Analysing Green Roof Effects in an Urban Environment: A Case of Bangbae-dong, Seoul

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Abstract

Green roofs have been considered as an alternative to providing green spaces in urban areas. Recently, many researchers have suggested that green roofs could contribute to urban flood mitigation by reducing the amount of stormwater runoff. However, the stormwater runoff reduction effect has not yet been fully understood. In this study, two analyses have been performed to investigate the stormwater runoff reduction effect and economic feasibility of green roofs. First, as simulated using PCSWMM, the stormwater runoff effect of green roofs was identified and then the rooftop attributes were considered to acquire results that are more precise. As a result, two of three scenarios demonstrated an average 20% reduction of runoff, which is comparatively smaller than the results of preceding studies. Second, benefit-cost analysis was performed to evaluate the economic feasibility of green roofs. Two of the three scenarios had a benefit-cost ratio narrowly above 1.0 over a period of 20 years. Our results seem to suggest that a green roof has benefits that surpass costs; yet it is insufficient to say that it is an economically sound approach. Overall, green roof does have some stormwater runoff reduction effects and economic effects, but these were not as significant as has been previously described.

Keywords: green roof; SWMM; stormwater runoff reduction and benefit-cost analysis

1. Introduction

1.1 Research Background and Objectives

Green spaces in urban areas have been decreasing due to rapid urbanisation and densification in cities. This phenomenon is known for producing environmental problems that threaten quality of life. The green roof is gaining importance as an alternative to providing green spaces in urban areas. Dense blocks and high land prices make it more difficult to establish green space in an urban area; a green roof is considered, as it could be installed on top of pre-existing infrastructure (Bae et al., 2012).

Many researchers have reported that green roofs are environmentally beneficial, providing varied services such as carbon sequestration, habitat restoration and urban heat island effect mitigation (Getter and Rowe, 2006). Recent studies have also suggested that green roofs are effective for stormwater management (Roehr and Kong, 2010). Therefore, there is a need for an empirical study that examines the effects of green roofs from individual buildings to entire urban environments (Park et al., 2010).

As a means of promoting and encouraging green roof construction in urban environments, many municipal governments have provided various initiative programs. Building owners with green roofs are able to obtain tax abatements or financial support (Doshi and Peck, 2013; Nurmi et al., 2013). In addition, green roofs are regarded as economically beneficial. Green roofs have been reported to produce economic effects such as seasonal energy savings and increased rooftop lifespan. However, the overall economic feasibility of green roofs has not yet been fully elucidated.

In terms of this, the objectives of this study are (1) to examine the stormwater runoff reduction effect of green roofs; and (2) to evaluate the economic feasibility of a green roof system.

1.2 Study Scope and Methods

(1) Study Scope

Bangbae-dong was selected as a study site to simulate the stormwater runoff reduction effect of a green roof. The study area is approximately 4.7km² in size, and located within Seocho-gu, Seoul (Fig.1.). This region has been recognised as a flood prone area in Seoul since the 1980s, due to its annual flooding. The area's locational and geographical factors are thought to cause this flooding. Although there is a relatively large portion of green space in the study area, this is not distributed throughout Bangbae-dong. The statistical data show that flood damage tends to mainly occur in the middle part of the study area.
In order to achieve the aforementioned purposes, this study was carried out in the following order. First, previous studies and relevant theories were reviewed. The review encompassed basic concepts of green roof, flood mitigation, stormwater management model (SWMM) and benefit-cost analysis (BCA).

Followed by background studies, the data were collected and variables were determined. There were two sets of data: one for SWMM analyses, and another for BCA. Third, a flood event was simulated by PCSWMM\(^3\) to compare and determine the stormwater runoff reduction effects of the green roofs. SWMM analysis requires the property of subcatchments, conduits and nodes to build up the model, and requires that the land use properties resemble the study area. The rooftop attributes were collected from the building registration and categorised by observing aerial photos and through field study. They were structured using AutoCAD 2013 and ArcGIS 9.3.

Finally, BCA was conducted. The relevant benefit and cost items were estimated by the data collected from interviews, quotes and literature reviews. The net benefit (NB) and benefit-cost ratio (B/C ratio) were then calculated to examine the economic feasibility of the green roof scheme.

This study employs three sets of scenarios to evaluate the effects of green roofs. Scenario A assumes that there are no green roofs installed in the study area. Scenario B presumes that a green roof is installed on rooftops that are flat and suitable for construction. The rooftops in Seoul provide a number of different uses to the building owners, such as additional storage or rooftop housing. These predominantly prevent the application of a green roof. Therefore, this scenario aims to reflect a more realistic situation for the study area. Lastly, Scenario C supposes that all buildings have flat rooftops, upon which a green roof can be constructed. Approximately 51% of rooftops have a green roof installed in Scenario B, and 100% in Scenario C. Fig. 3. displays input data including conduits, junctions, subcatchments and rooftop attributes.

### 2. Backgrounds

#### 2.1 Green Roof

(1) The Concepts of Green Roof

A green roof has been known to have a wide range of environmental benefits such as carbon sequestration, cooling and heating energy savings, urban heat island effect mitigation, and aesthetic improvement. Moreover, Getter and Rowe (2006) reported that green roofs are known to have an effect on stormwater management, delaying stormwater runoff, energy conservation, improving aesthetic value and increasing a roof's lifespan.

The types of green roof are classified by the thickness of their soil layer and the level of maintenance they require. An extensive green roof has dense, drought-resistant vegetation to minimise the needs of irrigation, and to maximise water absorption (Mentens et al., 2006). As an intensive green roof resembles natural flora, a building needs to be well structured to support the extra weight of soil and plants.

A Structural Safety Inspection (SSI) takes place to determine whether a building is suitable for such extra weight. There is also the mixed type of green roof in Korea. This classification applies to buildings with a high demand for a roof garden but with a too weak structure to sustain an intensive green roof. It has the form of an extensive green roof, and more variety of plants and installed utilities. In Korea, many mixed green roofs can be found in public buildings or department stores, as they provide a leisure space for visitors. Table 1. summarises the different types of green roof.

| Classification | Extensive | Inclusive | Mixed |
|----------------|-----------|-----------|-------|
| Maintenance    | Low       | High      | Low/High |
| Growth Media   | Soil/Artificial | Soil | Soil |
| Age of Building | Old/New | New | New |
| Slope of RoofTop | Flat/Sloped | Flat | Flat |
| Soil Layer     | < 20cm | > 20cm | > 20cm |
| Suitability    | Residential | Commercial | Commercial |

Source: Korean Green Roof and Infrastructure Association

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**Table 1. Classification of Green Roofs**

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Eunha Shin
(2) Green Roofs as a Flood Mitigation Strategy

Flood disaster is a factor that contributes to the creation of vulnerability of urban environments. Shin et al. (2011) reported that the conceivable causes of Seoul floods are related to the issues of high-density cities; these issues include increased incidence of impervious surfaces, development in low regions, and changes in land use patterns. In this context, flood disaster mitigation is strongly linked to urban forms; hence it should be considered as an important part of urban planning.

Koh and Lee (2012) also report that in Seoul, the size of the flooded area has decreased compared to previous years; however urban areas are currently experiencing more devastating flood damage. This has resulted from densification, which concentrates population and assets at specific points.

Choi et al. (2011) pointed out that some possible causes of flooding in southwest Seoul could be due to the insufficiency of the stormwater management system and sewer network.

The current flood mitigation scheme in cities relies heavily on structural approaches such as gutters, rainwater pump stations and rainwater retention facilities. However, due to continuous urbanisation, it is difficult to secure space for additional facilities. Different methods of mitigating urban flooding are being investigated; particularly alternatives that place less pressure on the environment.

It has been reported that green roof systems could contribute to urban flood mitigation by (1) delaying peak runoff time; and (2) retaining a portion of the rainwater within the system (Getter and Rowe, 2006; Mentens et al., 2006). Several empirical studies have dealt with green roofs, but the mechanism for their effect has yet to be fully identified. As an example the analysis result varies from less than 10% (Cho, 2012) to 99% (Lee et al., 2011), which indicates that there are additional factors affecting the functionality of a green roof. Possible factors can be found in Mentens et al. (2006). The annual precipitation, land cover types, roof structure and depth and the number of substrate layers have effects on the annual runoff.

Roehr and Kong (2010) also demonstrated that climate and city density affect green roof functionality. They have simulated the stormwater runoff reduction effects of green roofs in different climate conditions and urban densities, and attained variable runoff reduction amounts.

2.2 Stormwater Management Model (SWMM)

To interpret the runoff trends in urban catchment areas, a suitable model should be selected according to the characteristics of that catchment. Several types of model are able to calculate and simulate runoff quantities and discharge within an urban catchment area: Rational method, RRL, ILLU DAS, STORM and SWMM (Song, 2011). They aim to quantify and model the physical processes from precipitation to runoff.

The study area, the Bangbae-dong region, is highly urbanised and has a greater proportion of impervious surface area. The modelling tool must be able to design an urban catchment, which is different from a natural catchment. Therefore, SWMM was selected as an adequate tool for modelling urban catchment consisting of an artificial drainage system with fewer limitations than other models.

SWMM was first developed by the U.S. Environmental Protection Agency in 1971. It is widely used for runoff simulation and overflow discharge calculations in urban areas (Obropta and Kardos, 2007). The advantages of SWMM include: the ability to simulate continuous rain events, and consider land use patterns of catchment in runoff analysis. The runoff quantity is detailed and the simulated value is reasonable. However, the physical and biological processes have not yet been fully described in the analysis (Park, 2012).

SWMM5 has been extended to model Low Impact Development (LID) controls such as green roofs, rain gardens, and permeable plants to examine their hydrologic performance in an urban area. It enables a detailed study of LID applications in urban areas to determine effective approaches to stormwater management in different study areas.

2.3 Economic Feasibility Study

BCA aims to provide criteria for the decision-making process. The result of BCA intends (1) to provide a foundation for comparing alternatives; and (2) to help select economically feasible alternatives. It involves the comparison of total expected costs and benefits to see if the benefits are greater than the costs. The estimated values help determine economically favourable alternatives (Kim, 2012).

There are several economic feasibility studies for green roof systems. Nurmi et al. (2013) estimated benefit and cost items, separated into public and private. Choi and Kim (2013) calculated a wide range of benefit and cost items for green roof initiatives in Jung-gu, Seoul. They used a Contingent Valuation Method (CVM) to quantify noise reduction, aesthetic value and provide leisure places. They considered the variety of benefits and costs relatively well, but some items were left out.

On the other hand, Kim and Chang (2007) only estimated the economic and environmental benefits of green roofs, excluding the cost items that could arise during the construction of a green roof. Similarly, Lee and Lee (2010) looked at one benefit item: the increase in rent profits. Similarly, Wong et al. (2003) only considered air quality improvement as a benefit.

It is difficult to consider every cost and benefit item associated with a green roof. This could be because the cost and benefit aspects of a green roof are non-marketable and hard to quantify and valuate. One way to evaluate non-marketable items is CVM, in which interviewees are asked whether they have the willingness...
to pay (WTP) for a particular project. This reflects the amount of indirect benefit that could be produced by the project (Kim, 2012; Kim and Park, 2014).

3. Analyses
3.1 SWMM Analysis
(1) Analysis Framework
SWMM analysis was conducted to evaluate the stormwater reduction and retention effects of green roof systems in the Bangbae-dong region. For the evaluation, three scenarios were set to carry out the simulation: one for existing land cover and the other two for green roof construction scenarios.

The Bangbae-dong region was modelled by employing CHI’s PCSWMM. The domain was simplified to 37 subcatchments, 139 conduits and 278 junctions (Fig.3.). The division of subcatchments was based on their similar properties, such as land use patterns, location of conduits and administrative districts. Green roofs were applied to each subcatchment using a LID control tool. Rooftop attributes and the properties of extensive green roofing were entered to design suitable LID control. The calibration was performed before the analysis to ensure the reliability of the constructed model.

(2) Variables and Data
Input data for SWMM analysis included: sewage network (conduit), manhole (node), climate conditions (rainfall event and inundation) and subcatchment areas (geographical features and building attributes).

For the conduit attribute, rectangular-shaped conduits and circular conduits exceeding 900mm in diameter were applied to the analysis.

Precipitation data were collected from the Seocho Automatic Weather Station (AWS) located within Bangbae-2 dong Community Service Centre. The selected rainfall event in 2011 occurred for 90 minutes, and the runoff duration was 1,800 minutes.

For the construction of scenarios, rooftop attributes for the study area were collected: 5,020 buildings in four administrative-dongs were considered in this analysis. Aerial photos and field surveys were used to confirm rooftop types.

3.2 Benefit Cost Analysis (BCA)
The given time period for this analysis is 20 years, which is the average durability of a building in Korea(4). The social discount rate applied in this study was 5.5% (Korea Development Institute, 2012). The cost and benefit items employed in this study were derived from previous studies and related laws.

Table 3. displays the cost and benefit items considered in the present studies, and the equations for each estimation process are listed in Appendix 1.

(1) Cost Estimation
First, the Structural Safety Inspection (SSI) is in accordance with the Ministry of Land, Infrastructure,
and Transport's Regulation (2009). In regard to the green roof, it is required to check whether a building's structure is capable of holding the additional weight of soil and plants.

Construction costs in the present study include foundation work, labour, and planting costs. As there are no guidelines for estimating construction costs, related businesses were interviewed to collect data. It is possible for construction costs to vary, as they are determined by method, plant species and the material used to form a green roof system.

Operational and maintenance (O&M) costs are required two to four times annually and the maintenance requirement would vary according to the type of green roof system. In the present study, three maintenance sessions are assumed per annum for the analysis. As O&M costs are not regulated, landscape businesses were interviewed to estimate the maintenance cost.

Safety management and environment costs are specified in the Construction Technology Management Act in Korea and are calculated according to the Administrative Regulation. The suitable rate for safety management is specified in Appendix 1, which categorises constructions according to their type and size. For the analysis, 2.48% of the total construction cost was used. In the case of Environment costs, the rate is equivalent to 0.5% of the total construction cost.

Removal cost assumes that a green roof installation is removed after 20 years. No green roof has yet been recorded as having been uninstalled in Seoul. Therefore the removal cost was estimated based on an interview with a related business.

Scenario A is Do Nothing Alternative, assuming there is no green roof construction in the study area. Therefore, the cost items estimated for scenario A are: SSI and O&M. Meanwhile, scenarios B and C suppose that a green roof is installed in the study area and all of the cost items listed above are considered.

### Table 3. Costs and Benefit Items Considered in Precedent Studies

| Classification | Cost       | Benefit               |
|----------------|------------|-----------------------|
|                | Groundwork | Construction          | Maintenance | Safety | Environment | Planning | Incentives | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
|----------------|------------|-----------------------|
| Groundwork     |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Construction   |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Maintenance    |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Safety         |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Environment    |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Planning       |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Incentives     |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Stormwater     |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| management     |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Biodiversity   |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Air quality    |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| UHI mitigation |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Rooftop lifespan|            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Property values|            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Noise abatement|            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Green space    |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Energy cost    |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| savings        |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Sewer system   |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| maintenance    |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Employment     |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |
| Community area |            |                       |            |        |             |          |            | Stormwater management | Biodiversity | Air quality | UHI mitigation | Rooftop lifespan | Property values | Noise abatement | Green space | Energy cost savings | Sewer system maintenance | Employment | Community area |

### (2) Benefit Estimation

There are three types of benefit from green roof construction: economic, environmental and social. Economic benefits include: savings associated with rooftop O&M, seasonal energy, sewer system O&M, compensation and employment opportunities while air quality improvement, carbon sequestration, stormwater management and urban heat island (UHI) effect mitigation are considered environmental benefits. While social benefits including: noise reduction, aesthetic improvement, and the provision of a community area are not considered in the present study, they are known to result from an intensive green roof.

The economic benefits of a green roof imply that certain costs have been reduced because of the creation of a green roof. First, it is known that green roof construction increases the lifespan of a rooftop and decreases the requirement for its frequent maintenance (Doshi and Peck, 2013). Second, green roofs contribute to a building's rooftop insulation. In addition, a green roof is able to save seasonal energy (i.e. cooling and heating) (Hong et al., 2011); and to estimate this, the method used by Kim and Chang (2007) was employed. Approximately 2.2 m² of water evaporates daily if the heat energy of the water evaporating is converted into electrical energy.

Compensation savings were estimated by employing PCSWMM's flood inundation analysis. The Seocho-gu office currently provides 70 million KRW per flooded building as compensation. Thus the number of flooded buildings in Scenarios A, B and C were subtracted to obtain the compensation savings. Lastly, employment opportunities considered as transfer payments (TP) are not estimated in this study.

Several environmental effects of green roofs are considered in this study. First, plants are known to absorb air pollution substrates such as SO₂, NOₓ, and PM₁₀. A green roof is also able to purify air...
pollutants and reduce the need to process them. Second, the carbon sequestration effect was valorised by multiplying the carbon trade price per tCO$_2$ to the amount of CO$_2$ absorbed by a green roof plant annually (Ahn et al., 2011). The amount of wastewater treated by plants decreases, because of the stormwater reduction effect of a green roof, and as purifying wastewater also results in harmful matter by-products, it could be said that producing less wastewater is beneficial to the environment. In this sense, the decreased quantity of stormwater that goes to the wastewater plant was multiplied by the treatment cost. Lastly, the UHI effect is the result of urbanisation. Instead of absorbing heat energy from sunlight during the day (Jung and Yoon, 2011), a green roof reflects heat energy. The stored heat energy in the concrete roof is then discharged at night, keeping the atmosphere warmer in urban areas. A green roof lessens the UHI effect at night by cooling the atmosphere. Therefore, the UHI effect mitigation was estimated by converting the temperature into electrical energy (Uhm et al., 2012).

### 3.3 Findings and Discussion

#### (1) SWMM Analysis

The SWMM analysis results represented that for considering a single event, Scenario B has a 14.7% runoff reduction, whilst Scenario C has 25.6% (Table 6. and Fig.4.). It is noticeable that the peak runoff time has been delayed by 10 minutes in Scenario C.

#### (2) Benefit Cost Analysis (BCA)

The result for BCA applies to Scenario B and C, as Scenario A is the Do Nothing Alternative. Scenario B and C have respective net benefits of KRW 21.7 billion, and KRW 89.3 billion. Both scenarios have benefit-cost ratios that barely exceed 1.0 (Table 7.).

#### (3) Discussion

First, the SWMM results of this study are in close agreement with those of previous studies that have utilised SWMM as the analysis tool (Table 8.).

### Table 4. Summary of Cost Estimation

| SSI          | Construction | O&M* | Safety | Environment | Removal* | Total          |
|--------------|--------------|------|--------|-------------|----------|----------------|
| A            | 7,860,747,480 | N/A  | 260,661,700,498 | N/A        | N/A       | 246,127,529,434 |
| B            | 3,667,835,670 | 127,446,784,643 | 183,811,425,503 | 3,160,680,259 | 6,222,772,826 | 37,262,334,904 |
| C            | 7,860,747,480 | 250,918,259,102 | 341,373,212,467 | 637,233,923  | 1,254,591,296 | 49,708,942,386 |

*: Discount rate applied

### Table 5. Summary of Benefit Estimation

|                      | Scenario B | Scenario C |
|----------------------|------------|------------|
| Benefit              | KRW        | KRW        |
| Discounted Benefit   | KRW        | KRW        |
| Rooftop O&M savings  | 7,044,422,927 | 13,869,116,762 |
| Seasonal energy savings | 4,389,371,702 | 8,641,830,463 |
| Sewerage system O&M savings | 115,211,482 | 123,489,767 |
| Air quality          | 2,244,154,303 | 4,418,309,119 |
| Carbon sequestration | 17,299,300,456 | 396,423,746,156 |
| Stormwater management | 193,757,890 | 7,854,883,702 |
| UHI effect mitigation | 1,159,829,281 | 2,283,481,257 |
| Compensation savings | 0          | 77,700,000  |
| Total                | 32,307,156,276 | 746,636,844,341 |

### Table 6. Result of SWMM Analysis

| Scenario     | Peak time (min) | Peak runoff (m$^3$) | Total runoff (m$^3$) | Reduced runoff (%) |
|--------------|-----------------|--------------------|---------------------|-------------------|
| Scenario A   | 65              | 19.38              | 182.4956            | N/A               |
| Scenario B   | 65              | 15.71              | 155.6732            | 25.6              |
| Scenario C   | 75              | 14.25              | 135.787            |                   |

### Table 7. Summary of Benefit Cost Analysis Result

|                      | Scenario B | Scenario C |
|----------------------|------------|------------|
| ∑Cost                | KRW 355,986,294,902 | KRW 657,338,525,556 |
| ∑Benefit             | KRW 4,389,371,702 | KRW 8,641,830,463 |
| NB                   | KRW 77,700,000  | KRW 904,375,432 |
| B/C Ratio            | 1.060       | 1.135      |

### Table 8. SWMM Analysis Results in Previous Studies

| Authors          | Study Area            | Stormwater reduction % |
|------------------|-----------------------|------------------------|
| Bae et al. (2012)| Residential area (Incheon) | 35                     |
| Cho (2012)      | Mixed area (Busan)    | < 10                   |
| Yoon (2012)     | Industrial area (Busan) | 3.9                    |

The majority of studies have reported that green roofs exhibit the stormwater runoff reduction effect in urban areas. Therefore, the result of this study is
reliable as the green roofs in the Bangbae-dong region do exhibit the stormwater runoff reduction effect to some degree, though just not as strongly as has been publicised by the media. The media have reported that the stormwater runoff reduction provided by green roofs in urban areas is substantial, with figures reaching an average of about 70% and above (Seoul Metropolitan Government, 2007; MBC, 2013). The figures cited by the media are from studies conducted by monitoring the effects of actual green roofs installed on single buildings under controlled conditions. Relatively few previous studies monitoring the effects of actual green roof installation in a relatively small spatial scope (i.e., from control units to the roof of a single building) have reported stormwater runoff reduction estimates of 90% and above (Table 9.).

Table 9. Monitoring Analysis Results in Previous Studies

| Authors          | Study Area                  | Stormwater reduction % |
|------------------|-----------------------------|------------------------|
| Lee et al. (2011) | Educational facility (Seoul) | 90.3                   |
| Lee et al. (2006) | Educational facility (Seoul) | > 90                   |
| Chang et al. (2008) | Educational facility (Seoul) | 87.8                   |

Estimates of green roofs on single buildings demonstrate their effect in terms of retaining and using rainwater. However, the stormwater runoff effect of a green roof system in an urban area is dependent on land use and geographic and topologic factors (Yoon, 2013). Targeting a single building under controlled conditions is insufficient to illustrate the overall effect of multiple green roofs in an urban environment. Based on the analysis results of previous studies and of the present study, the stormwater runoff reduction effect of green roofs may have been exaggerated.

Roehr and Kong (2010) pointed out that annual precipitation and impervious area ratio are factors affecting the performance of a green roof’s runoff reduction. In addition, Ahiablame et al. (2012) suggested that studies on LID performance should be performed on a larger scale than a single building. This could imply that the runoff effects of green roofs are indeed tangible yet are affected by many other factors.

Second, the BCA results of the present study are similar to those of Choi and Kim (2013) and Nurmi et al. (2013). The former reported a benefit-cost ratio of 1.06 for 100% application of extensive green roofs in Jung-gu, Seoul. The latter described the total benefit-ratio as ranging from 0.9 to 2.2. These results suggest that the benefits of a green roof are greater than the costs but not to an overwhelming degree.

Green roofs are known to be of financial benefit to building owners (Seoul Metropolitan Government, 2007). However, this is dependent on the type of green roof and the tax abatement provided by the municipal government. An intensive green roof system usually provides more value such as provision of community space and biodiversity enhancement than an extensive green roof. In addition, tax abatement schemes differ from place to place. Hence, it may be too early to determine whether green roofs have high economic feasibility.

4. Conclusion

The objectives of this study are: (1) to investigate the effect of green roofs on mitigating stormwater runoff in an urban area and (2) to examine whether green roof systems are economically feasible. It is controversial whether many of the effects of a green roof are valid in an urban area.

This study demonstrates that green roofs can be used to reduce stormwater runoff in urban areas. However, the effect is not as great as has been reported. Palla et al. (2008) also pointed out that the stormwater runoff problem cannot be solved in urban areas by the construction of green roofs alone. Therefore, more research remains to be done to investigate various green roof effects and understand their mechanisms.

Moreover, this study evaluates the economic feasibility of green roofs and finds that the total benefits exceed costs by a negligible amount. Green roofs will eventually result in economic benefits, but these benefits are not as significant as expected. In summary, the effect of green roofs is not as great as determined in previous studies.

The first limitation of this study is the small size of the study area. However, the study area is a suitable size for SWMM modelling and analysis. Second, non-marketable items that are difficult to evaluate were not included in the economic feasibility study. Next, inclusive green roofs were not considered, as these are difficult to standardise due to the numerous designs according to plant types and their utility, needs, and purposes. The last limitation of this study is that only direct factors such as analysis conditions and the size of the spatial scope were included. Additional indirect factors that may be related to the stormwater reduction effect were not fully considered.

Nevertheless, the results of this study may be applicable as policy data for future green roof initiative projects.

Acknowledgements

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014S1A5A2A01012259).

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Notes

1. Seoul Metropolitan Government (SMG) (2007) The manual for Selecting and Maintaining Green Roof Systems.

2. A Dong is the smallest level of urban government with its own office and staff members, branching from the primary division of districts (Gu).

3. PCSWMM is software that has been employed the EPA’s SWMM5 hydrology and hydraulic engine.

4. Ministry of Land, Transport and Maritime Affairs (2011) Building and Housing Statistics (http://www.molit.go.kr/).

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8. Transfer Payment (TP) refers to transactions in which no economic value has been created or consumed. That is, one individual's benefit becomes the cost of another (Kim, 2012).

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[Appendix 1] Summary of Cost and Benefit Items

| Item                        | Estimation                                                                 |
|-----------------------------|---------------------------------------------------------------------------|
| S&I                         | Inspection cost (KRW/m²) * Area (m²) + [Number of buildings * Labour (KRW)] |
| Construction                | Average cost of construction (KRW/m²) * Area (m²) * Number of buildings |
| O&M                         | [Material (KRW) * Area (m²)] + [Labour (KRW) * Number of buildings] * 3  |
| Removal                     | [Removal (KRW/m²) * Area (m²)] + [Labour (KRW) * Number of buildings] + Tax (KRW) |
| Safety Management*          | Construction (KRW) * 0.0248                                              |
| Environment†                | Construction (KRW) * 0.005                                               |
| Rooftop O&M Savings         | Average cost of rooftop O&M (KRW/m²) * Area (m²)                         |
| Sewer System O&M Savings    | Review of related statistics annual reports, half-yearly settlements and research reports |
| Air Quality Improvement     | Air pollutant (kg/m²) *Removal cost (KRW/building) *Area (m²) *Number of buildings |
| Carbon Sequestration        | Plant absorption (CO₂/m²yr) *CO₂ price (KRW)                           |
| Stormwater Management       | Stormwater management (KRW/ton) *Reduced amount of stormwater (ton)     |
| Compensation                | (Number of Flooded building in Scenario A – Scenario C) *Seepo-gu compensation (KRW/building) |
| UHI Effect Mitigation       | Atmospheric temperature change (°C) *0.5Km W/C *Area (m²) *Electricity cost (kWh/KRW) |

*Predefined by enforcement †Labour cost: based on the unit price of wages announced by Construction Association of Korea (CAK)