

Increasing Urban Resiliency by Examining the Flood Mitigation Effect of LID Practices in Urban Regeneration Project Areas

Jin Hee Lee[#], Hyun Woo Kim⁺

Department of Urban Policy and Administration, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon, Korea

Abstract

Urban flooding occurs more frequently these days due to the increase of abnormal rainfall. A number of old city centers in South Korea have been participating in the urban regeneration project to improve their competitiveness, and low impact development (LID) practices have been used as one of the crucial measures to secure urban resilience and sustainability. By employing the LIDMOD3 simulation tool, this study examines and compares the runoff reduction effect of LID practices across different scenarios. Two existing urban regeneration project areas in Incheon were chosen as the study area, including 'Bupyeong 11th Avenue' in Bupyeong-gu and 'Village of Empathy' in Jung-gu. The results show that the annual runoff depth reduced by 39–64% and the infiltration depth increased by 252–423% in Bupyeong-gu, depending on each scenario. The runoff depth also diminished in Jung-gu by 41–69% and the infiltration depth escalated by 268–457%, varying by scenario. This study has significance by identifying the appropriate types and locations of various LID measures, in linkage with the actual regeneration projects. The findings of this study can provide a practical guideline for local governments in establishing long-term policy alternatives for flood mitigation using LID practices during the development of an urban revitalization plan.

Key words: flooding, low impact development; green infrastructure, urban regeneration, LIDMOD3, resilience

1. Introduction

The rapid increase of impervious surfaces in urban areas induced serious environmental issues, such as flooding, water quality degradation, and groundwater depletion (Jennings & Jarnagin, 2002; Makepeace, *et. al.*, 1995). Damages by these problems have been exacerbated due

to the recent climate change.

Enhancing urban resiliency thus become more important and low impact development(LID) practices are receiving attentions as a significant alternative. The overall goal of LID is to reserve permeable aquifer as much as possible within an urban space and mimic the hydrological cycle of a site as pre-development conditions(Dietz, 2007;

[#] The 1st author: Jin Hee Lee, Tel. +82-32-835-4418, Fax. +82-32-835-0796, e-mail. leejh610@inu.ac.kr

⁺ Corresponding author: Hyun Woo Kim, Tel. +82-32-835-8874, e-mail. kimhw@inu.ac.kr

McDonald, *et al.*, 2005). While traditional drainage systems focused on expanding sewer pipelines to mitigate urban flooding, it has a huge limitation when controlling the non-point source(NPS) pollutants as well as heavy torrential rainfalls, which often occurs in South Korea. Since the role of conventional pipelines is still very crucial in managing urban stormwater, we may need a comprehensive flood mitigation alternatives that may combine both traditional sewer systems and LID measures.

While constructing LID approaches, various conditions such as users, site conditions, and land-use planning are considered. They can be established by combining diverse facilities with different types(e.g., vegetation, infiltration, and retention), which allows to have less physical limitations in developing current urban spaces(Choi *et al.*, 2010). That is, LID practices can be readily placed in old city center areas, where urban infrastructures are falling behind and have a high vulnerability of floods. Since a number of urban regeneration projects are recently occurring within old city center areas in South Korea, LID practices should be adopted by linking with these projects.

Kim & Kim(2019) identified that more than 90% of citizens agreed to adopt LID measures after understanding their functions and effects through the education process. They have recognized that the overall city environments can be improved by adopting diverse LID approaches. Particularly, vegetation LIDs had a high satisfaction from individuals, which increased the landscape view as well as aesthetic gratification(Choi, *et al.*, 2017). In sum, LID practices may not only have a significant impact on preventing disasters, but also improve the entire atmosphere of a typical space. These effects correspond with the key goals of urban regeneration, and thus, LID can be a suitable implementing measures while conducting future urban regeneration projects.

Until now, however, urban regeneration and hazard mitigation alternatives in South Korea are not sufficiently tied together, which cause a vicious cycle that a damaged area from natural disasters become a backward region and eventually turn into a damaged area once again(Han, *et al.*, 2018). That is, urban safety issues can hinder the influx of residents and it may eventually cause the failure of urban regeneration. Cities like Incheon, where old and new towns coexist, tend to have higher risks to lose population in old city center. In this reason, two urban regeneration project areas('Bupyeong 11th Avenue'in Bupyeong-gu and'Village of Empathy'in Jung-gu) in Incheon that are currently receiving the national urban regeneration funds from the Korea Ministry of Land, Infrastructure, Transport(MLIT) were chosen for the study area. To secure the competitiveness of old city center, Incheon has chosen three different types(economic-based, central district, and neighborhood-based programs) of urban revitalization areas¹⁾. However, two study areas that are selected for this study are currently located inside or adjacent to flood-prone areas. This study attempts to enhance resiliency and sustainability of urban regeneration sites by employing various LID measures. Specifically, we have estimated runoffs generated by different LID scenarios using the runoff simulation tool(LIDMOD3) and discussed the effective policy alternatives to mitigate future flooding in urban regeneration project sites.

While adopting various types of LID practices, it is important to evenly distribute different LID measures in multiple places with the consideration of local characteristics (Jeon & Seo, 2018). Several studies have proved the positive effectiveness of LIDs on minimizing stormwater runoff (Jeon, *et al.*, 2014; Kim & Park, 2016). Diverse simulation tools, such as System for Urban Stormwater Treatment and Analysis Integration(SUSTAIN; Jeon, *et al.*, 2014),

1) Incheon Metropolitan City(2016), 2025 Incheon Urban Regeneration Strategic Plan

Table 1. Previous LID simulation research

Studies	Study area	Simulation tool	LID types	Results
Lee, <i>et. al.</i> (2011)	Asan Tangjeong new city	SWMM	Mulden regolen, Bioretention, etc.,	The effect of LID was not clear in the new city plan with relatively large green areas, but it was effective in improving water circulation.
Yeon, <i>et. al.</i> (2014)	Busan BEXCO watershed		Green roof, Porous pavement	The effect of LID was directly proportional to the applied area and the permeable pavement showed a higher reduction effect.
Woo, <i>et. al.</i> (2012)	Hongcheon river watershed		Green roof, Porous pavement	The runoff reduction effect of 30.05% is effectively derived when both of them are applied.
Shin, <i>et. al.</i> (2013)	Busan Suyeong river Downstream		Green roof, Porous pavement	The runoff rate is reduced by 15.62% and 13.01% than before LID application
Jeong, <i>et. al.</i> (2018)	Daejeon LHI		Rain barrel, Infiltration trench, Bioretention, etc.	Infiltration rate increased by 11.2% and runoff rate decreased by 12.5% compared to before LID application.
Jeon, <i>et. al.</i> (2014)	Andong bus terminal	SUSTAIN	Rain barrel, Infiltration trench, Bioretention, etc.,	The runoff reduction effect of 14 ~ 28% was derived according to the investment cost.
Choi, <i>et. al.</i> (2017)	Gyeongsangbuk-do office new city	SET	Bioretention, Porous pavement	Storage facilities like bioretention have greater hydrological effects than infiltration facilities.
Choi, <i>et. al.</i> (2010)	Cheongsong-gunYa ngpyeong-gun	LIDMOD2	Bioretention, Porous pavement, etc.	The runoff reduction was improved by 7.4% in Cheongsong and 17.4% in Yangpyeong.
Kang, <i>et. al.</i> (2017)	Sejong 6 district		Compact development, Road relocation, etc.	The runoff reduction rate decreased by 19%.
Kim, <i>et. al.</i> (2011)	Mohyeon developing area		Wetland, Wet pond, Bioretention	Bioretention area showed a high reduction effect of 41.43%.
Jeon & Seo (2018)	Seoul R apartment	LIDMOD3	Porous pavement, Bioretention	The runoff rate is reduced by 37% and the infiltration rate is increased by 64% than before LID application.
Jeon & Jeong (2019)	Andong city		Bioretention	It is found to be more effective when the soil grade is B grade or higher.

Site Evaluation Tool(SET; Choi, *et. al.*, 2017), Storm Water Management Model(SWMM; Jeong, *et. al.*, 2018; Lee, *et. al.*, 2011; Shin, *et. al.*, 2013; Woo, *et. al.*, 2012; Yeon, *et. al.*, 2014), LIDMOD2(Choi, *et. al.*, 2010; Kang, *et. al.*, 2017; Kim, *et. al.*, 2011), and LIDMOD3(Jeon & Seo, 2018; Jeon & Jeong, 2019) have been employed to estimate the hydrological effect of LID measures.

<Table 1> summarizes the recent LID studies that have examined the runoff reduction effect by using multiple modelling programs. After reviewing the previous studies, we found that only Choi *et. al.*(2010) have examined the hydrological change of LID practices, linking with the urban regeneration project. However, the effect of LID measures were estimated only in waterfront areas, where it will be impacted after the four major river refurbishment project. To fill the gaps from previous research, this study selected the study area in old city centers, where the sites have high vulnerability in urban flooding. The findings of this

study will identify the benefits of LID practices in both disaster prevention and urban aesthetic aspects. Policy suggestions will be made to effectively implement and link LIDs with the existing urban revitalization projects in Korea.

II. Study Methods

1. LIDMOD3

LIDMOD3, an excel-based runoff simulation program that is co-developed by the Korea National Institute of Environmental Research and Andong University, uses CN values and EMCs based on Korea land covers and previous

Table 2. Data information

Data	Source	Year
Land cover, Road	Korea Ministry of the Interior and Safety	2019
Soil drainage class	Korea Rural Development Administration	2005
Precipitation	Korea Meteorological Administration	2018
Slope	National Geographic Information	2015

study results. Since the LID retention storage is calculated by following the Korean Ministry of Environment guideline, the effects of LID practices can be more precisely simulated with this tool(Jeon & Seo, 2018). <Table 2> shows the spatial data, such as soil drainage class, land cover, daily precipitation, and slope, which were acquired from diverse sources to run the program.

2. Study Area

Study area was selected based on two main criteria. The site must be included in 1) flood prone areas that

are designated by City of Incheon and 2) located within the urban regeneration new deal project areas chosen by the national government. By using the 2017 flooded area location data of Incheon, we have first determined the potential areas prone to flood, and discovered areas that overlap with urban regeneration new deal project sites. <Figure 1> shows two sites('Bupyeong 11th Avenue' in Bupyeong-gu and 'Village of Empathy' in Jung-gu) that were finally selected for this study, where the flood risk is relatively high and located within the existing urban regeneration project area.

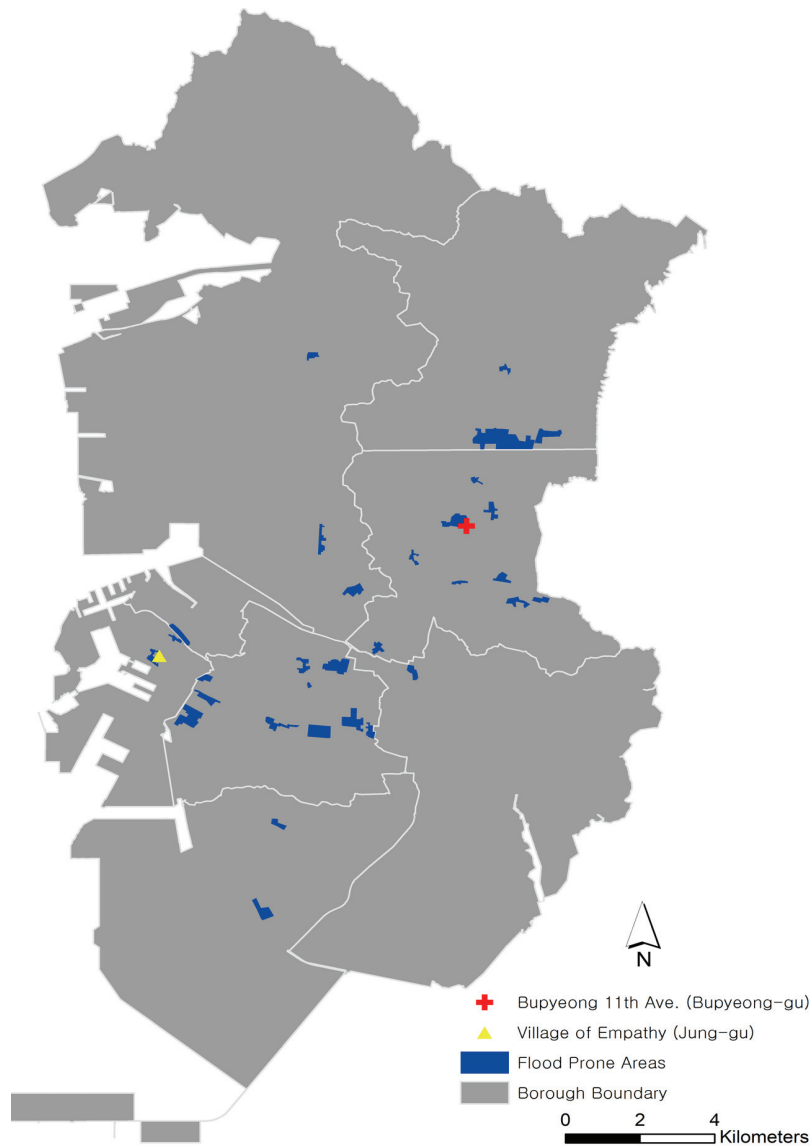


Figure 1. Study areas

1) Bupyeong-gu

The first study area is located in Bupyeong 11th Avenue urban regeneration new deal project site. This site is specifically chosen as a central district-type revitalization area and its main purpose is to establish innovative economic-bases and revive surrounding commercial sphere. Our study area(Bupyeong-1dong, PP: 59-25) is included in this regeneration site with its size of approximately 13,135.09 m². see <Figure 2>.

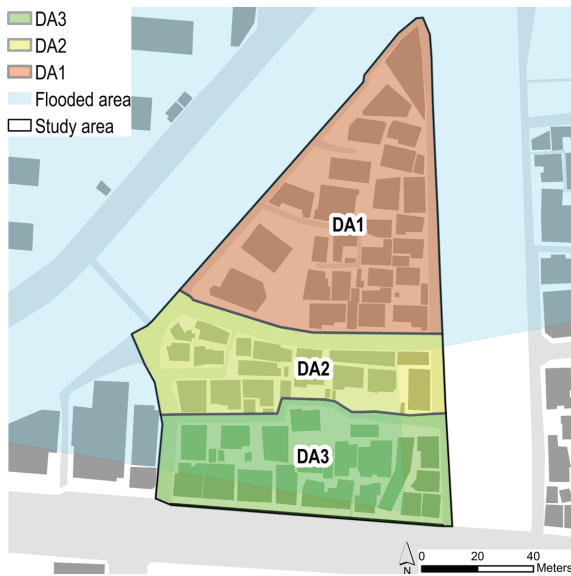


Figure 2. Study area in Bupyeong-gu

Currently, the study area is mostly developed with low-rise single-family housings(5,930.4 m²) and the roadsides that divide the district are quite congested due to the existence of large parking lots located in the east and west side of the site. Soil drainage condition is generally bad, whereas the overall slope is quite even. Permeable areas, such as barrens(21.95 m²) and lawns(31.01 m²), take only 0.41% of the overall study area. Drainage areas are divided into three sections by considering the study area’s slope. <Table 3> illustrates the detailed size of each land use <Figure 3> shows the typical view of site’s present condition.

Table 3. Land use and hydrologic soil group of the study area in Bupyeong-gu

Classification	Land Use	Drainage Area(m ² , %)
		Soil Group C
Pervious	Barren	21.95(0.17)
	Lawn	31.01(0.24)
Impervious	Rooftop	5,930.4(45.15)
	Driveway	2,495.79(19.0)
	Walkway	104.38(0.79)
	Playground	255.18(1.94)
	Others	4,296.38(32.71)
Total		13,135.09(100.0)



Figure 3. Present condition of the study site(Bupyeong-gu)

The study site is planned to be developed as a ‘nest village,’ according to the existing urban revitalization plan. To be specific, vacant/deserted buildings will be transferred into public rental buildings and restaurants, and housing redevelopments will be conducted mainly through the local residents’ agreement. Since the study area is located between the east side of public parking lot(where Gulpho-stream restoration occurs) and the

west side of public parking lot(where cultural art development project arises), there is a high chance that the pedestrian volume, as well as passing amount may significantly increase within the study site after the redevelopments. see <Figure 4>. Considering this fact, LID practices that may maximize the pedestrian environments should be adopted in this area.



※ Source: Bupyeong-gu Bupyeong 11th avenue revitalization plan of urban regeneration(2018: 20)

Figure 4. Bird's-eye view in Bupyeong-gu

2) Jung-gu

The second study site is situated in the ‘Village of Empathy’ urban revitalization project area in Jung-gu, Incheon. The project type is ‘residential and housing support,’ which emphasizes promoting autonomous resident organizations, strengthening inhabitants’ capabilities, and constructing healthy living environments. Our study site is near Dap-dong 19-39 and takes 21% of the entire regeneration project area, which is about 18,360.84 m². see <Figure 5>.

As similar to the first study area, this site was also developed mainly by old low-rise single family housings (7,663.7 m²) and the spacing between buildings were very

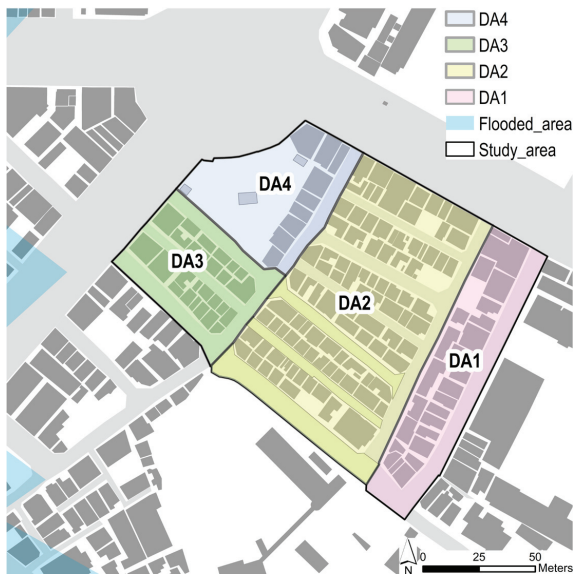


Figure 5. Study area in Jung-gu

narrow. Pervious surfaces existed as flower gardens(354 m²) in Dap-dong pocket park and some bare lands(111.7 m²) between housings. Bare lands were predominantly used as individual parking lots and small yards. Soil drainage conditions were generally poor, while the slope was flowing from the east to southwest side, which may exacerbate flood damages in adjacent communities. <Table 4> presents the size of each land use element and <Figure 6> shows the common environment of the study area.

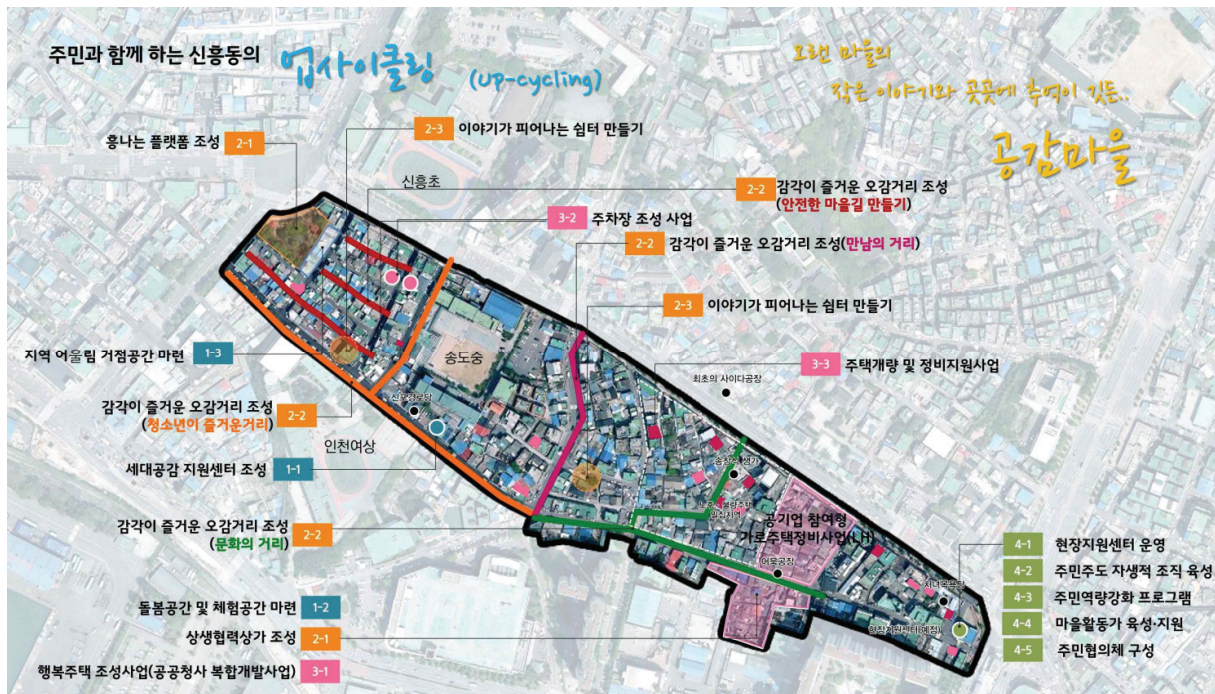
Table 4. Land use and hydrologic soil group of study area in Jung-gu

Classification	Land Use	Drainage Area(m ² , %)	
		Soil Group B	Soil Group C
Pervious	Barren	-	111.69(0.61)
	Lawn	-	370.50(2.02)
Impervious	Rooftop	137.55(0.75)	7,526.15 (40.99)
	Driveway	571.72(3.11)	5,212.79 (28.39)
	Walkway	-	782.60(4.26)
	Playground	-	1,101.30(6.0)
	Others	-	2,546.54 (13.87)
Total		18,360.84(100.0)	



Figure 6. Present condition of the study site(Jung-gu)

According to the existing regeneration plan(2019), the study site will establish ‘Enjoyable Street for Teenagers’ with the development of several public parking lots and shelters. see <Figure 7>. Because the main purpose of this project area is to increase the resident satisfaction on living environment, LID measures that could meet the inhabitants’



※ Source: Jung-gu village of empathy revitalization plan of urban regeneration(2019: 73)

Figure 7. Urban regeneration master plan in Jung-gu

demand on green spaces can be an appropriate development direction to fulfil the overall regeneration goal in this site. Moreover, LID approaches that could effectively catch the stormwater runoff are required to be installed in this place.

3. Scenario Development

Considering the urban regeneration projects in Bupyeong and Jung-gu that are in progress, three scenarios with different levels of LID practices have been developed per each district. LID elements that were adopted in this study were infiltration chamber, pervious pavement, rain garden, bioretention, and tree box filter, whereas the adopted sizes of LID measure were given differently by each scenario, in order to estimate the LID efficiency. While the size of infiltration chamber, porous pavement, and bioretention were given differently

by considering the local conditions, we have provided the uniform criteria for rain gardens and tree box filters. see <Table 5>.

1) Bupyeong-gu

Drainage areas(DA) for the nest village were divided by reflecting the study area's building uses and zoning. DA1(5,899.74 m²) has been assigned in the northern part of site(above the center road), where housing and small factories were mixed together. DA2 (3,347.02 m²) was allocated in the middle part of site, where housing-oriented developments occurred in the past. DA3(3,888.33 m²) is a densely commercialized area at the bottom of site.

Infiltration chambers, porous pavements, and rain gardens were basically applied in all DAs. Bioretentions and tree box filters were additionally installed in DA3 due to the existence of bare lands and tree-lined streets. Specifically, bare lands have been transferred into bioretentions to increase the aesthetical effect of nearby landscape. A rain garden has been established by following in line with the right

Table 5. LID practices adopted in each scenario

Practices	S1	S2	S3
Rain garden(width)	1m	0.8m	0.6m
Tree box filter(space)	3m	5m	7m

* The size of tree box filter is 1m × 1m.



Figure 8. LID practices for each scenario in Bupyeong-gu

side street(182.44 m) of the site. This is mainly because to alleviate the borderline between a stream and road and minimize rainfall runoffs that flow into the stream after the Gulpo stream restoration.

Scenario 1 applied the most number of LID practices, while Scenarios 2 focused on applying infiltration chambers within the single-family housing district and porous pavements on roads and walkways. Scenario 3 only employed infiltration chambers within the single-family housings of DA1 and 2 and installed pervious pavements in the left-side of roads and in the central road.

<Figure 8> shows the applied LIDs for each scenario and <Table 6> describes the size and ratio of constructed LID measures within the study area.

Table 6. LID practices adopted in each scenario (m²; %)

Practices	S1	S2	S3
Infiltration chamber	595 (4.53)	264 (2.01)	206 (1.57)
Porous pavement	2508.53 (19.1)	2015.89 (15.35)	1328.82 (10.12)
Rain garden	182.44 (1.39)	145.95 (1.11)	109.46 (0.83)
Bioretention	21.95 (0.17)	15 (0.11)	10 (0.08)
Tree box filter	30 (0.23)	18 (0.14)	12 (0.09)
Total	3,337.92 (25.41)	2,458.84 (18.72)	1,666.28 (12.69)

2) Jung-gu

Four drainage areas have been divided in this site based on the overall slope: DA1(3,589.39 m²) covers the right side of site from Songdo Middle School to adjacent road, which are mostly residential zone; DA2(8,946.92 m²) includes the areas from the street nearby Incheon Women’s Commercial High School to the housings densely located in the center; DA3(2,816.80 m²) involves the southern part of Dapdong minipark; and DA4(3,007.73 m²) embraces the northwest part of the site around Dapdong minipark.

While porous pavements were basically applied in all DAs, infiltration chambers and tree box filters were only installed in DAs 1-3. Since bare lands and some buildings in DAs 1 and 2 will be transferred into parking lots(203 m²) according the current plan, infiltration chambers were installed below the parking lots. Considering the inhabitants’ demand on green spaces, rain gardens were applied following the retaining walls near the Songdo Middle School and Incheon Women’s Commercial High School.

Similar to the Bupyeong’s case, the most number of LID approaches were established in Scenario 1. For Scenario 2, infiltration chambers and pervious pavements have been placed in the southern part of DAs 1 and 2, as well as in some buildings or roads in DA 3. In addition, only 50% of walkways(55.65 m²) within Dap-dong minipark were replaced into pervious pavements. Scenario 3, the least LIDs applied scenario, adopted infiltration chambers



Figure 9. LID practices for each scenario in Jung-gu

only below the buildings in the southwest part of study area. Porous pavements were partially installed in two central roads in the southern part and 30% of walkways within the park. <Figure 9> and <Table 7> shows the locations as well as the detailed size and ratio of LID practices applied in each scenario.

Table 7. LID practices adopted in each scenario (m²; %)

Practices	S1	S2	S3
Infiltration chamber	844.80 (4.60)	438.80 (2.39)	275.40 (1.50)
Porous pavement	7474.31 (40.71)	5124.49 (27.91)	3221.48 (17.55)
Rain garden	139 (0.76)	111.20 (0.61)	83.40 (0.45)
Bioretention	49.41 (0.27)	29 (0.16)	15 (0.08)
Tree box filter	65 (0.35)	39 (0.21)	27 (0.15)
Total	8,572.52 (46.69)	5,742.49 (31.28)	3,622.28 (19.73)

III. Results

1. Bupyeong-gu

Annual average precipitation that was taken at Bupyeong weather station in 2018(1,046 mm²) and the average slope(0.011 m/m) of study area was used as the fundamental data for running the simulation. Assuming that the site was in natural conditions without any pre-developments

occurred in the past, generated runoff depth was estimated to be 90 mm/yr, with the infiltration depth of 271 mm/yr, peak flow of 0.13 m³/sec, and peak time of 13.52 minute. Considering the site has been developed without any LIDs applied, the estimated peak flow was 1.41 m³/sec, while the peak time was 1.21 min. for all scenarios. Runoff and infiltration depths distinguished in each scenario, and thus, we have demonstrated the ratio of differentiated values while illustrating the findings of each scenario below.

First, when we applied the maximum LID facilities within the site(Scenario 1) and compared its efficiency with site conditions that have not adopted any LID practices, runoff depth diminished by 417 mm/yr and infiltration depth increased by 542 mm/yr, indicating that the efficiency of LIDs on both values were -64% and 423%, respectively. In addition, peak flow reduced by 0.905 m³/sec, while the peak time delayed for about 2.18 minute. The amount of rainfall that each DA can capture was 35.5 mm(DA1), 39.7 mm(DA2), and 44.0 mm(DA3), respectively, with the total average rainfall captured amount of 39.7 mm. NPS pollutions, such as BOD, SS, T-N, and T-P, were estimated to be reduced by 26.9 kg/yr, 206.6 kg/yr, 52.7 kg/yr, and 1.6 kg/yr, respectively, compared to the pre-LID development conditions.

Scenario 2 adopted 879.08 m²(6.69%) less LID measures than Scenario 1. Runoff depth minimized by 363 mm/yr,

but the infiltration depth increased by 428 mm/yr(LID efficiency of -51% and 333%, respectively). There were -13% and 90% differences with the results of Scenario 1. Peak flow lessened by about 0.77 m³/sec, while the peak time increased by 1.46 minute than the pre-LID development conditions. While all DAs may absorb 28.9 mm of rainfall on average, the amount of rainfall that can be captured in each DA was 26.3 mm(DA1), 33.3 mm(DA2), and 27.0 mm(DA3).

Unlike Scenario 1, the rainfall capturing capacity of DA2 was higher than DA3. This is because the infiltration chambers have been reduced about 52% in DA3 due to the reduced number of single-family housings and the porous pavements, which have the highest effectiveness on runoff mitigation, were smaller than DA2 by 4.35%. NPS pollutants were less generated than conditions before implementing LID practices: BOD(23.4 kg/yr), SS(180.0 kg/yr), T-N(45.9 kg/yr), and T-P(1.4 kg/yr).

In Scenario 3, LID measures were less applied than Scenario 1 by about 1671.6 m²(12.7%) and Scenario 2 by about 792.6 m²(6.0%). Although the LID efficiency has been reduced compared to other two scenarios, this resulted less runoff depth(296 mm/yr) and more infiltration depth(324 mm/yr), with the LID efficiency of -39% and 252% for both values. Peak flow was simulated to be reduced by 0.66 m³/sec, whereas, peak time increased by 1.07 minute in comparison to site conditions that did not install LID practices. Captured rainfall amount was 20.5 mm for DA1, 30.0 mm for DA2, and 15.3 mm for DA3, while all DAs may collect up to 21.9 mm on average. Considering that the key objective of LID is to collect the first one-inch(25.4 mm) of rainfall, DAs 1 and 3 should employ more LID practices. It is assumed that DA2 had higher rainfall capturing capacity since the area lost relatively less amount of porous pavements.

2. Jung-gu

Similar to Bupyeong's simulation, the annual average precipitation(1,134 mm³) obtained from the nearest weather station and the average slope of 0.061 m/m were used for the modelling. Supposing that the site was in natural conditions without any prior developments, estimated hydrological values were as follows: runoff depth: 269 mm/yr, infiltration depth: 362 mm/yr, peak flow: 0.22 m³/sec, and peak time: 10.58 minute.

Compared to the conditions that LID practices have never been installed within the site, runoff depth and peak flow decreased about 342 mm/yr and 2.45 m³/sec, while the infiltration depth and peak time increased about 643 mm/yr and 1.43 minute in Scenario 1. An average of 52.45 mm rainfall can be captured in the entire DA, with DA1 having the most amount of captured rainfall(54.2 mm). LID efficiency on NPS pollutants was -69% for all four pollutant loadings.

Scenario 2 applied about 15.4% less LID practices than Scenario 1. We could identify that the runoff depth and peak flow reduced, while infiltration depth and peak time have been enlarged. Particularly, LID efficiency on runoff depth was -54%(about 15% lesser than Scenario 1) and the delayed peak time reduced by 1.17 minute. The entire DA can cover up to 38.3 mm of rainfall(DA1: 47.3 mm, DA2: 28.0 mm, DA3: 47.2 mm, DA4: 30.8 mm). The amount of captured rainfall in DA2 and DA4 reduced more than 50%, and this can be explained by the decreased size of infiltration chambers and porous pavements within two drainage areas. With regard to the NPS pollutants, BOD was less generated than pre-LID development conditions by 31.0 kg/yr, SS by 238.3 kg/yr, T-N by 60.8 kg/yr, and T-P by 2.0 kg/yr.

Finally, Scenario 3, which adopted 26.9% less LID practices than Scenario 1 and 11.6% less than Scenario

3) Weather Data Open Portal, <https://data.kma.go.kr/data/grnd/selectAwsRltnList.do?pgmNo=56>

Table 8. Runoff reduction efficiency for each scenario

Scenario		Runoff depth	Infiltration depth	Peak flow	Peak time
Bupyeong-gu	S1	234 mm/yr (-64%)	673 mm/yr (423%)	0.500 m ³ /sec (-64%)	3.40 min. (181%)
	S2	346 mm/yr (-51%)	557 mm/yr (333%)	0.637 m ³ /sec (-55%)	2.67 min. (121%)
	S3	466 mm/yr (-39%)	453 mm/yr (252%)	0.745 m ³ /sec (-47%)	2.28 min. (88%)
Jung-gu	S1	154 mm/yr (-69%)	784 mm/yr (457%)	1.135 m ³ /sec (-69%)	2.09 min (217%).
	S2	293 mm/yr (-54%)	645 mm/yr (358%)	1.472 m ³ /sec (-59%)	1.61 min. (144%)
	S3	447 mm/yr (-41%)	519 mm/yr (268%)	1.872 m ³ /sec (-48%)	1.27 min. (92%)

2, diminished runoff depth by 304 mm/yr and peak flow by 0.71 m³/sec compared to the pre-LID development scenario. Peak time was delayed by about 1.52 minute. Except DA3(41.0 mm), all other DAs(DA1: 13.2 mm, DA2: 23.6 mm, DA4: 24.6 mm) need to increase the ratio of LID practices, in order to store the first one-inch of precipitation. Specifically, LIDs were likely to be needed in DA1, where the rainfall capture capacity was significantly lower than other DAs. The capacity of DA3 was not so different amongst every scenario. This is because the DA is located on the hillside, and the size of LIDs did not impact much on generating runoff. Compared to Scenarios 1 and 2, the difference of runoff depth was -28% and -13%, while infiltration depth was 189% and 90%, respectively. All four NPS pollutants were produced about 40% less than the pre-LID development conditions. <Table 8> summarizes the simulation effect of LID practices for each scenario in both study areas.

IV. Conclusion

This study examined the hydrological impact of various LID practices in two distinguished urban revitalization project areas in Incheon by running a runoff simulation tool, in order to secure the urban resiliency for abnormal

rainfall caused by climate change and enhance the sustainability of South Korea's existing urban regeneration new deal projects. Specifically, we have simulated the runoff reduction effect of various LID practices in Bupyeong's 11th Avenue Project and Jung-gu's Village of Empathy Project by using the LIDMOD3 and identified the proper type and size of LID measures, which can be most effective in controlling the area's overall stormwater runoff.

For Bupyeong-gu's case, the findings show that runoff depth decreased by 39-64% and infiltration depth increased by 252-423%, depending on different scenarios. Moreover, peak flow before adopting LID practices within the site was 1.41 m³/sec, but it has been dropped down to 0.5-0.75 m³/sec level. Peak time also has been delayed from 1.21 minutes to 2.28-3.40 minutes.

In Jung-gu, runoff depth minimized by up to 41-69%, while the infiltration depth increased by 268-457%, depending on different scenarios, after the adoption of LID practices. The volume of peak flow reduced from 3.58 m³/sec to 1.14-1.87 m³/sec level, whereas peak time escalated about two to three times higher than before.

In sum, Scenarios 1 and 2 for both study areas were suitable to capture the first one-inch of stormwater runoff. However, Scenario 3 in Bupyeong lacked 3.5 mm, while Jung-gu only exceeded about 0.2 mm. These results were mainly due to

the conditions of DA2 in Bupyeong and DA3 in Jung-gu. To receive the maximum effect on runoff reduction, LID measures should be implemented by following the case of Scenario 1. However, when it comes to the cost-effectiveness, LID practices should be installed based on Scenario 2's DA1 and DA3 and Scenario 3's DA 2 for the case of Bupyeong. For Jung-gu case, applying LIDs based on Scenario 2 can be more cost-effective than adopting any other scenarios even though all drainage areas did not meet the first one-inch LID goal. If we could modify the drainage areas by mixing with Scenario 3 (e.g., DA2 and DA3), hydrological effect can be more productive in this area.

The results demonstrated that LID practices have a positive effect on reducing generated runoff from impervious surfaces. Considering that urban regeneration projects generally maintain the existing building structures and overall urban form, LID practices can be a suitable and cost-effective approach for localities to prevent future floods without reinstalling or constructing the expensive sewer pipelines. Although this study did not examine the aesthetic effect of LIDs, several previous studies identified the positive impact of LIDs on improving the community landscape. This indicates that LIDs may provide much higher values not only in the physical side, but also in the social aspect compared to the traditional sewer infrastructure system. Since the Korea Ministry of Environment is now emphasizing the role of LID practices and providing various incentives and supports in implementing LID facilities, local planners are highly suggested to grasp these chances and actively apply LID measures within the newly redeveloping areas. In addition, local urban management plans, such as stormwater management plan, hazard mitigation plan, and urban regeneration plan should be updated by including detailed requirements and strategies on LID implementation. Furthermore, comprehensive plans should engage broad visions and goals regarding green infrastructure and LID

to pursue a resilient community in long-term.

Although this study provides some valuable insights in terms of the effects of LIDs on runoff reduction, several limitations still exist, in which should be further discussed in future research. First, since this study relied on the simulation to find out the efficiency of LID practices, future study should conduct the calibration by collecting the field observed runoff data for an accurate assessment. Second, further research need to focus more on the water quality improvement side by employing more sophisticated modelling tools and discuss the effectiveness of LIDs on water quality management. Third, LIDMOD3 is a simple excel-based tool, which exempted the correction of parameters while running the simulation. It also cannot sufficiently consider the geographical elements at the watershed-level. Modelling tools, such as SWMM or SUSTAIN, are highly required to be analyzed together to minimize the uncertainty threats of LIDMOD3. Fourth, multiple in-site surveys as well as a concrete review of urban regeneration plan should be accompanied together with the consideration of a site's land use planning in order to practically implement LID measures. Finally, economic benefits of LIDs were not substantially considered in this study. LID approaches may partially replace the role of conventional sewer pipelines while their costs are likely to be inexpensive. Thus, a cost-benefit analysis should be further investigated in order to better estimate the potentials of various LID practices.

Acknowledgement

The authors would like to thank the National Institute of Environmental Research for providing the modelling tool and information regarding LIDMOD3. We also appreciate anonymous reviewers for their helpful comments in improving this paper.

References

- Bupyeong-gu. 2018. Bupyeong-gu Bupyeong 11th Avenue Revitalization Plan of Urban Regeneration. Incheon, Bupyeong-gu office.
- Choi, Dong Hyuk, Ji Hong Jeon and Tae Dong Kim. 2017. Effect of Urban Development on Watershed Hydrology and Pollutant Load Considering Regional Climate Change. *Journal of the Korean Society of Urban Environment*. 17(4): 425-431.
- Choi, Hui Seon, Dong Hyeon Kim, and Seong Yun Jo. 2010. Application and Effects of Low Impact Development in Urban Regeneration of Waterfront Areas. Korea Environment Institute.
- Choi, Hye Seon, Dan Bi Hwang, Hye Jin Jo, and Lee Hyung Kim. 2017. Establishment of Guidelines Through Community Awareness and Participation in LID Maintenance. In Proceedings of Korean Society of Civil Engineers 2017 Convention. October 19, 2017. Busan EXHibiton & Convention center.
- Dietz, M. 2007. Low Impact Development Practices: A Review of Current Research and Recommendations for Future Direction. *Water, Air, and Soil Pollution*. 186(1-4): 351-363.
- Han, Seoung Uk, Hyung Jun Park, and Ju Chul Jung. 2018. Enhancing Natural Hazard Prevention Function in Urban Regeneration Project. *Journal of the Korean Society of Hazard Mitigation*. 18(4): 65-72.
- Incheon metropolitan city. 2016. 2025 Incheon Urban Regeneration Strategic Plan. Incheon city hall.
- Jennings, D. B. and S. T. Jamagin. 2002. Changes in Anthropogenic Impervious Surfaces, Precipitation and Daily Streamflow Discharge: A Historical Perspective in a Mid-Atlantic Subwatershed. *Landscape Ecology*. 17: 471-489.
- Jeon, Ji Hong and Kwang Wook Jung. 2019. The Effects of Infiltration Rate of Foundation Ground Under the Bioretention on the Runoff Reduction Efficiency. *Journal of Korean Society on Water Environment*. 35(1): 72-77.
- Jeon, Ji Hong and Seong Cheol Seo. 2018. LIDMOD3 Development for Design and Evaluation of Low Impact Development. *Journal of Korean Society on Water Environment*. 34(4): 383-391.
- Jeon, Ji Hong, Sang Sun Park, Chan Gi Park, and Tae Dong Kim. 2014. Evaluating Implementation of EPA SUSTAIN Model for Cost-effective LID Design. *Journal of the Korean Society of Urban Environment*. 14(2): 135-143.
- Jung, Jong Suk, Kwang Wook Jung, Su Man Kang, and Kyong Hak Hyun. 2017. Evaluation of Water Cycle Improvement in LH Institute Using SWMM-LID Model. *Journal of Korean Society on Water Environment*. 34(3): 308-315.
- Jung-gu, 2019. Jung-gu Village of Empathy Revitalization Plan of Urban Regeneration. Incheon, Jung-gu office.
- Kang, Ki Hoon and Kyung Hwan Lee. 2017. The Development of Land Use Planning Technique Applying Low Impact Development and Verifying the Effect of Non-point Pollution Reduction: A Case Study of Sejong City 6 District. *Journal of the Korea Academia-Industrial*. 18(7): 548-553.
- Kim, Hyun Woo and Yun Mi Park. 2016. Urban Green Infrastructure and Local Flooding: The Impact of Landscape Patterns on Peak Runoff in Four Texas MSAs. *Applied Geography*. 77: 72-81.
- Kim, Jung Jin, Tae Dong Kim, Dong Hyuk Choi, and Ji Hong Jeon. 2011. Design of Structural BMPs for Low Impact Development(LID) Application and Modelling Its Effect on Reduction of Runoff and Nonpoint Source Pollution: Application of LIDMOD2. *Journal of Korean Society on Water Quality*. 27(5): 580-586.
- Kim, Young Man and Lee Hyung Kim. 2019. Awareness of Urban Environment and LID for Expanding LID Application. *Journal of Wetlands Research*. 21(1): 27-33.
- Lee, Jung Min, Kyoung Hak Hyun, Yun Sang Lee, Jung Gon Kim, Yong Boo Park, and Jong Soo Choi. 2011. Analysis of Water Cycle Effect by Plan of LID-decentralized Rainwater Management Using SWMM-LID Model in a Low-carbon Green Village. *LHI Journal of Land, Housing and Urban Affairs*. 2(4): 503-507.
- Makepeace, D. K., D. W. Smith, and S. J. Stanley. 1995. Urban Stormwater Quality: Summary of Contaminant Data. *Critical Reviews in Environmental Science and Technology*. 25(2): 93-139.
- McDonald, L., W. Allen, M. Benedict, and K. O'connor. 2005. Green Infrastructure Pan Evaluation Frameworks. *Journal of Conservation Planning*. 1(1): 12-43.

- Shin, Dong Soo, Jae Beom Park, Doo Kee Kang, and Deok Jun Jo. 2013. An Analysis of Runoff Mitigation Effect Using SWMM-LID Model for Frequently Inundated Basin. *Journal of the Korean Society of Hazard Mitigation*. 13(4): 303-309.
- Shon, Tae Seok, Dong Ho Kang, Jong Kyung Jang, and Hyun Suk Shin. 2010. A study of Assessment for Internal Inundation Vulnerability in Urban Area Using SWMM. *Journal of the Korean Society of Hazard Mitigation*. 10(4): 105-117.
- Weather Data Open Portal. <https://data.kma.go.kr/data/grnd/selectAwsRltmList.do?pgmNo=56>.
- Woo, Won Hee, Ji Chul Ryu, Jong Pill Moon, Chun Hwa Jang, Dong Hyuk Kum, Hyun Woo Kang, Ki Sung Kim, and Kyoung Jae Lim. 2012. Development of Coupled SWAT-SWMM to Evaluate Effects of LID on Flow Reduction in Complex Landuse. *Journal of Korean Society on Water Environment*. 28(4): 495-504.
- Yoen, Jong Sang, Young Su Jang, Jae Hyuk Lee, and Hyun Suk Shin. 2014. Analysis of Stormwater Runoff Characteristics for Spatial Distribution of LID Element Techniques Using SWMM. *Journal of the Korea Academia-Industrial*. 15(6): 3983-3989.
- Korean References Translated from the English*
- 강기훈, 이경환. 2017. 저영향개발(LID)을 적용한 토지이용계획 기법 개발 및 적용효과 분석: 세종시 6생활권을 대상으로. *한국산학기술학회 논문지*. 18(7): 548-553.
- 기상자료개방포털. <https://data.kma.go.kr/data/grnd/selectAwsRltmList.do?pgmNo=56>
- 김영만, 김이형. 2019. LID 적용확대를 위한 시민의 도시환경 및 LID 인식. *한국습지학회지*. 21(1): 27-33.
- 김정진, 김태동, 최동혁, 전지홍. 2011. 저영향개발(LID)적용을 위한 구조적 BMPs의 유출량 및 비점오염저감 효과모의: LIDMOD2 적용. *한국물환경학회지*. 27(5): 580-586.
- 부평구청. 2018. 부평구 부평11번가 도시재생활성화계획. 인천, 부평구청.
- 손태석, 강동호, 장종경, 신현석. 2010. SWMM을 이용한 도시지역 내수침수 취약성 평가. *한국방재학회논문집*. 10(4): 105-117.
- 신동수, 박재범, 강두기, 조덕준. 2013. SWMM-LID를 이용한 상습침수구역 내 유출저감효과 분석. *한국방재학회 논문집*. 13(4): 303-309
- 연종상, 장영수, 이재혁, 신현석, 김응석. 2014. SWMM 모형을 이용한 LID 요소기술의 공간적 분포에 따른 우수유출특성 분석. *한국산학기술학회 논문지*. 15(6): 3983-3989.
- 우원희, 류지철, 문종필, 장춘화, 금동혁, 강현우, 김기성, 임경재. 2012. 복합토지구역에서의 LID적용에 따른 유출량 저감효과 분석을 위한 SWAT-SWMM 연계모델 개발. *한국물환경학회지*. 28(4): 495-504.
- 이정민, 현경학, 이운상, 김정근, 박용부, 최종수. 2011. SWMM-LID를 이용한 저탄소 녹색마을의 LID 분산형 빗물관리 계획에 따른 물순환 효과 분석. *토지주택도시연구* 2(4): 503-507.
- 인천광역시. 2016. 2025 인천광역시 도시재생전략계획. 인천광역시.
- 전지홍, 박상선, 박찬기, 김태동. 2014. 최적의 LID 설계를 위한 SUSTAIN 모델 적용성 평가. *한국도시환경학회지*. 14(2): 135-143.
- 전지홍, 서성철. 2018. 저영향개발기법 설계 및 평가를 위한 LIDMOD3 개발. *한국물환경학회지*. 34(4): 383-391.
- 전지홍, 정광욱. 2019. 식생체류지의 원지반 침투율이 유출량 저감효과에 미치는 영향모의. *한국물환경학회지*. 35(1): 72-77.
- 정종석, 정광욱, 강수만, 현경학. 2018. SWMM-LID 모델을 이용한 토지주택연구원의 물순환 개선효과 평가. *한국물환경학회지*. 34(3): 308-315.
- 중구청. 2019. 중구 공감마을 도시재생활성화계획. 인천, 중구청.
- 최동혁, 전지홍, 김태동. 2017. 지역 기후변화를 고려한 도시개발에 따른 수문 및 오염부하 변화 연구. *한국도시환경학회지*. 17(4): 425-431.
- 최혜선, 황단비, 조혜진, 김이형. 2017. LID에 대한 시민 인식과 주민 참여를 통한 유지관리 가이드라인 구축. *대한토목학회 학술대회*. 10월 19일. 부산, 백스코.
- 최희선, 김동현, 조성윤. 2010. 수변지역 도시재생에 있어 저영향개발기법(LID)의 적용방안 및 효과. *한국환경정책·평가연구원*
- 한승욱, 박형준, 정주철. 2018. 도시재생사업의 자연재해 예방기능 강화방안에 관한 연구. *한국방재학회 논문집*. 18(4): 65-72.

도시재생사업지 내 저영향개발(LID)기법의 홍수저감 효과 분석을 통한 도시 레질리언스 향상에 관한 연구

국문초록 이상강우의 급증으로 인해 도시홍수의 발생이 더욱 빈번해지고 있으며, 최근 많은 원도심들이 경쟁력 제고를 위해 도시재생사업을 시행하는 만큼, 레질리언스 확보 및 사업의 지속가능성을 높이기 위한 수단으로써 LID 도입이 필요하다. 본 연구의 대상지는 최근 도시재생 뉴딜사업에 선정된 인천광역시 부평구의 부평 11번가와 중구 공감마을 사업지 일부이며, LIDMOD3를 통하여 각 시나리오별 LID 기법들의 홍수저감 효과를 산출·비교하였다. 연구 결과, 시나리오별 연간 우수유출량에서 부평구 대상지는 39%~64%, 중구 대상지는 41%~69% 감소했으며, 연간 우수침투량의 경우 부평구 대상지는 252~423%, 중구 대상지는 268%~457% 증가하였다. 본 연구는 도시재생의 지속가능성 제고에 관한 요인으로 LID를 선정하여, 실제 사업과 연계한 적정 LID기법과 그 효과를 제시하였다는 의의가 있으며, 향후 각 지자체의 도시재생계획 수립 시 LID를 활용한 장기적인 홍수저감 대안을 마련하는 데 큰 도움을 줄 것이라 판단된다.

주제어 : 홍수, 저영향개발, 그린인프라, 도시재생, LIDMOD3, 레질리언스

Profiles **Jin Hee Lee** : He received his B.A. from Incheon National University, Korea in 2019. He is a M.A. student in the Department of Urban Policy and Administration at Incheon National University. His interesting subject and area of research is sustainable urban planning and urban regeneration(leejh610@inu.ac.kr).

Hyun Woo Kim : He received his Ph.D. from Texas A&M University, USA in 2015. He is an Assistant Professor in the Department of Urban Policy and Administration at Incheon National University, in which he has taught since 2017. His research interests include urban flood management, low impact development(LID), green infrastructure planning, and environmental plan assessment(kimhw@inu.ac.kr).