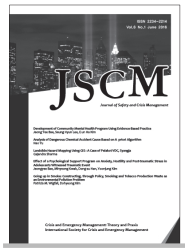

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Examining the Impact of LID Practices on Mitigating Stormwater Runoff in a Repetitively Flooded Area

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ABSTRACT

The interests on low impact development(LID) practices have been continuously increased as an alternative approach to alleviate the impacts of urban flooding. This study examines the effectiveness of LID practices on stormwater runoffs by employing LIDMOD3. A flood-prone area in Juan-dong, Incheon, South Korea, was selected for the study site. The findings show that LID measures are shown to be effective in managing stormwater runoff in two developed scenarios. While annual runoff depth within the site decreased by 45% and 29%, respectively, peak flow was reduced by 1.38-1.81 m^3/second and peak time was delayed by up to 0.92-1.55 minute, depending on the scenario. Drainage areas are divided into four sections within the study area, and the drainage area located on the north side of Scenario A had the highest runoff reduction effects. Among three LID practices applied in both scenarios, rain garden captured the greatest amounts of rainfall, followed by porous pavement and infiltration chamber. The study concludes by providing several spatial suggestions to local environmental planners while implementing LID practices in flood vulnerable old city centers.

Key words: urban flooding, LID, runoff, LIDMOD3, green infrastructure, Incheon

Introduction

The risk of urban floods has been continuously escalating due to abnormal climate change impact and rapid urbanization (Abebe, *et. al.*, 2018; IPCC, 2014). Existing cities are pursuing sustainable development by introducing various urban planning elements to overcome uncertain internal and external threats, which have been caused by climate change. Conventional stormwater management alternatives focused highly on meeting the given performance standards and their role in controlling stormwater runoffs still remains questionable, especially on the cost-effectiveness side (Pyke, *et. al.*, 2011). As the vulnerability to disaster increased globally due to uncertain weather conditions, alternative measures that could capture stormwater runoffs at the source have received significant attentions in various countries (Hu, *et. al.*, 2019; Lee & Kim, 2019). One of the most popular non-point source control techniques is low impact development (LID) practices (i.e., rain garden, bio-retention, infiltration trench, tree box planter, green roof, etc.), which have been introduced by the USPEA (2000) and many other countries with different terms (e.g., sustainable urban drainage (SUD) or water sensitive urban design (WSUD)). The main goal

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of LID is to expand the proportion of pervious surfaces within urban areas so that the water circulation system in urban environments can become similar to the pre-development conditions. Urban flooding in these days was mostly resolved by expanding the capacity of sewage pipes. However, these pipelines cannot be constantly replaced every year to cope with the increased stormwater runoffs. LID practices have the advantage of applying various techniques by adopting diverse plants and water-repellent materials to existing urban spaces (Choi, *et. al.*, 2010). They can be applied in a variety of ways without occupying large-scale space within urban areas, and thereby, enhance the city's resilience and competitivity by minimizing flood damages caused by abnormal rainfalls.

While the City of Incheon pursues sustainable development through developing multiple new towns and facilitating several urban regeneration projects, internal gap in the level of urban infrastructure between old city centers and new towns has worsened the competitiveness of old towns, triggered population outflows, and accelerated urban decline. The average precipitation in Incheon has been increasing steadily since 1990 and approximately 2.6 billion won worth of property damages in 2017 were caused by flooding in low-lying areas, especially in Michuhol-gu and Bupyeong-gu. Particularly, Michuhol-gu, one of the representative old city centers in Incheon, has the highest population density of 16,466 person/km^2 as of 2019 and is more vulnerable to floods due to the high impervious surface ratio (76.9%).

Considering the above facts, a high demand for LID practices exist in old city centers of Incheon. This study computed the effect of LID techniques in reducing stormwater runoff in one of districts in Michuhol-gu through a simulation tool called LIDMOD3. LIDMOD3 is a relatively simple excel-based runoff modelling tool, which has been co-developed by the Korea National Institute of Environmental Research and Andong University in 2018 (Jeon & Seo, 2018). While the Storm Water Management Model (SWMM) is the most popular modelling program that can interpret various watershed characteristics through several periods of simulations, it has a limitation for planning officials because of time constraints and the necessary of expertise, which requires significant efforts to modify the modelling to suit in Korean conditions (Jeon, *et. al.*, 2010). LIDMOD3 allows calculating the efficiency of LID practices with relatively less input data and simplifying the implementation of the simulation. Thus, the results can be effectively used by local policy-makers and planners while adopting, installing, and developing various types of LID techniques and spatial strategies in specific areas.

Literature Review

A great number of domestic and foreign studies exist by using various modelling programs to examine the stormwater runoff and non-point source reduction effects of LID applications. For instance, the US Environmental Protection Agency's SWMM (Han & Seo, 2014; Bae, *et. al.*, 2012; Kim, *et. al.*, 2017; Kim, *et. al.*, 2017; Lee, 2017; Jeon, *et. al.*, 2013), SUSTAIN (Jeon, *et. al.*, 2014), and LIDMOD2 and 3 (Jeon, *et. al.*, 2010; Jeon & Seo, 2018; Jeon, *et. al.*, 2019; Kim, *et. al.*, 2011; Kim & Choi, 2013; Lee & Kim, 2019) were often employed for the estimation in Korea.

By using SWMM, Han & Seo (2014) simulated the runoff reduction effects with several scenarios based on the degree of application of green roofs, permeable pavers, wood pollens, and rainwater cisterns in the upper Gwanpyeong stream in Daejeon. The results showed that the maximum flow rate was diminished by 0.4-11.9%, depending on the applied LID techniques. Bae, *et. al.*(2012) used the RCP scenarios to apply green roofs and porous pavements for examining the runoff change in Guwol residential area, Incheon. The application of LIDs across all periods of the scenario resulted in an outflow reduction of approximately 38%. Kim, *et. al.*(2017) assessed the runoff reduction effect of LID facilities installed in the industrial complex (Zero Rainfall Runoff Complex Construction Project) and found that the average reduction rate for each facility was 76.6%, with the efficiency ordered by plant breeding, infiltration ditch, and vegetation retention basin. Kim, *et. al.*(2017) analyzed the rainfall reduction effect of LID measures at the basin-level that were built in Ochang Science Industrial Complex. In the short-term, a basin that integrates plant cultivating pot and pervious paver was shown to be effective in diminishing runoffs by 30.7% on average, while a basin that encompasses bioretention, infiltration trench, and porous paver was most effective in the long-term (31.9%). Lee (2017) computed the eight LID scenarios to analyze the reduction effects of LID facilities (porous pavement, vertical penetration tube, and rainwater detention) installed at K Research Center in Goyang. Scenario 8, which applied all three LID facilities, minimized the peak runoff by up to 64.4% and total runoff by approximately 35.2%. Jeon, *et. al.*(2013) investigated the characteristic of runoff change for porous pavements and rainwater detentions near Towol stream, Changwon, and revealed that peak runoff was diminished by 1.2-6.2% for permeable pavers and 2.1-11.7% for rainwater detentions.

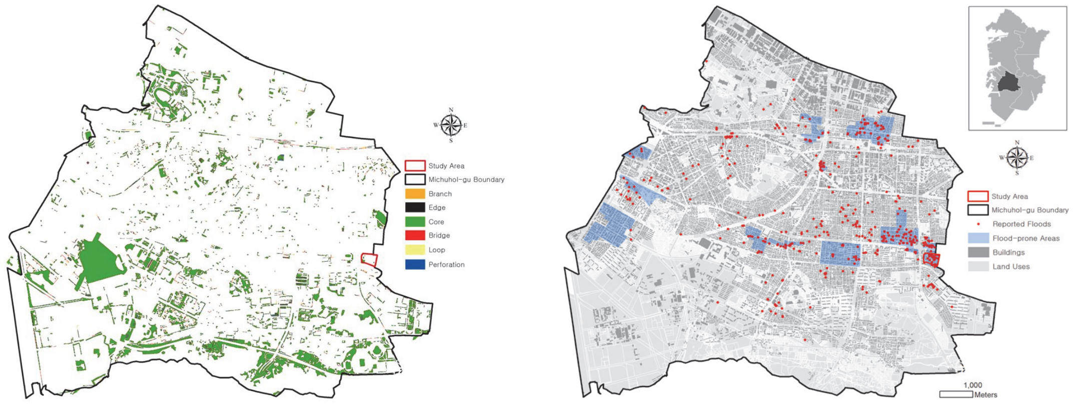
SUSTAIN is a modelling tool for examining the outflow reduction effect and cost-efficiency of LID practices. Jeon, *et. al.*(2014) applied rainwater cisterns, bioretentions, infiltration trenches, and porous pavements around Andong intercity bus terminal and found that the runoff reduction effect was 14-28% within the financial budget of $18,670-$62,108. Jeon, *et. al.*(2010) also examined the reduction impact of porous pavement, green roof, and vegetation strip in the same area using LIDMOD2. Compared to the existing condition, the annual runoff depth can be minimized by 192 mm/year and the annual infiltration depth was likely to increase by up to 51 mm/year. Employing the same modelling tool, Kim, *et. al.*(2011) found that green swale had the highest runoff reduction effect (41.4%) among three different LID practices in Mo-hyun urban development project site, Yongin. Kim & Choi (2013) estimated the runoff reduction effect by land use changes, which applied LID techniques. The findings showed that annual surface runoffs decreased by 7.4%, while the annual infiltration rate improved for about 6.7%.

LIDMOD3 assigns land use and soil drainage status for each specific LID element while calculating the direct amount of runoff. Thus, it can better estimate the effect of LID techniques with the consideration of domestic soil drainage status (Jeon & Seo, 2018). Using this tool, Jeon, *et. al.*(2019) explored the annual runoff reduction effect of bioretention based on the past 10 years of precipitation data in Andong. The results suggested that the runoff reduction was effective when the soil drainage grade of the surface was higher than B-level. Lee & Kim (2019) also adopted LIDMOD3 for their simulations in two specific areas within Incheon. Depending on the scenarios, they found that the annual runoff depth can be diminished by 39-69%, whilst the infiltration depth may increase up to 457% compared to the existing site condition. While previous studies used various modelling tools to precisely estimate future runoffs, they did not fully explain why the selected study area should be an adequate site for adopting specific LID techniques. Although this study also uses a simulation tool that has been frequently employed in the prior research, it can provide meaningful insights to urban planners by estimating the runoff reduction effect where urban flooding problems are urgent in old inner Incheon neighborhood and suggest stepwise approaches for constructing specific techniques within a proper site.

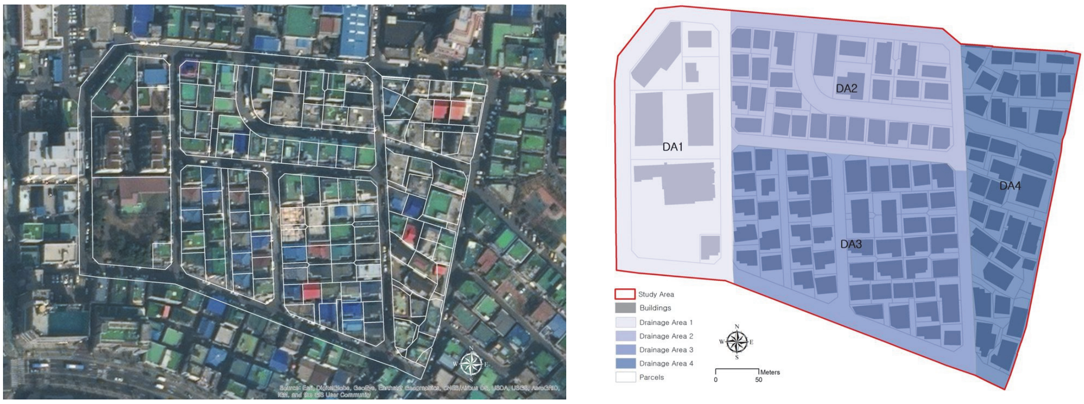
Research Methods

Study Area Setting

The target area of this study was chosen by following two steps. First, we have identified areas that have been repeatedly suffered from flooding in Incheon, Korea. While 31 flood-prone zones were pre-designated by the city in 2017, Michuhol-gu (or borough) encompassed the greatest number of areas (n=11), containing more than one-third of overall flood-prone zones. Within this borough, candidates were determined by comparing with the number of reported incidents that have been recently damaged by floods. Three sites on the east side of borough were firstly selected at this stage. Second, we have considered the network of green spaces in Incheon by employing the morphological spatial pattern analysis (MSPA). MSPA, a software that analyzes and visualizes the geometric characteristics of patches and corridors, has been often adopted by previous research (Choi & Kim, 2019; Vogt, *et. al.*, 2007; Wei, *et. al.*, 2018), and it may help recognizing the network structure of existing green spaces (<Figure 1>). Because LID practices can work as bridging the fragmented landscapes (McDonald, *et. al.*, 2005), places that can link the existing green spaces were considered to be a suitable candidate for this study. The results of spatial pattern analysis show that key green space hubs were located in the southern part of borough, while several small hubs are scattered on the northern area. Considering that the central park in Namdong-gu



<Figure 1> MSPA results (Left) and study area location (Right)



<Figure 2> Bird-eye view (Left) and drainage areas (Right) of the study site

is the core green space that Incheon has designated in their Park and Green Space Plan, the candidate that is placed on the far-right side of Michuhol-gu may play a significant role in connecting key green hubs of inner Incheon. In addition, this area is the nearest place to the central park and incorporates several critical green spaces, while buildings and roads are densely constructed.

After the above selection process, final target area has been chosen, which is the 1570 Juan-8 dong nearby area (<Figure 2>). The total size of selected area is approximately 34,950 m^2, surrounded with low-rise (less than fifth story) multifamily housings. The land use of entire site is classified as the 2nd general residential zone, with a great number of aged housings, which were mostly constructed by more than 20 years. The average yearly precipitation of the site was 1,192.5 mm from 2001 to 2010 (Korea Meteorological Administration, 2017). The mean slope of the site was around 2-3%, while the slope falls from the northeast to southwest side. Only about 3% of the site is covered with pervious area (e.g., lawn), indicating that stormwater runoff can always be an issue in this area due to the high impervious rate.

Modelling Scenarios

The runoff reduction effect of LID practices was examined by using LIDMOD3. This modelling tool basically estimates both storage capacity of LID practices and infiltration capacity of different soil types by considering various domestic guidelines and case studies (Jeon & Seo, 2018; National Institute of Environmental Research, 2019). Although other sophisticated runoff simulation tools (e.g., SWMM, SET, and SUSTAIN) may provide higher accuracy in estimating stormwater runoffs, a number of physical, geographical, meteorological variables should be needed to conduct the simulation. Compared to those tools, LIDMOD3 only requires small number of data, better reflects the conditions of Korea, and can be simply estimated within a short-time. Given these benefits, the application of LIDMOD3 modelling can provide better valuable insights into the recognition of runoff reduction effects of LID techniques.

Several input data are required for running the LIDMOD3. First, land cover data has been acquired from the Korea Environmental Spatial Information Services. Urban infrastructure data, such as land use, road, and building footprint, were collected from the Korea Ministry of Land, Infrastructure and Transport. Elevation and the most recent information for soil drainage class (2005) were obtained from the Korea Rural Development Administration. Incheon's precipitation data from 2001-2010 has been gathered from the Korea Meteorological Administration. Finally, other basic spatial data (e.g., city and borough boundary, flood-prone area, recorded flood) were obtained from the City of Incheon and National Geographic Information. All data have been re-adjusted for the study area by using ArcGIS.

Two scenarios were developed to examine the impact of LID practices in this study (<Figure 3>). The portion of LIDs was differently distributed in each scenario, with Scenario A incorporating the maximum number of practices and Scenario B integrating the least amount of facilities. Particularly, Scenario A adopts three different types (rain garden, porous pavement, and infiltration chamber) of LID facilities with the total percentage of LIDs covering up to 27% of entire site. Scenario B, however, only includes two LID measures (permeable pavement and infiltration chamber) and their coverage was less than 16%. In specific, all the existing streets within the site have been transformed into porous pavers in Scenario A. Because the width of streets was fairly narrow with less than 4-meters, it was difficult to install bioretentions or vegetated strips nearby the roads. Moreover, walkways were rarely existed within the site, which made difficult to create tree

<Table 1> Study area land cover

Classification		Present Condition		Scenario A		Scenario B	
		Area(m^2)	**%**	**Area(m^2)**	**%**	**Area(m^2)**	**%**
Pervious Surface	Lawn	926.8	2.7	926.8	2.7	926.8	2.7
Impervious Surface	Rooftop	13,358.0	38.2	13,358.0	38.2	13,358.0	38.2
	Street & Parking Lot	9,057.2	25.9	400.0	1.1	3,987.0	11.4
	Walkway	1,552.2	4.4	1,552.2	4.4	1,552.2	4.4
	Others	10,055.9	28.8	9,301.9	26.6	9,662.4	27.6
LID Practices	Infiltration Chamber	-		667.9	1.9	399.0	1.1
	Porous Pavement	-		8,657.2	24.8	5,064.7	14.5
	Rain Garden	-		86.0	0.2	-	
Total		**34,950**	**100**	**34,950**	**100**	**34,950**	**100**

<Figure 3> Adopted LID practices in Scenarios A and B

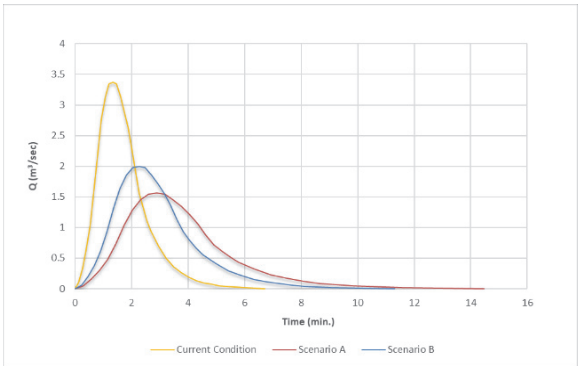
box filters or planter boxes. Due to the existing barriers and insufficient spaces around multiple intersections, eleven small rain gardens are installed at the edge of specific intersections. Assuming that rainfalls will be collected from building rooftops, infiltration chambers are designated in all rooftops. The main hypothesis of LID practices is to collect the first one-inch (25.4 mm) of rain water. Scenario B was designed to construct the least number of LID measures to compare the runoff reduction effect with Scenario A. Same type of permeable pavements are installed only on the core streets within the site. While no rain gardens are developed at the corner of roads, infiltration chambers have been created only below the certain buildings within drainage areas (DA) 2 and 3. This is because several residents in DAs 2 and 3 have repetitively reported flood damages according to the Incheon's flood data. <Table 1> shows the basic information of two scenarios, as well as the present conditions of study site.

Results and Discussions

In current condition, the site's annual runoff depth was estimated to be around 679 mm/year, while the annual infiltration depth was 141 mm/year. According to Scenario A, we discovered that annual runoff depth can be reduced by approximately 45% (371 mm/year) and annual infiltration depth increased by more than 291% (551 mm/year). Percentage of impervious surfaces has been reduced from 97% to 70%. Peak flow diminished by 1.81 m^3/sec., whereas peak time increased for about 1.55 minute (<Figure 4>). When we look at the efficiency of LID practices by each drainage area, DA 2 had the most significant reduction impact (-56%), followed by DA 3 (-52%), DA 1 (-47%), and DA 4 (-28%). This result corresponds with the portion of LID measures in each DA, since DA 2 encompassed the most amount of LID practices (38.9%). However, DA 3 (28.1%) had slightly less LID portions compared to DA 1 (28.4%). While DA 1 comprised more amounts of porous pavements by about 150 m^2, DA 3 contained more rooftop spaces (about 140 m^2) to install infiltration chambers. Extra edges near

<Table 2> Adopted LID practices and runoff reduction effects in each drainage area

Scenario	Classification		DA 1	DA 2	DA 3	DA 4
Scenario A	Area (m^2)	Infiltration Chamber	106.1	151.4	247.5	162.8
		Porous Pavement	2653.4	3002.5	2503.5	497.8
		Rain Garden	7.0	12.4	58.2	8.5
	Runoff Depth (mm/year)		499.1	452.0	480.9	698.6
	LID Efficiency (%)		-47%	-56%	-52%	-28%
	Rainfall Storage Volume (m^3)		197.6	233.3	251.5	73.0
Scenario B	Area (m^2)	Infiltration Chamber	0	151.4	247.5	0
		Porous Pavement	1888.8	1332.9	1694.1	148.8
		Rain Garden	-			
	Runoff Depth (mm/year)		616.5	626.8	586.4	906.0
	LID Efficiency		-34%	-36%	-41%	-5%
	Rainfall Storage Volume (m^3)		120.9	118.6	162.9	9.5



<Figure 4> Peak flow and peak time of Scenario A and B

the intersections within DA 3 also provided more chances to construct rain gardens. This partially implies that installing blended LID practices may lead the synergy impact in minimizing runoffs, even though the effects were not so substantial. The storage volume of precipitation was ordered by DA 3 (251 m^3), DA 2 (233 m^3), DA 1 (198 m^3), and DA 4 (73 m^3), indicating that rain gardens have higher runoff reduction impact than other two LID facilities. Except DA 4, the rest of DAs may sufficiently capture the first one-inch of rainfall: DA 1 = 27.5 mm, DA 2 = 34.5 mm, DA 3 = 30.5 mm, DA 4 = 15.2 mm.

In Scenario B, the overall impervious surface has only been reduced by 19% (from 97% to 82%) since relatively less amounts of LID practices were assumed to be built. Regarding the annual runoff and infiltration depth, LID efficiency was shown to be about -29% and 181%, respectively. Because the peak flow diminished by 1.38 m^3/sec., peak time increased accordingly by about 0.92 minute. Compared to Scenario A, we could identify that peak flow increased by 0.43 m^3/sec., and thus, peak time has been shortened by almost 0.63 minute. Specifically, runoff depth has been reduced the most in DA 3 (-41%), followed by DA 2 (-36%), DA 1 (-34%), and DA 4 (-5%). Infiltration depth increased for all DAs, with the same order as runoff depth. However, a significant gap existed between DA 1 and DA 2 in the infiltration depth. While there were only 2% efficiency differences in runoff depth, 127% variances occurred in infiltration depth. This can be possibly explained due to the elimination of infiltration chambers in the rooftops and a significant reduction of permeable pavers within DA 1. Similar amount of LID practices was installed in DAs 1 (19%), 2 (18%), and 3 (20%), while only 2% of LID measures were covered in DA 4. Storage rainfall volumes in each DA were 36-76% less than Scenario A. Due to the relatively small portion of LIDs in this scenario, none of DAs can capture the first one-inch of rainfall. <Table 2> shows the detailed information of installed LID facilities in each DA and summarizes the storage rainfall volume and LID efficiency on runoff depth.

Conclusion

The effectiveness of LID practices on urban stormwater runoff mitigation was measured in this study under the uniform storm event by employing LIDMOD3. The study area was selected based on two factors: 1) the site has been historically experienced flood damages and 2) it should connect the existing green infrastructure hubs. The site chosen in this study was located within the old city center, surrounded by low-rise residential buildings. Considering this fact, appropriate LID techniques (infiltration chamber, porous pavement, and rain garden) were assumed to be installed in specific places with two different scenarios. While both scenarios revealed that the LID practices have a positive efficiency on minimizing the annual runoff depth, Scenario A, a LID-friendly designed scenario, demonstrated a better efficiency with the percentage of 45%. Compared to the present site condition, runoff was attenuated by 19% in Scenario B, even though the difference of LID coverages was only 11% with Scenario A. This indicates that Scenario A cannot only be effective in flood mitigation, but also be a proper choice when financial aspects are considered. LID measures have also been revealed to be effective in minimizing peak flow (1.81 m^3/sec. and 1.38 m^3/sec.) and delaying peak time (1.55 min. and 0.92 min.) for both scenarios. Annual infiltration depth was increased by 181-292%, depending on the scenario.

As far as each drainage area is concerned, DA 2 in Scenario A was shown to have the highest LID efficiency with the runoff percentage deduction of 56%. Although the orders of LID efficiency corresponded with the coverage size of LID measures in each DA, we may identify that rain gardens have better impact on capturing runoffs compared to other two facilities. This indicates that installing rain gardens can be a cost-effective approach for local municipalities. Because neighborhoods within the old city centers are unlikely to have sufficient open spaces, local planners should focus on preserving and securing vacant lots while adapting their land-use plans. In addition, existing open spaces and pervious lands (e.g., lawn and barren) should be appropriately re-designed with LID techniques and detailed LID guidelines should be provided for low-rise densely developed areas. Finally, none of DAs in Scenario B may capture the first one-inch of rainfall. While Scenario B can be more financially attractive for localities, the main purpose of LIDs is to reduce the burden of existing pipelines by collecting the first one-inch of precipitation. Thus, Scenario B cannot be a retrofittable alternative for solving the urban drainage issue in this site. If a specific municipality still insists to apply Scenario B to reduce the financial burden, they must re-arrange the LID installation locations or choose different LID techniques for each drainage area to capture the sufficient amount of runoff volume.

Although this study provides several valuable insights for local policy-makers and environmental planners regarding the capabilities of LID practices on flood mitigation, some limitations still exist, which should be further considered in the future research. First, the lack of observed runoff data around the study site disallowed us to conduct the calibration process. To increase the accuracy and reliability of estimation, further field research is in need to collect the past runoff data. Second, LIDMOD3 may not fully consider the various environmental factors surrounding the study site during the simulation process. Further research is recommended to employ additional modelling tools that could reflect complex urban settings, including the capacity of pipeline, basin characteristic, and socio-economic status. Third, this study presumed to use the uniform designed storm for the rainfall event. Because the performance of LID practices can be affected significantly from different rainfall and weather patterns, we recommend future research to adopt various rainfall events during the simulation process. Finally, applied LID practices in each scenario have been selected without the consideration of various stakeholders' opinions, municipalities' financial circumstances, and site's detailed surrounding environments. Future research may enhance the validity of LID selection by conducting multiple surveys from local inhabitants and government officials. Moreover, implementation effect can be further measured through conducing a cost-benefit analysis, which will allow researchers to provide more concrete policy suggestions by comparing the installation costs with the traditional sewer lines.

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