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The Economic Effect of Green Roofs on Non-Point Pollutant Sources Management using the Replacement Cost Approach

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Abstract

A green roof is one of the sustainable management alternatives for mitigating non-point source discharges which have increased along with expanding impervious areas due to urbanization. Although technically viable, it is also necessary to assess its validity by economic analysis because green roof projects typically require a substantial amount of budget. Four scenarios were established to (1) analyze the effectiveness of green roofs for alleviating non-point source pollution; (2) present the criteria of economic analysis; and (3) estimate benefits by using the replacement cost approach. The Cheonggyecheon watershed in Seoul, Korea is selected as a study area because of its large impervious surface, and XP-SWMM is used for rainfall-runoff and water quality simulations. Our analyses showed that 817,884 kg/yr, 683,781 kg/yr, 452,758 kg/yr, and 356,523 kg/yr of Biochemical Oxygen Demand (BOD) loading can be reduced in the four scenarios (S-1 > 65 m^2; S-2 > 100 m^2; S-3 > 200 m^2; S-4 > 300 m^2) based on building roof area, respectively. And the benefits for 30 years resulting from those scenarios were estimated to be United States Dollars (USD) 257.3 million, USD 228.8 million, USD 174.6 million, and USD 149.2 million with currency exchange rate 1USD = 1,182 KRW. We expect that this study will contribute to a more economically accurate assessment for the validity of green roof projects to sustain environmental health in urban areas.

Keywords: *green roofs, impervious area, non-point source pollution loads, water quality improvement, replacement cost approach, benefit estimation*

1. Introduction

Nonpoint Source Pollution (NPSP) is typically defined as diffuse agricultural and urban runoff which can affect water quality (Barbour *et al*., 1999). NPSP contributing to the total pollutant loads in 4 major river basins (Han River, Geum River, Nakdong River, and Youngsan River) in Korea was reported to be 42-69% in 2003 and it was estimated that the portion would increase to 65-70% by 2015 (Korea Ministry of Environment; KMOE, 2005a). Most local governments in Korea have focused on the construction and expansion of Wastewater Treatment Plants (WWTP) to meet the goals of the current Total Water Pollution Load Management plan. However, as the estimated contribution of NPSP indicates, the overall improvement of water quality will be limited only with point source reduction schemes. Although, policies for reducing NPSP have been developed for industrial and agricultural areas, substantial policies for urban areas are still lacking.

Urbanization has significantly threatened the long-term sustainability of hydrology and environment. Impervious surfaces such as pavements and buildings in urban regions increase surface runoffs by which pollutants accumulated on those surfaces are flushed into streams (Wang *et al*., 2011; Qin *et al*., 2013; Zhang *et al.,* 2013). Generation and discharge of NPSP primarily depend on land use patterns, ratio of vegetated area, and impervious area. As NPSP caused by land cover are typically the major contributing factors in urban regions, it will be effective to reduce the pollutant sources from generation stage by changing the land cover. In this study, we examine and analyze the effectiveness of green roofs as the changed land cover, by which initial rainfall is filtered through soil layer, for mitigating urban NPSP. Moreover, we also suggest a method, which can be used for a feasibility study, to estimate benefits gained from green roof installation.

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Many local governments, including Seoul in Korea, provide direct and indirect financial supports for green roof projects. Although the effects of building an individual green roof may not be significant compared to its installation costs, in an urban or catchment scale, the aggregated effects of many green roofs are substantial and also attractive in ecological and environmental management perspectives in urban regions (Blackhurst *et al*., 2010). Nonetheless, as a high cost project, it is necessary to assess the feasibility of the projects by economic analysis to gain the highest utilities with limited budgets. However, green roof projects in Korea has been generally driven by the will of final decision makers with the expectation that the projects would bring benefits to the region anyway without considering engineering analysis and economic effectiveness.

Most studies on green roofs have focused on policies for encouraging installation, construction methods, and plant growing media (e.g. Oberndorfer *et al*., 2007; Getter and Rowe, 2006; Carter and Fowler, 2008). Recently, studies on effects gained from green roof installation are also increasing as new green roof technologies are more developed (Morgan *et al*., 2012; Speak *et al*., 2013). However, as far as we recognize, economic analysis for feasibility assessment on green roofs and technical assessment on the effectiveness of green roofs for reducing NPSP are lacking. Clark *et al.* (2008) proposed net present values (NPVs) regarding the effects of green roofs on the reduction of stormwater runoff, building energy consumption, and air pollution in both individual building and city scales (e.g., Chicago and Detroit). Carter and Keeler (2008) used stormwater runoff and building energy data collected from their own experimental green roof plot for life-cycle cost-benefit analyses of thin layered green roof systems in an urban watershed. They also applied data from others for setting the target beneficiaries, quantifying the effects from green roofs, and monetizing the benefits. According to their results, NPV for installing green roofs is 10-14% more expensive compared to conventional rooftops. However, they suggest that the cost is actually 20% less when considering the positive social benefits such as stormwater management, energy insulation, and air quality, and strongly recommend installing green roofs in urban centers. Alcazar and Bass (2006) demonstrated that more the region urbanized, higher the environmental benefits in terms of the reduction of air pollutants, air-conditioning, heating bills, climate change, and stormwater runoffs. Their study also utilized data from others to estimate benefits. To clarify the issues regarding the determination of environmental benefits from green roofs, Hitesh (2006) proposed a method for estimating benefits in a city scale by using a case study of Toronto city, Canada. According to their estimation, which considers the selection of beneficiaries in a local government level, quantification of effects from green roofs, and the spatial distribution of buildings, the total benefits include initial savings of 313 million CAD and annual savings of 37 million CAD when 49,840,000 m^2 of green roofs are installed.

Wong *et al*. (2003) conducted a life-cycle cost analysis on a lightweight green roof to emphasize the environmental benefits gained from the green roofs compared to conventional rooftops. They concluded that, although the initial cost for installing a green roof was high, the life-cycle cost, which had not taken into account the energy cost (energy cost reduction), was lower than that of the conventional rooftops. On the other hand, City of Waterloo (2004) conducted the life-cycle cost analysis of the green roofs (lightweight type, 1,600 m^2) of the buildings owned by the city with the durable years set at 50 years. Their analyses on life-cycle cost included the installation cost, donations, and benefits of stormwater management (runoff reduction, water quality improvement, and erosion regulation), energy cost reduction, and provision of green spaces. In their study, the current value was roughly estimated based on the data from preceding studies and the cash flow for benefits and cost was not clearly analyzed within a set economic analysis period for the purpose of benefit estimation. Thus, strictly speaking, it cannot be regarded as a validity assessment. Moreover, City of Portland (2008) performed an economic analysis of the green roofs of 5-story commercial buildings (3,720 m^2) with the analysis period of 40 years, which is the expected lifetime of lightweight green roofs. Private and public benefits such as stormwater management fees, reduced labor hours and management facility cost, reduced demand for cooling and heating energy, increased durable years of the building, smaller size of the air conditioning system, reduced carbon dioxide emission, improvement of air quality and creation of habitat among others as well as the project costs such as the construction, maintenance costs were calculated, taking into account the inflation and discount rate, to present the NPV. In the first 5 years after the construction of a green roof, the cost was found to exceed the benefits by $15,000, but during the economic analysis period, set at 40 years, the benefits were found to exceed the cost by about $700,000. Although this study set the economic analysis period and took into consideration the discount rate, it cited existing literature for quantitative analyses of various effects of the green roof and used rough basic units to assign monetary value to the effects to calculate the benefits. Thus, it is difficult to claim that the effects of the project in question were accurately analyzed from the engineering aspect and the basic units are deemed to be unreliable. Another example of a life cycle analysis of a green roof system was the study done in Korea by Kim and Yoon (2011), who conducted a prediction of energy insulation for different types of green roof system.

As such, studies in which an economic analysis of a green roof system was performed usually employed the method of life cycle cost analysis (e.g. Lee, 2004; Coffman and Martin 2004; Kosareo and Ries 2007; Carter and Keeler, 2008). While a life cycle cost includes all the costs incurring during the life cycle of the facility concerned such as the initial investment (construction, design and compensation costs, etc.), maintenance costs, user cost, socioeconomic losses, scrapping cost and residual value among others (Shield and Young, 1991; Shan and Govindarajan, 1993), life cycle cost analysis refers to the calculation of the total or partial life cycle cost, which includes the initial investment, maintenance costs, incurring during the durable years of the facility (Artto, 1994; Korpi and Ala-Risku, 2008). Although a life cycle cost analysis can be performed to compare the total costs of the options selected for a given project, it cannot replace an economic analysis performed to assess the validity of the project.

Accordingly, this study aims to present an appropriate method for validity assessment of a green roof project by performing an economic analysis based on a prescribed procedure that includes the preparation of the criteria for water quality improvement analysis, benefit estimation, cost estimation and economic analysis (durable years, discount rate, etc.). In this regard, this study involves three specific objectives: (1) assessment on the effectiveness of green roofs as the changed land cover, by which initial rainfall is filtered through soil layer, for mitigating urban NPSP; (2) suggestion of the criteria such as duration period and discount rate for economic analysis; and (3) benefits estimation using the replacement cost approach. For this purpose, a green roof scenario was set at the Cheonggyecheon watershed in Seoul, Korea which is an area of a severe urbanization. The water quality improvement effect from land use change was calculated using XP-SWMM, a collection of the Storm Water Management Model (SWMM) developed by US Environmental Protection Agency (EPA) (Rossman, 2007), and the benefits were estimated using the replacement cost approach (RCA), in which the costs of operating an alternative facility are calculated; we considered sewage treatment facilities as alternative facilities to green roof systems.

2. Material and Methods

A green roof project refers to the creation of green spaces on the rooftops of buildings for various purposes and it initially aimed to improve the landscape of urban areas, which often have insufficient green spaces (Peck *et al.*, 1999). However, green roofs were shown to provide additional benefits such as creation of a rest area, amelioration of air pollution resulting from plant cultivation, creation of an ecological habitat, insulation effect contributing to the reduction of cooling and heating costs, noise reduction and flooding reduction (VanWoert *et al*., 2005). The improvement of water quality resulting from providing better land cover, which was examined in this study, is another important effect produced by the green roof project. In Korea, neither the central government nor the local government authorities were aware of the importance of the green roof system, and the majority of building owners felt burdened by the cost to install green roofs. These were the main reasons the green roof system had not been as widely implemented compared to the developed nations overseas. In the recent years, however, a number of local governments such as the Seoul Metropolitan Government, Gyeonggi Province, and Daegu Metropolitan City have been encouraging green roof projects.

Urbanization, which is accompanied by an increase in population, number of automobiles and industrial activities, ultimately results in higher emission of various pollutants such as automobile exhaust, tire fragments, pollutants caused by industrial activities, atmospheric depositions, dust scattering from construction sites, food remnants, and toxic substances in leachate (Shao *et al.*, 2006; Park *et al*., 2013). At the same time, it also broadens the impervious surface area by which, in the event of rainfall, NPSPs temporarily and rapidly flush into the public water systems such as rivers and deteriorate the water quality of those systems. Thus, transforming the land cover and usage status from impervious to pervious will reduce the amount of pollutants generated and flushed by the rainwater, and in turn improve the water quality of rivers.

This study was conducted to analyze the effect of green roof systems on the water quality of the Cheonggye (CG) stream, which has an urbanization ratio of over 70%, in the watershed area of the Jungnang stream passing through Seoul, and to perform an economic analysis using the RCA. The area around the CG stream is concentrated with office and commercial buildings, while the areas surrounding its tributaries such as the Seongbuk (SB), Jeongneung (JN), and Wolgok (WG) streams are concentrated with residential buildings. In this regard, it was determined that the effect of the green house system could be maximized in this particular area due to its current lack of green spaces.

The XP-SWMM model was used to analyze the changes in the runoff and water quality arising from the green roof system for each scenario described in the following section. A method of changing the ratio of impervious surface area was applied to reflect the phenomenon contributing to the hydrological processes, resulting from transforming the impervious areas of the building rooftops into pervious green spaces. To determine the effect on the stream water quality, the area concentrated with residential and commercial buildings was considered to be transformed into green spaces or non-urbanized area. In order to estimate the benefits of improving the water quality by changing the land cover and use, the sewage treatment facilities located in Seoul were investigated and the relationships between the treatment volume versus facility capacity, facility capacity versus project cost, as well as facility capacity versus maintenance costs were determined based on the data on the treatment performance of the sewage treatment facilities. Also, in order to estimate the green roof project cost for each scenario, the existing green roof area, types and project costs were examined and the relationship between the green roof area and project cost was determined based on a statistical analysis. In addition, cost estimation was performed, taking into account the durable years, installation cost, and maintenance costs, for an economic analysis.

2.1 Green Roof Scenarios

2.1.1 Current Status of the Cheonggyecheon Watershed

Cheonggyecheon watershed, which accounts for 8.2% of the total area of Seoul (605.208 km^2), is consisted of four sub-watersheds of the CG, SB, JN, and WG streams (Table 1). CG stream joins with SB stream and then with JN stream before flowing into Jungrang stream from the right bank. The upstream

Table 1. Characteristics of Cheonggye Watershed (Korea Ministry of Land Transport and Maritime Affairs; KMLRM, 2008)

Watersheds[a]	Cumulated Area (km^2)	Channel length (km)	Average slope
CG+[SB+JN]	23.176+[7.340+19.104] = 49.621	14.21	0.0458
SB	7.340	6.46	0.0260
JN+[WG]	14.272+[4.832] = 19.104	11.13	0.0554
WG	4.832	4.06	0.0241

[a]CG: Cheonggyecheon stream; SB: Seongbuk stream; JN: Jeongneung stream; WG: Wolgok stream

area is comprised of mountainous terrains, but the area of focus, which is the CG sub-watershed, is mainly concentrated with residential and commercial buildings.

2.1.2 Setting Green Roof Scenarios

Building layers were extracted from the digital map 2.0 retrieved at Korea National Geographic Information Institute (KNGII). The building uses could largely be divided into factory/plant, educational and research facilities, neighborhood living facilities, welfare facilities for seniors and children, cultural and assembly facilities, livestock manure and waste treatment facilities, accommodation facilities, office facilities, sports facilities, storage and treatment facilities for hazardous materials, medical facilities, automobile-related facilities, funeral facilities, religious facilities, residential buildings, storage facilities, and stores. The buildings could also be classified, based on their type, as general residential building, row house building, apartment building, non-residential building, wall-less building, greenhouse, building under construction, temporary building and unclassified. In this study, some of the aforementioned buildings were excluded in the analyses as they are not eligible for green roof installation, and these included religious facilities, miscellaneous facilities, funeral facilities, storage facilities and cemetery-related facilities as well as wall-less buildings, buildings under construction, temporary buildings, greenhouses and unclassified buildings.

Since green roofs are created on the rooftops of buildings, the buildings in each of the watersheds that are eligible for a green roof system were classified using the building layers extracted from the digital map 2.0, the latest data in South Korea, and scenarios were prepared based on the building area. To this end, the building area was considered as the roof area, and all the roofs were assumed to be flat and smooth. Also, although the applicable type of green roof system should be determined based on the structural safety diagnosis of the buildings, it was

Fig. 1. Cheonggyecheon Watershed and Spatial Distribution of Buildings

Table 2. Green Roof Areas in Sub-watersheds by Each Scenario (km^2)

Watersheds	Watershed area (A)	Scenarios							
		S-1 (65 m^2)		S-2 (100 m^2)		S-3 (200 m^2)		S-4 (300 m^2)	
		Building area (C)	Green roof ratio (%) (C)/(A)	Building area (D)	Green roof ratio (%) (D)/(A)	Building area (E)	Green roof ratio (%) (E)/(A)	Building area (F)	Green roof ratio (%) (E)/(A)
CG	23.176	5.094	21.98	4.169	17.99	2.762	11.92	2.229	9.62
SB	7.340	1.423	19.39	1.109	15.11	0.666	9.08	0.478	6.51
JN	14.272	1.891	13.25	1.479	10.36	0.907	6.35	0.749	5.24
WG	4.832	1.250	25.87	0.802	16.60	0.417	8.62	0.339	7.01
Total	49.621	9.658	19.46	7.559	15.23	4.751	9.58	3.794	7.65

assumed that three types of green roof system (low maintenance/lightweight type, maintenance/heavyweight type, and mixed type) could be applied. However, a common roof style of Korean traditional building is the gable roof. In this regard, it should be noted that the effect of green roof can be overestimated in this study. Fig. 1 shows the spatial distribution of buildings in the Cheonggyecheon watershed. Table 2 shows the ratios of building area to the area of individual watersheds for each scenario. Here, S-1 (over 65 m^2) represents the criteria for providing support for green roof creation set forth by the Seoul Metropolitan Government. Also, the 'building area' refers solely to the area of the building.

2.2 Runoff and Water Quality Analysis

2.2.1 Runoff and Water Quality Model

In this study, the XP-SWMM model, which is widely used for the analyses of urban watersheds, was used to analyze the improvement of water quality resulting from the green roof system in each scenario. XP-SWMM is well suited to simulate the rainfall runoff, surface and subsurface flow of pollutants, runoff from the drainage pipe network, and to estimate retention volume and pollutant treatment cost (Rossman, 2007). The impervious ratio was adjusted to reflect the rainwater retention effect in each scenario by dividing the CG sub-watershed into 52 sub-watersheds, SB sub-watershed into 24, and JN sub-watershed into 34 and WG sub-watershed into 34. In the event of rainfall, discharge of pollutants from the drainage area occurs due to the pollutant build-up prior to the rainfall and the pollutant wash-off caused by the impact of the rain on the surface and the tractive force of the surface runoff. Pollutant build-up is caused by a complex set of physical, chemical and biological processes, and it is affected by various factors such as the preceding dry period, land use status, frequency of road clean-up, and local weather phenomena. However, it is difficult to consider all of these contributing factors, and thus, in SWMM, a formula must be chosen from the power linear, exponential and Michaelis-Menten equations. Pollutant transport process involves pollutants building up during the non-raining period and later eroded and dissolved from the surface during a rainfall; the relationship can be expressed as the following exponential function (Eq. (1)) (Deletic *et al*., 1977).

$$P_w(t) = P_0(1 - e^{-W \cdot t}) \tag{1}$$

where, $P_w(t)$ is the amount of solids available on the surface at time t, P_0 is initial amount of solids, and W is the accumulation constant.

2.2.2 Event Mean Concentration by Land Use

The characteristics of pollutant runoff caused by rainfall can be represented as peak concentration, arithmetic mean concentration, peak pollutant load and total runoff load. Because there is some mixing that occurs in a water body receiving the rainfall runoff, rainfall causes a significant change in the total load rather than the concentration of individual load in the runoff. Therefore, the event mean concentration (EMC, mg/l) is considered and widely used as the most appropriate factor to assess the NPSP runoff. EMC is generally better than the arithmetic mean concentration as it takes into account the changes in the flow caused by rainfall (Kim *et al*., 2002).The correlations between the flow and water quality factors have shown close association in most of the water quality assessments. EMC was calculated by Eq. (2) (Sansalone and Buchberger, 1997).

$$EMC = \frac{\sum(Q_t \times C_t)}{\sum Q_i} \tag{2}$$

where, C_t is pollution concentration (mg/L), and Q_t is runoff (m^3/hr). EMC represents the total amount of discharged pollutants to a total runoff at a given period. This study used EMC values for five different land uses suggested by Korea National Institute of Environmental Research (KNIER) (2006) and Harper (1998) (Table 3).

2.2.3 Input Data for Rainfall Volume

In order to simulate and estimate the effect of the green roof system on the water quality in the Cheonggyecheon watershed, a representative stormwater pattern during a 1-year period is required. The Thiessen coefficient was calculated for the meteorological (rainfall) observatories located around the watershed, and it was found to be 100% at the 'Seoul' point. Also, the runoff and water quality were analyzed based on the observed hourly rainfall data, where the relative differences of the volumes of monthly mean rainfall received from 1991 to 2010 (20-year periods) were the minimum. Table 4 and Fig. 2 show the statistics of the monthly rainfall from 1991 to 2010 and the selected rainfall events. Here, when rainfall in an event was converted to the monthly-scale, rainfall events most close to the average monthly rainfall from 1991 to 2010 for individual months were respectively selected as representative events. The hourly rainfall in the representative events were implemented to XP-SWMM for each month. The simulated streamflow for the representative events were converted to the monthly-scale, and

Table 3. Event Mean Concentrations (EMCs) of BOD, TSS, TN and, TP by Land Use (mg/L)

Land use	BOD	TSS	TN	TP	Sources
Residential and Commercial	60	150	11.36	1.657	KNIER (2006)
Industrial	13.34	43	4	0.309	KNIER (2006)
Public	45	120	7.23	1.038	KNIER (2006)
Transportation	55	146	5.06	0.587	KNIER (2006)
Green and open space	1.4	8.4	1.2	0.055	Harper (1998)

Table 4. Statistics of Monthly Rainfalls During 1991-2010 and Selected Rainfall Values for Simulating Water Quality [mm]

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991-2010	Min.	2.2	1.0	3.1	8.1	16.5	15.7	114.7	68.2	4.8	0.0	10.9	2.6	
	1st Quartile	10.7	9.2	27.0	42.5	69.6	82.6	269.5	194.4	60.8	26.0	27.0	12.0	
	Average	20.8	25.0	47.2	64.5	105.9	133.2	394.7	364.2	169.3	51.8	52.5	21.5	1,489.9
	3rd Quartile	30.7	38.9	63.1	83.3	135.4	163.1	487.5	501.1	231.1	67.9	66.8	26.7	
	Max.	62.2	69.5	123.5	155.1	291.3	497.2	1014.0	1237.8	671.5	214.5	164.8	71.4	
Selected rainfall	Selected year	2008	1991	1998	2009	1999	2009	1993	1992	1992	2005	2005	2009	1,529.8 (+2.68%)
	Monthly rainfall	17.7	28.4	45.1	66.5	109.7	132.0	424.4	418.8	168.5	52.6	44.6	21.5	
	Relative difference	-1.1%	5.7%	5.0%	-5.2%	-3.5%	-0.7%	4.6%	4.9%	2.2%	4.1%	1.4%	2.7%	

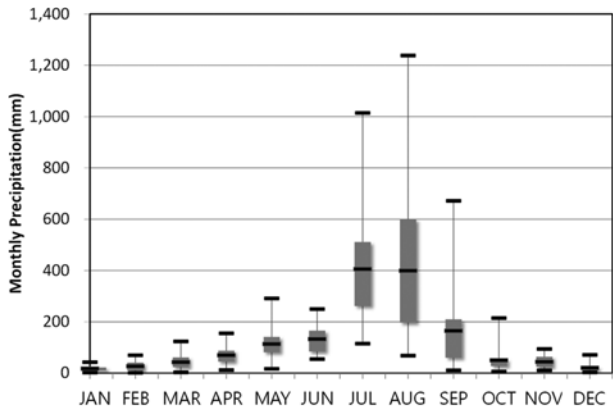

Fig. 2. Monthly Statistics of Precipitation During 20 years (1991-2000)

the yearly streamflow were calculated by the sum of the converted streamflow for all months.

3. Analysis of the Water Quality Improvement Effect of the Green Roof System

3.1 Measures to Reflect the Green Roof Scenarios

The CG watershed is a highly urbanized region, with the impervious area accounting for 59.70% of the total area, and WG watershed has a large impervious ratio of 67.27%. The upstream area of JN stream has a relatively lower impervious ratio of 42.86% as it is adjacent to the eastern part of Mt. Bukhan, but the mid- and downstream areas are concentrated with buildings. As shown in Fig. 1, the impervious area is mostly comprised of buildings, and thus, the implementation of the green roof system seems appropriate for creating a pleasant urban environment and reducing the impervious area for the purpose of improving the water quality by managing the NPSP.

In order to reflect the green roof scenarios, the 2010 Seoul Urban Ecological Land Use Map available at Seoul Metropolitan Government was used, and Table 5 shows the values of the areas

Table 5. The Ratios of Individual Land Use Areas to Total Area in Each Watershed by Scenarios (%)

Scenarios		Housing	Residential-commercial complex	Commercial and office	Industrial	Public/Urban support/Special uses/Bare grounds	Transportation	Green and open spaces
CG	No GR	15.57	14.61	25.11	0.06	14.33	12.47	17.84
	S-1	8.54	8.01	13.77				42.82
	S-2	9.81	9.21	15.83				38.28
	S-3	11.75	11.03	18.96				31.38
	S-4	12.49	11.73	20.15				28.77
SB	No GR	23.77	28.23	5.20	-	11.40	6.09	25.30
	S-1	15.18	18.03	3.32				45.97
	S-2	17.08	20.28	3.74				41.42
	S-3	19.75	23.46	4.32				34.98
	S-4	20.89	24.81	4.57				32.25
JN	No GR	38.24	10.46	6.06	-	12.72	7.99	24.53
	S-1	23.29	6.37	3.69				45.93
	S-2	26.55	7.26	4.21				41.27
	S-3	31.07	8.50	4.92				34.79
	S-4	32.32	8.84	5.12				33.00
WG	No GR	50.66	17.31	9.17	0.00	10.09	6.92	5.85
	S-1	31.28	10.69	5.66				35.35
	S-2	38.23	13.07	6.92				24.78
	S-3	44.20	15.11	8.00				15.68
	S-4	45.40	15.52	8.22				13.85

of different land uses by individual watersheds and changes resulting in each green roof scenario. The lands were classified according to their uses. For the purpose of this study, the land uses were re-classified as residential-commercial land (land for housing, land for residential-commercial uses, land for commercial and office facilities), land for industrial uses, public and special lands (land for public use, land for urban support facilities, land for special uses and bare ground), land for transportation facilities, and green and open spaces. As for the green roof scenarios, only the area of the residential-commercial lands was assumed to be transformed into green and open spaces.

3.2 Effect on Rainfall Runoff and Water Quality Improvement

When the impervious surface area is reduced by applying the green roof system on buildings in a watershed, the runoff of NPSP into the stream will be reduced. Thus, accurate analysis of rainfall and runoff must be performed for the application of the XP-SWMM model. In this study, a manual trial and error method was implemented to find optimal parameters values of depth of depression storage for the hourly streamflow data measured at the Yongdu Bridge of the JN Stream on June 23 2003 (Seoul Development Institute, 2003). For this, the hourly rainfall data retrieved from the Korea Meteorological Administration (KMA) was used as input data. For the goodness-of-fit test, the root mean square error (RMSE),

Table 6. The Results of Goodness-of-fit Test

	Observed (O)	Simulated (S)	O-S	$(O-S)^2$
Total	72.630	62.002	10.628	38.547
N (# of samples)		11		
F2		3.5043		
RMSE		1.8720		
Correlation coefficient		0.9417		
Determination coefficient		0.8868		

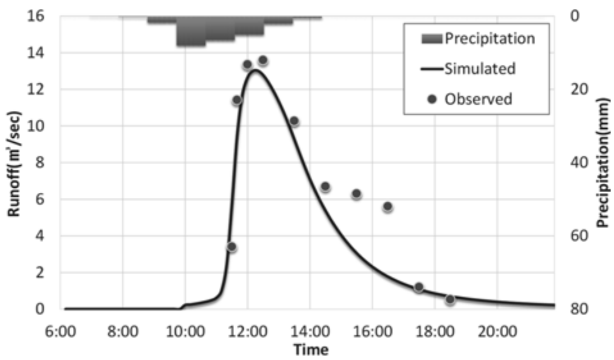

Fig. 3. Calibration of XP-SWMM

Table 7. Annual Reduction of Runoffs by Green Roofs in Each Scenario (unit: m^3)

Watersheds	Before green roof	S-1	S-2	S-3	S-4
Total	35,826,645	24,729,141 (30.98%)	26,654,912 (25.60%)	30,324,223 (15.36%)	31,402,385 (12.35%)
Downstream of SB	4,948,596	3,434,064 (30.61%)	3,773,209 (23.75%)	4,241,118 (14.30%)	4,440,854 (10.26%)
Downstream of JN	10,400,935	7,051,042 (32.21%)	7,933,549 (23.72%)	8,951,319 (13.94%)	9,205,418 (11.49%)
Downstream of WG	3,562,315	2,212,276 (37.90%)	2,691,434 (24.45%)	3,103,868 (12.87%)	3,185,975 (10.56%)

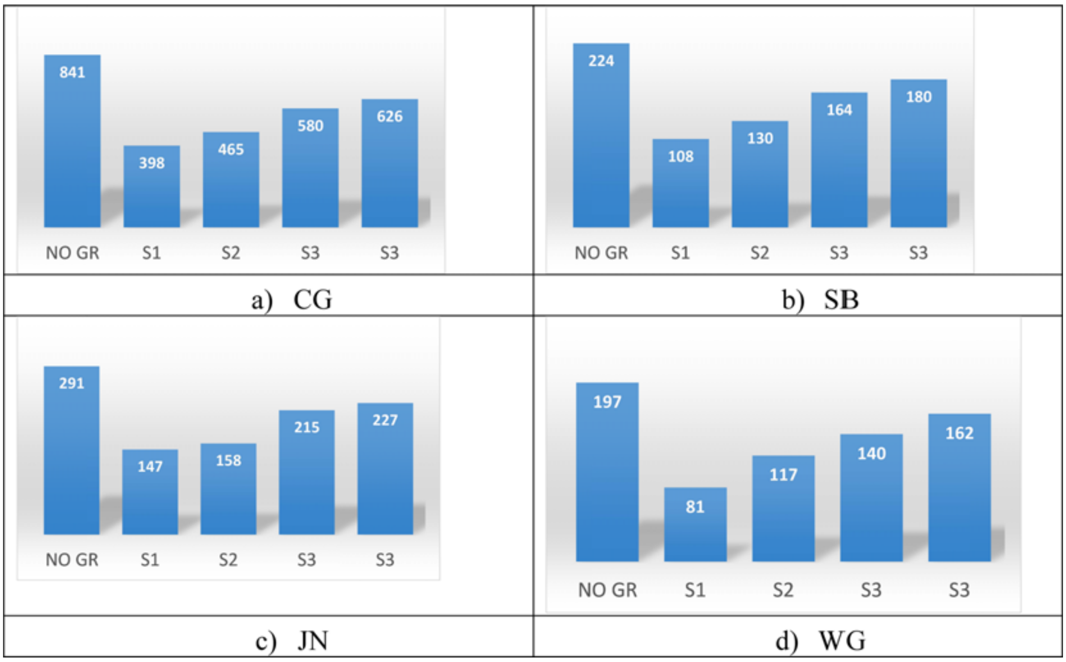

Fig. 4. Annual BOD by Green Roofs in Each Scenario (unit: kg)

Table 8. Annual Reduction of BOD by Green Roofs in Each Scenario (unit: kg)

Water-shed	Effluent before green roof	S-1			S-2			S-3			S-4		
		Effluent	Reduction	Reduction rate	Effluent	Reduc-tion	Reduc-tion rate	Effluent	Reduc-tion	Reduc-tion rate	Effluent	Reduc-tion	Reduc-tion rate
CG	840,664	398,232	442,432	52.63%	464,738	375,926	44.72%	580,222	260,442	30.98%	625,675	214,988	25.57%
SB	224,175	107,664	116,511	51.97%	129,732	94,443	42.13%	164,443	59,732	26.65%	180,364	43,811	19.54%
JN	290,879	147,133	143,746	49.42%	157,517	133,362	45.85%	214,919	75,960	26.11%	227,393	63,486	21.83%
WG	196,562	81,367	115,195	58.60%	116,512	80,051	40.73%	139,938	56,624	28.81%	162,325	34,237	17.42%
Total	1,552,280	734,396	817,884	52.69%	868,499	683,781	44.05%	1,179,226	373,054	24.03%	1,195,757	356,523	22.97%

correlation coefficient and coefficient of determination were used (Table 6 and Fig. 3). In this study, only 11 observed streamflow data for a rainfall event can be a limitation to assess prediction ability of the model. However, considering a difficulty of measurement in just the short time of 6 hour after a rainfall event, the use of 30-min interval observed streamflow data seems to capture characteristics of hydrograph for a rainfall event. In this regard, the observations for more rainfall events will help to enhance the prediction of the model for the rainfall-runoff relationship. The annual reduction effect on the runoff in each scenario is shown in Table 7. In order to reflect the green roof scenarios in the XP-SWMM model, the land uses for each scenario were changed as shown in Table 5. Although there was a need for water quality calibration, EMC for each land use shown in Table 3 was used instead due to the lack of appropriate data on the water quality of the target points. The annual reduction effect on the non-point pollutant loads, expressed in BOD, in each scenario is shown in Table 8 and Fig. 5.

4. Estimating the Benefits of Improving Water Quality with a Green Roof

4.1 Benefit Estimation

The exact value of water quality improvement by a green roof is hard to determine as other goods which are traded in a market because its characteristics are close to public goods. Thus, in order to estimate the benefits of improving water quality using a green roof, we employed the RCA from the supplier end. In this approach, the cost to produce the same effect as a green roof using an arbitrary replacement is regarded as equivalent to the economic value of the green roof system. Thus, there should be a comparable replacement to the green roof system and the investment and operation costs related to using this replacement must be included in the calculation of the replacement cost. This approach, however, is viewed as more of an engineering technique rather than an analytical method based on the concept of economic benefits as it does not take into account such as the personal utility maximization behavior.

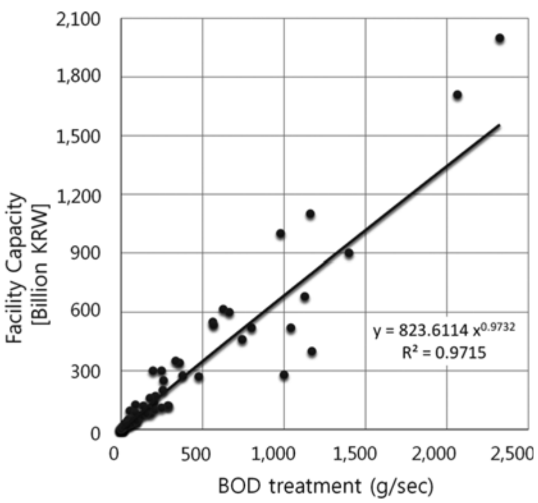

Fig. 5. Relationship between the Facility Capacity and the BOD Removal Rate

In order to achieve the same water quality improvement effect as that from installing the green roof system, the replacement facility must be able to remove the pollutants flowing into the river system. We designated a sewage treatment facility, of which the water quality improvement effects and related costs are predictable, as the replacement facility. A review has shown that the total target reduction to be achieved through the establishment and extension of sewage treatment facilities and maintenance of sewage pipes was proposed to be 74.04% in the TMDL plan of Yeoju-gun, Icheon-si, Gapyeong-gun, Jeonju-si, Iksan-si, Gunsan-si, Jeongeup-si, Gimje-si and Namwon-si.

The procedure for applying the RCA is as follows; first, analyze the water quality improvement by the green roof system and determine the capacity of the sewage treatment facilities that can produce the same effect as from the green roof. And then calculate the construction costs of the sewage treatment facility with the determined capacity. Lastly, a cash flow chart is prepared based on the durable years (economic analysis period) of the green roof system, discount rate, and maintenance costs before calculating the benefit and cost during the entire project period for a benefit-cost (B/C) analysis. The detailed procedure is described in next section.

4.2 Cost Estimation for the Replacement Facilities

4.2.1 Determining the Facility Capacity for BOD Treatment

The extent of the biochemical oxygen demand (BOD) level that needs to be reduced by sewage treatment facilities in the river basin in order to produce the same effect as the BOD reduction (mg/L) by the green roof system was calculated to estimate the required treatment capacity, taking into account the fact that the cost of operating a sewage treatment facility is proportional to its capacity. First, the annual BOD level in the target assessment area prior to the green roof project was estimated and the sewage treatment facilities were set up to produce the same change in the BOD as the project in order to calculate the extent to which the BOD needs to be reduced.

In order to determine the capacity of the sewage treatment facilities that can meet the target reduction level for each scenario in Table 8, the data retrieved from KMOE were used (KMOE, 1981-2004, 2005b, 2006-2010, 2011ab, 2012). Since the Cheonggyecheon watershed is in Seoul, the 84 sewage treatment facilities in Seoul as well as metropolitan cities and cities in Gyeonggi Province were selected for this study. Table 9 shows the capacity, BOD removal rate, total construction cost, and maintenance cost of each of the treatment facilities.

Figure 5 shows the relationship between the facility capacity and the BOD removal rate (g/s) derived based on the data on facility capacity and BOD concentrations of the influent and effluent.

$$\ln Q_{STP} = \alpha + \beta \ln R = 6.71370 + 0.97324 \ln R$$
$$Q_{STP} = 823.61138 R^{0.97324} \quad (3)$$

where, Q_{STP} (m^3/day) is the capacity of the sewage treatment facilities, and R is the BOD removal rate (*g/sec*).

Some of the loads released from the upstream are reduced by self-purification, while the rest reaches the downstream of the river. Because Eq. (3) does not consider the relationship between the total release load of the entire watershed and the amount of load that reaches the outlet of the CG stream, the delivery rate was taken into account when determining the capacity of the sewage treatment facilities. The delivery rate of Jungnang stream provided by Seoul Metropolitan Government (2007) was used.

Construction Cost for Sewage Treatment Facilities

The relationship between the facility capacity and construction cost must be understood in order to calculate the total construction cost for sewage treatment facilities. In order to determine the relationship between BOD reduction amount and total construction costs, the costs for new construction and facility extension were examined using annual data for Korean sewer system obtained from KMOE (1981-2004, 2005b, 2006-2010, 2011a, 2012). Because each sewage treatment plant differed in terms of establishment and extension periods and there was a need to reflect the economic value corresponding to the timeline to which the cost distribution was applied, the construction costs were converted to what they would have cost in late 2011 using the deflator used in the construction industry. The results of the regression analyses using the data on the 84 plants are shown in Fig. 6.

$$\ln C_c = \alpha + \beta \ln Q_{STP} = 4.10997 + 0.67340 \ln Q_{STP}$$
$$C_c = 60.9451 Q_{STP}^{0.6734} \quad (4)$$

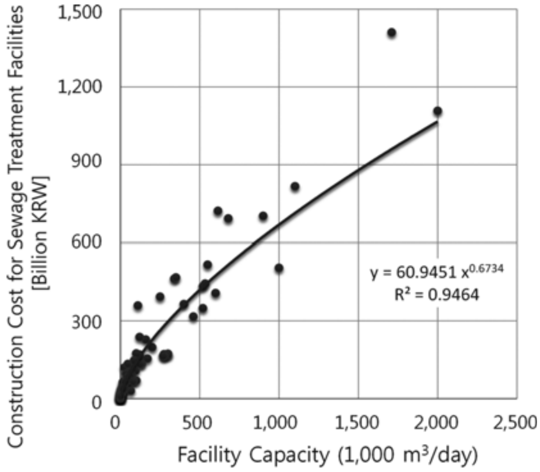

Fig. 6. Relationship between the Facility Capacity and Construction Cost

where, Q_{STP} (m^3/day) is the capacity of the sewage treatment facilities , and C_c is the construction cost (billion USD).

4.2.3 Costs for the Sewer Pipes

Different from green roof systems, sewer pipes are an essential part of a sewage treatment plant. Thus, construction and maintenance costs for the sewer pipes need to be included in the calculation of the replacement cost. Since there were no data on the sewer pipe cost for each treatment facility, the 10-year facility and pipe cost ratios from the sewerage statistics estimated by KMOE (2003-2004, 2005b, 2006-2010, 2011a, 2012) were used instead. The facility and pipe costs (facility, repair, operation, maintenance costs, etc.) were USD 14.3 billion (1 USD = 1,182 KRW) and USD 17.1 billion, respectively, as 2011 reference value. Thus, the sewage treatment facility cost was multiplied by 1.19986 to calculate the sewer pipe cost.

4.2.4 Annual Maintenance Cost for Sewage Treatment Facilities

There are costs related to the operation of sewage treatment process to maintain the water quality after the plant and pipe construction. These costs include labor, electricity, chemical supplies, sludge treatment, and repair, which are necessary for maintenance and operation of the facility. These costs must be considered in addition to the construction costs. In this study, the annual average maintenance costs were calculated using Eq. (5) which expresses the relationship of the facility capacity, QSTP, and maintenance costs, C_M (Fig. 7), of 84 treatment facilities in Table 9 in reference to a report on the water quality and maintenance cost of sewage treatment plant published by KMOE (2005c).

$$\ln C_M = \alpha + \beta \ln Q_{STP} = 0.30952 + 0.68083 \ln Q_{STP}$$
$$C_M = 1.3628 Q_{STP}^{0.68083} \quad (5)$$

where, Q_{STP} (m^3/day) is the capacity of the sewage treatment facilities , and C_M is the maintenance cost.

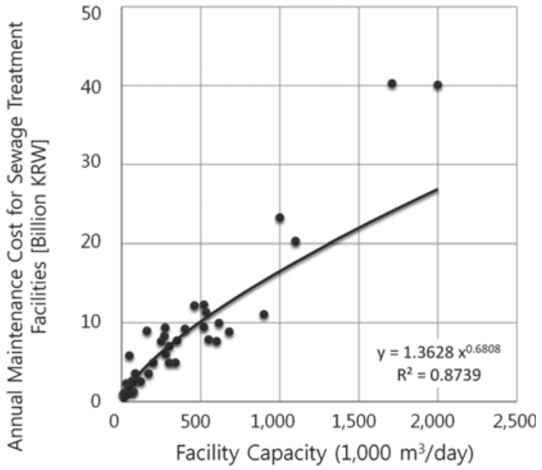

Fig. 7. Relationship of the Facility Capacity and Maintenance Costs

4.2.5 Estimation of Total Costs for the Replacement Facilities

Table 10 reports the summary of costs for the plant and pipe construction and the annual maintenance for each scenario. In addition, construction period, durable years, residual rate and major repair ratio must be considered to apply these figures to the economic analysis.

4.3 Criteria for the Economic Analysis for Benefit and Cost Determination

4.3.1 Economic Analysis Period and Discount Rate of Green Roof

The analysis period is basically an assumption for the durable years of green roof system. To establish this assumption, the lifetime of both green roof system and building on which the green roof is installed should be considered. However, as there were no data on the architectural type of the buildings in the Cheonggyecheon watershed or year of their construction, the analysis period was set as 30 years in reference to ‘the Standard Durable Years of Buildings, etc. and the Table on the Scope of Durable Years (Article 15 (3))’ of the Enforcement Regulations of the Corporate Tax Act in Korea (amended on Feb. 28, 2011) and it was assumed that the lifetime of the green roof system would be the same as that of the building.

Determining the discount rate for the future value and costs is

Table 9. Selected Wastewater Treatment Facilities Operated by Local Governments of South Korea from 1981 to 2010 (KMOE, 1981-2004, 2005b, 2006-2010)

Facilities	Capacity (/day)	Construction cost (million KRW)	BOD treated (mg/L)	Treatment amount (g/sec)	Facilities	Capacity (/day)	Construction cost (million KRW)	BOD treated (mg/L)	Treatment amount (g/sec)	Facilities	Capacity (/day)	Construction cost (million KRW)	BOD treated (mg/L)	Treatment amount (g/sec)
Jungnang	1,710,000	1,410,789	137.5	2,065.0	Gwangju (2)	120,000	158,783	264.7	291.0	Siwha	279,000	162,565	373.4	1,000.5
Tancheon	1,100,000	816,790	129.1	1,161.2	Guryong	45	1,085	93.7	0.0	Neunggok	7,000	21,198	295.2	12.0
Seonam	2,000,000	1,107,990	119.1	2,325.0	Geumgok	110	368	200.3	0.1	Daeya	5,000	31,382	194.5	4.5
Nanji	1,000,000	504,465	131.4	979.2	Hwaam	60	442	647.4	0.4	Bugok	4,500	17,692	204.6	5.2
Jungang	120,000	2,547	128.0	136.5	Kasam	45	538	159.2	0.1	Uiwang	15,000	45,665	111.4	18.2
Yeongdo	95,000	107,320	122.4	54.1	Kasam	45	814	133.0	0.1	Giheung	50,000	74,306	185.4	71.5
Suyeong	550,000	516,536	140.0	563.2	Yongyeon	250,000	392,914	89.9	260.6	Gugal	35,000	96,677	232.7	84.8
Gangbyeon	615,000	722,095	134.7	626.7	Bangojin.	100,000	174,516	161.4	205.2	Suji	110,000	359,120	213.0	248.1
Nambu	340,000	462,261	101.3	358.8	Geumcheon	70	611	165.2	0.1	Sanghyeon	13,000	43,113	195.9	13.2
Noksan	80,000	129,438	218.3	180.8	Suwon	520,000	432,811	145.5	800.7	Gomae	6,200	31,159	225.5	11.7
Dongbu	135,000	135,243	145.9	201.5	Seoho	47,000	133,611	178.9	76.9	Seocheon	7,800	33,411	170.6	4.9
Haeundae	65,000	30,505	229.5	106.3	Seongnam	460,000	316,488	189.5	743.5	Cheon-ri	9,000	23,383	210.7	7.6
Seobu	15,000	55,146	116.3	9.3	Pangyo	47,000	80,861	215.9	58.4	Namsa	2,000	18,000	162.2	2.7
Sincheon	680,000	692,703	213.0	1,126.8	Bakdal	300,000	173,208	93.0	195.0	Songjeon	2,300	14,575	204.4	4.7
Seobu	520,000	348,949	237.9	1,041.9	Seoksu	300,000	168,030	107.7	247.8	Wonsam	430	6,742	194.7	0.5
Dalseocheon	400,000	364,385	451.8	1,170.7	Gulpo	900,000	702,528	156.7	1,398.3	Baegam	3,000	21,040	165.2	2.9
Bukbu	170,000	154,080	149.6	210.2	Yeokgok	50,000	100,971	106.8	44.5	Chugye	1,000	11,716	162.2	0.6
Ansim	47,000	90,356	193.2	91.5	Tongbok	75,000	70,507	143.7	97.4	Dongbu	800	9,740	178.5	0.6
Jisan	33,750	73,517	209.6	53.4	Jangdang	65,000	83,855	129.5	93.3	Mohyeon	16,000	63,972	97.5	14.5
Gajwa	350,000	467,467	113.9	334.8	Ansan	534,000	443,706	120.0	567.5	Yeongdeok	13,000	42,993	226.6	16.0
Seunggi	275,000	171,566	151.1	377.8	Dongducheon	86,000	146,952	90.1	85.1	Yongin	48,000	68,610	214.6	94.5
Namhang	125,000	133,263	87.9	87.5	Gwacheon	30,000	63,198	173.1	47.5	Geumchon	27,000	38,607	207.9	60.0
Gongchon	26,000	119,997	169.1	55.9	Guri	160,000	227,515	105.3	177.0	Anseong	17,500	38,158	142.9	38.0
Unbuk	12,000	20,590	169.1	11.7	Jingeon	100,000	69,529	132.6	160.2	Icheon	43,000	82,587	228.1	95.9
Geomdan	40,000	98,324	94.9	35.6	Gaun	4,000	21,245	310.2	8.9	Uijeongbu	200,000	198,146	145.7	256.4
Mansu	70,000	92,112	162.9	126.5	Jinjeop	14,000	42,928	207.3	17.4	Wonneung	80,000	66,302	201.2	153.8
Songdo	30,000	57,432	161.7	39.8	Osan	121,000	237,682	221.9	287.4	Byeokje	30,000	66,117	102.1	24.2
Gwangju (1)	600,000	407,007	103.0	664.2	Sema	8,300	36,100	259.4	12.0	Ilsan	270,000	164,495	229.5	476.7

Table 10. Construction and Maintenance Costs of Wastewater Treatment Facilities as Replacement Facilities in Green Roof Scenarios

Scenarios	Annual reduction of BOD (kg/yr)	Treatment rate (g/s)	Treatment capacity (m^3/day)	Construction cost (million KRW)			Annual maintenance cost (million KRW)
				Treatment plant	Sewer system	Total	
S-1	817,884	56.380	41,686	78,711.8	94,442.3	173,154	1,904.2
S-2	683,781	47.136	35,018	69,995.1	83,983.6	153,979	1,691.2
S-3	452,758	25.716	23,444	53,422.1	64,098.6	117,521	1,286.9
S-4	356,523	24.577	18,580	45,678.0	54,806.7	100,485	1,098.5

especially important in the economic feasibility analysis of the green roof project. Discount rate is the rate applied to make the future value equivalent to the current value. The current value, in this case, means the value of the cash flow in the future that is converted into the present-day monetary value. Determining whether the project is feasible or not heavily depends on the discount rate applied. Inappropriate discount rate may cause the validity of the project to be degraded. Therefore, it is essential to determine and apply an appropriate discount rate. However, because there are no official guidelines on the discount rate for a green roof project, the discount rate of 5.5% suggested by Korea Development Institute (KDI) (2008) was adopted.

4.3.2 Determining the Durable Years, Residual Rate and Major Repair Ratio of the Replacement Facilities (Sewage Treatment Facilities)

Sewage treatment plants, chosen as the replacement facility for this study, typically have a short lifetime due to their nature of treating contaminants and are comprised of various civil, electrical and machinery structures and components. Thus, the durable years of the sewage treatment plants, over which the cost is distributed, as well as repair costs, which is required until the end of the durable years, should be considered. The durable years of the sewage treatment plants were set following 'the Standard Durable Years Prescribed by the Decree of the Ministry of Strategy and Finance' in the Enforcement Decree of the Corporate Tax Act (amended on March 31, 2008) and 'the Scope of the Durable Years Prescribed by the Decree of the Ministry of Strategy and Finance'. Table 11 shows the application criteria for the proportion of cost, durable years, and large-scale repair ratio for each construction area of a sewage treatment plant. The durable years and construction period of sewage treatment facilities were set as 20 years and one year, respectively, based on the criteria. Also, considering the proportion of construction cost in each field, total period for large repairs was assumed as 10 years, which is same as the durable years of the major structures. As the ratio of the total sum of large repair costs to the total construction cost is 43.35%, we assumed that 43.35% of the total construction cost would necessarily be spent for large repairs in 10 years after the initial construction in order to maintain the facility for a total of 20 years.

Table 11. Factors of Major Components in a Sewage Treatment Plant Applied for Economic Analyses

Components	Portion in construction cost	Durable years	Ratio of major repairments
Machinery	26	14	26
Electricity	15	14	15
Instruments		10	
Civil	38	10	0.05
Architecture	17	10	2.3
Landscape	4	-	-

4.4 Estimating the Benefits of Improving Water Quality with a Green Roof

Although green roof projects are implemented by private sectors, their effects are essentially public and the local government agencies provide substantial amount of financial subsidies for the projects. Thus, we assumed a green roof project as a public project. Economic analysis of public projects is to analyze the feasibility of the project in the aspect of public economy. For this purpose, various benefits and costs that are expected to arise from the project are estimated and economic feasibility is assessed using economic indicators such as NPV, internal rate of return, and benefit-cost ratio.

In order to estimate an approximate overall project cost for each scenario, the costs for the construction, maintenance, and facility improvement of the green roof facility are required. Also, discount rate, service life, and residual value are considered for the estimation of the overall cost. A sensitivity analysis of the impact of varying discount rates on the economic feasibility was carried out to reduce the error in the estimates used in the economic analysis. The discount rate of 5.5% for 30-years term was used to calculate the benefits and costs shown in Table 12. The total benefits for each scenario over the course of 30 years starting from late 2011 were estimated to be United States Dollars (USD) 257.3 million, USD 228.8 million, USD 174.6 million, and USD 149.2 million, respectively.

Of the diverse benefits resulting from installing the green roof system, only the water quality improvement effect was considered in this study. Therefore, it is impossible to perform an economic (B/C) analysis to its full extent. In order to do this, all the effects

Table 12. Estimated Benefits After the 30 years of Green Roof Installation by Each Scenario

Scenarios	S-1	S-2	S-3	S-4
Maintenance cost (million KRW)	1,904.2	1,691.2	1,286.9	1,098.5
Total benefits (million KRW)	304,118	270,408	206,327	176,390

Table 13. Sensitivity Analyses of Benefits by Different Discount Rates (million KRW)

Scenarios	Discount rate					
	3.5%	4%	4.5%	5%	5.5%	6%
S-1	348,411	335,817	324,304	313,769	304,118	295,270
S-2	309,788	298,590	288,354	278,988	270,408	262,541
S-3	236,368	227,826	220,017	212,872	206,327	200,326
S-4	202,069	194,767	188,093	181,985	176,390	171,260

arising from the green roof system must be estimated and summed as benefits and be divided by the total cost as mentioned above. However, as shown in Table 13, benefits generally vary depending on the discount rate applied.

5. Conclusions

Economic analysis is typically performed to determine the validity of a project in the economic perspective by assessing its economic feasibility. Compared to cost estimation, benefits are more difficult to estimate because all the utilities of the project must be monetized. In this study, the RCA was applied to estimate the benefit of water quality improvement resulting from the reduction of the nonpoint pollutant sources by green roof systems. Water quality before and after project implementation for each scenario was analyzed. In order to estimate the cost of the replacement facility, the data on the sewage treatment facilities in selected cities and districts were obtained to derive the relationships between the amount to treat versus facility capacity, facility capacity versus facility construction cost, facility construction cost versus pipe construction cost, and facility capacity versus maintenance costs. Also, the economic analysis period for the green roof project and discount rate were determined, by which the total benefits arising until the end of the durable years were estimated.

The limitations of this study can be stated as follows. A finding of this study was that green roofs would improve water quality be reducing BOD. However, there were recent studies suggesting that green roofs can be a source of pollutants (Emilsson *et al.*, 2007; Hathaway *et al.*, 2008; Toland *et al*., 2012; Speak *et al.*, 2014). This is a limitation in this study which excluded pollutants from green roofs due to lack of data. In this regard, the economic benefit estimated in this study can be reduced by pollutant from green roofs. The more detailed measurement for pollutant from green roofs is required to better estimate accurate economic benefit of green roof installing. On the other hand, the benefits from green roof systems proposed in this study may be underestimated because cost to reduce the same amount of non-point pollutant sources via the replacement facilities, which is for treating point pollutant sources, would cost lesser than green roof systems. Despite this issue, however, sewage treatment plants are the only type of facility on which there are sufficient data regarding water quality improvement, making them the most appropriate choice as a replacement facility. Also, the water quality analysis was only limited to BOD in this study; however, various other factors such as total nitrogen (T-N) and total phosphorous (T-P) are needed to determine the water quality improvement effects and the costs of the replacement facility, and use the results to estimate the benefits with more accuracy. With the accumulation of data on water quality and flux, and the use of these data for verification and supplementation of the water quality analysis, it is expected that analyzing the effects of the green roof system on decreasing NPSP across the seasons will be possible.

As a case study, of the Cheonggyecheon watershed area of the Jungnang stream passing through Seoul, green roof scenarios were set at the CG sub-watershed with an urbanization ratio of over 70%. The reduction of NPSP resulting from the green roof system was analyzed using the XP-SWMM model and the cost of the replacement facilities was calculated. Also, the durable years of the green roof system and the sewage treatment facilities, selected as the replacement facilities, were set as 30 years and 20 years, respectively, and it was assumed that 43.35% of the total construction cost would be spent toward large repairs in 10 years after the initial construction in order to maintain the facility for a total of 20 years. Also, a discount rate of 5.5% was applied for a 30-year term to calculate the current value and estimate the benefits. With the aforementioned conditions, the benefits resulting from those scenarios were estimated to be United States Dollars (USD) 257.3 million, USD 228.8 million, USD 174.6 million, and USD 149.2 million, respectively.

The methodology proposed in this study is expected to ensure the validity of the recent projects carried out by the local government agencies to expand green roof projects as a means to induce more efficient green roof projects and resolve the various problems arising from urbanization. In addition, the information on water quality improvement obtained through the benefit estimations can be provided to decision-makers to allow them to make better decisions. Furthermore, because green roof projects require a massive budget and the feasibility of the project is heavily dependent on the financial capacity of local government agencies, this methodology can be applied to clarify the areas benefiting from the project in order to assign the burden of cost to the appropriate parties and facilitate the process of the central and local governments for a mutual agreement.

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