국토연구 제102권(2019.9): pp49~67 http://dx.doi.org/10.15793/kspr.2019.102..04

Analysis of Stormwater Runoff Reduction Effect Through Applying Low Impact Development Practices in a Flood Prone Area : Case of Incheon, South Korea*

상습침수지역의 LID 적용을 통한 우수유출량 저감에 관한 연구 : 인천광역시를 중심으로

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Abstract

Flood damages are continuously growing in urban areas due to the increase of impervious surfaces and the occurrence of extreme rainfalls caused by climate change. While traditional drainage systems are still effective in controlling stormwater runoffs, they are inefficient in terms of costs and performance since they are only used for stormwater management. Low impact development (LID) practices, a comprehensive soft-engineering approach, provides multiple benefits in diverse aspects, and has been recently adopted as a key concept for sustainable stormwater management in many countries. By using the LIDMOD3 modelling tool, the present study simulates the hydrologic performance of LID practices in three different scenarios and explores the cost effectiveness of LID measures compared to the conventional sewer pipeline infrastructures. A flood-prone area in Bupyeong borough, Incheon, South Korea, was selected as the study site. The findings show that the district's total runoff volume and peak flow are reduced by 14-36% and 33-66%, respectively, in comparison with conditions without LID installation. Non-point source pollutant loads diminish by 15-36%, depending on the LID designed scenarios. Upon the consideration of construction costs, the results indicate that LID practices can be more efficient when they are partially developed rather than when various LID practices are applied to an entire area. The study concludes by suggesting policy implications as to how government agencies and local jurisdictions can more effectively adopt LID practices as part of sustainable stormwater management planning and link with future urban regeneration projects.

Keywords: Stormwater Runoff, LID, Green Infrastructure, LIDMOD3, Flood, Incheon

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* This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government(MSIT; No.NRF-2019R1G1A1010318).

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Ⅰ. Introduction

The average precipitation of Incheon, South Korea, for the last 10 years (2009～2018) was around 1,195mm (KMA Open Weather Data Portal[1]), which was not significantly different from previous years. However, flood damages within urban areas kept increasing over the years due to the frequent occurrence of local torrential rainfalls, which increased the intensity of precipitation. Particularly, damages caused by inland inundation are rapidly increasing because of the limited capacity and storage of urban sewer systems. This eventually resulted to an overflow which exacerbated the flood damage, especially during the heavy rain (Lee 2013). I nland inundation is mostly affected by three major causes: sediment deposits within the sewage conduit, tangled underground facilities and sewer pipes, and overflow from the sewer line due to increased river / stream stage. Climate change, which altered the precipitation pattern and increased the occurrence of natural disasters, has aggravated these three causes all over the world (IPCC 2007). To properly adapt and minimize impacts from these climatological changes, environmentally friendly urban storage and drainage approaches are required in the long-term.

The concept of low impact development (LID) techniques was first introduced in the mid-1990s by the Department of Environmental Resources of Prince George's County, Maryland in the U.S., to address solutions for sustainable and cost -effective stormwater management (USHUD 2003). LID refers to various practices regarding infiltration, detention, treatment, and flow control of stormwater close to its source in order to minimize runoff and prevent the deterioration of water quality (UACDC 2010; USEPA 2018). The overall goal is to mimic the site's natural hydrological functions as pre-developed conditions (Benedict and McMahon 2006). Currently, more than 30 techniques have been developed and adopted to collect and treat stormwater runoff. The USEPA broadened the concept of LID and included these practices for key green infrastructure planning (USEPA 2018). Since 2013, when the Ministry of Environment (ME) in South Korea adopted the LID manual for environmental impact analysis, a number of agencies in South Korea started to actively control non-point pollution sources through implementing LID practices (ME 2013). To recover the urban water circulation system, various countries are now using a similar concept of LID, while its terms vary: Water Sensitive Urban Design (WSUD) in Australia, Sustainable Urban Drainage (SUD) in England, Low Impact Developments Urban Design (LIDUD) in New Zealand, and Sound Water Cycle on National Planning (SWCNP) in Japan (Kang, Lee, Koo and Cho et al. 2011). China is also paying numerous attentions in green infrastructure planning by pursuing the concept of "Sponge City". Since 2015, the government has been requiring 30 pilot sponge cities to retrofit at least 20% of lands serving a pervious function (Chan, Griffiths, Higgitt and Xu et al. 2018). While the terms were used differently in diverse countries, the replacement of impervious pavements with various eco-friendly alternatives, making places more resilient to floods and bringing back the natural water

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1) https://data.kma.go.kr/stcs/grnd/grndRnList.do?pgmNo=69 (accessed on January 13, 2019).

circulation systems, is a common characteristic.

Increase of impervious surfaces induces much more amounts of peak flow and reduces the time to peak, which eventually increases the total flood volume, decreases groundwater storage, and minimizes the baseflow of urban streams (Kim and Li 2016; Choi and Shin 2002). One of the major goals of LID is to capture the first 1-inch (25.4mm) of rainfall, which contains the most harmful substances that remain on the roads or impervious surfaces, in order to minimize the pollutants flowing into the sewerage systems. Although various drainage techniques have been continuously introduced to rapidly reduce the initial rainfall, the past sewerage systems have failed to manage the quality of stormwater outflows. Particularly, major limitation still exists during the heavy downpours with the frequent occurrence of back flow from sewer grates. LID practices are not only efficient in controlling and capturing the stormwater at the initial stage, but also effective in managing both quality and quantity of runoff (USEPA 2018; ME 2013). Several studies identified that the construction of LID practices is more cost-effective compared to retaining the traditional sewer lines and detention facilities (USHUD 2003). Considering the environmental and economic aspects of LID, more active technical and political efforts should be paid for restoring the hydrologic and ecological functions of urban watershed in the long-term.

This study examines the reduction effect of LID practices in stormwater runoff by adopting the LIDMOD3. A district prone to floods in Bupyeong borough, Incheon, was selected for the study area. This paper is constructed according to the following sections. First, previous studies that used multiple modeling approaches to examine the impact of LID practices are reviewed and the gap of existing studies is identified. Second, research methodologies, including study area, modeling technique, scenario setting, and analyzing method are presented. Third, runoff reduction effects of LID, as well as installing costs for both traditional drainage systems and LID practices, are compared and analyzed. The study concludes by suggesting policy alternatives for the effective and sustainable management of stormwater runoffs.

II. Previous Studies on Examining the Effects of LID Practices

LID practices have been introduced to minimize the runoff and increase the water quality that flows into the existing sewer lines. Several studies have adopted different types of LID by using various rainfall-runoff simulation models, for estimating the runoff reduction effects (Rosa, Clausen and Dietz 2015). The US Environmental Protection Agency (USEPA)'s Storm Water Management Model (SWMM) and System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) are the most typical simulation models that have been employed to examine the runoff reduction effect of LIDs (Gao, Wang, Hunag and Liu 2015; Jeon, Park, Park and Kim 2014; Luan, Fu, Song and Wang et al. 2017; Nam, Kim, Kim and Kim et al. 2017; Park, Yoo, Park and Yoon et al. 2008; Rossman 2010; Suh and Lee 2013; Jeon, Park and Lee 2013; Jang, Mun and Yang 2013). However, other tools, such as the

Long-Term Hydrologic Impact Assessment-Low Impact Development (L-THIA-LID) model (Liu, Bralts and Engel 2015), LIDMOD2&3 (Kim, Kim, Choi and Jeon 2011; Jeon, Yoon, Lee and Cho et al. 2015; Jeon and Seo 2018), Soil and Water Assessment Tool (Woo, Ryu, Moon and Jang et al. 2012), and the improved Soil Conservation Service Curve Number (SCS-CN model) (Cronshey, Roberts and Miller 1986; Roehr and Kong 2010) were also often used to measure the effects of LIDs in specific regions.

By using the SWMM, Park, Yoo, Park and Yoon et al. (2008) applied porous pavements and green roofs in the Geo-du district (25.2ha) of Chuncheon, South Korea, and identified that runoffs have been reduced by 32.7% in 44.44mm (2-yr design storm) rainfall and 23.6% in 73.16mm (10-yr design storm) precipitation. With the same method, Suh and Lee (2013) simulated the effect of infiltration trench and chamber in three different cities' residential areas in South Korea and found that stormwater runoff reduced from 19.4% to 23.7%, while infiltration amount increased by up to 20%. Luan, Fu, Song and Wang et al. (2017) simulated five different LID scenarios in the mountainous Fragrance Hills region of Beijing, China. All LID practices had a positive effect on runoff reduction, but the results showed that the concave greenbelt was the most effective in controlling the storm events with the runoff reduction percentages ranging from 5.2% to 57.3% for 1, 2, 5, and 10-year rainfall events, whilst the vegetative swale provided the least reduction effect, ranging from 0.3% to 3.0%. Jeon, Park and Lee (2013) applied porous pavements and rainwater detention tanks in Towoul stream basin, Changwon, and discovered that peak runoff reduced by 1.2~6.2% for porous pavements, while the reduction effect of detention tanks ranged from 2.1~11.7%, depending on the size of a tank. Jang, Mun and Yang (2013) also found that porous pavements near the Mokgam stream basin (5,569ha) minimized the maximum daily rainfall runoff up to 9.5%.

Gao, Wang, Hunag and Liu (2015) used the SUSTAIN to find out the impact of five different best management practices (BMPs; green roof, wet pond, vegetated swale, porous pavement, bioretention basin) in an industrial site located in Ma'anshan, Anhui Province, China, and discovered that approximately 41% of total runoff volume was reduced after running the simulation. Employing both SWMM and SUSTAIN, Nam, Kim, Kim and Kim et al. (2017) analyzed the runoff reduction amount, as well as the mitigation effect in relation to construction costs for different LID scenarios (mix of permeable pavement, infiltration ditch, and ecological detention pond) in Oncheon Creek Watershed in Busan, South Korea. The results showed that there were 31.7-49.1% of runoff volume reduction through LID measures, while infiltration ditch was most cost-effective. Jeon, Park, Park and Kim (2014) applied the SUSTAIN while evaluating four LID practices (e.g., bioretention, infiltration trench, rainwater harvesting, and porous pavement) near the Andong city bus terminal site. The study found that a site's surface runoffs have diminished by up to 14-28% on average during the 550 simulations.

The LIDMOD model was often performed for measuring the runoff reduction effect of LID practices in South Korea. With the LIDMOD2, Kim, Kim, Choi and Jeon (2011) demonstrated that the bioretention was the most effective means of controlling runoff compared to the artificial wetland and wet pond in a residential district of Yongin, South Korea. A study from Jeon, Yoon, Lee and Cho et al. (2015) revealed that the annual stormwater runoff volume was reduced by 23% while the annual infiltration rate increased by 23.1% when porous pavement, green roof, and bioretention was developed in a site near the Andong city hall, in South Korea. Jeon and Seo (2018) recently updated the previous LIDMOD2 into LIDMOD3 and used them for assessing the function of permeable pavement and bioretention in an apartment complex in Seoul, South Korea. The results of runoff analysis revealed that the discharge volume decreased by a maximum of 37% with the 64% increase of infiltration rate. Roehr and Kong (2010) used the improved SCS-CN model to examine the effect of green roofs and identified that the annual rooftop runoff was minimized by 29% in Vancouver, Canada, and 55% in Shanghai, China.

To summarize the previous studies, simulation analyses that had relatively large study sites tended to construct porous pavements, which comparatively had less spatial restrictions. In addition, a majority of studies were likely to simulate LID practices, such as bioretention, permeable pavement, and green roof, while their runoff reduction effects were mostly 10% higher compared to other LID measures (Jeon and Jung 2019). However, most of the study sites were located in a relatively small municipality that did not have severe flooding issues in the past whereas only a limited number of LID techniques were introduced during the simulation processes. Moreover, the USEPA's SWMM and SUSTAIN could not sufficiently integrate Korea's geographical conditions while running the simulation. By employing the LIDMOD3 and choosing the flood prone area for the study site, this research attempts to fill the previous literature gaps and determine the practical runoff reduction effects of diverse LID practices.

III. Research Methods

1. Study Area

Bupyeong borough has the third highest impervious surface proportion (63.3%) in the entire 10 boroughs of Incheon (i.e., overall impervious surface ratio of Incheon: 19.9%; Kim and Park 2017). Among 31 flood prone zones, eight areas are located in Bupyeong and the number of accumulated flooded areas was 1,250 as of 2017, which was the highest among the overall boroughs. The study area is located within the Shipjung-1 district of Bupyeong borough in Incheon, with the total size of 42,690.6m^2 (see <Figure 1>). It mostly consists of single-family housings with some commercial buildings at the edge of streets and a small park on the southeast. Most of the land uses are classified as 2nd class general residential zone and overpopulated constraint district. The target area has historically suffered from floods due to it s high impervious ratio (97.3%) and low-lying location. Since the slope near the study area is falling from the northeast to south-west side, runoff flows at the same direction, following the impervious surfaces. This has triggered more flood damages on the southern part of the study area. In addition, dwelling units in the study area stand close together and roads are fairly small, which prevent the construction of large-scale

Figure 1_Study Area Surrounding Environments and Slope

Table 1_Land Cover and Size of the Study Area

(unit:㎡)

Classification		Pervious Surface		Impervious Surface						Total Size
Land Cover		Barren	Lawn	Rooftop	Drive-way	Walk-way	Parking-lot	Play-ground	Others	
Area Size by Each Hydrologic Soil Type	B	0	0	1870.2	224.0	0	0	0	670.0	2,764.2
	C	199.6	927.5	18,145.8	7,477.8	988.0	2,567.4	178.0	6,384.5	36,868.6
	D	0	22.4	1,262.9	148.3	0	497.3	0	1,126.9	3,057.8
Total Size		199.6	927.5	20,016	1,701.8	988.0	2,567.4	178	7,054.5	39,632.8

stormwater detention or mitigation facilities. Thus, the study area can be a suitable modeling site for investigating the implementation effect of small-scale, soft-engineering approaches, such as LID practices. <Table 1> shows the detailed land cover and size of the study site.

2. Scenario setting

This study analyzed the runoff reduction effect of LIDs by applying three different LID scenarios in one of the flood prone areas in Bupyeong borough, Incheon. Each scenario is constructed as LID-friendly design (Scenario1), LID-partially adopted design (Scenario 2), and LID- conservative design (Scenario 3). Scenarios have adopted LID practices by balancing the three types of LID functions (vegetated facility, retention facility, and infiltration facility),

Table 2_LID Techniques Adopted in Each Scenario

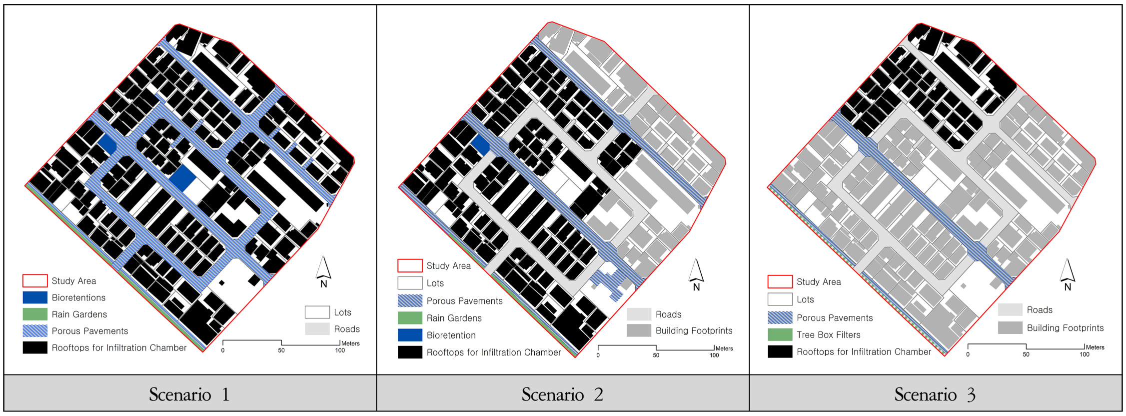
Scenario	LID Type	Practice	Installation Location	Size(m^2)
Scenario1	Vegetated Facility	Rain Garden	Walkways in the southwest part	380.0
	Retention Facility	Bioretention	Two bare lands	459.5
	Infiltration Facility	Porous Pavement	Walkways in the southwest part	608.0
		Infiltration Chamber	Rooftops in the study area	2,135.0
		Porous Pavement	Entire roads, walkways within park, and parking lots	11,405.1
Scenario2	Vegetated Facility	Rain Garden	Walkways in the southwest part (within flood prone area)	250.0
	Retention Facility	Bioretention	Bare land located in the West side	165.1
	Infiltration Facility	Porous Pavement	Walkways in the southwest part	738.0
		Infiltration Chamber	Rooftops within flood prone area	1,450.0
		Porous Pavement	Two large roads and walkways within park	3,660.4
Scenario3	Vegetated Facility	Tree Box Filter	50 tree box filters in the southwest part	200.0
	Infiltration Facility	Porous Pavement	50% of walkways in the southwest part	304.0
		Infiltration Chamber	Rooftops within northwestern side (two blocks)	558.0
		Porous Pavement	Central road (middle part) and walkways in the park	1,852.9

which have been listed as the key LID elements in the Korean ME and Korea Environment Corporation's LID Implementation Manual. Appropriate LID practices for multi-family housing complexes, roads, parking lots, and rooftops were determined through considering the previous projects that adopted LID facilities in practice. <Table 2> shows the type, installed facility, location, and size of LID techniques for each scenario.

Scenario 1 adopted the most numbers of LID practices, while Scenario 2 concentrated the installation of LID facilities within the flood prone area. Scenario 3 included a limited number of LID techniques in certain places that could minimize the flood damage. Specifically, LID practices were installed based on the geographical characteristics of site and features of each measure. The overall size of LID facilities for each scenario was 35% (14,988m^2), 15% (6,263m^2), and 7% (2,915m^2), respectively, out of total drainage area.

In Scenario 1, rain gardens and porous pavements replaced the existing walkways, which were located on the southwest part of the study site. Since the slope of this area flows from northeast to southwest, two practices, which have a high efficiency in capturing stormwater runoff within the limited space, are the most suitable approaches in this site. Bioretentions were created in two empty bare lands, where their locations allowed to efficiently collect the northeast side of stormwater and provide a rest area for residents. Every driveway, walkway within a park, and parking lot was designed as permeable pavers, while infiltration chambers were installed to receive runoffs from the rooftops. Since the major purpose of bioretention and infiltration chamber is to collect the first 25.4mm runoff, which contains the significant portions of non-point pollutant, the size of those facilities was calculated based on collecting the first inch (25.4mm) of stormwater (Jeon and Seo 2018; Prince George's County 1999). In Scenario 2, rain gardens

Figure 2_Applied LID Techniques for Each Designed Scenario



Scenario 1 Scenario 2 Scenario 3

and infiltration chambers were preferentially implemented where they over-lap with the flood prone area. Two major driveways that pass through the study area were replaced to permeable pavement, whereas walkways within a park and located on the southwest part of the study area were transformed into porous pavers. Major driveways that penetrate the east-west side of site can be relatively installed with low construction cost and they can intersect the runoffs in phases at the middle. Installing porous pavements in narrow alleys are likely to be inefficient in economic and environmental aspects. Bioretention was only installed on the west side of the existing bare land. This is due to the slope, which falls from Ship-jung park induces the runoff in western area. Bioretention may capture some of these runoffs and delay the peak time. Lastly, Scenario 3 employed the least amount and type of LID facilities. Instead of installing rain gardens above the walkways in the southwest area, 50 tree box filters were implemented, following the main road. Porous pavements were only given to 50% of existing southwest side walkways, walkways within a park, and a driveway located on the center, which penetrates from east to west. Since the slope flows from the northeast to southwest side, infiltration chambers were mainly installed on two blocks of the northwest corner to cover the rooftop runoffs. <Figure 2> shows the locations and adopted LID techniques for three different scenarios.

3. Data Acquisition and Analysis

The data in this study have been analyzed in two phases. First, LIDMOD3, a site evaluation tool (Tetra Tech 2005) that has been recently co-developed by the Korea National Institute of Environmental Research and Andong University (Jeon and Seo 2018) was used to assess the runoff reduction effect of LID practices. This modeling tool was continuously updated from 2010 in order to estimate the runoff depth, infiltration depth, peak flow, and annual loadings (e.g., BOD, SS, T-N, T-P). The significant update of its recent version (2018) includes the runoff curve

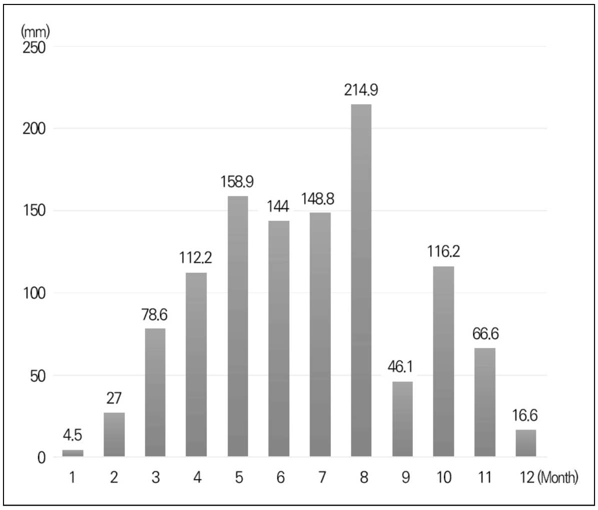
Table 3 _ Data Sources

Data	Source
Building Footprint, Road, Land Use	Korea Ministry of Land, Infrastructure and Transport
Soil, Elevation	Korea Rural Development Administration
Precipitation	Korea Meteorological Administration
Flood Prone Area	Incheon Metropolitan City
Digital Elevation Mode (DEM)	National Geographic Information

number (CN) being re-established based on a more detailed Korea soil map, which enabled the calculation of the direct amount of runoffs from specific land uses and LID practices (Jeon and Seo 2018). Since the storage capacity of LID practices are calculated based on the Ministry of Environment's LID Facility Design Guideline and the infiltration capacity was computed on the basis of domestic case study's soil drainage conditions, the simulation results of LIDMOD3 may estimate the runoff characteristics precisely as similar to other sophisticated simulation tools for Korea (Jeon and Seo 2018; National Institute of Environmental Research 2019). Because modelling tools, such as SWMM and SUSTAIN, estimate the runoff with the consideration of various drainage systems and land-use conditions, their assessments may work better in a complicated urban area than LIDMOD3, which mostly rely on hydrological soil group for the simulation. However, SWMM requires diverse variables (e.g., pervious level for each sub-basin, Manning's roughness coefficient, etc.), while LIDMOD3 has relatively simple modelling process with small number of variables. Thus, local governments may readily manage the impervious surfaces, prepare flood mitigation plans within a short-time, and concisely check the runoff reduction effect of LIDs during the environmental impact assessment.

To run the model, basic data, such as building footprint, road, land use, soil, elevation, precipitation, and flood prone area were needed (see <Table 3>).

Figure 3 _ Monthly Precipitation in 2018



By using the ArcGIS v10.6, locations, as well as sizes for each data were calculated. While building footprint, road, and land use data were acquired from the Korea Ministry of Land Infrastructure and Transport (MLIT), soil and elevation data were gathered from the Rural Development Administration. Other data, such as precipitation data for 2018 were obtained from the Korea Meteorological Administration (see <Figure 3>), flood prone area from the Incheon.

Metropolitan City, and digital elevation model (DEM) data from the National Geographic Information Institute.

Second, costs for LID practices that have been applied in each scenario were mostly estimated using the LID Practices Costing Tool developed by the Toronto and Region Conservation Authority and University of Toronto (2013). The costs for tree box filter, however, were not allowable for the calculation in the tool. Thus, the cost was drawn by adopting the LID manuals from the Korea Land and Housing Institute (2015), as well as previous projects that have recently constructed the best management practices in South Korea.

The cost efficiency of LID approaches was then shown by comparing the simulated construction costs of conventional drainage systems and LID practices. Two assumptions were made for installing the sewer pipes within the study area. First, it was hypothesized that all existing pipes (total length: 1,767.26m) would be replaced by 600mm-diameter pipes. This is because the current sewer pipes are old enough to be replaced by new ones. According to Lee, Kim, Park and Kim et al. (2016), a pipe diameter size less than 600mm was ineffective to control the urban runoff in South Korea. For this reason, sewer pipes that had a diameter of less than 600mm were replaced and calculated. Since sewer lines were generally replaced by stages, the entire pipeline replacement costs were not considered in this study, which may significantly increase the b/c ratio of LID practices. Target pipelines were determined by using the drainage system spatial data obtained from the City of Incheon.

The installation costs for sewer pipe were calculated based on the Korean ME's Subsidy Compilation and Execution Management Guideline for Sewer System (ME 2018). The guideline provides a detailed average fee for sewer pipe per 1-meter, including construction, basic design, construction document, and supervision expenses. Depending on the pipe type (e.g., concrete, steel, plastic, and cast iron) and diameter, the estimated price was different.

Ⅳ. Result and Discussion

1. Hydrological Performances of LID Practices

Hydrological performances of the three LID development scenarios were simulated based on the uniform storm event. The annual rainfall of Incheon in 2018 was 1,134mm. The results show the runoff/infiltration depth, as well as peak flow rate and time, and annual loadings for three circumstances ('pre-development,' 'development without LID,' and 'development with LID'). Study area slope was determined by adopting the average slope, which was about 11.3%. Considering that there were no developments in the study area, runoff and infiltration depths were 280.0mm/yr and 364.6mm/yr, respectively (see <Table 4>). In current condition (development without LID), the runoff depths of each scenario were fairly different. Scenario 3 had the most amount of runoff and Scenario 1 produced the least runoff depth. Even though the runoff depths for each scenario were different, infiltration, peak flow and time to peak were same with the values of 140.9mm/yr, 8.14m^3/sec. and 0.68 minute, respectively.

With the application of LID practices, Scenario 1, which applied the most numbers of LID technologies, had

Table 4 _ Hydrological Characteristics of the Three Designed Scenarios

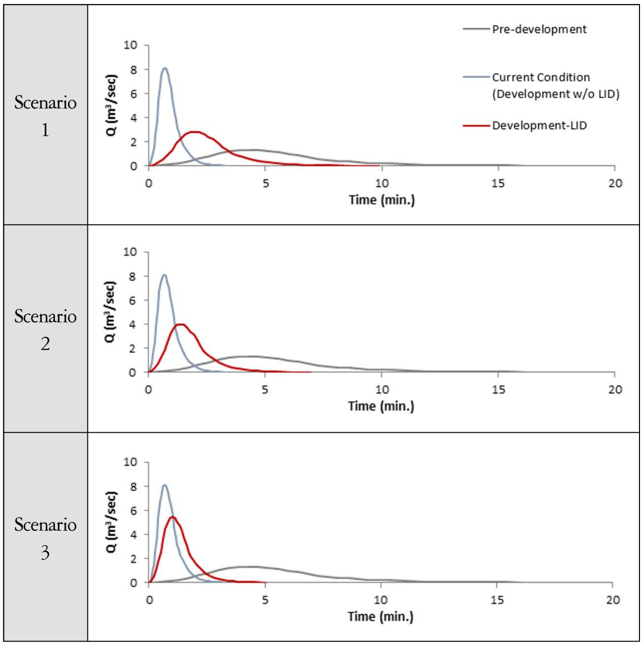
Circumstance	Scenario 1	Scenario 2	Scenario 3
Runoff Depth (mm/year)			
Pre-development	280		
Development without LID	610.62	798.11	869.98
Development with LID	389.64	570.81	744.15
Infiltration Depth (mm/year)			
Pre-development	364.57		
Development without LID	140.87		
Development with LID	604.19	421.81	267.33
Peak Flow (m^3/second)			
Pre-development	1.29		
Development without LID	8.14		
Development with LID	2.80	3.98	5.46
Time to Peak (minute)			
Pre-development	4.30		
Development without LID	0.68		
Development with LID	1.97	1.39	1.01

the largest impact on reducing runoff depth (−36.2%) and increasing infiltration depth (329.9%). The peak flow was also diminished significantly from 8.14 to 2.80m^3/sec., while the peak time was delayed for about 1.29 minute.

The peak flow was also diminished significantly from 8.14 to 2.80m^3/sec., while the peak time was delayed for about 1.29 minute. Even though the reduction impact was relatively lower than Scenario 1, the overall runoff depth and peakflow rate of Scenario 2 declined by about 28.5% and 51.1%, respectively, while the infiltration depth and time to peak increased by approximately 199.4% and 0.71 minute. The overall reduction effect of Scenario 3 was relatively low compared to other scenarios as the LID technologies were partially installed within the study site. Runoff depth decreased by only about 14.5% and the infiltration depth increased by 89.8%. While peak flow reduced by more than 2.68m^3/sec, peak time was delayed for only about 20 seconds. <Figure 4> compares the unit hydrograph for three scenarios.

Considering that the study site's pre-development runoff depth was 280mm/year, Scenario 1's runoff increased only about 110mm/year, while the two other scenarios' runoff exceeded more than two times the pre-development condition. Despite the fact that a significant portion of LID practices were planned in Scenario 1, the results demonstrate that the potential impact of LID techniques are fairly high and they can be a suitable option to replace the traditional

Figure 4 _ Unit Hydrograph for Each Scenario



drainage systems (Ahiablame and Engel 2012; Martin-Mikle, Beurs, Julian and Mayer 2015). Typical low-rise residential complexes in South Korea lack green areas, with a majority of the space covered by impervious surfaces and surrounded by multiple small alleys. This physical feature had eventually promoted more inundations during the heavy rainfall due to the reverse flow from the traditional sewer system. Locations like the study site, where the old low-rise residential blocks are clustered, will be particularly appropriate to employ LID practices not only to have beneficial effect on the environmental side, but also on the economic (e.g., saving sewer infrastructure budget) and social sides (e.g., improving overall landscape without a massive re-development) (Li, Deng, Li and Li et al. 2017). Further, many regeneration projects are currently implemented in South Korea to revitalize the old neighborhoods without demolishing the previous structures entirely. Because the present sewer pipeline infrastructures are insufficient to control stormwater runoffs and spaces are limited for large-scale drainage pumps and facilities' placement, LIDs can fit properly in these types of communities with the deployment of relatively small spaces while maintaining the neighborhood's own identity.

2. Storage Capacity of Each LID Practice

Storage volume for each LID practice was computed by using the coefficient of BMPs in order to compare the efficiency of LID types. Since vegetated facilities and retention facilities generally had a high unit storage volume, reduction widths were not so significant compared to the infiltration facilities when its size shrunk in different scenarios (see <Table 5>).

While the size of typical infiltration facility, such as porous pavement, was relatively larger than other practices in Scenarios 2 and 3, the storage volume was substantially low. Particularly, the size of porous pavements was about 10 times larger than tree box filters, but the storage capacity had no significant difference. Infiltration chambers also had low unit storage volume compared to other practices. This finding indicates that infiltration facilities are likely to be inefficient in capturing runoff flows, and thus, suggests that retention and vegetated facilities-centered

Table 5 _ LID Storage Volume in Each Scenario

Scenario	LID Type	Practice	Size (m^2)	Storage Volume (m^3)
Scenario 1	Vegetated Facility	Rain Garden	380.0	240.2
	Retention Facility	Bioretention	459.5	290.4
	Infiltration Facility	Porous Pavement	12,013.1	768.8
		Infiltration Chamber	2,135.0	469.7
Scenario 2	Vegetated Facility	Rain Garden	250.0	158
	Retention Facility	Bioretention	165.1	104.3
	Infiltration Facility	Porous Pavement	4,398.4	281.5
		Infiltration Chamber	1,450.0	319.0
Scenario 3	Vegetated Facility	Tree Box Filter	200.0	126.4
	Infiltration Facility	Porous Pavement	2,156.9	138.0
		Infiltration Chamber	558.0	122.8

Note: Coefficient by LID Practices
1) Bioretention and tree box filter: 0.632 m^3/m^2
2) Porous pavement: 0.064 m^3/m^2
3) Infiltration chamber: 0.220 m^3/m^2

installation should be mainly conducted with the infiltration facilities locating in a proper place.

3. Cost Efficiency of LID Practices

The cost efficiency of LID practices was investigated by comparing the cost of conventional sewer system with LID techniques implemented in each scenario. Regarding the costs for LID practices, each scenario's capital costs were calculated based on the size of the LIDs (see <Table 6>). Given that the costing tool showed the 2010-dollar value for the pricing, an inflation rate of 11.32% was employed to change it into a 2018-dollar value.

Table 6_ Capital Costs of Implemented LID Practices

Scenario	LID practice	Size(m^2)	Capital Cost($)
Scenario 1	Rain Garden	380.0	8,206.6
	Bioretention	459.5	21,303.7
	Porous Pavement	12,013.1	1,097,901.3
	Infiltration Chamber	2,135.0	136,558.4
	Total Cost		1,263,970.0
Scenario 2	Rain Garden	250.0	7,467.4
	Bioretention	165.1	15,661.1
	Porous Pavement	4,398.4	431,663.0
	Infiltration Chamber	1,450.0	95,713.3
	Total Cost		550,504.9
Scenario 3	Tree Box Filter	200.0	18,034.5
	Porous Pavement	2,156.9	234,750.0
	Infiltration Chamber	558.0	45,257.1
	Total Cost		298,041.6

Among LID practices, porous pavement had the highest unit(m^2) cost, followed by tree box filter, infiltration chamber, and bioretention. Rain garden relatively had a lower construction fee compared to other techniques. While Scenario 1 had the highest LID costs with $1,263,970, the total cost of Scenario 2 was only 43.5% of Scenario 1, albeit there was only an 8% difference in runoff reduction efficiency between both scenarios. This evidence demonstrates that the strategic installment of LID practices can be a better approach in the cost effect perspective rather than covering the entire area with LID controls. The number of LID techniques included in Scenario 3 was relatively small and the total capital cost was about $298,041, which was more than two times smaller than Scenario 2.

A construction cost (per 1-meter) of 600mm-diameter sewer pipe was different based on the pipe materials and by the following order: steel, plastic, concrete, and cast iron (see <Table 7>). The overall installment price included the construction fee, as well as the basic design, construction document, and supervision expenses.

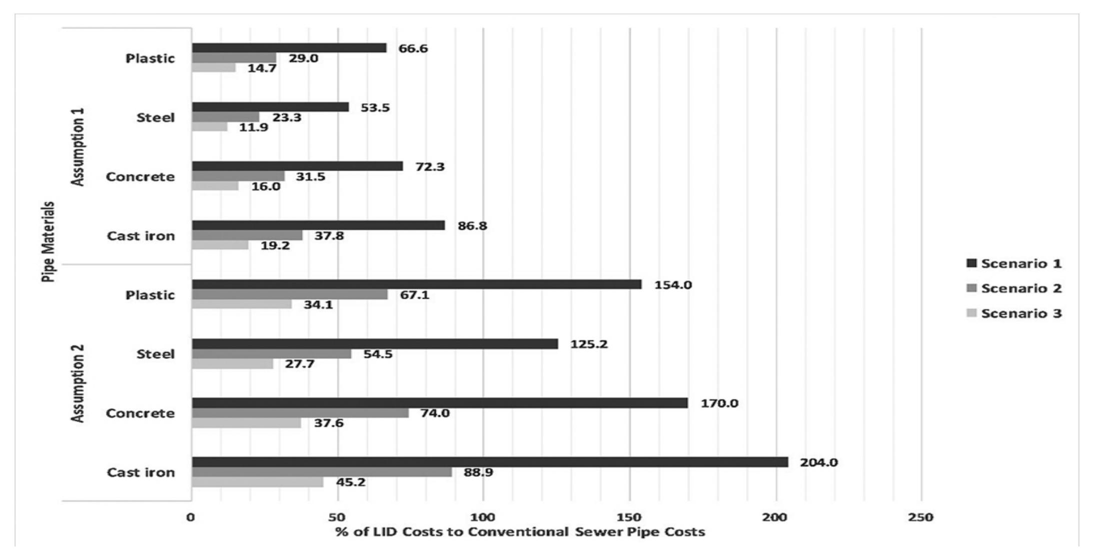
Table 7_ Overall Construction Costs for Sewer Pipe in Each Assumption

Pipe material	Overall Construction Cost($)	
	Assumption 1	Assumption 2
Cast Iron	1,456,101.9	619,504.8
Concrete	1,748,075.8	743,726.3
Steel	2,361,262.6	1,009,323.1
Plastic	1,899,185.5	820,586.7

In Assumption 1, the costs of replacing all the existing pipe with steel was about $2.3 million, while cast iron took only 62% ($1.45 million) of its cost. The length of sewer pipes under the 600mm-diameter was 707.2m. Replacement fees for these pipelines (Assumption 2) ranged from $0.6 to 1 million, depending on the materials.

<Figure 5> illustrates the percentage of LID costs

Figure 5 _ Proportion of LID Costs to Conventional Sewer Pipe Costs



to conventional sewer pipe costs for three different scenarios. In Assumption 1 (replacement of entire sewer pipelines within the study area), all scenarios' LID costs were lower than the pipe replacement costs. Particularly, LID costs were only 11.9~86.8% of pipe prices, with respect to the scenarios. Cast iron, the most commonly adopted pipe material in South Korea, had the cheapest price, with the costs of LIDs being even lower than their pipe costs by about 13.4% in Scenario 1. However, when the LID costs were compared with partially replacing pipe costs (Assumption 2), their costs in Scenario 1 were more expensive than with the pipeline replacement, no matter what the materials were. Except in the Scenario 1 case, the two other scenarios' LID construction costs were relatively lower than the sewer pipeline costs, ranging from 27.7% to 88.9%. In sum, the establishment of LIDs was financially effective compared to the pipeline replacement, except in a very conservative development case (Scenario 1 in Assumption 2). Particularly, Scenarios 2 and 3 were cost-effective in all assumptions. Considering the runoff reduction effects of LID scenarios, there were only 7.7% runoff depth difference between Scenarios 1 and 2, whereas the costs difference was about $713,465 (56%); that is, Scenario 2 can be more cost-effective in terms of runoff attenuation. A combination approach to conventional drainage systems and LID measures is necessary because one may not solely rely on LID practices in controlling the stormwater runoff; thus, Scenario 2 can be a practical approach in reality compared to Scenario 1. To fully address the cost-effectiveness of LID practices, life-cycle costs should be examined in future research. The findings from previous literatures revealed that the maintenance charges for LID practices are substantially low for long-term compared to fully re-constructing the whole pipeline infrastructure (Joksimovic and Alam 2014; Lee, Kim, Pak and Jang et al. 2010). From this view, LID measures can rise as a sustainable alternative in mitigating future flood damage.

V. Conclusions

This study simulated the hydrologic performance of the three LID designed scenarios under an identical storm event using the LIDMOD3 in a flood prone area, the Ship-jung district in Incheon, South Korea. While the runoff reduction effect was fairly different in each scenario, LID installments attenuated stormwater runoff volume from 14% to 36% and increased infiltration depth by 90-329% in comparison with conditions prior to the LID. This result corresponds with the previous simulation studies, which demonstrated that the LID controls typically have a reduction effect by about 30%, even though the degrees and levels of LID practice were dissimilar in each case (Ahiablame and Engel 2012). With consideration to construction costs, a blend drainage system that combines both traditional pipeline infrastructures and LID measures should be constructed to more effectively manage the stormwater runoff. As Scenario 1 was revealed to have inefficiency in reducing the runoff compared to the costs invested for the construction, local planners and decision-makers should identify appropriate places where LID practices can function the most rather than adopting all areas using LID techniques. Albeit this study considered the slope and other geographical features of a site to install appropriate LID measures where floods could be controlled the most, future research should further conduct spatial analyses (i.e., location analysis), in order to identify optimal sizes and places for each distinct LID practice.

One of the major concepts that the Korea ME is currently promoting for sustainable urban flood management is “Smart Water City.” The government is pursuing to upgrade the conventional sewer systems using various flood-resilient measures, such as up-to-date hard engineering approaches, LID techniques, and environmental land use policies. Until now, the pilot projects have been mostly given to new towns and cities, where there were no initial land uses, buildings, and infrastructures. Of course, LID practices may better perform and be well managed in a new planned city. However, existing cities are getting old and rapid industrialization during the 1960-70s in South Korea made various disruptive asphalts and concretes with a massive amount of impervious surface in the inner city. This eventually limited green spaces in the city center. Inland Incheon, the 2nd highest impervious surface ratio city in South Korea, is experiencing significant damages from stormwater runoff and losing valuable ecosystem functions due to the conventional urban settings. LID approaches can be more appropriate in these hard-engineered infrastructure–based cities by providing aesthetically pleasing places and enhancing the overall urban ecosystems. The study results, thus, may provide valuable insights to local decision-makers whilst redeveloping the old inner city and may successfully link these LID practices with the current urban regeneration projects for achieving sustainable urban water/stormwater management systems in the long-term.

Although this study provides several noteworthy insights in demonstrating the potential reduction effects of various LID practices, some limitations need to be acknowledged. First, calibration for the flow modeling could not be conducted since there were no available monitoring data. By adopting monitoring devices at the site, calibration should be checked in future studies to increase the reliability, as well as the validity, of research. Second, the study area of this research was focused on a specific plot in order to clearly identify the effects of LID practices within a residential-centered area. For a more accurate investigation of runoff reduction, further research is suggested in simulating the model at the watershed-level; thus, it may better estimate the generated runoff with the consideration of various hydrological and geographical features that may impact on final outlet. Third, this study may not fully consider various designed storms in estimating the produced runoff. With the actual past precipitation data, diverse designed storms as well as rainfall characteristics (e.g., heavy/average/limited water year) should be applied and classified for further study to predict the runoff in multiple meteorological conditions. Fourth, green roofs have not been applied during the simulation due to the current conditions of housings within the study site. Since the runoff reduction effect of green roofs has been proven effective in many previous literatures, further research is needed to better understand the influence of green roofs on attenuating stormwater runoff. Fifth, albeit this study applied a LID modeling tool in an attempt to discover the stormwater reduction, further study should focus more closely on the diverse water quality aspects with the usage of other simulation tools in order to discover more positive impacts and cost-efficiency in implementing LID practices. Finally, LIDMOD3 was widely adopted for the runoff estimation, but its usage is still limited to Korea. The benefit of this tool, which allows simple operation for users, was lacking in terms of considering the complex hydrological factors while running the simulation. Thus, further research is in need to expand this approach with the employment of other verified LID modeling tools (i.e., SWMM-LID) that may fully consider the complexity of urban drainage system and other geographical factors. In addition, modeling approaches that may consider the runoff efficacy of both LID controls and traditional drainage systems should be developed in the near future for a better estimation.

참고문헌

1. Ahiablame, L. M. and Engel, B. A. 2012. Effectiveness of low impact development practices: Literature review and suggestions for future research. *Water Air and Soil Pollution* 223, no.7: 4253-4273.
2. Benedict, M. A. and McMahon, E. T. 2006. *Green Infrastructure: Linking landscapes and communities*. 2nd ed. Washington, D.C.: Island Press.
3. Chan, F., Griffiths, J., Higgitt, D., Xu, S., Zhu, F., Tang, Y. T., Xu, Y. and Thorne, C. 2018. "Sponge City" in China-A breakthrough of planning and flood risk management in the urban context. *Land Use Policy* 76: 772-779.
4. Choi Jiyoung and Shin Changmin. 2002. *Management of Nonpoint Pollution by Reducing Storm Runoff.* Seoul: Korea Environment Institute.
5. Cronshey, R. G., Roberts, R. T. and Miller, N. 1986. Urban hydrology for small watersheds (TR-55 REV.). *American Society of Civil Engineers* 55: 1268-1273.
6. Gao, J., Wang, R., Hunag, J. and Liu, M. 2015. Application of BMP to urban runoff control using SUSTAIN model: Case study in an industrial area. *Ecological Modelling* 318: 177-183.
7. IPCC. 2007. *Climate Change 2007: The physical science basis*. Cambridge: Cambridge University Press.
8. Jang Yeongsun, Mun Sungho and Yang Sunglin. 2013. An

analysis of flood mitigation effect applying to LID in Mokgamcheon watershed using SWMM model. *International Journal Highway Engineering* 15, no.3: 75-83.

9. Jeon Sangmi, Park Jaehyeon and Lee Sangho. 2013. Analysis of flood reduction effect using decentralized rainwater retention facility in urban area. *Crisisonomy* 9, no.12: 79-96.
10. Jeon Jihong, Park Sangsun, Park Changi and Kim Taedong. 2014. Evaluating implementation of EPA SUSTAIN model for cost-effective LID design. *Journal of the Korean Society of Urban Environment* 14, no.2: 135-143.
11. Jeon Jihong, Yoon Yeongjun, Lee Suenghyeon, Cho Suhyeon and Kwon Taeyong. 2015. Analysis of reducing nonpoint source pollution by Low Impact Development (LID) application at Andong City Hall. In Proceedings of *2015 Joint Conference of Korean Society of Water & Wastewater–Korean Society on Water Environment*. August 27-28, Goyang: Kintex.
12. Jeon Jihong and Seo Sungchul. 2018. LIDMOD3 development for design and evaluation of low impact development. *Journal of Korean Society on Water Environment* 34, no.4: 383-391.
13. Jeon Jinhong and Jung Kwangwook. 2019. The effect of infiltration rate of foundation ground under the bioretention on the runoff reduction efficiency. *Journal of Korean Society on Water Environment* 35, no.1: 72-77.
14. Joksimovic, D. and Alam, Z. 2014. Cost efficiency of low impact development (LID) stormwater management practices. *Procedia Engineer* 89: 734-741.
15. Kang Jungeun, Lee Myeongjin, Koo Yusung, Cho Kwangwoo and Lee Jaewook. 2011. *Urban Renewal Strategy for Adapting to Climate Change: Use of green infrastructure on flood mitigation.* Seoul: Korea Environment Institute.
16. Kim Hyunwoo and Li, Ming-Han. 2016. Sustainable stormwater management: Examining the role planning capacity in mitigating peak surface runoff. *Sustainability* 8, no.9: 763.
17. Kim Jungjin, Kim Taedong, Choi Donghyuk and Jeon Jihong. 2011. Design of structural BMPs for Low Impact Development (LID) application and modeling its effect on reduction of runoff and nonpoint source pollution: Application of LIDMOD2. *Journal of Korean Society on Water Quality* 27, no.5: 580-586.
18. Kim Sungwoo and Park Kyungmoon. 2017. *Improvement Plan on the Environmental Competitiveness for Sustainable Water Circulation in Incheon.* Incheon: Incheon Institute.
19. Korea Land and Housing Institute. 2015. *Environmental Technology Development Project Annual Report*. Daejeon: Korea Land and Housung Institute. http://webcache.googleusercontent.com/search?q=cache:_SDqih6A10J:lhi.lh.or.kr/common/include/file_download.asp%3Fcategory%3Dmemberdata%26idx%3D341+&cd=1&hl=en&ct=clnk&gl=kr (accessed March 11, 2019).
20. KMA Open Weather Data Portal. Precipitation Analysis. https://data.kma.go.kr/stcs/grnd/grndRnList.do?pgmNo=69 (accessed January 13, 2019).
21. Lee Jeongho. 2013. Cause and countermeasure of inundation damage. *The Magazine of the Korean Society of Hazard Mitigation* 13, no.1: 43-51.
22. Lee, K., Kim, H., Pak, G., Jang, S., Kim, L., Yoo, C. and Yun, Z. et al. 2010. Cost-effectiveness analysis of stormwater best management practices (BMPs) in urban watersheds. *Desalination and Water Treatment* 19: 92-96.
23. Lee Sangeun, Kim Changhun, Park Taesun, Kim Mieun, Kim Seulye, Lee Taesam and Kim Jinhyun. 2016. *Development of the Urban Flooding Risk Prevention System(I)*. Anyang: Korea Research Institute for Human Settlements.
24. Li, J., Deng, C., Li, Y., Li, Y. and Song, J. 2017. Comprehensive benefit evaluation system for low-impact development of urban stormwater management measures. *Water Resources Management* 31, no.15: 4745-4758.
25. Liu, Y., Bralts, V. F. and Engel, B. A. 2015. Evaluating the effectiveness of management practices on hydrology and water quality at watershed scale with a rainfall-runoff model. *Science of the Total Environment* 511: 298-308.
26. Luan, Q., Fu, X., Song, C., Wang, H., Liu, J. and Wang, Y. 2017. Runoff effect evaluation of LID through SWMM in typical mountainous, low-lying urban areas: A case study in China. *Water* 9, no.6: 439.
27. Martin-Mikle, C., Beurs, K., Julian, J. and Mayer, P. 2015. Identifying priority sites for low impact development in a mixed-used watershed. *Landscape and Urban Planning* 140: 29-41.
28. Ministry of Environment(ME). 2013. *Application Manual of Low Impact Development (LID) Method for Environmental Impact Assessment*. Seoul: Ministry of Environment.

29. _____. 2018. *Subsidy Compilation and Execution Management Guideline for Sewer System*. Sejong: Ministry of Environment. http:// www.me.go.kr/home /web/index.do?menuId=65 (accessed January 14, 2019).

30. Nam Chilho, Kim Mieun, Kim Jaemoon, Kim Byungsung and Shin Hyunsuk. 2017. A study on urban stormwater reduction effectiveness based on SUSTAIN and SWMM model. In Proceedings of *Korean Society of Civil Engineers 2017 Convention.* October 18-20, Busan: Bexco.

31. National Institute of Environmental Research. 2019. Individual communication. raw data.

32. Park Junho, Yoo Younggu, Park Youngkon, Yoon Heetaek, Kim Jonggun, Park Younshik and Jeon Jihong et al. 2008. Analysis of runoff reduction with LID adoption using the SWMM. *Journal of Korean Society on Water Quality* 24, no.6: 806-816.

33. Prince George's County. 1999. *Low-impact Development Design Strategies: An integrated design approach; Department of environmental resources*. Prince George's County, MD: Programs and Planning Division.

34. Roehr, D. and Kong, Y. 2010. Runoff reduction effects of green roofs in Vancouver, BC, Kelowna, BC, and Shanghai, P.R. China. *Canadian Water Resources Journal* 35, no.1: 53-67.

35. Rosa, D., Clausen, J. and Dietz, M. 2015. Calibration and verification of SWMM for low impact development. *Journal of the American Water Resources Association* 51, no.3: 746-757.

36. Rossman, L. A. 2010. *Storm Water Management Model User's Manual Version 5.0*. Cincinnati, OH: U.S. Environmental Protection Agency.

37. Suh Joohwan and Lee Inkyu. 2013. The water circulation improvement of apartment complex by applying LID technologies: Focused on the application of infiltration facilities. *Journal of the Korean Institute of Landscape Architecture* 41, no.5: 68-77.

38. Tetra Tech, Inc. 2005. Mecklenburg county site evaluation tool-user's manual and guidance. Pasadena, CA: Tetra Tech, Inc. https://mecklenburgcounty.exavault.com/p/waterquality /SET2005/Meck%20Co% 20SET%20%20-%20Model%20 Documentation%20-%20draft%2003-23-05%20v7.pdf (accessed December 12, 2018).

39. Toronto and Region Conservation Authority and University of Toronto. 2013. LID practices costing tool. https://sustainabletechnologies.ca/home/urban-runoff-green-infrastructure/low-impact-development/low-impact-development-life-cycle-costs/ (accessed January 10, 2019).

40. United States Environmental Protection Agency(USEPA). 2018. Urban runoff: Low impact development. https://www.epa.gov/nps/urban-runoff-low-impact-development (accessed January 14, 2019).

41. United States Department of Housing and Urban Development (USHUD). 2003. *The Practice of Low Impact Development*. Upper Marlboro, MD: NAHB Research Center Inc. https://www.huduser.gov/portal/publications/practLow ImpctDevel.pdf (accessed January 14, 2019).

42. University of Arkansas Community Design Center(UACDC). 2010. *Low Impact Development: A design for urban areas.* Fayetteville, USA: University of Arkansas Press.

43. Woo Wonhee, Ryu Jichul, Moon Jongpill, Jang Chunhwa, Kum Donghyuk, Kang Hyunwoo and Kim Kisung et al. 2012. Development of coupled SWAT-SWMM to evaluation effects of LID on flow reduction in Complex landuse. *Journal Korean Society on Water Environment* 28, no.4: 495-504.

- 논문 접수일: 2019. 6. 17.
- 심사 시작일: 2019. 7. 3.
- 심사 완료일: 2019. 9. 9.

요약

주제어: 우수유출수, 저영향개발, 그린인프라, LIDMOD3, 홍수, 인천

불투수층의 증가 및 기후변화로 인한 빈번한 집중강우의 발생은 도시 내 홍수피해를 지속적으로 증가시키고 있다. 전통적인 배수시스템은 우수유출수를 조절하는 데 효과적이지만, 우수관리에만 초점을 두기에 건설비용과 성능적인 측면을 고려했을 때 비효율적이라 할 수 있다. 저영향개발(LID) 기법은 다양한 혜택을 제공하는 종합적인 물관리기법으로, 지속가능한 우수관리 실천을 위해 현재 많은 국가에서 이를 도입하고 있다. 본 논문은 LIDMOD3 모델링 툴을 활용하여 LID기법의 수문학적 성능을 세 가지 시나리오에 모의 적용하여 분석하였다. 또한, LID기법의 비용 효과를 하수도 기반시설 설치비용과의 비교를 통해 분석하였다. 연구대상지는 인천시 부평구의 상습침수구역인 십정동 일대이다. 연구결과, 대상지의 유출량은 LID를 설치하지 않았을 경우와 비교하여 약 14~36% 감소하였고, 첨두유출량은 약 33~66% 줄어들었다. 비점오염물질의 경우 각 시나리오에 따라 약 15~36% 감소한 것을 발견하였다. 건설비용을 고려했을 때, 전 지역에 LID를 설치하는 것보다는 일부 지역에 부분적으로 설치하면서 하수도 기반시설을 함께 융합하여 개발하는 것이 효과적이라고 나타났다. 본 논문은 정부기관 및 지자체가 지속가능한 우수관리 계획의 일환이자 향후 도시재생사업과도 연계한 체계적인 물관리 방안으로서 더욱 효과적인 LID 도입을 모색하기 위한 정책대안을 제공한다.