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Application of SWMM for evaluating NPS reduction performance of BMPs

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ABSTRACT

The nonpoint source (NPS) control facilities as best management practices (BMPs) were installed to manage NPS pollution in Korean and determining the pollutant reduction loads of BMPs is important to abide by the Korean total maximum daily load (TMDL). However, there are some inadequacies in the methodology to estimate the NPS reduction loads because of uncertainties in rainfall and runoff characteristics. For that reason, a Storm water management model (SWMM) model was used to eliminate uncertainties and to estimate more appropriate reduction loads. In this study, the annual total reduction load (ATRL) method was suggested to calculate annual reduction loads using a SWMM model for appropriate NPS pollution control in the TMDL. Also regression of EMCs (ROE) method was suggested to calculate the annual average removal efficiency (RE) compared to the four different methods, namely, the efficiency ratio (ER), summation of loads (SOL), regression of loads (ROL), and rainfall of frequency method (ROF). Therefore, the ROE method was suggested as the appropriate method to determine the average REs of the BMPs. Also the ATRL method was suggested as the appropriate method to determine the reduction load compared to the existing method in the Korean TMDL. This study provides a SWMM model to standardize BMPs data analysis. The SWMM model can be used to determine the RE and reduction loads of NPS pollution due to the implementation of BMPs and to complement their uncertainties in the TMDL.

Keywords: SWMM; Nonpoint sources; BMPs; Reduction loads; TMDL

1. Introduction

Pollutants causing water pollution are largely divided into two categories, point source and nonpoint source (NPS). Increased impervious surfaces due to urbanization have resulted in nonpoint pollution increases. According to the Korean water environment management plan, the contribution of NPS pollution loads in the four major rivers of Korea was about 42–69% in 2003. It is predicted to increase to between 65% and 70% by 2015 without any NPS management measure [1]. For this reason, The Ministry of Environment (MOE) established the total maximum daily load (TMDL) and it has been implemented for watershed management and effective control of NPS pollution. The TMDL is a management system which dictates total discharged pollution loads should not exceed assigned loads. In the case of NPS pollution, various types of NPS control facilities as best management practices (BMPs) have been installed to control that in Korea.

The first phase of the Korean TMDL technical guideline did not provide the calculation method for NPS reduction load of BMPs [2]. The second phase of the Korean TMDL technical guideline, which was modified in 2007, offered detailed methodology to calculate the NPS reduction loads by using removal efficiencies (REs) of NPS control facilities as BMPs [3]. However, there are

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some inadequacies in the methodology to estimate the NPS reduction loads in each NPS control facility, which are: (i) a difficulty in monitoring those facilities in every storm event; (ii) an impossibility to collect appropriate monitoring data optionally for reflecting frequency of storm events; and (iii) a difficulty to estimate annual average RE from wide range of REs in specifically monitored storm events.

There is a way to solve these problems by monitoring the NPS control facility automatically during whole storm events but this still has a problem if maintenance management. Therefore, storm water management model (SWMM) model, which has been used by simulating urban runoff quantity and quality annually, is considered in attempting to solve the presented problems. Tsihrintzis and Hamid verified the application of SWMM model in relatively smaller sub-catchments of urban areas [4]. Yoon et al. revealed that SWMM model was more reasonable than the regression method which had been usually used to estimate NPS pollutant loadings [5]. However, sufficient research on the application of the SWMM model in the field, at the NPS control facilities, has not yet been conducted.

The objective of this study is to suggest a modified method for calculating annual reduction loads for appropriate NPS pollution control in the TMDL using SWMM model. Furthermore, this study aims to examine the application of SWMM model to estimate the RE and NPS reduction loads from the performance of one of the BMP facilities.

2. Methods

2.1. Site description and monitoring

The study site is located on the riverside of a branch of the Han River in Kwangju city, Korea. The geographical characteristics of catchment are summarized in Table 1. Vortex flow separator (VFS) as a BMP facility was monitored to evaluate the RE and reduction loads during storm events. The VFS acts as a continuous reducing pollutant unit below ground and mechanism is filtration for solid separation and sedimentation. Storm events were monitored at the inlet of the VFS (Q_3) and outlet of the VFS (Q_4) from 2007 to 2008. Fig. 1 shows a diagram of monitoring sites and drainage networks. Total runoff from the catchment in rainy season is flowed into the inlet of the VFS and treated as much as designed volume. Overflow is discharged directly to the river without treatment. A storm was defined as having two antecedent dry days (ADD). An additional monitoring was performed at the two points (Q_1, Q_2) for model calibration to clarify the distribution of runoff in 2008. The monitoring program was performed following monitoring plan of MOE Guideline [6].

Table 1
Characteristics of catchment area.

Conduit	Catchment area (ha)	Imperviousness (%)	Width (m)	Slope (%)
Separated sewer system	1.63	100	540	0.075

Three pollutants were analyzed and used for the calibration of the model: total suspended solids (TSS), biological oxygen demand (BOD), and total phosphorus (TP) and especially BOD and TP were selected for calculation of reduction loads because they are often used as indicators of the quality of the water in the TMDL. The analytical methods followed the suggestions described by Standard Methods [7].

2.2. Model description

The SWMM, which is a comprehensive mathematical model for the simulation of annual urban runoff quantity and quality, was selected for estimation of runoff quantity and quality flowing into the VFS in this study. The runoff block simulates the hydrograph for study catchment, according to a hyetograph of entrance and the physical characteristics of the catchment, including area, width, average slope and imperviousness, resistance factor for the surface runoff, infiltration parameters and surface storage. Pollutographs are simulated according to the runoff volume and to the previous conditions of the catchment such as dry weather days, cleaning of streets and the land use.

In this study, the runoff flow to pipes or channels and inlet of the VFS is computed as the product of velocity, depth and width given as in Eq. (1).

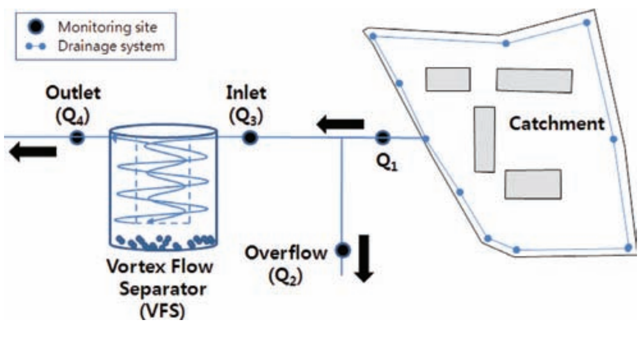

Fig. 1. A diagram of the monitoring sites and drainage networks.

$$Q = W / n \cdot \left(d - d_{\mathrm{P}}\right)^{5/3} \cdot S^{1/2}, \tag{1}$$

where, Q is the catchment runoff, W the catchment width, n the Manning's roughness coefficient, d the water depth, d_{P} the depth of depression storage, and s the slope.

In this study, the exponential buildup equation (Eq. (2)) was selected to simulate surface constituent quantity accumulation.

$$\mathrm{PSHED} = \mathrm{Lim}\left(1 - e^{ct}\right), \tag{2}$$

where, PSHED is the constituent quantity (kgha^{-1}), Lim the constituent accumulation limit (kgha^{-1}), c the accumulation rate, t the time (day).

Washoff is the process of erosion of constituents from a catchment surface during runoff. In SWMM, washoff is given as in Eq.(3).

$$\mathrm{POFF}(t) = \mathrm{PSHED_i}\left(1 - e^{-kt}\right), \tag{3}$$

where, POFF(t) is the cumulative amount of washed off at time t, and $\mathrm{PSHED_i}$ the initial amount of quantity on surface at $t = 0$.

$$k = \mathrm{RCOEF} \cdot r^{\mathrm{WASHPO}}, \tag{4}$$

where, RCOEF is the washoff coefficient, r the runoff rate over catchment, and WASHPO the power of runoff rate.

2.3. Calculation method of NPS reduction loads

This study proposes a modified method to calculate the NPS reduction loads using SWMM model. To assess the application of this method, it is compared with the reduction loads with removal efficiency (RLRE) method which was provided by the Korean TMDL technical guideline [3]. The RLRE method is based on the generated pollution loads (GL), the rate of runoff loads by the rainfall ($\mathrm{RL_R}$) and average RE of BMPs control facility. This RLRE method has been applied in a different way which depends on whether monitoring is performed in all storm events automatically or in several storm events manually. The latter is selected in this study because monitoring was performed in several storm events. The RLRE method is computed with those three variables as Eq. (5).

$$\mathrm{RLRE} = \mathrm{GL} \times \mathrm{RL_R} \times \mathrm{RE}, \tag{5}$$

where, GL is the generated pollution loads (kg/day), $\mathrm{RL_R}$ the rate of runoff loads, and RE the annual average removal efficiency (%).

Multiply GL by $\mathrm{RL_R}$ and the result is runoff pollution loads, or inflow pollution loads of BMP facility. The GL is pollution loads discharged from land cover of catchment, and it is calculated by Eq. (6). The pollution load rate ($\mathrm{PLR_i}$) is given in Korean TMDL technical guideline. The $\mathrm{PLR_i}$ of BOD generated in surface of urban area is 85.9 kg km^{-2}·day and 2.1 kg km^{-2}·day for TP is generated.

$$\mathrm{GL} = \sum_{i}^{n} (A_i \times \mathrm{PLR}_i), \tag{6}$$

where, n is the number of classified land use, A_{i} the area of i land use in catchment (km^2), and PLR_i the pollution load rate of i land use (kg day^{-1}km^{-2}).

$\mathrm{RL_R}$ is a function of the design rainfall intensity (R_{D}) (Eq. (7)). If the R_{D} is determined, $\mathrm{RL_R}$ is a given value in Korean TMDL. In this study, 5 mm h^{-1} of rainfall intensity is regarded as design rainfall intensity which is usually adapted in NPS control facility as BMPs.

$$\mathrm{RL_R} = f(R_{\mathrm{D}}), \tag{7}$$

where R_{D} is the design rainfall intensity and f the function.

It is very important to calculate the RE in an NPS control facility as BMPs because it decides the amount of the reduction loads in BMP facility. A variety of methods to calculate the RE of NPS BMPs could be evaluated. Lee et al. evaluated the annual average RE to eliminate uncertainty of insufficient storm event data using four different methods such as ER, SOL, ROL and ROF [8]. In this study, the existing four methods such as the ER, SOL, ROL, and ROF are used for calculation of the RE. The modified RE method, namely, ROE was considered along with the former four methods. ROE method is based on the ratio of the summation of total influent pollutant mass, which comes from simulated annual data using SWMM model, to the summation of total effluent mass. Total effluent mass was calculated by multiplying simulated outflow runoff volume by outflow EMCs which comes from regression efficiency (β) of a least squares linear of observed inflow and outflow EMCs. Table 2 provides the description of the RE methods with corresponding equations.

The annual total reduction load (ATRL) method suggested in this study is based on the reduction loads which were determined by total influent mass and effluent mass (Eq. (8)).

$$\begin{aligned}\mathrm{ATRL} &= \frac{\sum_{i=1}^{N_{\mathrm{T}}} M(\mathrm{in})_i - \sum_{i=1}^{N_{\mathrm{T}}} M(\mathrm{out})_i}{D_{\mathrm{T}}} \\ &= \frac{\sum_{i=1}^{N_{\mathrm{T}}} \mathrm{RM}_i}{D_{\mathrm{T}}} = \frac{\sum_{i=1}^{N_{\mathrm{T}}} M(\mathrm{in})_i}{D_{\mathrm{T}}} \times \mathrm{ROE}\end{aligned} \tag{8}$$

Table 2
RE evaluation methods with corresponding equations.

Method	Equation	Description
Efficiency ratio (ER)	$\mathrm{RE} = \dfrac{\sum_{i=1}^{N} \mathrm{RE}_i}{N}$	The average of REs monitored in every storm event
Summation of loads (SOL)	$\mathrm{RE} = \dfrac{\sum_{i=1}^{N} \mathrm{RM}_i}{\sum_{i=1}^{N} M(\mathrm{in})_i}$	The RE considering total observed reduction mass and influent mass
Regression of loads (ROL)	$M(\mathrm{out})_i = \beta \cdot M(\mathrm{in})_i$ $\mathrm{RE} = (1-\beta)\cdot 100$	The RE using the influent mass in each event and regression efficiency
Rainfall of frequency (ROF)	$\mathrm{RE} = \sum_{j=1}^{N_\mathrm{R}} (\mathrm{RE}_j \times \mathrm{RF}_j)$	The RE considering rainfall frequency of each rainfall range
Regression of EMCs (ROE)	$C(\mathrm{out})_i = \beta \cdot C(\mathrm{in})_i$ $M(\mathrm{out})_i = Q(\mathrm{out})_i \cdot C(\mathrm{out})_i$ $\mathrm{ROE} = \dfrac{\sum_{i=1}^{N_\mathrm{T}} M(\mathrm{in})_i - \sum_{i=1}^{N_\mathrm{T}} M(\mathrm{out})_i}{\sum_{i=1}^{N_\mathrm{T}} M(\mathrm{in})_i}$	The annual average RE considering total reduction mass and influent mass. Effluent mass is calculated by regression of observed EMCs with simulated outflow volume

N = No. of observed events, i = storm event, j = Rainfall range, RE = removal efficiency (%), RM_i = reduction mass (kg), $M(\mathrm{in})_i$ = inflow mass(kg), $M(\mathrm{out})_i$ = outflow mass (kg), β = regression efficiency, N_R = No. of rainfall range, RF_j = rainfall frequency, N_T = No. of total storm events, $C(\mathrm{in})_i$ = inflow EMCs (mgL^{-1}), $C(\mathrm{out})_i$ = outflow EMCs (mgL^{-1}), $Q(\mathrm{out})_i$ = outflow flow volume (m^3).

where

$$\sum_{i=1}^{N_\mathrm{T}} M(\mathrm{in})_i = \text{total influent mass}(\mathrm{kg}),$$

$$\sum_{i=1}^{N_\mathrm{T}} M(\mathrm{out})_i = \text{total effluent mass}(\mathrm{kg}),\ N_\mathrm{T} = \text{No. of total storm events},$$

$$\sum_{i=1}^{N_\mathrm{T}} \mathrm{RM}_i = \text{total reduction mass}(\mathrm{kg}) \text{ and } D_\mathrm{T} = \text{total runoff duration}(\mathrm{day}).$$

The total influent mass is simulated using SWMM model in the inlet of the VFS and total effluent mass is estimated by ROCs with outflow volume. In this study, it is estimated that the outflow volume is the same as the inflow volume because of the characteristics of the VFS.

3. Results and discussions

3.1. Monitoring event descriptions

A total of 12 storm events were monitored at sampling points of the VFS located in a residential catchment. Table 3 summarizes the monitored event data which contains of rainfall, runoff duration, average rainfall intensity, ADD, and total runoff volume. The rainfall varies from 6 to 67 mm and the runoff duration is in the range of 1.0–13.8 h. The average rainfall intensity is recorded from 2.5 to 12.4 mm h^{-1}. ADD is determined between 2 and 26 days and total runoff ranges from 25.7 to 340 m^3. The monitored data shows a wide distribution of every parameter. This means that there have been lots of uncertainties concerning to nonpoint pollution sources. Therefore, long term monitoring is needed to identify relationships among those parameters in every storm event.

3.2. Model calibration

For the aim of the study, the calibration was performed to estimate annual runoff data in the monitored sites. In the calibration process, the pollutograph related parameters such as build limit and accumulation ratio in Eq. (2) were controlled and also washoff parameters such as WASHPO and RCOEF were adjusted within the range of the established values in the literature [9]. Fig. 2 shows the calibration results of runoff flow and quality parameters. For the calibration of SWMM model, observed flow and water quality data in the

Table 3
Summary of monitored storm events.

BMPs	No. of observed events	Stats	Rainfall (mm)	Runoff duration (h)	Avg. rainfall intensity (mm h^{-1})	ADD (day)	Total runoff (m^3)
		Minimum	6	1	2.5	2	25.7
VFS	12	Maximum	67	13.8	12.4	26	340.1
		Mean	25	5.5	5.4	6	140.4

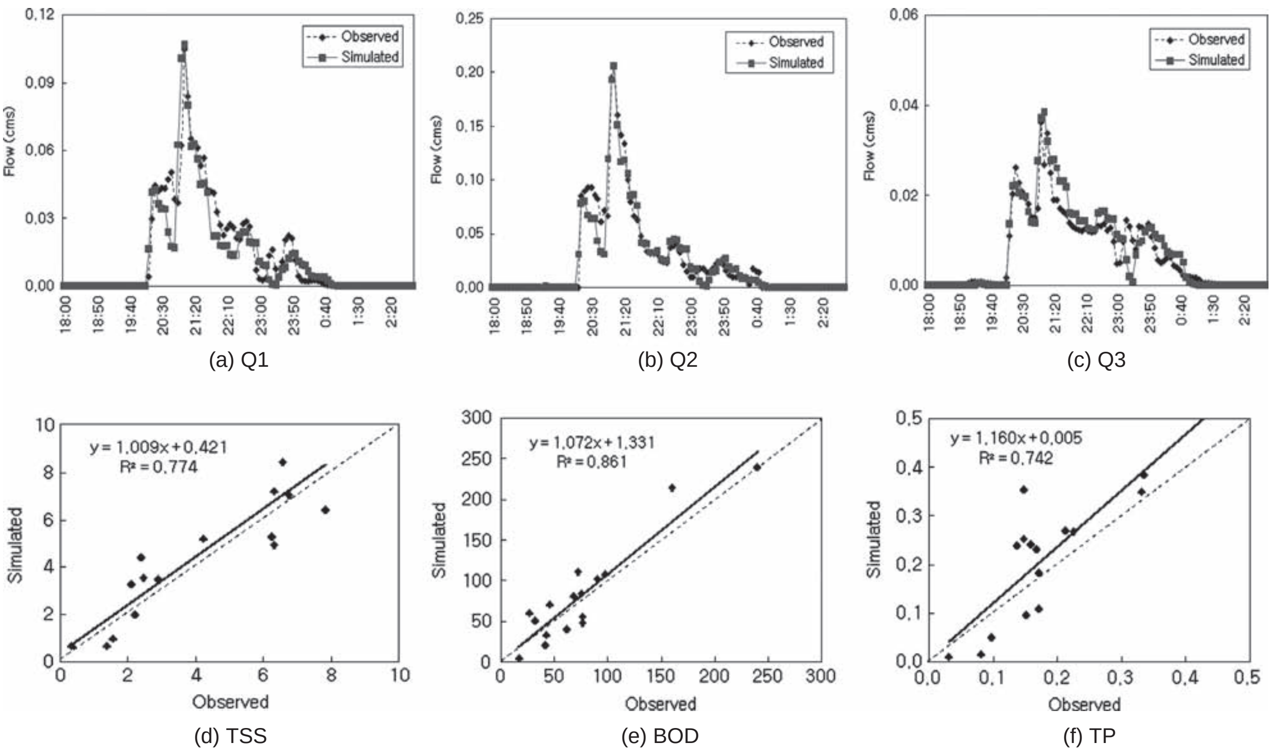

Fig. 2. Calibration of the runoff flow and quality parameters at Q_3.

storm event of June 2, 2008 was used. The calibration results of runoff flows at the monitoring points, namely, Q_1, Q_2, and Q_3 in consistency measure (R^2) were 0.93, 0.87, and 0.99 respectively. The calibration results of TSS, BOD, and TP at the Q_3 were 0.86, 0.77, and 0.74 respectively.

Furthermore, the verification of the calibrated model was performed in the storm event of July 23, 2008. The verification results are summarized in Table 4. The calibrated model was adjusted with high accuracy of all the variations in the observed runoff flow and quality. The simulated runoff volume and pollutant mass of each monitoring site are shown in Fig. 3. Only 33% of total runoff was flowed into the VFS during 2008. On the other hand, 73% of pollution mass for TSS, 62% for BOD and 54% for TP were flowed into the VFS. This means that initial runoff has the high concentration of pollutants even though having small amount of runoff volume.

3.3. Analysis of rainfall in monitoring site

In this study, the rainfall characteristics of the monitoring site were analyzed which can be used to determine the RE for NPS reduction loads in the BPMs. The rainfall characteristics such as average rainy day, rainfall and rainfall frequency are shown in Table 5. This data was analyzed during the monitoring period 2007–2008.

Accordingly, the average annual rainfall is 1,326 mm. The average number of rainy days is 54.0 and the value of average rainfall frequency is 65.3% for less than

Table 4
Summary of results of calibration and verification.

	Event	Location	R^2			
			Runoff	TSS	BOD	TP
Calibration	June 02, 2008	Q_1	0.93	–	–	–
		Q_2	0.87	–	–	–
		Q_3	0.99	0.86	0.77	0.74
Verification	July 23, 2008	Q_1	0.88	–	–	–
		Q_2	0.84	–	–	–
		Q_3	0.94	0.81	0.87	0.78

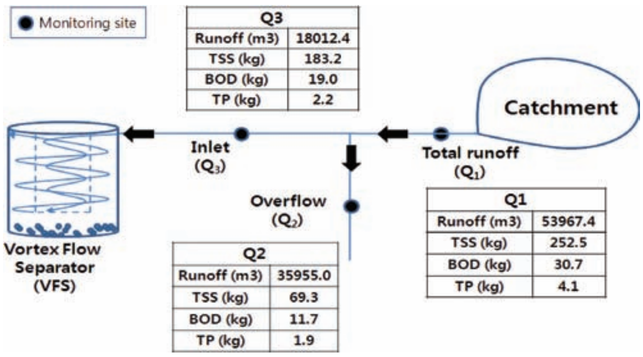

Fig. 3. Mass balance of the simulated runoff flow and quality parameters.

10 mm rainfall range. According to the cumulative probability of the rainfall data during the monitoring period, the rainfall which is less than 50 mm per day, account for almost 90% of annual rainfall data. This analysis was performed to reflect a predominance of monitoring results through rainfall frequency interpretation of probabilistic statistics.

3.4. Determination of NPS reduction loads

3.4.1. Reduction loads with removal efficiency method

The NPS reduction loads determined by the RLRE method were calculated following the equations as given in Eq. (5)–(7). Table 6 shows the calculated reduction loads using RLRE method with four different methods for REs such as ER, SOL, ROL, and ROF. The REs from the existing methods presented in Table 2 were computed using the 12 sets of monitored data. In the calculation process, generated pollutant loads (GL) on the catchment were found to be 1.914 kg/day for BOD and 0.047 kg/day for TP. The rate of runoff loads (RL_R) of the generated loads were 0.788 for BOD and 0.763 for TP. The REs computed the ER, SOL, ROL, and ROF methodologies were 8.2, 8.8, 9.5, and 9.0% for BOD and 12.5, 13.3, 13.4, and 9.5% for TP, respectively. The reduction loads by RLRE with four different REs ranged from 0.123 to 0.144 kg/day for BOD and from 0.0035 to 0.0049 kg/day for TP.

3.4.2. Regression of EMCs for ATRL method

First of all, the REs were calculated by ROE method proposed in this study. In the calculation process of ROE, regression analysis was performed using inflow and outflow EMCs which were monitored in the inlet and outlet of the VFS each. As shown in Fig. 4, outflow EMCs are significantly associated with inflow EMCs for TSS, BOD and TP. The slope coefficients (β) of those parameters were 0.883, 0.864, and 0.843 respectively. Table 7 presents the simulated inflow EMCs extracted from SWMM model and outflow EMCs determined by inflow EMCs with the corresponding slope values (Fig. 4). The total numbers of simulated storm events were 49 in 2008. The inflow EMCs of the VFS were ranged from 0.04 to 27.06 mgL^{-1} for BOD and from 0.004 to 1.538 mgL^{-1} for TP. The outflow EMCs were ranged from 0.04 to 23.38 mgL^{-1} for BOD and 0.003 to 1.297 mgL^{-1} for TP.

The pollutant mass of influent and effluent in each storm event were calculated using runoff volumes, inflow EMCs and outflow EMCs in each storm event. Total mass of influent and effluent were determined by summation of each influent and effluent mass for individual storm events. From those pollutant masses, the REs determined by the ROE method were calculated to be 11.7% for TSS, 13.6% for BOD, and 15.7% for TP respectively in the VFS.

3.4.3. Evaluation of ROE method

To evaluate the RE using ROE method, the other REs which are presented in Table 6 were considered. The REs calculated by using five methods were compared in Fig. 5. The highest value of the RE is shown that BOD

Table 5
Average rainfall and rainfall frequency for each rainfall ranges in study site.

Rainfall ranges (mm)	No. of monitoring	Average rainy day (day)	Average rainfall (mm)	Accumulated Rainfall (mm)	Average rainfall frequency (%)	Accumulated rainfall frequency (%)
R < 10	3	54.0	187.0	187.0	65.3	65.3
10 ≤ R < 20	3	8.5	119.0	306.0	10.2	75.5
20 ≤ R < 30	3	6.0	140.5	446.5	7.2	82.7
30 ≤ R < 50	1	7.5	300.5	747.0	8.3	91.0
50 ≤ R	2	8.0	579.0	1326.0	9.0	100.0

Table 6
Reduction loads using RLRE method with four REs.

Parameters	GL (kg/day)	RL_R	RE (%)				Reduction loads using RLRE (kg/day)			
			ER	SOL	ROL	ROF	ER	SOL	ROL	ROF
BOD	1.914	0.788	8.2	8.8	9.5	9.0	0.123	0.133	0.144	0.135
TP	0.047	0.763	12.5	13.3	13.4	9.5	0.0046	0.0049	0.0049	0.0035

GL = generated pollution loads (kg/day), RL_R = the rate of runoff loads, RE = annual average removal efficiency (%), and ER, SOL, ROL and ROF = calculation methods for RE.

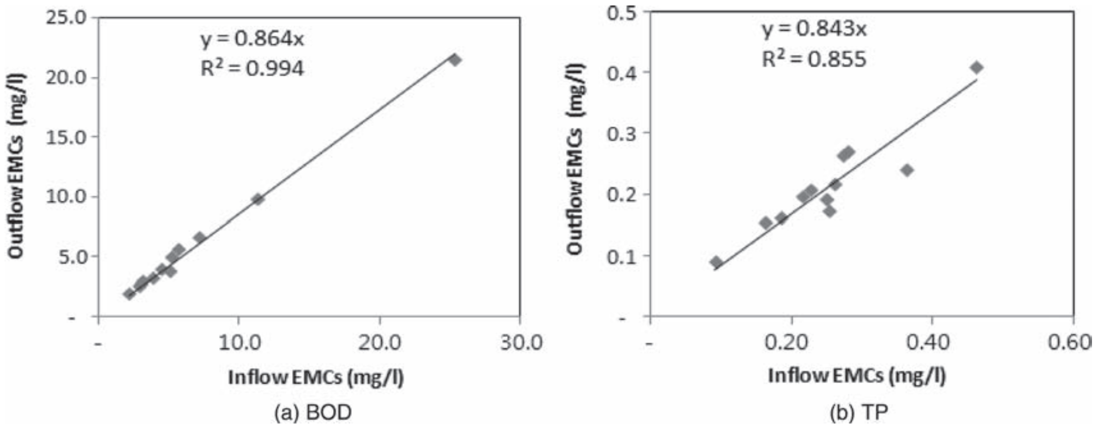

Fig. 4. Regression of the monitored EMCs for ROE method.

Table 7
Summary of simulated events and estimation of outflow EMCs and pollutant mass.

Parameters	N_T	$Q(\text{out})_i$ (m³)	$C(\text{in})_i$ (mg L^{-1})		$C(\text{out})_i$ (mg L^{-1})		$M(\text{in})_i$ (kg)		$M(\text{out})_i$ (kg)	
			BOD	TP	BOD	TP	BOD	TP	BOD	TP
Minimum		1.7	0.04	0.004	0.04	0.003	0.008	0.0004	0.007	0.0003
Maximum	49	1345.4	27.06	1.538	23.38	1.297	1.301	0.2361	1.124	0.1991
Mean		313.6	3.86	0.289	3.33	0.244	0.377	0.0433	0.326	0.0365

N_T = No. of total annual events, i = storm event, $C(\text{in})_i$ = inflow EMCs (mgL^{-1}), $c(\text{out})_i$ = outflow EMCs (mgL^{-1}), $Q(\text{out})_i$ = outflow flow volume (m^3), $M(\text{in})_i$ = inflow mass (kg), $M(\text{out})_i$ = outflow mass (kg).

was 13.6% in the ROE and TP was also 15.7% in the ROE method. Minimal variations were presented although apparently, the ROF method seems to be the most efficient method when compared to the others. The RE using the ROF method is the lowest in the case of TP, compared with ER, SOL and ROL method. It means that RE of TP was low in the monitored storm events which have high rainfall frequency. Even though ROF method can consider a rainfall frequency and estimate average RE using REs form the monitored storm events, this monitored storm events are not representative of the whole storm events. Therefore, the monitoring should be undertaken for various storm events during long term period. The ROE method is appropriate compared to the RE, ROL and ROF in that it can decrease uncertainties of storm characteristics by considering variable storm events annually, and it can reduce the cost for monitoring BMPs. Compared to the SOL, the ROE is more appropriate in that it can calculate the total annual influent mass and effluent mass. Therefore, the ROE method tends to be more suitable when compared with the others in regards to accuracy and cost benefits.

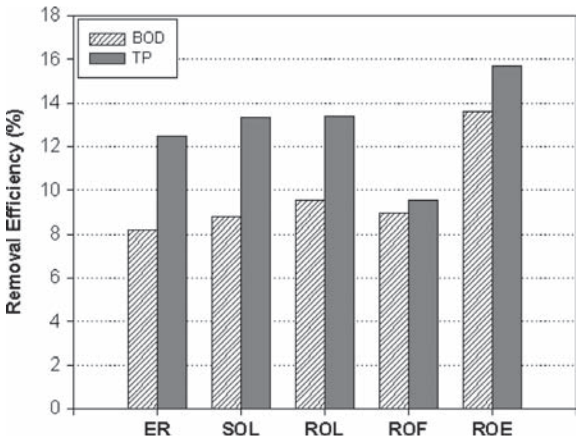

Fig. 5. Comparison results of REs using the five methods.

3.4.4. Annual total reduction load method

In this study, the ATRL method using SWMM modeling data was examined to calculate the NPS reduction loads in the VFS compared with that found using the RLRE method. Table 8 shows the reduction loads using the ATRL. The total inflow, outflow and reduction mass and reduction loads for BOD were calculated as 18.50, 15.98, and 2.52 kg and 0.141 kg/day. For TP, those were calculated as 2.12, 1.79, and 0.33 kg and 0.0186 kg/day, respectively.

3.5. Appropriate method evaluation of reduction loads

The NPS reduction loads calculated using ATRL and RLRE method were compared in Fig. 6. Bar graphs of reduction loads calculated using RLRE method displays the same trend to the REs in the case of BOD and TP because the RLRE method is determined by the REs which was calculated using the 12 sets of monitoring data. However, in the case of BOD, The reduction load using the ATRL method was similar to the other reduction loads calculated by the RLRE method. On the other hand, the TP reduction load using ATRL was markedly high over three times the others even though their REs have little differences between five difference methods. Some analyses were conducted to

Table 8
Reduction loads using the ATRL method.

Parameters	$\sum_{i=1}^{N_T} M(\text{in})_i$ (kg)	$\sum_{i=1}^{N_T} M(\text{out})_i$ (kg)	$\sum_{i=1}^{N_T} \text{RM}_i$ (kg)	D_T (day)	Reduction loads using ATRL (kg/day)
BOD	18.50	15.98	2.52	18	0.141
TP	2.12	1.79	0.33		0.0186

$\sum_{i=1}^{N_T} M(\text{in})_i$ = total influent mass(kg),

$\sum_{i=1}^{N_T} M(\text{out})_i$ = total effluent mass(kg), N_T = No. of total storm events,

$\sum_{i=1}^{N_T} \text{RM}_i$ = total reduction mass(kg) and D_T = total runoff duration(day).

find the reason for differences between them. It may be caused by uncertainties of monitored storm characteristics and variables for reduction loads in the calculation process.

To verify the uncertainty of monitored storm characteristics, therefore, probability distribution of influent pollutant mass was analyzed. Fig. 7(a) shows that all the monitoring events were covered in upper 95% probability of total events in terms of the influent mass for BOD. This means that high concentration of BOD pollutant was flowed into the VFS in the most of the monitored storm events from all the storm events.

Because of this, even though REs of ER, SOL, ROL, and ROF using the 12 sets of monitoring data were lower than that of ROE as shown in Fig. 5, the reduction loads of RLRE methods increased as much as the reduction loads using ATRL method. According to the Fig. 7(b), in the case of TP, monitored influent mass is relatively low in the upper 50% probability of total storm events. This means that monitoring was conducted in several storm events which have low influent concentrations of TP pollutants. For that reason, the reduction loads calculated using the RLRE method were lower than that calculated using ATRL method.

From this result concerning the probability distribution of influent pollutant mass, it is very important to consider the number of monitoring storm events and their pollutant transportation characteristics for calculating the reduction loads. However these graphs cannot explain why the reduction load of TP using the ATRL method is extremely high, and consequently another uncertainty which is from variables for reduction loads was analyzed in the calculation process.

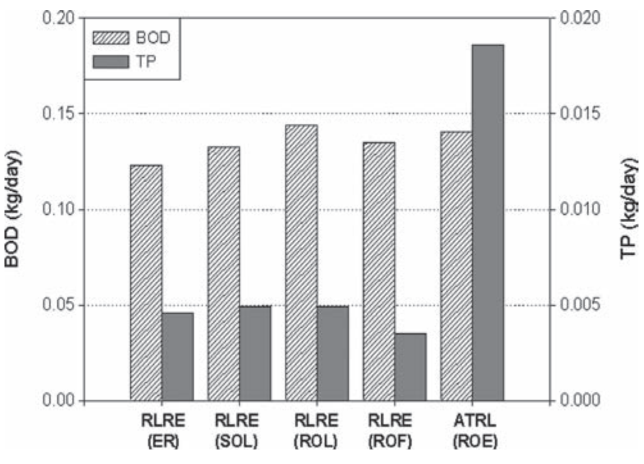

Fig. 6. Comparison results of reduction loads between RLRE with four REs (ER, SOL, ROL, and ROF) and ATRL with ROE.

There are three variables for determining calculated reduction loads in the RLRE method such as generated loads (GL), the rate of runoff loads (RL_R) and RE. Table 9 shows the pollution loads determined by the variables in the process of RLRE method. For comparison, the pollution loads, which resulted in the ATRL calculation process, corresponding to them is expressed on the same table. In the case of TP, especially, ATRL method results in extremely higher generated loads compared to the RLRE method. This means that the PLR of TP which was provided by Korean TMDL technical guideline seems to be too small. Because of this, even though the rate of runoff loads which is one of the determination

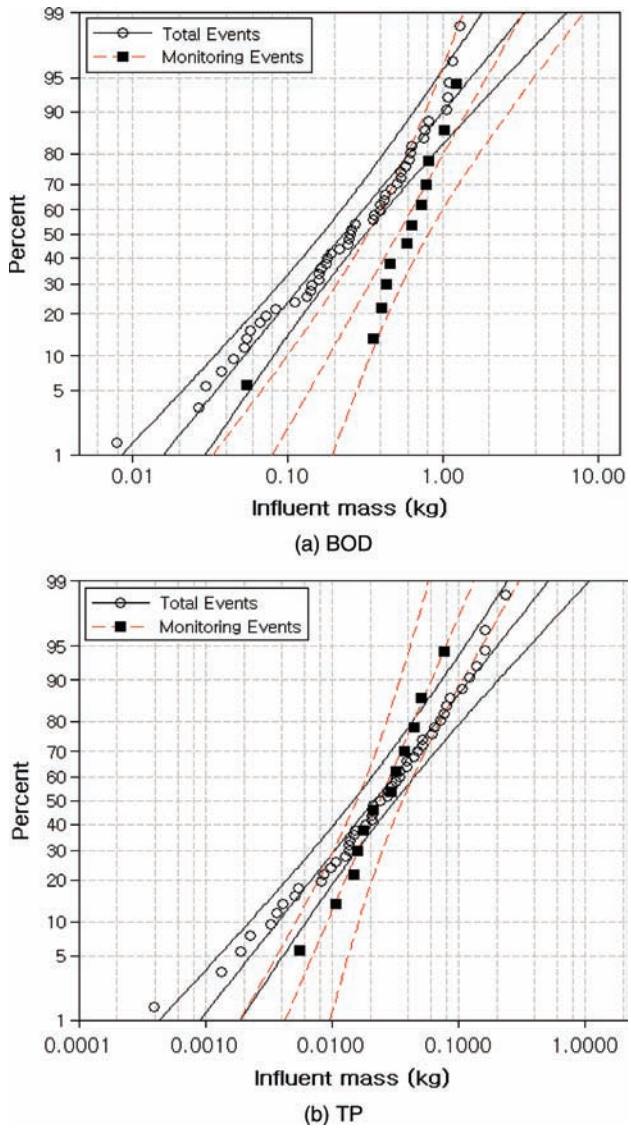

Fig. 7. Probability distribution of the influent mass at the inlet of the VFS.

Table 9
Comparison of variables for reduction loads between RLRE and ATRL method.

Descriptions	RLRE			ATRL		
	Variables	BOD	TP	Variables	BOD	TP
Generated loads (kg/day)	GL	1.91	0.05	$Run(Q_T)$	2.64	0.35
Rate of runoff loads	RL_R	0.79	0.76	$Run(Q_3)/Run(Q_T)$	0.39	0.34
Inflow loads into VFS (kg/day)	$GL \times RL_R$	1.51	0.04	$Run(Q_3)$	1.03	0.12
RE (%)	Ave. of RE	8.86	12.19	ROE	13.60	15.70
Reduction loads (kg/day)		0.13	0.004		0.14	0.019

$Run(Q_T)$ = total runoff loads of catchment, $Run(Q_3)$ = runoff load.

variables is low, influent pollution loads of VFS is still high. Moreover RE of the ATRL method (ROE), which is higher than that of RLRE, causes significant difference in the reduction loads between the two methods.

These results are caused by uncertainties of RLRE method such as the characteristics of storm events and runoff and the PLR to calculate the generated pollutant loads. If accurate NPS reduction load is required in the NPS control facility, hydrological characteristics such as annual rainfall, runoff quantity and quality for monitoring site should be analyzed. The ATRL method uses the SWMM model in this study which can apply the all storm events annually to eliminate such uncertainties. Therefore, the ATRL method is suggested as the appropriate method to determine the reduction load compared to the existing RLRE method. Particularly, this study allows the SWMM model to standardize the NPS control facility data analysis. The results can be used to determine the RE and reduction loads of NPS pollutant by the BMPs and to apply the modified method using SWMM model to complement their uncertainties in the TMDL.

4. Conclusion

The NPS control facilities as BMPs were installed to manage NPS pollution and determining the pollutant reduction loads of BMPs is important to abide by the Korean TMDL. However, there are some inadequacies in the methodology to estimate the NPS reduction loads because of uncertainties in rainfall and runoff characteristics. For that reason, a SWMM model was used to eliminate uncertainties and to estimate more appropriate reduction loads. In this study, the ATRL method was suggested to calculate annual reduction loads in the VFS for appropriate NPS pollution control in the TMDL. The RE for RLRE method was estimated using the five different methods, namely, the ER, SOL, ROL, ROF, and ROE method.

The conclusion drawn from this study is summarized as follows:

(i) The ROE method uses the SWMM modeling data to calculate the RE in the BMPs. The ROE compared to the ER, ROL, and ROF, it can decrease uncertainties of storm characteristics by considering variable storm events annually. Compared to the SOL, the ROE can calculate the total annual influent mass and effluent mass. Therefore, the ROE method is suggested as the most appropriate method to determine the average REs of the BMPs.

(ii) The reduction load of BOD using the ATRL is similar to others using the RLRE method. However, the TP reduction loads using RLRE are prominently lower than using ATRL. It is caused by uncertainties of monitored storm characteristics and variables for reduction loads in the calculation process of RLRE method. The ATRL method uses the SWMM model that can apply the all storm events annually to eliminate such uncertainties. Therefore, the ATRL method is suggested as the appropriate method to determine the reduction load compared to the existing RLRE method.

(iii) This study allows the SWMM model to standardize BMPs data analysis. The SWMM model can be used to determine the RE and reduction loads of NPS pollutant by the BMPs and to complement their uncertainties in the TMDL.

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