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# Analysis of the characteristics of non-point pollutant runoff applied LID techniques in industrial area

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## ABSTRACT

Various techniques are being developed and applied for the management of non-point pollutants. Especially, there has been an increasing interest in the techniques which work for both the restoration of hydrologic cycle and management of non-point pollutants. When the need for the management of non-point pollutants first arose, structural concept of BMP was developed. Recent years saw the expansion of management plans including precautionary land use techniques such as low impact development (LID). LID is usually applied to new development areas but lately is in extensive use with existing city areas. To analyze the effect of LID application on an industrial complex by using Strom Water Management Model (SWMM), a point with clear division of the soil pipe and rainwater pipe sections was selected for monitoring non-point pollutant runoff and analyzing the characteristics of the runoff in this study. Furthermore, to construct a SWMM-LID model of a small-scale catchment, RUNOFF blocks were subdivided into sections and six event data with satisfactory flow pattern were selected from 24 monitoring data collected over three years (2009–2011) to be calibrated, two more event data were used for verification to complete the construction of the model. LID key technologies were applied as four CASEs: existing condition of the city (CASE 1), application of rain barrel (CASE 2), rain barrel and tree filter box (CASE 3), rain barrel, tree filter box, and porous pavement (CASE 4) for short-term and long-term (seasonal) simulation analyses.

*Keywords:* Industrial area; Non-point pollutant; SWMM; LID

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## 1. Introduction

Non-point pollutants are produced when pollutants on road, dust, and waste in city areas, accumulated pollutants on earth surface, pesticides spreading on farmland, waste from livestock shed, etc. run off during rainfall. The non-point pollutants from industrial region concentrated with industrial complexes require special care because they are high in

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pollutant load per unit area and include various toxic materials.

Many studies have had lots of efforts of water quality management about point source by constructing environment-friendly facilities such as sewage plants, non-point pollutant has become a relatively bigger cause for water pollution. For this reason, various techniques for the management of non-point pollutants are developed and applied widely, in particular, interest in techniques such as the restoration of hydrological cycle and management of non-point pollutants is increasing. As the need for the management of non-point pollutants first arose, structural concept of Best Management Practices (BMP) was mainly developed. In the recent years, the expansion of management plans has been shown including precautionary land use techniques such as low impact development (LID). LID is a rainwater management technique which maintains or restores hydraulic function before development. It uses various manmade structures and natural objects that decrease the runoff, filter pollutant, and increase underground water recharge, leading to the improvement of hydrological cycle and reduction of pollution. In sum, LID applied various techniques of natural and optimum management, which is to reduce the rainfall runoff and increase underground water recharge rate, achieving hydrologic cycle improvement and reduction of pollution at the same time. Such LID unit technique and dispersal management technique can be combined with complex design techniques, and can be integrated to buildings, infrastructures, and landscape designing. They employ dispersal method which manages runoff on the point of origin rather than managing runoff by using large-scale rainwater management facility or using pipeline or waterway to gather and manage water. Moreover, the regulations, conservation of resources, and restrictions of complex can all come into consideration, because LID includes techniques managing various rainwater runoff.

LID emerged from Prince George's County, Maryland Department of Environmental Resources in the USA. LID in Prince George's County began with the development and use of a bio-retention cell. In 1998, the LID manual was first published in the USA at a local government level. They evolved into the national level in 2000. The LID center conducted a validity examination in 2002 to study how LID can be used as guidance in improving various problems in city areas. Many local governments including Portland and Oregon have integrated LID techniques to their city resources conservation programs. Even in the USA, the concept and techniques of LID are not familiar to many designers and engineers, but European countries have recognized the importance of this field and consistently make lots of efforts to expand it.

Meanwhile, the increase in awareness of non-point pollutant in Korea has led to active researches related to non-point pollutant as well as rainfall runoff. The collective housing area was examined according to the type of land use in residential and business district. For the industrial complex, the runoff characteristics in target points were classified by industry such as engineering, metal, textile, and food industry. Ministry of Environment (2004) compared the pros and cons and the effectiveness of facilities for managing rainfall runoff, and Lee et al. [1] have conducted a hydrological analysis on the installment plans for LID rainwater-managing facilities before and after the development of a new town, using Strom Water Management Model (SWMM)-LID model. Han et al. (2009) used SWMM to make a simple correction to the interface and engine in order to evaluate the effect of the rain barrel. Kwon et al. [2] modified the NRCS-CN value in some of the areas of Chung-joo City to analyze the effects of green roof and permeable parking garage according to different scenarios. Lee et al. [3] used SWMM for evaluating NPS reduction performance of BMPs. Lee et al. [4] suggested appropriate determination method of removal efficiency for non-point source best management practices.

LID is usually applied to newly developing sites, but its use has expanded to existing cities which need management of non-point pollutant recently. In designing LID for blocking and disposing non-point pollutant, flood hydrograph of the target needs to be decided according to the rainfall-runoff model, annual suspended sediment and other loads of non-point pollutant need to estimate the volume of the reduction facility. However, all monitoring sites to decide the pollutant discharge are impossible in terms of finance and time. Therefore, in reality, the indexes stated in the literature are being used [9].

In this study, a point with clear division of the soil pipe and rainwater pipe sections in Noksan National Industrial Complex, Songjeong-dong, Gangseo-gu, Busan was selected to analyze the effect of LID application on an industrial complex by using SWMM model. The site was monitored to observe non-point pollutant runoff and analyze the characteristics of the runoff. Furthermore, a SWMM-LID model was constructed to apply LID key technologies, and the effect was analyzed over short-term and long-term in seasonal.

## 2. Methodologies

### 2.1. Non-point pollutant monitoring

In the study, as shown in Fig. 1, the monitoring site is Noksan National Industrial Complex located in Songjeong-dong, Gangseo-gu, and Busan. As mentioned before, monitoring for every non-point pollutant accompanies time and financial limitations as well as the inconvenience of attaining permission for observation from each district. Therefore, a suitable site was selected and visited according to the assessment criteria whose emphasis was on accessibility, measurability, rainwater pipe system, and safety of long-time monitoring. At the end of this process, a point in Noksan National Industrial Complex, which has clear divisions of the soil pipe and rainwater pipe section, was selected as the target monitoring point. More detailed information of the monitoring point can be found in Table 1.

Monitoring of the non-point pollutant from the target industrial complex was conducted by selecting the point where only the rainwater spills through rainwater pipeline in the rainy season. The flow was measured by setting the automatic flow meter (flow tote III—open type, channel type current meter) for one-minute interval automatic measurement. The sampling onset was set to the rainfall beginning time as 0 min. In the case of short rainfall duration, sampling was done eight times in 5 min intervals for the first 40 min, then the interval was adjusted to 15 min, 30 min, and 1 h for sampling. In the case of long rainfall duration, the samples collected in 5-min intervals in the beginning were sequentially mixed with 15 min interval samples in three containers. And sampling was done after eight times in 2 h, then the interval was adjusted gradually from 30 min to 4 h to sample the runoff spilling from the rainwater pipe until the termination point. The water temperature, pH, dissolved oxygen were measured at each sampling time on-site. To minimize the external influences, the samples were sealed in containers and instantly moved to the laboratory and analyzed. The categories which need long-term analysis were properly processed and stored refrigerated below 4℃ until used for biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solid (SS), total nitrogen (TN), and total phosphrus (TP) analysis based on the official test method for water pollution (2003).

Table 1
Description of the target monitoring site of industrial complexes in the Busan

| Target site | Basin area ($m^2$) | Occupants | Type of business | Imperviousness of watershed (%) |
|---|---|---|---|---|
| Noksan National Industrial Complex in busan | 13,000 | Kukdo Chemical, Hwaseung T&C, Hyedong Corporation | Petrochemistry, Fabricated metal | 100 |

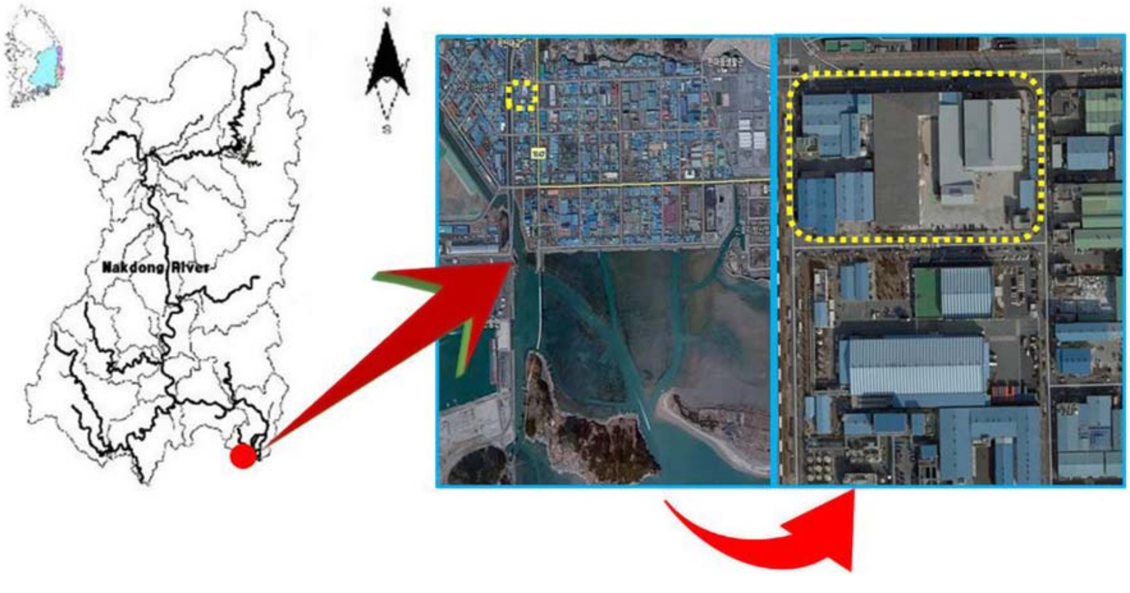


Fig. 1. Location of the target monitoring point of industrial complexes in the Busan.

### *2.2. Construction, calibration, and verification of SWMM model*

The organization of the SWMM model as shown in Fig. 2 constitutes of five executive blocks, (1) RUNOFF, (2) TRANSPORT, (3) EXTRAN, (4) STORAGE, (5) EXECUTIVE, and five assistant blocks, which are divided into 126 sub-programs for performance (Fig. 2)

For the application of the SWMM, geographic data and drainage characteristics data of small catchments were used for the surface runoff simulation on flow calculation, pipe and manhole data for the routing of the flow in pipes, and pollutant data for water quality simulation.

In this study, RUNOFF blocks were set as small-scale sections to construct SWMM, as can be seen in Fig. 3, using the initial calculation that simulates the flow and pollutant loads of the drainage catchments, and using the RUNOFF block which calculates hydrograph and pollute graph using data including rain gauge, preceding conditions for rainfall, land use, topographical map, pipeline data, the buildup and wash-off data for land use type and pollutant types. Especially, input data for calibration and verification of SWMM is as Table 2. Using the input data, as Table 3, characteristics of runoff, rainfall and load for all storm events were analyzed.

Fig. 2. Composition of SWMM model.

To construct a model for the target-monitoring site, observed rainfall and runoff data were reviewed to extract the data which would show satisfactory pattern of rainfall and runoff when applied for calibration and verification. Six rainfall-runoff data for calibration and two rainfall-runoff data for verification are presented in Table 4.

The rainfall event used for calibration was applied to the constructed model to estimate the sensitivity to each parameter. Parameter uncertainty was set to ±50% (for surface area, ±5%) in considering the sensitivity of the objective function (peak runoff) according to the changes in parameter in each rainfall event.

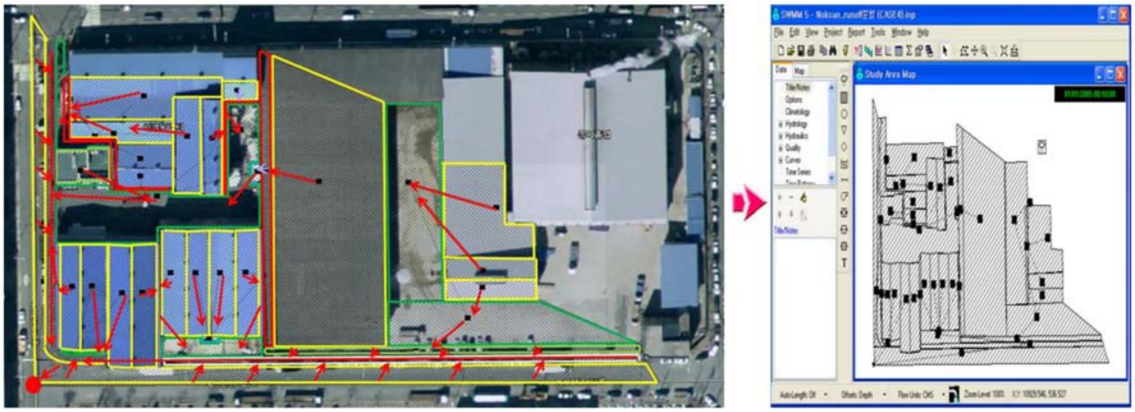


Fig. 3. Division of runoff block by small scale sections.

Table 2
The events for applying calibration and verification for SWMM

| | Date | Rainfall (mm) | Rainfall intensity (mm/h) | Runoff ($m^3$) | Dry time (day) |
|---|---|---|---|---|---|
| Calibration of applied to storm event | 2009/04/13 (event 2) | 20.5 | 2.55 | 144.05 | 21 |
| | 2009/06/20 (event 4) | 4 | 4 | 8.50 | 9 |
| | 2009/07/07 (event 5) | 125.5 | 25.10 | 564.16 | 4 |
| | 2009/0721 (event 6) | 20.5 | 3.62 | 141.42 | 9 |
| | 2011/04/27 (event 15) | 1 | 4.0 | 1.01 | 3 |
| | 2011/05/26 (event 17) | 21.5 | 2.51 | 251.08 | 2 |
| Verification of applied to storm event | 2010/09/02 (event 12) | 37.5 | 4.08 | 208.80 | 1 |
| | 2011/07/08 (event 20) | 119.7 | 3.60 | 1189.03 | 13 |

Table 3
Characteristics of runoff, rainfall and load of all storm events

| | Runoff ($m^3$) | Rainfall (mm) | Load ($kg/km^2$) | | | | |
|---|---|---|---|---|---|---|---|
| | | | BOD | COD | SS | TN | TP |
| 09/02/19 (event 1) | 1.96 | 15.5 | 14.21 | 42.63 | 4.11 | 1.03 | 0.03 |
| 09/04/13 (event 2) | 144.05 | 20.5 | 172.43 | 200.40 | 438.17 | 28.82 | 10.97 |
| 09/04/20 (event 3) | 270.64 | 44.5 | 127.56 | 150.47 | 201.43 | 33.19 | 1.84 |
| 09/06/20 (event 4) | 8.50 | 4.0 | 12.37 | 20.17 | 17.04 | 3.08 | 0.56 |
| 09/07/07 (event 5) | 564.16 | 125.5 | 129.46 | 194.44 | 409.96 | 79.04 | 2.44 |
| 09/07/21 (event 6) | 141.42 | 20.5 | 143.21 | 285.01 | 150.94 | 18.63 | 0.97 |
| 09/09/27 (event 7) | 37.75 | 18.0 | 69.48 | 105.16 | 74.14 | 6.55 | 1.13 |
| 10/04/26 (event 8) | 260.24 | 24.5 | 95.62 | 130.29 | 186.87 | 41.07 | 4.30 |
| 10/06/18 (event 9) | 3.32 | 3.5 | 5.64 | 8.76 | 12.01 | 1.71 | 0.15 |
| 10/06/25 (event 10) | 37.7 | 11.0 | 15.16 | 37.67 | 12.26 | 2.27 | 0.37 |
| 10/07/28 (event 11) | 694.95 | 57.0 | 238.90 | 342.69 | 301.77 | 69.19 | 5.90 |
| 10/09/02 (event 11) | 208.8 | 37.5 | 238.90 | 342.69 | 301.77 | 69.19 | 5.90 |
| 10/09/06 (event 12) | 39.49 | 5.0 | 47.95 | 73.66 | 79.32 | 30.25 | 3.24 |
| 10/09/11 (event 13) | 68.01 | 8.5 | 83.23 | 135.86 | 77.75 | 32.83 | 4.43 |
| 11/04/27 (event 14) | 1.01 | 1.0 | 0.92 | 2.92 | 2.87 | 0.53 | 0.10 |
| 11/04/30 (event 15) | 140.58 | 11.5 | 196.49 | 318.40 | 245.36 | 39.61 | 5.31 |
| 11/05/26 (event 16) | 251.08 | 21.5 | 133.40 | 209.64 | 141.11 | 29.60 | 2.86 |
| 11/06/10 (event 17) | 118.21 | 10.0 | 172.53 | 260.66 | 163.99 | 36.97 | 5.96 |
| 11/06/30 (event 18) | 109.65 | 13.2 | 105.44 | 191.27 | 284.49 | 26.15 | 5.47 |
| 11/07/08 (event 19) | 1,189 | 119.7 | 471.83 | 765.62 | 1132.32 | 269.04 | 21.69 |
| 11/08/19 (event 20) | 20.1 | 3.7 | 8.10 | 12.44 | 33.17 | 4.21 | 1.24 |
| 11/09/29 (event 21) | 29.94 | 4 | 24.11 | 78.22 | 552.96 | 4.15 | 0.05 |
| 11/10/14 (event 22) | 70.47 | 9.6 | 34.31 | 92.30 | 0.29 | 5.72 | 0.76 |
| 11/10/21 (event 23) | 61.49 | 7.2 | 11.23 | 16.53 | 0.20 | 8.36 | 0.43 |
| Average | 186.36 | 27.4 | 106.35 | 167.41 | 201.01 | 35.05 | 3.59 |
| Max | 1189.03 | 125.5 | 471.83 | 765.62 | 1132.32 | 269.04 | 21.69 |
| Min | 1.01 | 1.0 | 0.92 | 2.92 | 0.20 | 0.53 | 0.03 |

Selected parameters were changed and objective function was calculated simultaneously from the model applied with six rainfall events to examine if error is within the error function tolerance. Parameter which satisfies the error function tolerance was calculated by the rule of trial and error, and error was calculated from the model applied with four rainfall events according to the verification process to examine if error is within the error tolerance. This study has selected the root mean square error as an objective function (1).

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum^{N}(\hat{Q}(t) - Q(t))^2} \qquad (1)$$

In this formula, t is the time, and N is the number of data.

As shown in Fig. 4, Eight rainfall-runoff data were used for calibration, and the changes of parameter, which is a repetitive task, were applied to compute the optimum parameter which satisfies the threshold (<0.15) of evaluation function. As a result, the error function was changed from 0.41 to 0.12 in the course of calibration.

In the calibration process, to verify the parameter value which satisfies the permitted range, the parameter computed from event 12 and 20 was applied to examine the satisfaction of the error tolerance (<0.3). The calibration result can be seen in Fig. 5. The error tolerance was 0.25.

The discharging process of the pollutant in the catchment can be widely categorized into the buildup process before the rainfall and the wash-off process at the onset of the rainfall. Their simulation processes can be computed with SWMM runoff process. The pollutant buildup process in the catchment can be affected by both artificial and natural factors such as antecedent dry days, the degree of land use, the condition of the rainfall and wind, and the condition of

Table 4
Seasonal reduction effect of runoff and simulated load on each CASE

| Season | CASE | Runoff ($m^3$) | BOD (kg) | COD (kg) | TSS (kg) | TN (kg) | TP (kg) |
|---|---|---|---|---|---|---|---|
| Spring | CASE 1 | 12470.97 | 92.15 | 135.47 | 117.82 | 39.62 | 1.49 |
| | CASE 2 | 12436.02 (−0.28%) | 78.10 (−15.24%) | 114.81 (−15.24%) | 94.09 (−20.14%) | 33.58 (−15.24%) | 1.28 (−14.57%) |
| | CASE 3 | 11928.56 (−4.35%) | 76.22 (−17.28%) | 112.05 (−17.28%) | 91.83 (−22.06%) | 32.77 (−17.28%) | 1.24 (−16.70%) |
| | CASE 4 | 5833.66 (−53.22%) | 39.62 (−57.00%) | 58.24 (−57.00%) | 41.81 (−64.51%) | 17.04 (−57.00%) | 0.65 (−56.39%) |
| Summer | CASE 1 | 29349.97 | 143.36 | 210.75 | 181.29 | 61.64 | 2.50 |
| | CASE 2 | 29064.85 (−0.97%) | 120.02 (−16.28%) | 176.44 (−16.28%) | 142.45 (−21.42%) | 51.61 (−16.28%) | 2.09 (−16.28%) |
| | CASE 3 | 28581.52 (−2.62%) | 128.35 (−10.47%) | 188.69 (−10.47%) | 156.96 (−13.42%) | 55.19 (−10.47%) | 2.23 (−10.47%) |
| | CASE 4 | 13770.59 (−53.08%) | 75.70 (−47.19%) | 111.29 (−47.19%) | 80.17 (−55.78%) | 32.55 (−47.19%) | 1.32 (−47.19%) |
| Fall | CASE 1 | 6097.70 | 45.81 | 67.35 | 58.40 | 19.70 | 0.80 |
| | CASE 2 | 6076.50 (−0.35%) | 39.26 (−14.29%) | 57.72 (−14.29%) | 47.44 (−18.78%) | 16.88 (−14.29%) | 0.68 (−14.29%) |
| | CASE 3 | 5791.77 (−5.02%) | 38.70 (−15.52%) | 56.89 (−15.52%) | 46.37 (−20.61%) | 16.64 (−15.52%) | 0.67 (−15.52%) |
| | CASE 4 | 2757.07 (−54.79%) | 18.99 (−58.56%) | 27.91 (−58.56%) | 19.98 (−65.80%) | 8.16 (−58.56%) | 0.33 (−58.56%) |
| Winter | CASE 1 | 3519.45 | 35.01 | 51.47 | 45.79 | 15.06 | 0.61 |
| | CASE 2 | 3513.75 (−0.16%) | 30.15 (−13.90%) | 44.32 (−13.90%) | 37.65 (−17.78%) | 12.96 (−13.90%) | 0.46 (−24.31%) |
| | CASE 3 | 3147.80 (−10.56%) | 25.49 (−27.21%) | 37.47 (−27.21%) | 31.14 (−31.99%) | 10.96 (−27.21%) | 0.37 (−40.10%) |
| | CASE 4 | 1428.66 (−59.41%) | 10.72 (−69.39%) | 15.76 (−69.39%) | 11.49 (−74.91%) | 4.61 (−69.39%) | 0.19 (−69.39%) |

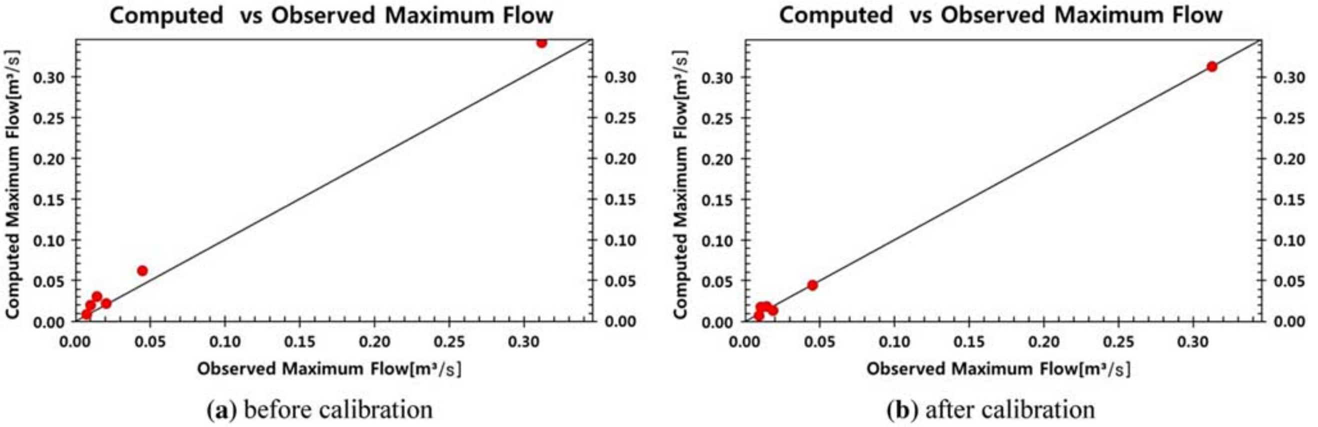
the streets. Many studies have been conducted for the successful simulation of the process. The wash-off process of the accumulated pollutants consists of erosion or dissolution process of the pollutants from a small watershed due to the rainfall and the wash-off rate takes on the form of an exponential curve, decreasing in the process of time. The study selected power-linear as the buildup function to calculate buildups and Exponential for wash-off function and used event 11 (28 July 2010) data to correct the initial parameters for calibration. Because the observed graph of concentration change for each pollutant is almost similar to all of the events, the amount of buildup was set to the maximum buildup of the observed figure for each pollutant. Other parameters were the same. For the wash-off, parameters other than the exponent of the exponential function were set the same and the water quality calibration was performed by adjusting the exponent Figs. 6 and 7 showed the results of comparative calibration of simulated and observed data.

### 3.2. Application of SWMM-LID

SWMM Ver. 5.0 LID model consists of three layers based on the characteristic per unit area [5]. This characteristic allows the LID equipment with the same data to be applied to other small catchments with different land cover, and also enables to figure out the degree of retention and cycle in each layer while maintaining the hydrologic balance during the SWMM simulation.

Possible techniques for simulation using SWMM 5 can be categorized into five: bio-retention cell, porous pavement, infiltration trench, rain barrel, and vegetative swale. SWMM-LID model, however, can simulate various techniques by changing the factors that decide hydrologic and hydrographic characteristics [6]. For example, bio-retention can design green roof, rain garden, and street planter which cause delay in runoff including vegetation and infiltration to the mixed soil horizon.

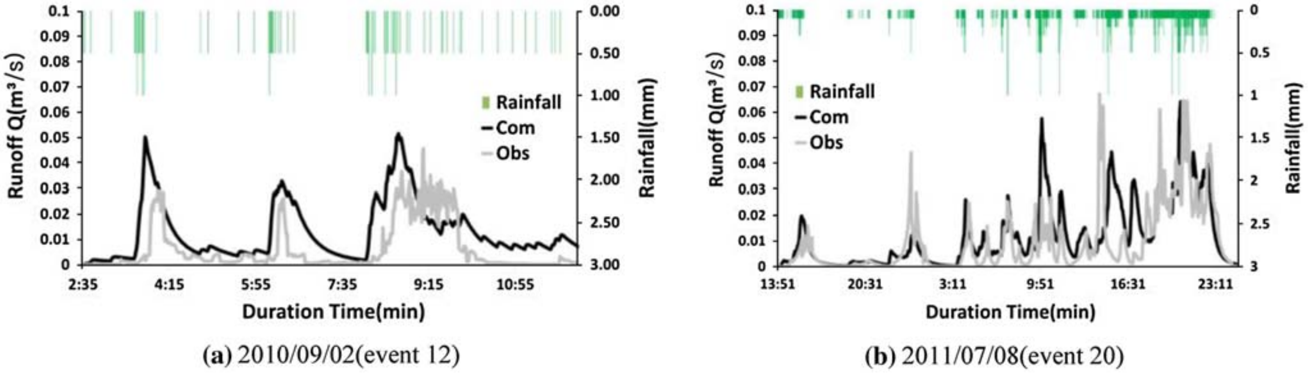
The target industrial complex of this study has its 83% of its site as panel-type buildings. Panel-type buildings cannot endure the soil load due to structural problem. Considering the small size of the site and qualitative evaluation, the LID techniques to be applied to the monitoring site were decided: tree filter box, porous pavement as infiltration techniques, and rain barrel as retention facility. The key technologies of rain barrel have effects on rainwater runoff quality improvement, reservation of water resources, and peak runoff reduction and the key technologies of tree filter box have effects on rainwater runoff



(a) before calibration

(b) after calibration

Fig. 4. The observed and computed values in rainfall-runoff calibration.



(a) 2010/09/02(event 12)

(b) 2011/07/08(event 20)

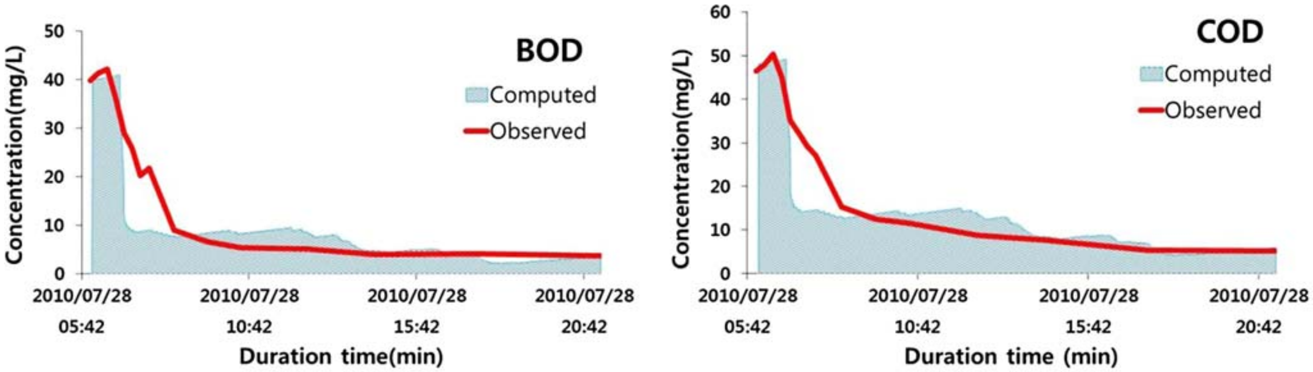
Fig. 5. Runoff verification results for event 12 and event 20.

quality improvement and reduction of heat island. Considering the processing area of the impermeable layer, LID technologies were classified and applied according to four cases:

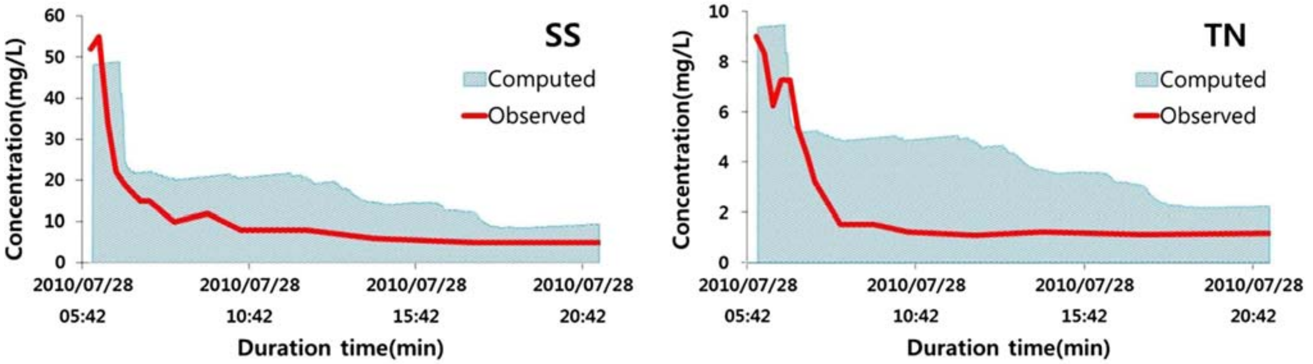
- CASE 1: existing condition of the industrial are (LID-applied area 0%).
- CASE 2: rain barrel (LID-applied area 6%).
- CASE 3: CASE II + tree filter box (LID-applied area 9%).
- CASE 4: CASE III + porous pavement (LID-applied 17%).

To design SWMM-LID model, the retention water level of 24 in., approximately 609.6 mm, and vegetation volume of 90% as proposed by a manual from Fairfax County, was adopted. The coefficient of surface roughness referred to the Manning coefficient of roughness from SWMM manual. Based on SWMM manual and presentation data from 2011 Philadelphia LID conference, the thickness of the soil horizon was set to 6 in., approximately 152.4 mm and the void fraction was set to 64% in reference to the study by Palla et al. [7]. Field capacity of 0.2–0.3 and wilting point of 0.05 were adopted as proposed by Palla et al. [7]. In reference to Fairfax County [8], hydraulic conductivity was set to 0.5 in./h, or 127 mm/h, increasing the speed of infiltrated rainwater moving to the retention layer which results in increased water recharge. Moreover, this study chose the slope of sand layer since according to the SWMM manual, the slope of hydraulic conductivity is close to five when the soil is similar to sand and close to 15 when the soil is silt clay. Finally, suction head of the soil horizon usually takes the variable of Green-Ampt infiltration model, because this study adopted Horton infiltration, 5 in/hr, approximately 12.7 mm/hr, used by Fairfax County was applied through literature review. The height of the reservoir ranges from 6 to 18 in. in the case of gravel layer. This study applied 18 in., about 457.2 mm, in order to maximize the retention effect of the tree filter box. To review the SWMM manual which suggests void rate between 0.5 and 0.75 when selecting the gravel layer as the reservoir, void rate of 0.75 was applied. The filtration rate was also set based on the gravel rate, 10 in., approximately 254 mm, and it was hypothesized that there was no clogging in the reservoir by setting the clogging factor as 0. SWMM simulation was conducted to estimate the runoff coefficient in accordance with the aimed amount of runoff reduction in the culvert layer. Coefficient of 0.5 in./h, approximately 12.7 mm/h was applied and the exponent was set to 0.5, a common value recommended by the SWMM manual.

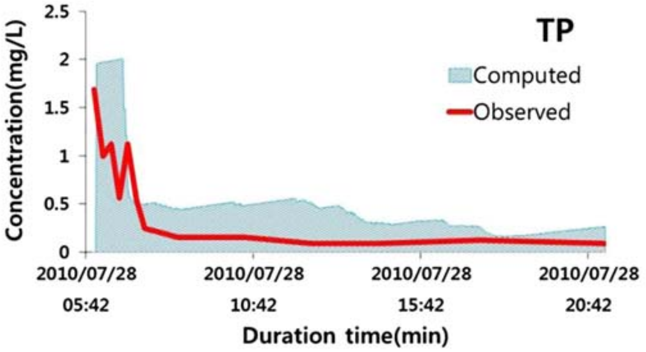
Further, to design the pavement layer that only exists in porous pavement, the design criteria of Philadelphia LID conference was applied; the thickness of the pavement was selected as 6 in., approximately 101.6 mm, and the void rate was set to 0.12, in reference to the range of 0.12–0.21 recommended by the SWMM manual. The impermeable surface area was set to 0, as continuous porous pavement was hypothesized, the degree of permeability is usually as high as 100 in./h in the case of newly constructed permeable concrete and asphalt, so this study set 50 in./h, approximate 1,270 mm/h, considering clogging coeffi-



(a) BOD (b) COD

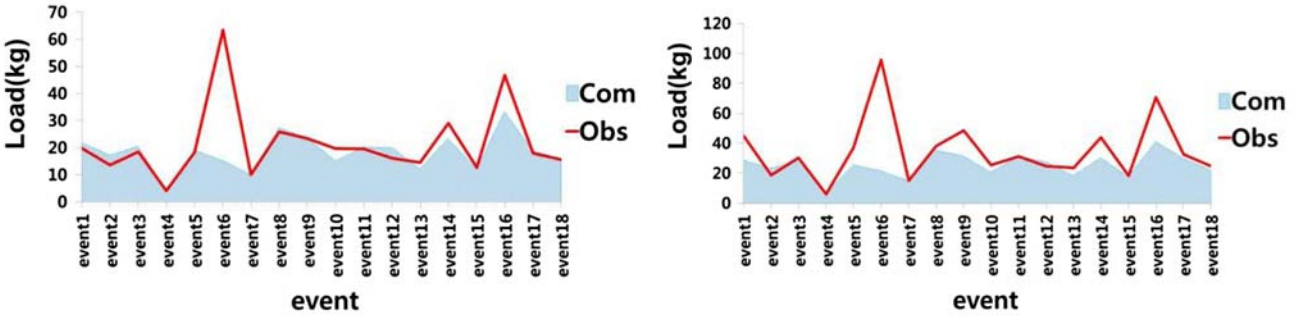


(c) SS (d) TN

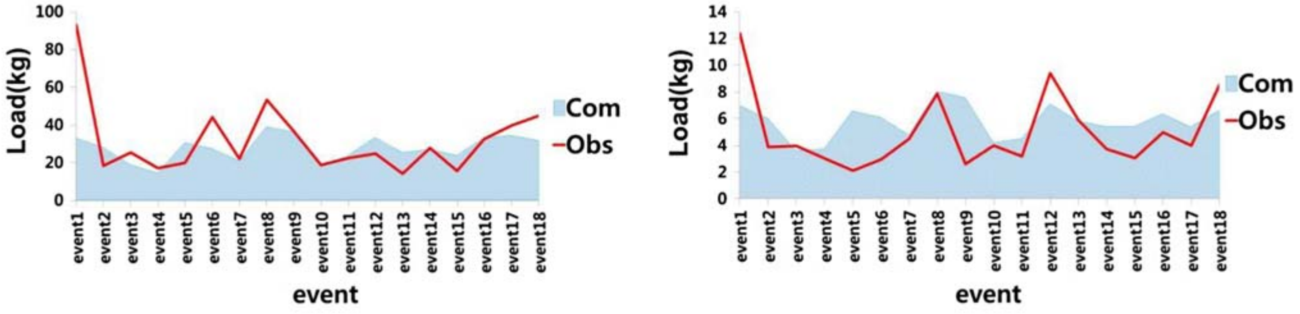


(e) TP

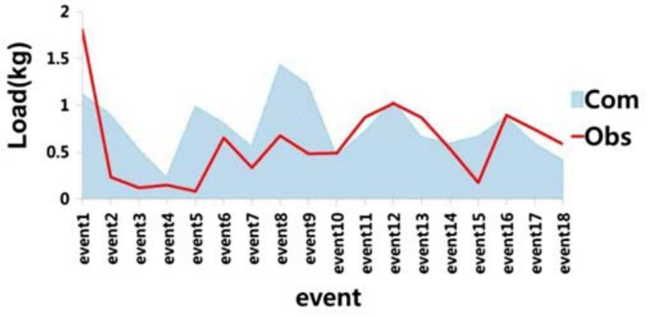
Fig. 6. Comparative calibration of computed and observed water quality data for each pollutant.



**(a)** BOD **(b)** COD



**(c)** SS **(d)** TN



**(e)** TP

Fig. 7. Comparative verification of the computed and observed data of pollution load for each event.

cient in accordance with the equation proposed by SWMM, it is close to the target amount of runoff and the reduction of non-point pollutants.

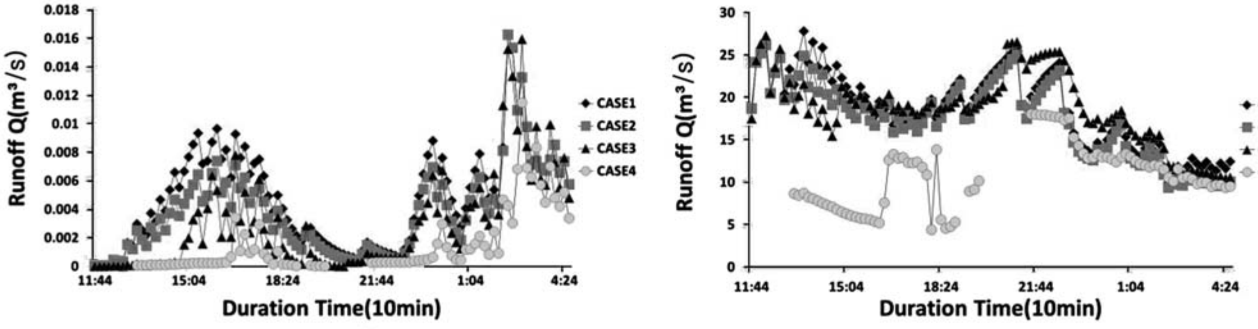
## 3. Results and considerations

### 3.1. Monitoring results

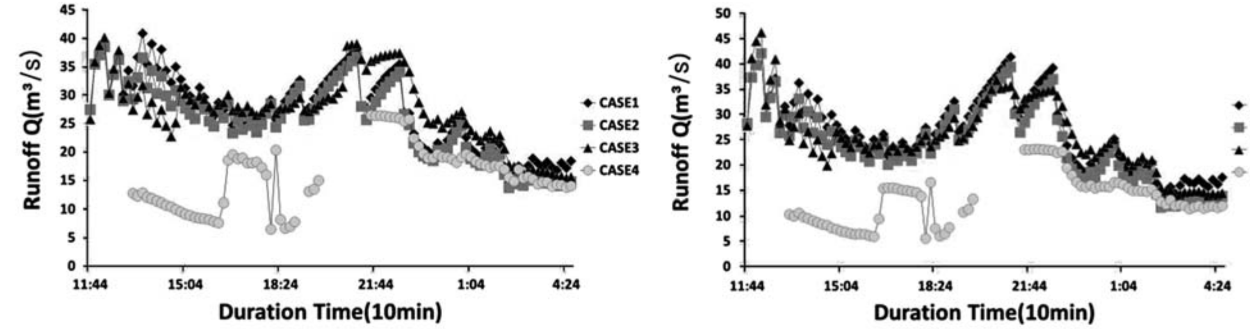
From the monitoring conducted from 2009 to 2011, a total of 24 valid monitoring results were drawn, investigations on diverse rainfall events with the amount ranging from 1 to 125.5 mm were carried out, and the amount of runoff was found to be 1.01–1189.03 $m^3$ depending on the rainfall event. The runoff average loads for each rainfall event showed BOD 106.35 kg/$km^2$ COD 167.41 kg/$km^2$, SS 201.01 kg/$km^2$, TN 35.05 kg/$km^2$, TP 3.59 kg/$km^2$, the range being BOD 0.92–471.83 kg/$km^2$, COD 2.92–765.62 kg/$km^2$, SS 0.20–1132.32 kg/$km^2$, TN 0.53∼269.32 kg/$km^2$, TP 0.03∼21.69 kg/$km^2$. Monitored pollutant runoff loads greatly differed depending on rainfall intensity, and the runoff load for each pollutant was found to be more of organic matters than nutrient salts.

### 3.2. Analysis of non-point pollutant runoff character

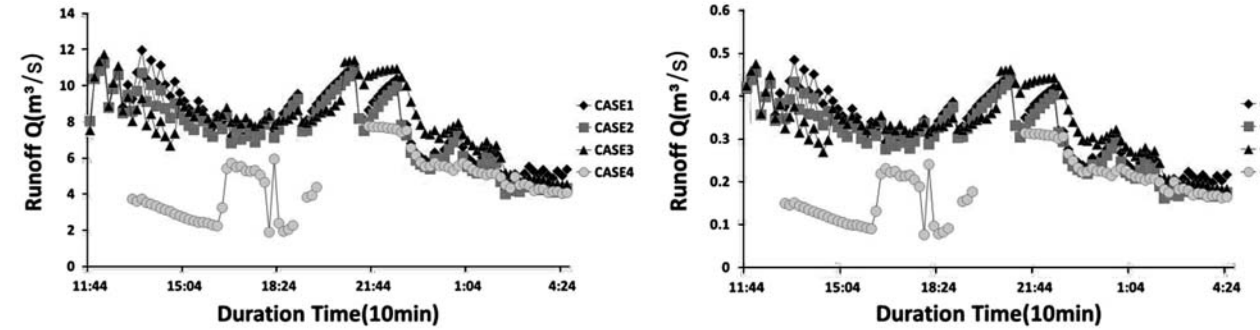
Analysis for each CASE, using constructed SWMM-LID model with event 8 (26 April 2010), the reduction effect on runoff was CASE 4(54.01%) > CASE 3(39.92%) > CASE 2(19.46%), and the reduction effect on non-point pollutant was CASE 4(mean



(a) Runoff (b) BOD



(c) COD (d) SS



(e) TN (f) TP

Fig. 8. Effect of LID for short-term event.

71.58%) > CASE 3(mean 44.38%) > CASE 2(mean 30.00%). This study estimated same wash-off parameter except SS. As the results of effect of LID over the short term events in Fig. 8, when LID techniques applied, efficiency reduction has an equal value without SS. So each water quality parameter considered same value for SWMM character.

The AWS rainfall data in Jinhae, the closest city to the target site, was applied to SWMM-LID model to conduct long-term simulation and analyzed seasonally. The amount of runoff in CASE 3 and CASE 4 showed greater reduction effect in the following order; winter(December, January, February) > fall(September, October, November) > spring(March, April, May) > summer(June, July, August). CASE 2, where only rainfall retention tanks were applied, the reduction effect occurred in the following order; summer > fall > spring > winter. Non-point pollutant showed the same reduction effect, the order of CASE 4 > CASE 3 > CASE 2, as short-term simulation in spring, fall, and winter. As increasing a level of the runoff reduction, winter > fall > spring > summer, pollutant loads also reduced (Table 4).

When compared to short-term simulation, the reduction effect of runoff in long-term simulation was significantly lower, 98% in CASE 2 and 73% in CASE 3. There seems to be an error in deciding the scale of reservoir on the target site by applying the parameters proposed in foreign studies which were not verified with Korean rainfall pattern. Simulation of the non-point pollutant showed lower efficiency in water quality categories except SS in winter, 50.47–99.50% in all seasons. In addition, CASE 3 in the summer showed 35% lower reduction effect for non-point pollutants than CASE 2.

## 4. Conclusions

This study used SWMM model to analyze the effect of LID for developed industrial complex in city area. Three LID techniques were applied and both short-term and long-term (seasonal) simulations were conducted. Runoff loads for each pollutant were higher in organic matter than nutrient salt. The amount and intensity of rainfall, and the number of dry days influenced the range of runoff pollutants. Analysis on the effect of LID showed different reduction tendencies of non-point pollutants for each technique and the period of time. A comparison with short-term simulation showed a significantly lower runoff reduction effect in long-term simulation. There seems to be an error in deciding the scale of reservoir on the target site by applying the parameter proposed in foreign studies which was not verified with Korean rainfall pattern. For efficient application of LID techniques, analysis to find the optimum combination of technologies is needed.

The reduction effect of LID presented in this study is limited in that it adopted the parameters suggested by international studies and EPA, lacking consideration of the verification of parameters. Moreover, for categorized analysis of the reduction effect on each non-point pollutant, categorization for particulate pollutants and dissolved pollutants to select highly correlative water quality simulation and LID layer design is needed. This study focused on constructing SWMM water quality model and analyzing effects of LID using rainfall-runoff-water quality measurement in developed industrial complex, but the ideal application of parameters for elements in the domestic use is insufficient. Through continuous empirical research based on domestic rainfall characteristics, the design method for Korean LID could be developed.

The results of this study showed possibility to be considered as important data to be submitted for the theoretical and technical basis of water environment management in Nakdong River, and improvement policies on various rivers.

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