Desalination and Water Treatment
www.deswater.com

1944-3994/1944-3986 © 2012 Desalination Publications. All rights reserved
doi: 10.1080/19443994.2012.698805

Taylor & Francis
Taylor & Francis Group

48 (2012) 138–147
October

Appropriate determination method of removal efficiency for nonpoint source best management practices

Soyoung Lee, Marla C. Maniquiz, Lee-Hyung Kim*

Department of Civil and Environment Engineering, Kongju National University, 275 Budae-dong, Cheonan-si, Chungnamdo 330-717, Republic of Korea
Email: leehyung@kongju.ac.kr

Received 25 August 2011; Accepted 30 April 2012

ABSTRACT

In Korea, best management practice (BMP) pilot facilities were installed to manage nonpoint source (NPS) pollution from the watershed areas. These BMPs are consistently monitored to determine the accurate pollutant removal efficiencies. However, the difficulty of removal efficiency determination in NPS BMPs is generally caused by uncertainties of site and storm characteristics. For that reason, removal efficiency determination has to apply appropriate method to eliminate uncertainties. In this study, the monitoring program was performed during 3 years in order to verify the efficiency of the infiltration trench during storm events. The pollutant removal efficiency was determined by four different methods namely the efficiency ratio (ER), summation of loads (SOL), regression of loads (ROL) and rainfall of frequency (ROF) methods. In comparison to other methods, the ROF method uses the rainfall frequency which is practical to eliminate uncertainties of NPS. Therefore, the ROF method is suggested as the appropriate method to determine the removal efficiencies and optimum among the four methods.

Keywords: Nonpoint sources; Best management practices; Efficiency ratio; Summation of load; Regression of load; Rainfall of frequency

1. Introduction

Since the 1960s, the Korean government has attempted to improve the water quality of rivers and lakes. This has been done by means of securing stable financial resources for sewage treatment facilities as part of the stream environment restoration initiative for controlling point source pollution. Despite of the effort, the water quality has continued to deteriorate because of nonpoint source (NPS) pollution caused by urbanization. The high imperviousness was reflected by the increase in runoff flows and pollutant concentration that affects the watershed hydrology and posts detrimental impacts to the receiving water bodies [1–4].

In Korea, the contribution of NPS loadings to the four major rivers in 2003 was about 42–69%. Nevertheless, it is predicted to increase more between 65% and 70% in 2015 [4]. For this reason, the recent emphasis in Korea is to manage NPS pollution in the watershed areas. The Ministry of Environment (MOE) established the Comprehensive Measures for NPS pollution Management in March 2004 to protect the four major rivers. The main policies include the implementation of total maximum daily load (TMDL), riparian buffer zones, land acquisition, and a water use charge to support the programs' efforts. The MOE is aggressively pursuing the implementation and compliance with TMDL for watershed

*Corresponding author.

protection, and effective control of NPS is believed to be the key method for successfully meeting the TMDLs [5].

NPS pollution is caused by various boundary inputs, polluting processes and human activities occurring on the land. Many types of pollutants accumulate on the road surface during dry periods. The accumulated pollutants are wash-off during storms which highly degrade the water quality of the receiving water bodies. Thus, NPS pollution could be highly variable because of watershed and hydrological characteristics such as differences in landuse, rainfall intensity, topography, vehicle activities, etc. that might result to various pollutant levels, mass loadings, etc. In order to effectively control the NPS pollution and reduce the high uncertainties that NPS pollution possessed, management measures have to be well programmed and understanding the characteristics of runoff and pollutants is necessary [6–8].

Table 1 shows the average pollutant concentrations of different land-uses calculated using event mean concentration (EMC) method and arithmetic averaging method. Typically, arithmetic averaging method is applied to estimate pollutant concentration from point sources while EMC method is often used for NPS. Using the arithmetic averaging, the average sample concentrations for most pollutants are in magnitude of 1.3–3.5 times the average EMCs for each respective landuses [9]. It has been mentioned that EMCs represent more adequately the actual runoff quality [10]. This

Table 1
Comparison of pollutant EMCs and sample concentration [9]

Parameters	Avg. EMC (mg/L)			Avg. sample concentration (mg/L)		
	Highway	Parking lot	Bridge	Highway	Parking lot	Bridge
TSS	85.7	25.0	155.4	225.8	49.2	321.8
COD	66.5	43.2	137.1	134.8	75.9	475.5
TN	2.6	1.7	3.2	3.7	2.2	5.2
TP	0.4	0.2	0.6	0.6	0.4	0.9

Table 2
Removal efficiency of NPS BMPs [4]

BMP type		Removal efficiency (%)				
		BOD	COD	TSS	TN	TP
Detention systems	Retention basin	30	30	70–90	20–60	10–60
Constructed Wetland (advance)		64–86	20–80	73–93	15–40	47–80
Constructed Wetland						
(Oxidation pond)		40–60	10–40	40–60	~25	~12
Wet pond		10–70	10–70	50–70	10–70	20–70
Infiltration systems	Porous pavement	60–90	60–90	60–90	60–90	60–90
Infiltration basin		50–80	50–80	50–80	50–80	50–80
Infiltration trench		50–90	50–90	50–90	50–90	50–90
Vegetated systems	Vegetated filter strip	~50	~50	40–60	20–30	30–60
Grassed swale		~25	~25	20–40	10–30	20–40
Package systems	Screen system	20	20	60	10	20
Filtration system		60	40–70	60–90	20–40	~80
Swirl system		–	5–10	10–25	5–10	5–10
Wastewater treatment system	High speed flocculation system	80	60	85	20	85

implies that inaccurate estimation of pollutant mass loading might result if arithmetic average concentration instead of EMC is used. In addition, the determination of removal efficiencies of BMPs also depends on the mass loadings of pollutants and therefore relies specifically from EMC values.

Recently, various types of NPS pilot facilities for NPS pollution control were installed in the four major rivers in Korea [5]. Since 2005, studies are being conducted to assess the performance of the BMPs. Table 2 shows some examples of best management practices (BMPs) with its corresponding removal efficiencies. The data were taken from the MOE which were gathered from various monitoring studies in USA. The MOE utilized the data in the design of the BMP pilot projects; however, the need to verify the effectiveness of the BMPs is necessary since NPS is high site-specific and depend on numerous demographic, geographic and hydrologic factors.

The objective of this research is to address the importance of accurate pollutant removal efficiency determination by attempting to calculate the performance of one of the BMP pilot facilities maintained by the MOE using four different methods. Finally, the most appropriate method could be suggested and employed for all the BMP monitoring studies.

2. Materials and methods

2.1. Site description and monitoring

The infiltration trench was monitored to evaluate pollutant removal efficiency in treating stormwater runoff. The site is located alongside of Route 45 in Yongin city, Gyeonggi province, Korea as shown in Fig. 1. The characteristics of the sites and design parameters are summarized in Table 3. The stormwater runoff from road is carried through a concrete gutter and treated as pretreatment system of infiltration trench which is sedimentation tank serves to limit the amounts of large particles that enter along with the influent and treating stormwater is removed and infiltrated at gravel-filled trench. Finally, the stormwater runoff infiltrated through the trench is discharged into the Kyungan Stream. The monitoring was started in June 2006 and until October 2008 for about 3 years during rainy seasons. The monitoring program was performed following monitoring plan of MOE Guideline [4]. Series of grab samples from the two inflow monitoring units were collected, six during the first hour. The first sample was collected at the very beginning of runoff and additional samples were collected at the beginning of runoff and 5, 10, 15, 30 and 60 min [11]. On the other hand, the outflow samples were also collected from the outflow monitoring unit originally intended to be used to compute mass balance efficiencies of the infiltration trench. Typical water quality parameters were analyzed such as total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved organic carbon (DOC), total nitrogen (TN), total phosphorus (TP), heavy metals (total Pb and total Zn). Analyses were conducted in accordance with standard methods for the examination of water and wastewater.

2.2. Determination of EMC and removal efficiency

Inflow and outflow EMCs were calculated to evaluate removal efficiency in infiltration trench using Eq. (1). EMC is one of the important factors in predicting

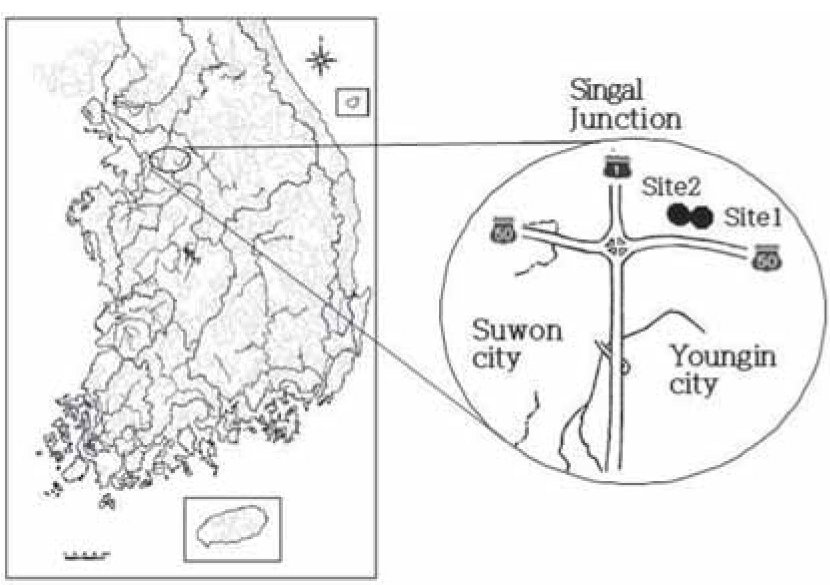

Fig. 1. Location of the infiltration trench.

Table 3
Characteristics of the monitoring sites

Monitoring site	Site 1	Site 2
Catchment area (m^2)	3000	5000
Facility area (m^2)	195.6	275.2
Total storage volume (m^3)	39.0	55.0
Hydraulic retention time (h)	0.37	0.38

the total pollutant load, which has made the EMC the critical parameter for estimating the contribution of runoff to receiving waters [12,13]. The wide distribution of EMCs depends on several factors such as site and storm characteristics [7]. In this study, a statistical summary of the inflow and outflow EMCs is identified graphically using SYSTAT 9.0 software.

$$\mathrm{EMC}(\mathrm{mg/L}) = \frac{\sum_{t=0}^{T} C(t)\cdot q_{\mathrm{run}}(t)}{\sum_{t=0}^{T} q_{\mathrm{run}}} \tag{1}$$

where $C(t)$ is pollutant concentration, and $q_{\mathrm{run}}(t)$ is the runoff flow rate at time t.

A variety of pollutant removal methods have been utilized in BMP monitoring studies to evaluate efficiency. The removal efficiency of NPS BMPs can be evaluated in a number of ways. In this study, the pollutant removal efficiency was determined by four different methods namely the efficiency ratio (ER), summation of loads (SOL), regression of loads (ROL) and rainfall of frequency (ROF) methods. Historically, the three methods (ER, SOL and ROL) have been used to calculate BMP efficiency [14]. The challenge in removal efficiency determination in NPS BMPs is generally caused by lack of sufficient data in rainfall intensity and magnitudes. For that reason, removal efficiency determination in NPS BMPs has to apply appropriate method to reduce uncertainties. ROF method is based on rainfall of frequency at each rainfall range and reflected rainfall characteristics of monitoring site. Therefore, it is appropriate method to reduce uncertainties of NPS compare to the other three methods. Consequently, rainfall frequency in Yongin city was analyzed to determine removal efficiency for ROF. Table 4 provides the description of the removal efficiency evaluation methods together with its corresponding equations.

3. Results

3.1. Monitoring event descriptions

The monitoring was performed over 18 and 23 storm events at site 1 and 2, respectively. Table 5 summarizes the

Table 4
Removal efficiency evaluation methods

Method	Component	Equation
ER	Inflow EMC	
	Outflow EMC	$\mathrm{ER}(\%) = \frac{\sum_{i=1}^{N} \mathrm{RE}_i}{N}$
	Flow volume	
SOL	Inflow mass	
	Outflow mass	$\mathrm{SOL}(\%) = \frac{\sum_{i=1}^{N} \mathrm{RM}_i}{\sum_{i=1}^{N} M(In)_i}$
	Reduction mass	
ROL	Inflow mass	$Outflow\ loads\ (kg) = \sum M(In)_i \quad ROL\,(\%) = (1 \times Out) \times 100$
	Outflow mass	
ROF	Inflow EMC	$\mathrm{ROF}(\%) = \sum_{j=1}^{N_R} (\mathrm{RE}_j \times \mathrm{RF}_j)$
	Outflow EMC	
	Flow volume	
	Rainfall range	
	Rainfall frequency	

Note: N = number of storm events, i = storm event, j = rainfall range, RE_i = removal efficiency, RM_i = reduction mass, $M(In)_i$ = Inflow mass, NR = number of rainfall range, RE_j = removal efficiency, RF_j = removal frequency

Table 5
Summary of monitored rainfall events

Monitoring site	Parameter	ADD (day)	Rainfall (mm)	Runoff duration (h)	Avg. rainfall intensity (mm/h)	Total runoff (m^3)
Site 1	*n*	18	18	18	18	18
Mean	12.0	16.6	5.6	3.14	44.1	
Minimum	2.0	2.0	1.0	1.00	2.1	
Maximum	94.0	50.5	13.0	11.43	118.4	
Site 2	*n*	23	23	23	23	23
Mean	6.8	22.8	7.1	3.45	26.4	
Minimum	1.0	1.5	1.0	0.21	0.1	
Maximum	33.0	84.0	14.0	16.17	121.1	

monitored event data which include antecedent dry day (ADD), rainfall, runoff duration, average rainfall intensity and total runoff. For site 1, the ADD is between 2 and 94 days, total rainfall varies from 2.0 to 50.5 mm, runoff duration is in the range of 1.0–13.0 h and the average rainfall intensity was determined between 1.00 and 11.43 mm/h. For site 2, the ADD ranges from 1 to 33 days and the total rainfall varies from 1.5 to 84.0 mm. Runoff duration is in the range of 1.0–14.0 h and the average rainfall intensity was determined between 0.21 and 16.17 mm/h. The data indicated a wide distribution of values. Also, the ADD, rainfall and runoff are varying with respect to each event which means that there have been a lot of uncertainties concerning to NPS. Therefore, long monitoring is needed to identify relationships among parameters (Fig. 2).

3.2. Determination of influent and effluent EMCs

A statistical summary of the inflow and outflow EMCs is identified graphically by the box and whisker plots in Fig. 3. The 95% confidence interval is ranged from 79.3 to 176.6 mg/L for inflow TSS EMC and 15.8–30.1 mg/L for outflow TSS EMC for site 1. For site 2, confidence interval of 95% is ranged from 43.1 to 149.2 mg/L for inflow TSS EMC and 11.6 to 25.5 mg/L for outflow TSS EMC. Also, sites 1 and 2 were grouped together and analyzed. As a result, the 95% confidence interval in combined sites is ranged from 74.7 to 145.5 mg/L for inflow TSS EMC and 16.3 to 25.8 mg/L for outflow TSS EMC. Outflow EMCs appear to have smaller coefficient of variations compare to inflow EMCs. On the other hand, the wide distribution of the EMCs greatly depends on the site characteristics as well as in the monitoring methods, traffic, ADD and other environmental conditions that implies high uncertainties concerning to NPS.

3.3. Determination of removal efficiency

3.3.1. Efficiency ratio (ER) method

The ER method is defined in terms of average removal efficiency of pollutants for each storm

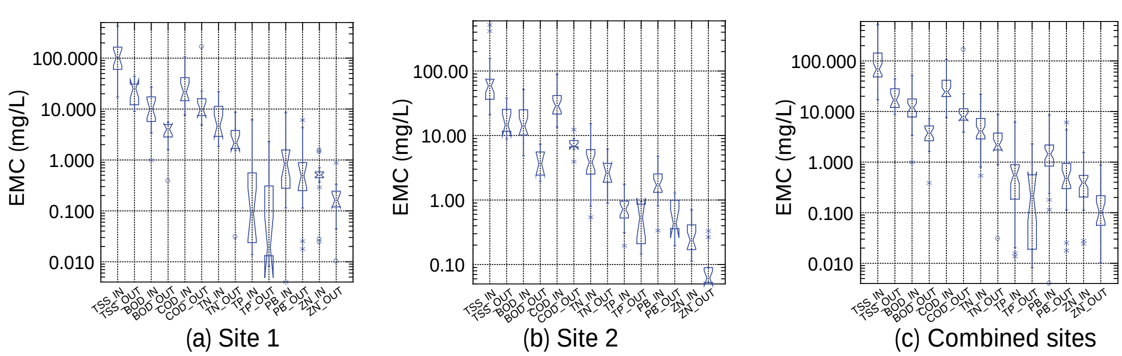

Fig. 2. Statistical summary of inflow and outflow EMCs. (a) Site 1. (b) Site 2. (c) Combined sites.

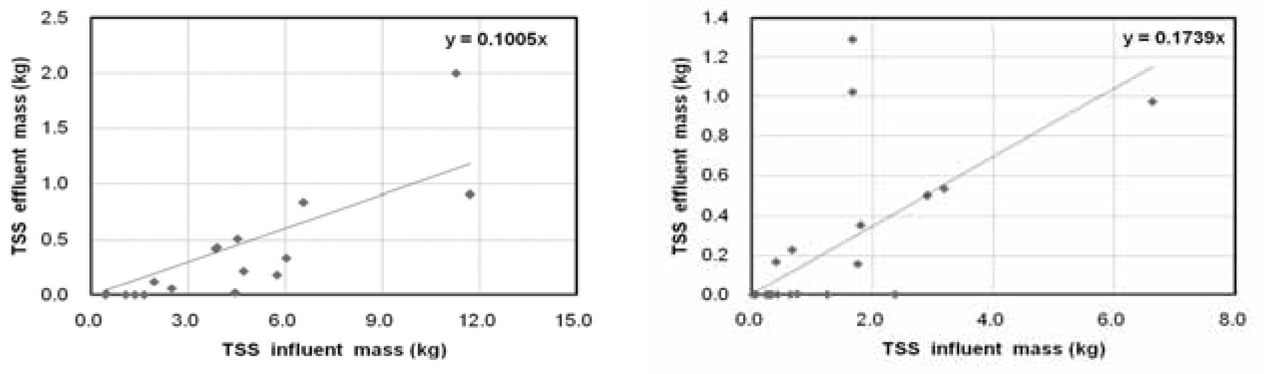

Fig. 3. ROL plot for use in calculating efficiency for TSS in monitoring sites. (a) Site 1 (Slope = 0.1005). (b) Site 1 (Slope = 0.1739).

event. It was determined by inflow and outflow EMCs, and flow volumes. Table 6 shows the removal efficiencies determined by ER method. For site 1, the average efficiency of TSS and BOD are high, 94.7% and 87.2%, respectively. COD, DOC and total metal (Pb and Zn) removal efficiencies averaged about 80%. For site 2, the removal efficiency of most pollutants averaged about 90% except for TN and TP. Within the monitoring periods, no outflow occurred from infiltration trench at below 10 mm total rainfall. The runoff occurred below 10 mm total rainfall might be recharged into groundwater. For that reason, removal efficiency was regarded as 100% if there was no outflow. Generally, ER method is taken from point source studies and does a good job characterizing inflows but fails to take from NPS studies into account some of the complexities of BMP design and rainfall characteristics for the monitoring sites.

3.3.2. Summation of load (SOL) method.

The SOL method is based on the ratio of the summation of total incoming loads to the summation of total outgoing loads. The removal efficiencies determined by using SOL method are summarized in Table 7. The table shows the total mass of influent and effluent for individual storm event and includes the total reduction mass and removal efficiency. The total inflow and outflow mass and removal efficiency for TSS was calculated as 72.66 and 6.05 kg and 91.7%, respectively for site 1. The reduction mass for BOD was calculated as 5.14 kg with a corresponding removal efficiency of 86.0%. For site 2, the reduction mass for TSS and BOD were 22.69 and 5.84 kg, with 81.3% and 83.5% removal efficiencies, respectively. Monitoring data accurately represents the actual entire total load in and out of the BMP for a monitoring period long enough to overshadow any temporary storage or export of pollutants. Therefore,

Table 6
Removal efficiencies (%) using ER method

Monitoring site		TSS	BOD	COD	DOC	TN	TP	Total Pb	Total Zn
Site 1	*n*	18	18	18	18	18	18	18	17
95% CI Upper (%)	97.4	93.9	93.2	89.7	94.5	94.7	91.9	96.7	
95% CI Lower (%)	92.0	80.5	76.7	65.2	71.3	70.3	69.0	84.5	
Avg. efficiency (%)	94.7	87.2	85.0	77.4	82.9	82.5	80.5	90.6	
Site 2	*n*	23	23	23	23	23	23	23	23
95% CI Upper (%)	96.6	96.9	97.4	96.8	93.2	93.1	97.6	97.1	
95% CI Lower (%)	78.0	84.6	87.7	80.6	73.0	71.2	90.5	83.6	
Avg. efficiency (%)	87.3	90.7	92.5	88.7	83.1	82.2	94.0	90.4	

Table 7
Removal efficiencies (%) using SOL method

Monitoring site		TSS	BOD	COD	DOC	TN	TP	Total Pb	Total Zn
Site 1	Inflow mass (kg)	72.66	5.97	16.80	7.64	3.83	0.28	1.45	0.38
Outflow mass (kg)	6.05	0.83	2.47	1.70	0.88	0.02	0.17	0.05	
Reduction mass (kg)	66.61	5.14	14.33	5.94	2.95	0.26	1.28	0.33	
Efficiency (%)	91.7	86.0	85.3	77.7	77.1	93.2	87.9	87.6	
Site 2	Inflow mass (kg)	27.92	6.99	15.16	7.64	2.08	0.38	1.16	0.18
Outflow mass (kg)	5.23	1.15	2.11	1.32	0.80	0.13	0.13	0.04	
Reduction mass (kg)	22.69	5.84	13.05	6.32	1.28	0.25	1.03	0.14	
Efficiency (%)	81.3	83.5	86.1	82.7	61.8	64.3	88.6	79.6	

the removal efficiency using SOL method for BMPs will be able to expect the accuracy efficiency compared to ER method.

3.3.3. Regression of loads (ROL) method

The ROL method as described by Martin and Smoot defines the regression efficiency as the (β) of a least squares linear of inflow loads and outflow loads of pollutant, with the intercept constrained to zero [14]. The data is well represented by a least squares linear regression that is using an analysis of variance on the regression, the slope coefficient is significantly different from zero [15]. Fig. 3 shows the ROL plot for use in calculating efficiency for TSS in the monitoring sites. As depicted, slope coefficients (β) were 0.1005 for site 1 and 0.1739 for site 2. All points were used for regression. However, the ROL method is not valid due to failure of simple linear regression assumptions. Table 8 presents the removal efficiencies determined by ROL method together with the corresponding slope values. The TP and Pb removal efficiencies for site 1 are high values of 95.9% and 95.4%, respectively. Among the pollutants, TN and TP for site 2 have the least removal efficiency values of 50.8% and 57.6%, respectively. In the ROL method, a large number of data points are required in order to get a good fit of the data. Often a meaningful regression cannot be made using the data that was collected.

Table 8
Removal efficiencies (%) using ROL method

Parameters	Site 1		Site 2	
	β	Efficiency (%)	β	Efficiency (%)
TSS	0.1005	90.0	0.1739	82.6
BOD	0.1473	85.3	0.1982	80.2
COD	0.1502	85.0	0.1610	83.9
DOC	0.2168	78.3	0.1459	85.4
TN	0.2764	72.4	0.4918	50.8
TP	0.0411	95.9	0.4242	57.6
Total Pb	0.0464	95.4	0.1316	86.8
Total Zn	0.1286	87.1	0.2271	77.3

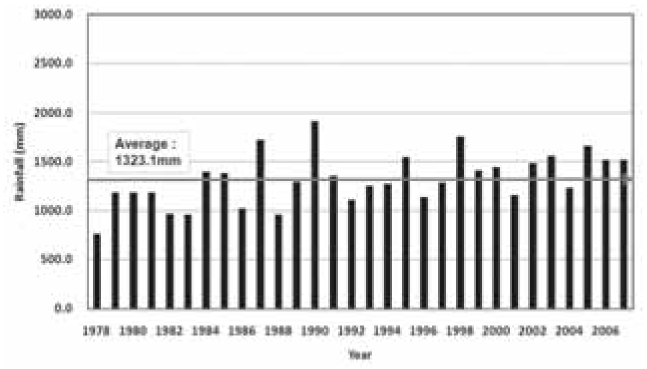

Fig. 4. Annual rainfall over the last 30 years in Yongin City.

3.4. Appropriate determination method of removal efficiency

3.4.1. Analysis of rainfall in monitoring sites

In this study, the rainfall characteristics of the monitoring site were analyzed which can be easily used to determine the removal efficiency of the NPS pollutants from the BMPs. Fig. 4 shows the annual rainfall data over the last 30 years (1978–2007) in Yongin City. Accordingly, the average annual rainfall is approximately 1323 mm, which is somewhat greater than the world's average precipitation (973 mm). The rainfall characteristics as well as the number of rainy day, accumulated rainfall and rainfall frequency for each rainfall ranges are shown in Table 9. The value of average rainfall frequency over the last 30 years is 63.4% for less than 10 mm rainfall and 15.8% for 10–20 mm rainfall range. This analysis was performed to revise predominance actual condition of monitoring results through rainfall occurrence frequency interpretation of probabilistic statistics. Therefore, accurate efficiency for NPS BMPs can be determined using data of rainfall characteristics.

3.4.2. Rainfall of frequency (ROF) method

ROF method is based on rainfall of frequency for each rainfall ranges and reflected rainfall characteristics for monitoring site. The removal efficiencies determined by ROF method are provided in Table 10. The monitoring data from the 41 storm events from sites 1 and 2 were used in the calculation of removal efficiencies using the ROF method considering the rainfall frequency over last 30 years for each rainfall ranges. The removal efficiency of the infiltration trench was above 85% for all the parameters. The average efficiency for 10 mm rainfall range is higher compare to other rainfall ranges. In big rainfall ranges (>30mm), the removal efficiency appeared to have low values. The pollutant removal efficiency by ROF method considered the rainfall characteristics of monitoring sites and long-term monitoring results during 3 years.

3.5. Comparison of removal efficiency evaluation methods

The removal efficiencies calculated using the four methods are compared in Fig. 5. Minimal variations were observed although apparently, the ROF method appeared to be the most efficient methods compared to the other three. In addition, ER method also yields comparable efficiency which is attributed to the use of EMC and flow volumes. However, lower efficiencies in the case of ROL and SOL methods, that is because the mass loads of pollutant were considered and not including the rainfall frequency. Indeed, rainfall characteristics govern among the factors affecting the removal efficiency. The four different methods are only few of the methods available for computing BMP pollutant removal efficiencies. In general, the difficulty of removal efficiency determination of NPS BMPs is generally caused by uncertainties of site and storm characteristics. Therefore,

Table 9
Number of rainy day, accumulated rainfall and rainfall frequency for each rainfall ranges in Yongin City

Rainfall ranges (mm)	ARD 10 (day)	ARD 30 (day)	AAR 10 (mm)	AAR 30 (mm)	ARF 10 (%)	ARF 30 (%)	ACRF 10 (%)	ACRF 30 (%)
$R < 10$	61.7	56.6	185.9	180.1	64.6	63.4	64.6	63.4
$10 \le R < 20$	12.6	13.9	174.5	192.9	13.1	15.8	77.7	79.2
$20 \le R < 30$	7.6	5.9	189.2	144.1	7.9	6.5	85.6	85.7
$30 \le R$	13.6	12.6	927.3	811.0	14.4	14.3	100.0	100.0

Note: ARD 10: Average rainy day over the last 10 years; ARD 30: Average rainy day over the last 30 years; AAR 10: Average accumulated rainfall over the last 10 years; AAR 30: Average accumulated rainfall over the last 30 years; ARF 10: Average rainfall frequency over the last 10 years; ARF 30: Average rainfall frequency over the last 30 years; ACRF 10: Accumulated rainfall frequency over the last 10 years; ACRF 30: Accumulated rainfall frequency over the last 30 years.

Table 10
Removal efficiencies (%) using ROF method

Rainfall ranges (mm)	Rainfall frequency (%)	TSS (%)	BOD (%)	COD (%)	DOC (%)	TN (%)	TP (%)	Total Pb (%)	Total Zn (%)
$R < 10$	63.4	97.2	95.8	93.9	95.1	95.9	95.4	95.7	97.0
$10 \leq R < 20$	15.8	96.8	94.7	93.0	85.6	93.5	90.9	96.5	95.4
$20 \leq R < 30$	6.5	86.8	77.9	81.7	73.3	79.8	82.5	69.1	89.3
$30 \leq R$	14.3	73.9	78.8	81.9	68.4	50.4	49.3	77.2	75.0
Overall efficiency	93.0	91.8	91.1	88.1	87.8	87.1	91.2	93.0	

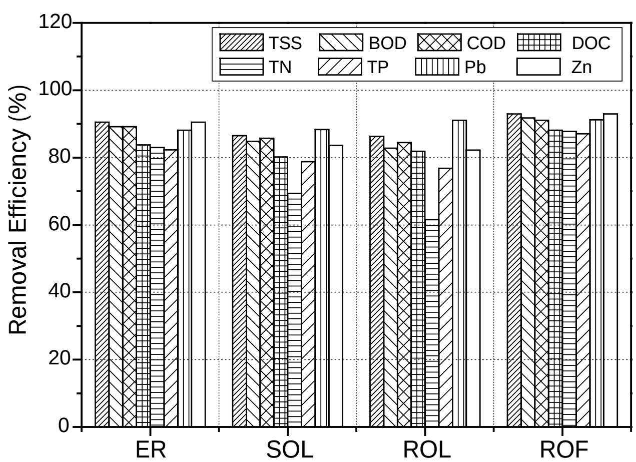

Fig. 5. Comparison of removal efficiencies for combined sites using the four methods.

the monitoring should be undertaken for several storm events during long-term period. Also, storm characteristics such as annual rainfall and rainfall frequency for monitoring site should be analyzed if accurate removal efficiency is required. Particularly, this research is needed in this area in order to standardize BMP data analysis and reporting. The results can be used to determine the removal efficiency of the NPS pollutants from the BMPs and to apply in the TMDL programs.

4. Conclusions

The effective control of NPS is consistently employed in fulfilling the TMDL programs. In Korea, NPS BMPs were installed to manage NPS pollution from the watershed areas and it is important to determine the pollutant removal efficiencies of these pilot projects. However, the difficulty of removal efficiency determination in NPS BMPs is generally caused by uncertainties of site and storm characteristics. For that reason, removal efficiency determination in NPS BMPs has to apply appropriate method to reduce uncertainties. In this study, the monitoring program was performed during 3 years in order to verify the efficiency of the infiltration trench during storm events. The pollutant removal efficiency was determined using the four different methods namely ER, SOL, ROL and ROF methods. The conclusions drawn from this research can be summarized as follows:

1. Outflow EMCs appear to have smaller variations compare to inflow EMCs. On the other hand, the wide distribution of the EMCs greatly depends on the site characteristics as well as in the monitoring methods, traffic, ADD and other environmental conditions that implies high uncertainties concerning to NPS.
2. The four methods applied are only few of the methods available for computing BMP pollutant removal efficiency. The ROF method uses the rainfall frequency which is practical to eliminate uncertainties of NPS. Therefore, the ROF method is suggested as the appropriate method to determine the removal efficiencies and optimum among the four methods.
3. The monitoring should be undertaken over several storm events during long-term period. Also, storm characteristics such as annual rainfall and rainfall frequency for monitoring site should be analyzed to determine accurate removal efficiency.

Acknowledgements

The funding of this research was provided by the Eco Star Project under the grant of the Korea Ministry of Environment. The authors are very thankful for their support.

References

[1] F.H.S. Chiew and T.A. McMahon, Modelling runoff and diffuse pollution loads in urban areas, Water Sci. Technol., 39 (1999) 241–248.
[2] J. Paul and J. Meyer, Streams in the urban landscape. Annu. Rev. Ecol. Syst., 32 (2001) 333–365.
[3] L.H. Kim and S.H. Lee, Characteristics of washed-off pollutants and dynamic EMCs in a parking lot and a bridge during storms. J. Korean Society Water Qual., 21 (3) (2005) 248–255.
[4] Ministry of Environment (MOE), The Strategy of water control in four major large rivers in Korea, Ministry of Environment, Korea, 2004.
[5] Y.J. Jung, M.K. Stenstrom, D.I. Jung, L.H. Kim and K.S. Min, National pilot projects for management of diffuse pollution in Korea. Desalination, 226 (2008) 97105.
[6] L.H. Kim, H.M. Kang and W. Bae, Treatment of particulates and metals from highway stormwater runoff using zeolite filtration. Desalin. Water Treat., 19 (2010) 97–104.
[7] L.H. Kim, S.O. Ko, S.M. Jeong and 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.
[8] L.D. Sabin, J.H. Lim, K.D. Stolzenbach and K.C. Schiff, Contribution of trace from atmospheric deposition to stormwater runoff in a small impervious urban catchment. Water Res., 39 (2005) 3929–3937.
[9] E.J. Lee, S.O. Ko, H.M. Kang, J.K. Lee, B.S. Lee, K.H. Lim and L.H. Kim, Determination of EMCs and comparison with sampled concentration in paved areas. J. Korean Society Water Qual., 22 (1) (2006) 104–109.
[10] R. Hranova and M. Magombeyi, Assessing and managing urban storm water quality. In: R. Hranova, Editor, Diffuse Pollution of Water Resources. Taylor and Francis, NY, 2006, pp. 69–75.
[11] L.H. Kim and J.H. Kang, Determination of event mean concentrations and pollutant loading in highway storm runoff. J. Korean Society Water Qual., 20 6 (2004) 631–640.
[12] L.B. Irish Jr., M.E. Barrett, J.F. Malina Jr. and R.J. Charbeneau, Use of Regression models for analyzing highway storm-water loads. J. Environ. Eng., 124 (10) (1998) 987–993.
[13] J. Marsalek, Pollution Due to Urban Runoff: Unit Loads and Abatement Measures, PLUARG, International Joint Commission, Windsor, Ontario, Canada, 1978.
[14] E.H. Martin and J.L. Smoot, Constituent-load changes in urban storm water runoff routed through a detention pond-wetland system in central Florida. Water Resources Investigation Report 85-4310, U.S. Geological Survey. 1986.
[15] EPA, Urban Stormwater BMP Performance Monitoring, US Environmental Protection Agency Washington, DC 20460, April 2002, EPA-821-B-02-001, 2002.