International Journal of Hybrid Information Technology
Vol. 9, No.8 (2016), pp. 161-172
http://dx.doi.org/10.14257/ijhit.2016.9.8.15

The Analysis of Stormwater Runoff Quality and Quantity of Water Cycle Sidewalk using Low Impact Development Technologies in Urban Areas

Daehee Lee[1], Jung-hun Lee2 and Reeho Kim[1,2]*

[1]*Construction Environmental Engineering,*
Korea Institute of Civil Engineering and Building Technology Campus,
University of Science and Technology,
283, Goyangdae-ro, Ilsanseo-gu, Goyang-si, Gyeonggi-do, Republic of Korea
[2]*Environmental & Plant Engineering Research Institute,*
Korea Institute of Civil Engineering and Building Technology,
283, Goyangdae-ro, Ilsanseo-gu, Goyang-si, Gyeonggi-do, Republic of Korea
daehee1212@ust.ac.kr, junghun3@kict.re.kr, rhkim@kict.re.kr
** Corresponding author*

Abstract

LID facilities on the green area-sidewalk-road in cities can be applied in different types and forms according to the status and characteristics of a space. There are some limitations of using LID facilities with respect to area, these limitations can overcome by using the suitable combination of LID practices in an area. For this purpose, the Water Cycle Sidewalk (WCS) was used through the connections of various LID techniques. The WCS could manage stormwater runoff and water quality in a space adjacent to green area-sidewalk-road as a part of WCS, a permeable block pavement (PBP) was installed on the sidewalk, and a vertical infiltration pipe (VIP) and an infiltration-storage tank were located underneath the PBP. Runoff on the sidewalk was pre-treated by a first flash treatment facility and then stored in a storage tank for watering the green area. The average infiltration capacity of a PBP with a storage tank under the pavement was 0.30 mm/sec, about 6 times higher than that of a general PBP section. From the results, the infiltration capacity of a single VIP was approximately 0.35 mm/sec. The overall efficiency rate of runoff reduction from this facility was between 50% and 70%. In addition, the rainwater in the Storage Tank analyzed to be appropriate to use water for landscaping.

Keywords*: Low Impact Development (LID), Water Cycle Sidewalk (WCS), Permeable Block Pavement (PBP), Vertical Infiltration Pipe (VIP), Storage Tank, Stormwater runoff*

1. Introduction

Increased impervious surface in urban area interrupts the infiltration of stormwater and increases the amount of runoff. This leads to the excess of sewage disposal capacity, which causes floods in the urban area, and the contamination of runoff due to the nonpoint pollution source on the road environment [1]. Low Impact Development (LID) is capable of managing the quantity and quality of stormwater runoff in the early stage of its development. However, there are spatial limitations to the installing additional facilities for controlling the excessive runoff and contaminated water in the concentrated urban area, due to the existing infrastructure [2]. Moreover, methods of LID applied to the urban area could vary, depending on its spatial form. However, the spatial form and purpose of each space can also lead to the limitations of LID facilities. Porous pavement, due to issues regarding the durability, can be difficult to maintain, while a large amount of

ISSN: 1738-9968 IJHIT

contaminated runoff occurs on common roads [3, 4]. In addition, the porous pavement might not be so effective in areas with large portions of artificial grounds or high clay contents. Since the soil erosion in greens can cause the clogging of porous blocks in PBP interval connected with green area, plans for maintaining the efficiency of porous blocks are required [5, 6]. Likewise, there are different problems for the application of LID methods, based on the characteristics of each space. Therefore, in order to make up for the issues regarding the space comprising green area, sidewalk, and roads, a new design for linking LID installations which respectively perform different functions. In this study, in order to resolve such problems, a sidewalk system, which links different kinds of LID technologies, designed on a space where the green, sidewalk, and road are connected. The WCS be also capable of managing the quantity and quality of rainfall runoff, it is also is applied, to assess the capabilities to control stormwater runoff and water quality on sidewalks and roads.

2. Materials and Methods

2.1. Structure and Principles of Water Cycle Sidewalk (WCS)

The concept and design of the water cycle sidewalk (WCS) is as shown in Figure 1. This element comprises PBP; Infiltration-Storage Tank; VIP; Protective Panel for Banded Green Area; First Flash Treatment Facility; Storage Tank; and Rainwater Utilization Device. The stormwater on the sidewalk infiltrates the soil through PBP, and is stored into the Infiltration-Storage Tank installed beneath the sidewalk when the soil is saturated. The water stored inside the Infiltration-Storage Tank overflowed to the Storage Tank, when exceeding a certain level. Rainfall runoff first infiltrate through the porous blocks, and then the excess rainfall runoff also infiltrates through the VIP, which helps to avoid the flash flooding in urban areas. The Protective Panel for Banded Green Area prevents soil erosion. The runoff from the surface is collected through the runoff inlet, and flows into the Storage Tank via the First Flash Treatment Facility. The stored water inside the Storage Tank can also use for gardening to the nearby green areas. When the water level inside the Storage Tank reaches a certain level, the water overflows to the rainwater pipe.

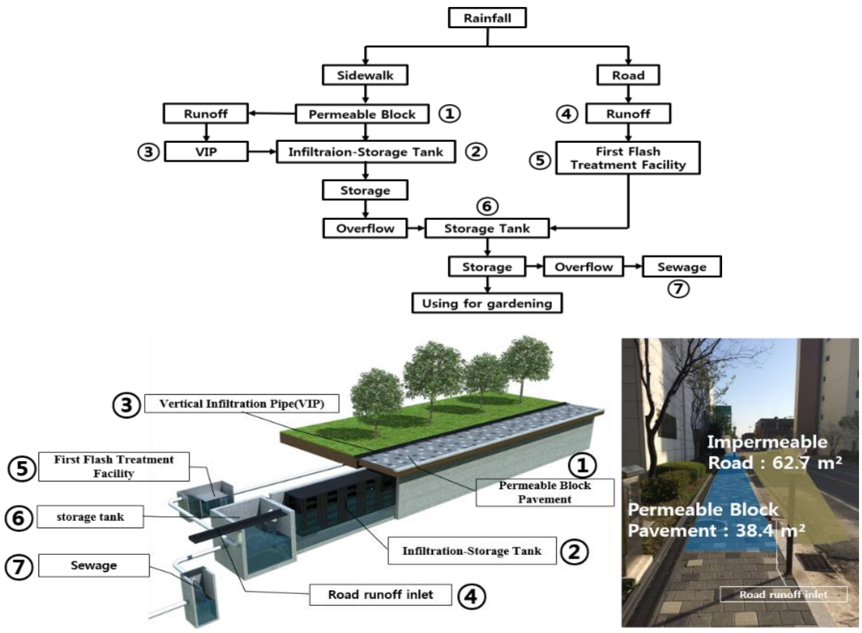


Figure 1. Overview of Water Cycle Sidewalk (WCS)

In this study, to evaluate facility's capacity for controlling the quantity and quality of stormwater runoff, the respective elements including the infiltration capacity of porous blocks, infiltration capacity of VIP, capacity for collecting road runoffs were analyzed. Especially, the evaluation of porous blocks infiltration capacity separately performed for the interval installed with the storage tank beneath, and the other without the installation. The performance for controlling stormwater runoff against comprehensive scenarios evaluated through the same concept. In addition, the quality of stormwater was checked before and after entering the first flash treatment facility for the analysis of its treatment efficiency. To analyze the amounts of inflow and outflow of stormwater on the surfaces of road and sidewalk, total four rainfall events that occurred from April to May 2016 were utilized. The catchment area comprises: 72 m^2 of road; 27 m^2 of permeable block pavement; and 2.7 m^2 of VIP that sum up to the total surface area of 101.7 m^2. The respective capacities of infiltration-storage tank, first flash treatment facility, and storage tank are 12 m^3, 0.13 m^3, and 1 m^3. A drainage hole, through which the water overflows to the collecting well, installed at the height of 70 cm inside the storage tank. Rainfall data was derived from the rain gauge installed on WCS. This system was installed at Korea Institute of Civil Engineering and Building Technology (KICT), Ilsan, Korea.

Table 1. Catchment Area and Capacity of Configuration of the WCS

Division	Contents	
Water Collection Surface	Road Surface: 18 m(Distance) × 4 m(Width) = 72 m^2	Total 101.7 m^2
	PBP : 18 m(Distance) × 1.5 m(Width) = 27 m^2	
	VIP : 18 m(Distance) × 0.15 m(Width) = 2.7 m^2	
Infiltration-Storage Tank	12 m^3	
First Flash Treatment Facility	0.13 m^3	
Storage Tank	1 m^3	

2.2. Structure and Principles of Water Cycle Sidewalk (WCS)

This experiment was conducted to calculate the amount of stormwater permeation on the sidewalk in the WCS, by measuring the infiltration capacity of individual porous block on the site. In addition, random points (A1, A2) on common permeable block pavement, and the other random points of PBP (B1, B2) installed with the infiltration-storage tank underneath, were compared of their infiltration capacity. The infiltration capacity test was performed by an on-site infiltration capacity test device. The test, based on the Korea Standards Service Network (KSSN)'s KS F 2394, and the Equation (1), calculated the infiltration capacity of the porous block [7]. The on-site infiltration capacity test should be performed 24 hours after the antecedent precipitation. This experiment was conducted after four antecedent dry dates. The installation of the permeable block had been done, when the test was conducted. Two random points on the common permeable block pavement (A1, A2), and the other two points on the permeable block pavement installed with the storage tank underneath (B1, B2) were selected, and were spaced 2 m from each other, for the measurement. The water used for the test was tapped out from the water supply. The infiltration capacity was calculated by measuring the time for the infiltration of water of 200 ml volume.

Table 2. Experimental Section of PBP Infiltration Capacity

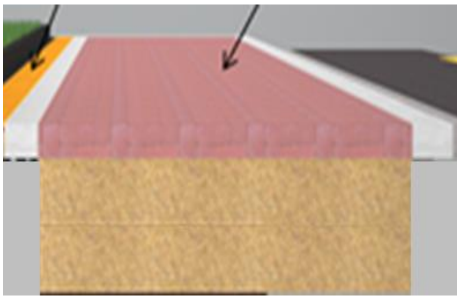
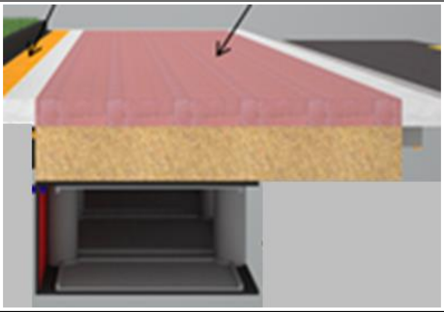
A1, A2: Common PBP area	B1, B2: PBP with Storage Tank underneath
	

Table 2. Experimental Condition of PBP Infiltration Capacity

Division	Contents	
Site Condition	- Antecedent precipitation: 47.5mm - Antecedent dry dates: 4 days ago - Avg. Temperature: 24.0 ℃ - Age of PBP: 24 months	
Experimental Method	- Measurement of permeability coefficient by on-site infiltration capacity tester - Respective 2 points at 2 areas - 3 repetition per minute at the same point - Water : 200 ml	

$$I = \frac{K \times M}{D^2 \times t} \quad (1)$$

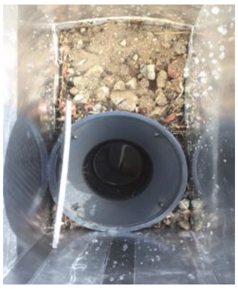
I: Infiltration capacity (mm/sec)
M: Weight of water (kg)
D: The inner diameter of the penetration ring (mm)
t: Time required to complete the infiltration (sec)
K: Unit conversion coefficient, 1273240.56 (mm^3/kg)

2.3. Measuring the Infiltration Capacity of Vertical Infiltration Pipe

The vertical infiltration pipe infiltrates stormwater runoff occurring on neighboring sidewalks or greens, by expanding the porosity of soil. In this experiment, the infiltration capacity of a single vertical infiltration pipe per unit area was measured, in order to calculate the amount of infiltration that can be handled by the vertical infiltration pipe of the WCS. The experiment was performed with an impermeable rectangular storage plate that can include a single water supply pipe. Depending on the existence of the infiltration-storage tank of the WCS, the interval was divided for comparison. The method observed the on-site infiltration capacity test according to ASTM C 1701, and used Formula (2) for the calculation. Details of the test are as below [8].

Prior to the main of the test, a pre-wetting of the surface was conducted. Water was injected from both sides from the center of the road by water supply pipes, until the occurrence of infiltration water (Amount of water used: 3.6 kg). The amount of constant water supply differed to 5 kg, and 10 kg, until the height of imminent overflow. In both cases, the antecedent precipitation occurred 24 hours before.

Table 3. VIP Infiltration Capacity Test Area

Area without VIP	Area with VIP
	
	

$$I = \frac{K \cdot M}{a \cdot b \cdot t} \tag{2}$$

I: Infiltration capacity (mm/sec)
M: Weight of water (kg)
a: Width of waterproof wall (mm)
b: Length of waterproof wall (mm)
t: Time required to complete the infiltration (sec)
K: Unit conversion coefficient, 1273240.56 (mm^3/kg)

2.4. Calculating the Runoff Reduction Efficiency of the WCS

The runoff reduction efficiency of the WCS was calculated by comparing the total catchment with the amount of storage and infiltration. The storage hereby refers to the amount of water stored inside the Storage Tank, while the infiltration refers to the infiltration capacity of porous block (area B) and VIP multiplied by the area. Since the stormwater inside the Infiltration-Storage Tank under the sidewalk is fully permeated, and no water is observed as the overflow to the Storage Tank, the infiltration and storage of the Infiltration-Storage Tank does not apply in this case.

WCS runoff reduction efficiency (%) = {(stormwater storage + stormwater infiltration)/total catchment} Ｘ 100 (3)

Total catchment = rainfall Ｘ (VIP area+ PBP area + road area) (4)

Stormwater storage = Storage Tank cross-section Ｘ increased water level (5)

Stormwater infiltration = (PBP infiltration capacity Ｘ PBP area) + (VIP infiltration capacity Ｘ VIP area) (6)

2.5. Water Quality Analysis of WCS Storage Tank

The stormwater stored inside the Storage Tank is used as gardening the nearby green area. The water is filtered by four wooden vertical filtering plates. The water should be determined of its suitability as the gardening water. However, there is no legal standard for the quality of stormwater use. The 'Guidelines for the design and maintenance of water recycle facility', enacted in 2013 by the Ministry of Environment and composed by the Korea Water and Wastewater Works Association, exist as the only suggestion for the recommended water quality standard [9]. According to the guidelines, it is recommended, that the removal of factors which can influence the aesthetic aspects of water (pH, turbidity), and the securement of microbiological soundness (total colon bacillus group) are required, when considering the procurement of favorable quality of the stormwater. Thus, in this study, the guidelines were referred to as the standard for determining the suitability of stormwater inside the Storage Tank as the gardening water. The guidelines were compared with one of the legal standards for water quality, the gray water quality standard.

When the antecedent precipitation occurred more than 3 days ago, the water inside the Storage Tank was sampled, on March and May 2016, for the measurement of water quality regarding pH, turbidity, chromaticity, total colon bacillus group, SS, T-N, T-P, and heavy metals (Cu, Fe, Zn and Pb). Also as a reference, the analyzed items were compared with the standard of treated sewage reuse and graywater quality standard.

3. Results

3.1. Infiltration Capacity of PBP

In the case of area A, there was no difference between the points A1, and A2. The infiltration capacity of the permeable block in the first experiment was 0.06 mm/sec, which was below the infiltration capacity standard of the Seoul (0.1 mm/sec). The average infiltration capacity of blocks in the area A 24 months after the installation was 0.05 mm/sec, which also did not follow up the infiltration capacity of the city's Standard. Area B, the target site of the present study showed a decrease in its PBP infiltration capacity as the trials of experiment progressed. Area B also showed no difference between the points B1, and B2. The infiltration capacity at point B1 in the first experiment was 0.43 mm/sec, which was approximately 4 times higher than the acceptable standards. The infiltration capacity in the second trial was 0.29 mm/sec, which showed a 34% decrease from the first one. In the third experiment, the infiltration capacity was 0.20 mm/sec, a 53% decrease in comparison with the first result. The infiltration capacity at point B2 was measured as 0.41 mm/sec in the first experiment, and was decreased by 30%, and 57% respectively in the following experiments. The average infiltration capacity of porous blocks in area B was 0.30 mm/sec, which was 3 times higher than the standards of the city of Seoul. Moreover, the average infiltration capacity of the porous block was 6 times higher in area B, then area A.

Table 4. Infiltration Capacity of PBP Installed in Accordance with the Infiltration-Storage Tank

(mm/sec)	A1	A2	B1	B2
1	0.06	0.06	0.43	0.41
2	0.05	0.05	0.29	0.29
3	0.04	0.04	0.20	0.17
Average	0.05	0.05	0.31	0.29
	0.05		0.30	

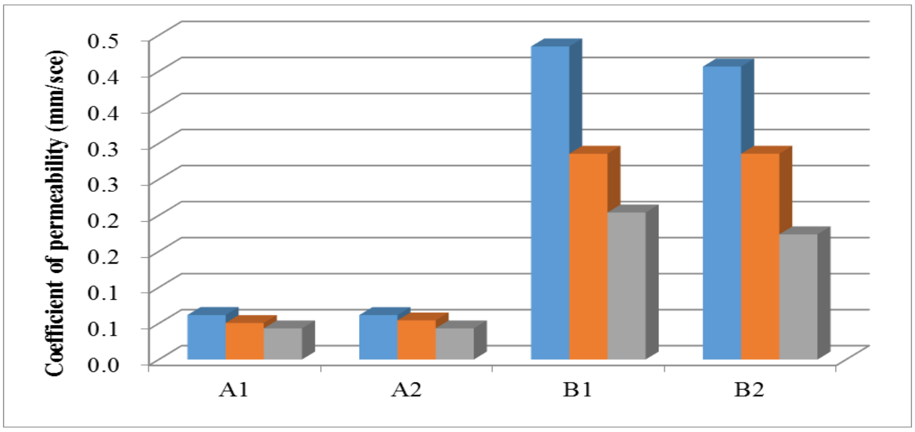


Figure 2. Coefficient Permeability of PBP In Accordance with Each Section

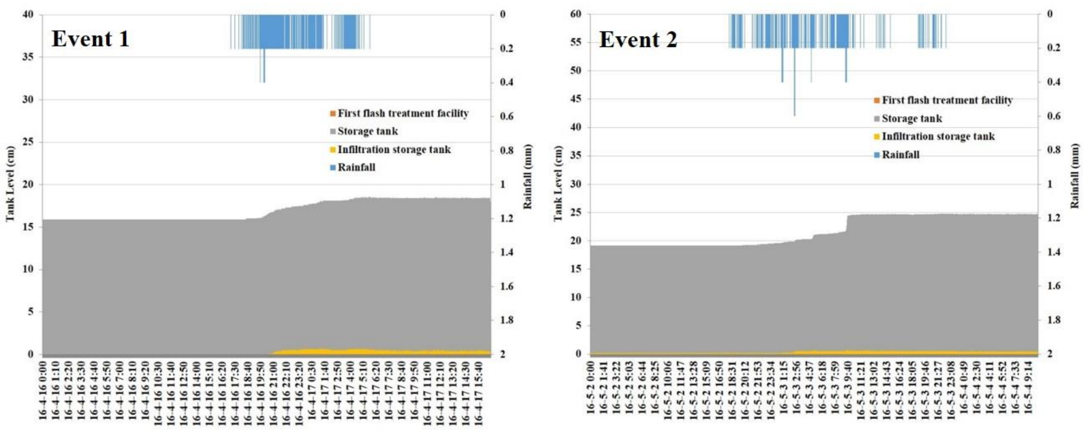
3.2. Infiltration Capacity of VIP

Water of 3.6 kg (prewetting), 5 kg and 10 kg was poured to areas with the VIP and without the VIP. As a result, the infiltration capacity (mm/sec) of one VIP was measured to be about 0.24~0.45 mm/sec, and the average of infiltration capacity was 0.35 mm/sec. That the capacity was higher than about 33.6% compared to the non-installed VIP. The infiltration capacity experiments of VIP were carried out on the same day as the experiments of PBP.

Table 5. Infiltration Capacity Installed in Accordance with the VIP

	Infiltration capacity (mm/sec)		Hours required to complete infiltration (sec)	
	Non-installed VIP	Installed VIP	Non-installed VIP	Installed VIP
Prewetting (3.5 kg)	0.56	0.64	203.26	185.27
1st (5 kg)	0.26	0.45	653.97	376.50
2nd (10 kg)	0.18	0.24	1852.43	1395.11

3.3. Runoff Reduction of WCS



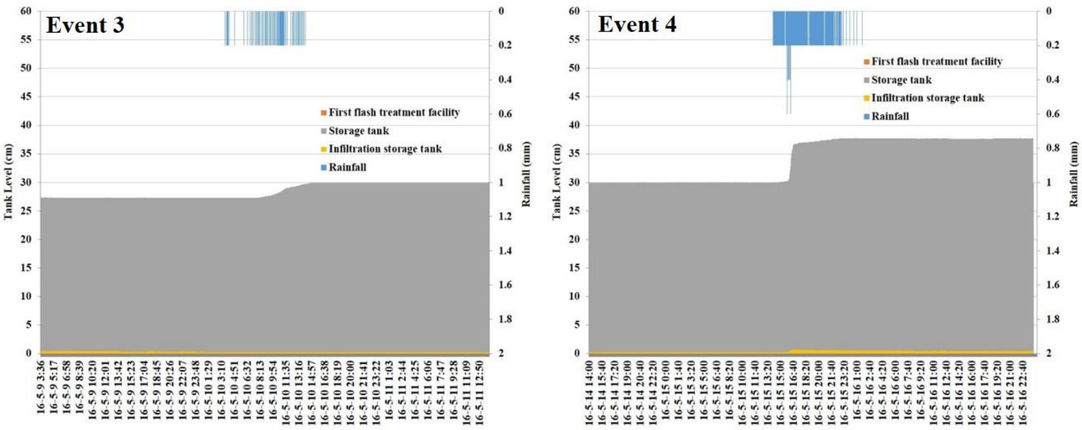


Figure 3. Variation of Water Levels in the WCS Depending on the Rainfall Depth

Table 6. Runoff Area and Amount of Collected Water: Total Catchment Area on the Road (M^2): 101.7

	rainfall (mm)	Max. rainfall intensity (mm/hr)	Total runoff (m^3)	Infiltration and storage (m^3)	Runoff reduction efficiency (%)
Event 1	55.2	10.6	3.9	2.1	53.7
Event 2	80.8	11.8	5.8	3.3	57.9
Event 3	13.4	2.6	1.0	0.7	69.0
Event 4	49.2	13.8	3.5	2.3	64.3

The infiltration capacity of PBP and VIP was sufficient for the accommodation of rainfall Event 4. Therefore, in both PBP and VIP, the infiltration mostly occurred. The water level change inside the storage-infiltration tank under the PBP ranged from 0 to 5 mm, which indicates that the stormwater infiltrating the PBP was not stored and infiltrated to the underground. Since the stormwater runoff on the road surface directly passes through the First Flash Treatment Facility, parts of the runoff are lost or causes temporary flux, which in turn trigger the overflows. The overall runoff reduction of the WCS turned out to be 53 to 69% efficient.

4.1. Water Quality

The water quality of the water inside the Storage Tank was analyzed when there was no antecedent precipitation for more than 3 days, in March and May of 2015. Affiliations are centered, italicized, not bold. Include e-mail addresses if possible.

Table 7. Recommended Water Quality for Rainwater Recycle Facility, and Water Quality of Storage Tank

Items for analysis	Non-drinkable		Rainwater Quality	
	Human body contact ＊	Noncontact ＊＊	March	May
pH	5.8~8.5		8.05	7.97
Turbidity (NTU)	Below 5	Below 2	0.61	0.68
Total colon bacillus group	-	Undetected	0	2

⁎ Non-drinkable water: WC cleaning, gardening, spraying, cleaning, laundry, agricultural, industrial, stream maintenance, *etc*.

⁎⁎ Drinkable water: fountains, anti-spattering, *etc*.

Table 7. Storage Tank Quality Comparisons between Stormwater, Greywater (Cleaning), and Standards for Wastewater Reuse (Waterfront)

Water Quality Constituents	Unit	Graywater (Cleaning water)	Treated Sewage Reuse (Waterfront)	Rainwater in the Storage Tank (March)	Rainwater in the Storage Tank (May)
pH	-	5.8~8.5	5.8~8.5	8.05	7.97
SS	mg/L	-	-	15.5	18.0
BOD	mg/L	Below 10	Below 3	-	-
COD	mg/L	Below 20	-	-	-
DO	mg/L	-	Above 2	-	-
Turbidity	NTU	Below 2	Below 2	0.61	0.68
Combined Residual Chlorine	mg/L	Above 0.2	-	-	-
Chromaticity	Degree	Below 20	Below 10	9	8
T-N	mg/L	-	Below 10	1.28	0.47
T-P	mg/L	-	Below 0.5	0.068	0.061
Total Colon Bacillus Group	MPN/100mL	Undetected	Undetected	Undetected	2
Electric Conductivity	uS/cm	-	-	-	-
Fe	mg/L	Standards for drinkable water Below 0.3		0.02	0.023
Cu	mg/L	Standards for drinkable water Below 1		Undetected	Undetected
Pb	mg/L	-		Undetected	0.0008
Zn	mg/L	Standards for drinkable water Below 3		Undetected	Undetected

-: Measurement of standards N/A

Compared with the recommendations cited on the guidelines for the design and maintenance of water recycle facility, the quality of water stored in the storage tank on March can be determined suitable for both the human body contact, and noncontact uses. Also, compared with the graywater quality standard (for cleaning water), and wastewater reuse quality standard (for waterfront space), the water quality met all the legal standards, except for the total colon bacillus group on May.

The above results could be utilized for the determination of water inside the Storage Tank for its use as the gardening water. The water can also be used for cleaning water closets, roads, *etc*.

6. Conclusions

The runoff reduction efficiency of WCS in complex scenarios was 53-69%, indicating the system's effectiveness for controlling stormwater runoff. Moreover, the infiltration capacity on the PBP area equipped with storage tank was approximately 1.5 times higher than that of common PBP area. Consequently, the utilization of underground space on sidewalk area that shows low infiltration performance can improve the infiltration capacity of the permeable blocks. In addition, through appropriate combinations of VIP and PBP, a spatially efficient runoff control on the sidewalk area can be materialized.

The quality of the water inside the storage tank was determined as suitable for its use as the gardening, and cleaning water. Further studies regarding the dimensions of storage tank and catchment basin are required, as well as the design for increasing the runoff collection on the road surface. Based on the achievement of the present study, more various studies are required for resolving the urban issues of flooding, and ponding on sidewalks, at the same time utilizing the stormwater as resource.

Acknowledgments

This work is supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant 1615007273).

References

[1] G. E. Harper, "Nine-month evaluation of runoff quality and quantity from an experiential green roof in Missouri, USA", Journal of Ecological Engineering, vol. 78, **(2015)**, pp. 127-133.
[2] H. Jia, "LID-BMPs planning for urban runoff control and the case study in China", Journal of Environmental Management, vol.149, **(2015)**, pp. 65-76.
[3] Y. Chen, K. Wang, X. Wang, W. Zhou, "Strength, fracture and fatigue of pervious concrete", Journal of Construction and Building Materials., vol.42, **(2013)**, pp. 97-104.
[4] K. J. Gilbert and J. C. Clausen, "Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut", Journal of Water Research, vol. 40, **(2006)**, pp. 826-832.
[5] P. W. B. Nichols, R. White and T. Lucke, "Do sediment type and test durations affect results of laboratory-based, accelerated testing studies of permeable pavement clogging?", Journal of Science of the Total Environment, vol. 511, **(2015)**, pp. 786-791.
[6] R. J. Winton, A. M. Al-Rubaei, G. T. Blecken, M. Viklander and W. F. Hunt, "Maintenance measures for preservation and recovery of permeable pavement surface infiltration rate – The effects of street sweeping, Vacuum cleaning, high pressure washing, and milling", Journal of Environment Management, vol. 169, **(2016)**, pp. 132-144.
[7] Korean Standards Service Network (KSSN), KS F 2394: Standard test method for permeability of porous pavement, http://www.kssn.net, **(2014)**.
[8] Korea Construction Quality Test Institute, Field Infiltration Capacity Assessment of the Permeable Roadside Tree Cover, **(2014)**.
[9] Korea Water and Wastewater Works Association, "Guidelines for the design and maintenance of water recycle facility, enacted in 2013 by the Ministry of Environment", **(2013)**.

Authors

Daehee Lee, He is a Master Student of Department of Construction Environment Engineering, Korea Institute of Civil Engineering and Building Technology campus, University of Science and Technology, Korea,daehee1212@ust.ac.kr.

Jung-hun Lee, He is a Researcher in Korea Institute of Civil Engineering and Building Technology, Environmental & Plant Engineering Research Institute (EPRI), Junghun3@kict.re.kr.

Reeho Kim*, He is a Professor, Korea Institute of Civil Engineering and Building Technology, Environmental & Plant Engineering Research Institute (EPRI) Senior Research Fellow: University of Science and Technology, Department of Construction Environment Engineering, rhkim@kict.re.kr, *Corresponding author.

