if a higher water quality level was intended: the design rainfall of the system could be increased that could result in bigger surface area or depth, utilization of other filter media to improve filtration and adsorption function, use of vegetation for nutrient uptake, or adoption of a hybrid system capable of post-treatment of runoff. Nevertheless, cost-efficiency should also be considered when applying a treatment system. Further analysis and study are needed to completely understand and determine other factors that affect the treatment performance of the gravel wetland system.

Acknowledgments

This research was supported by a grant (Code#'09 RTIP B-01) from Regional Technology Innovation Program (RTIP) funded by Ministry of Land Transport and Maritime affairs of Korea government.

References

[1] V. Whitford, A.R. Ennos, J.F. Handley, City from and natural process-indicators for the ecological performance of urban areas and their application to Merseyside, UK, Landsc. Urban Plan 57(2) (2001) 91–103.

[2] M.G. Mansell, Rural and Urban Hydrology, Thomas Telford, London, UK, 2003.

[3] A.B. Deletic, C.T. Maksimovic, Evaluation of water quality factors in storm runoff from paved areas, J. Environ. Eng. Sci. 124 (1998) 869–879.

[4] H. Genç-Fuhrman, P.S. Mikkelsen, A. Ledin, Simultaneous removal of As, Cd, Cr, Cu, Ni and Zn from stormwater: Experimental comparison of 11 different sorbents, Water Res. 41 (2007) 591–602.

[5] J. Vymazal, Review horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment, Ecol. Eng. 25 (2005) 478–490.

[6] J. Vymazal, Horizontal sub-surface flow constructed wetlands Ondřejov and Spálené Poříčí in the Czech Republic – 15 years of operation, Desalination 246(1–3) (2009) 226–237.

[7] J. Vymazal, The use constructed wetlands with horizontal sub-surface flow for various types of wastewater, Ecol. Eng. 35(1) (2009) 1–17.

[8] A. Albuquerque, J. Oliveira, S. Semitela, L. Amaral, Influence of bed media characteristics on ammonia and nitrate removal in shallow horizontal subsurface flow constructed wetlands, Bioresour. Technol. 100 (2009) 6269–6277.

[9] W. Liu, M.F. Dahab, R.Y. Surampalli, Nitrogen transformations modeling in subsurface-flow constructed wetlands, Water Environ. Res. 77(3) (2005) 246–258.

[10] Ministry of Land, Transport and Maritime Affairs (MLTM), Guidelines for the Friendly Road Construction, Ministry of Land, Transport and Maritime Affairs (MLTM), Seoul, 2007.

[11] Ministry of Environment (MOE), Manual for the BMPs Installation, Management and Maintenance, Ministry of Environment, Seoul, 2008.

[12] L.H. Kim, S.O. Ko, S.M. Jeong, J.Y. Yoon, Characteristics of washed-off pollutants and dynamic EMCs in parking lots and bridges during a storm, Sci. Total Environ. 376 (2007) 178–184.

[13] A.E. Greenberg, L.S. Clesceri, A.D. Eaton, American Public Health Association (APHA), American Water Works Association, Water Environment Federation. Standard Methods for the Examination of Water and Wastewater, 18th ed., APHA, Washington, DC, 1992.

[14] US Environmental Protection Agency (US EPA), Results of the Nationwide Urban Runoff Program, Volume I—Final Report, Water Planning Division, US Environmental Protection Agency, Washington, DC, 1983.

[15] M.C. Maniquiz, S.Y. Lee, L.H. Kim, Multiple linear regression models of urban runoff pollutant load and event mean concentration considering rainfall variables, J. Environ. Sci. 22(6) (2010) 946–952.

[16] T.W. Chui, B.W. Mar, R.R. Hornet, A pollutant loading model for highway runoff, J. Environ. Eng. 108(6) (1982) 1193–1210.

[17] N.E. Driver, B.M. Troutman, Regression models for estimating urban storm-runoff quality and quantity in the United States, J. Hydrol. 109 (1989) 221–236.

[18] W.J. Walden, Nonpoint Source Pollutant Export Estimation from Urban Catchments, Faculty of Engineering, University of Queensland, Brisbane, 1999.

[19] J. Vymazal, Nutrient Cycling and Retention in Natural and Constructed Wetlands, Backhuys, Leiden, 1999.

[20] C.G. Yoon, S.K. Kwun, S.H. Woo, T.Y. Kwon, Review of 3-year experimental data from treatment wetland for water quality improvement in rural area, J. Korean Soc. Water Qual. 15(4) (1999) 581–589.

[21] C.S. Akratos, V.A. Tsihrintzis, Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands, Ecol. Eng. 29(2) (2007) 173–191.

[22] M.S. Fountoulakis, S. Terzakis, A. Chatzinotas, H. Brix, N. Kalogerakis, T. Manios, Pilot-scale comparison of constructed wetlands operated under high hydraulic loading rates and attached biofilm reactors for domestic wastewater treatment, Sci. Total Environ. 407 (2009) 2996–3003.

[23] F. Zurita, J.D. Anda, M.A. Belmont, Treatment of domestic wastewater and production of commercial flowers in vertical and horizontal subsurface-flow constructed wetlands, Ecol. Eng. 35(5) (2009) 861–869.

[24] J.A.H. Melian, A.J.M. Rodriguez, J. Arana, O.G. Diaz, J.J.G. Henriquez, Hybrid constructed wetlands for wastewater treatment and reuse in the Canary Islands, Ecol. Eng. 36 (2010) 891–899.

[25] M.C. Maniquiz, J.Y. Choi, S.Y. Lee, H.J. Cho, L.H. Kim, Appropriate methods in determining event mean concentration and pollutant removal efficiency of a best management practice, Environ. Eng. Res. 15(4) (2010) 215–223.

[26] M.C. Maniquiz, S.Y. Lee, K.S. Min, J. Ha Kim, L.H. Kim, Diffuse pollutant unit loads of various transportation landuses, Desalin. Water Treat. 38 (2012) 308–315.

[27] E.J. Lee, M.C. Maniquiz, J.B. Gorme, L.H. Kim, Determination of cost-effective first flush criteria for BMP sizing, Desalin. Water Treat. 19 (2010) 157–163.