Desalination and Water Treatment
www.deswater.com

1944-3994/1944-3986 © 2012 Desalination Publications. All rights reserved
doi: 10/5004/dwt.2012.3586

38 (2012) 326–332
January

Taylor & Francis
Taylor & Francis Group

Flood reduction analysis on watershed of LID design demonstration district using SWMM5

Jung-min Lee[a], Kyoung-hak Hyun[a,*], Jong-soo Choi[a], Yeo-jin Yoon[b], Franz Kevin F. Geronimo[c]

[a]*Land and Housing Institute, Korea Land and Housing Corporation, 462-2 Jeonmin dong Yuseong gu Daejeonsi, 305-731, Korea Tel. +82 42 866 8444; Fax: +82 42 866 8472; email:khhyun@lh.or.kr*
[b]*Department of Civil and Environmental Engineering, Konyang University, 26 Nae-dong, 320-711, Nonsan, Chungcheongnamdo, Korea*
[c]*10, Department of Civil and Environmental Engineering, Kongju National University, 11 275 Budaedong, Seobukgu, Cheonan, Chungcheongnamdo, 331-717, Korea*

Received 14 October 2011; Accepted 24 December 2011

ABSTRACT

Urban development is the primary cause of the expansion of impervious areas. Urbanization reduces infiltration of rainwater, increases runoff volume, and finally has an effect on the hydrological cycle and urban environment. To solve these problems, Low Impact Development (LID) methods have been used to restore the natural hydrology of predevelopment sites using site design techniques such as infiltration, evaporation, and retention. SWMM5 has been developed as a model to analyze the hydrologic impacts of LID facilities. This study performed hydrologic analysis and evaluated the flood reduction effect of the Jangjae Stream watershed by the design of LID facilities of the rainwater management demonstration district of AsanTangjung New Town (Korea). LID facilities in this study were comprised of infiltration trench, rain barrel, vegetation swale, etc. SWMM5 was calibrated using rainfall data of the 7th and the 14th of July, 2011 and was verified using rainfall data of the 10th and the 11th of August, 2011. This study analyzed flood reduction effect on 50 to 100 y return period. Based on the results of this study, the reduction of flood peak discharge by each return period of storms was estimated to be about 7 to 15%.

Keywords: Flood simulation; Infiltration trench; Urban wetland; Decentralized rainwater management; Hydrological cycle

1. Introduction

Decentralized rainwater management at the sources of urban development areas is being developed to restore the natural state of hydrological cycle. Here, rainwater management means minimizing the impact of development, namely, low impact development (LID). LID has been established in order to reduce the negative effects of urbanization on our environment. These stormwater managements can be used to adapt to climate change, to control non-point sources and to decrease the heat island phenomenon. Source control of rainwater is a multi-functional technique that can prevent floods, manage water quality and solve water shortage problem. Many cities in Europe have applied the source control for stormwater management because

---

*Corresponding author.

source control is more cost-effective. LID application is important because it can act as a buffer for humankind and nature on the climate change by increasing water resource and improving river health. A difference between the existing stormwater management and the new LID-decentralized rainwater management was identified [1–4,14].

Studies on LID-decentralized rainwater management were conducted in order to analyze its effects. Runoff increase by the construction of new apartment complexes was analyzed to be increasing by 10–40%. Also, the effects of infiltration trenches and LID plans on water cycle were studied and reported in Korea [5–8]. Watanabe studied the effects of installation of permeable pavement and pipe penetration [9]. Warnaars et al., investigated the hydrologic behavior of infiltration trenches in park of Copenhagen City [10]. Infiltration trenches were analyzed in previous studies related to the modeling and simulation of their effects on urban runoff and their long-term impacts [11].

Typically, LID facilities (vegetation swale, infiltration trench, rain garden, etc.) were applied in small-scale development and were rarely used in large-scale development. In particular, studies about the application of LID facilities to urban flood protection were very limited.

In recent years, climate change and rapid urbanization resulted in several disasters in Korea. Particularly in 2010 and 2011, Seoul experienced severe urban floods and damages. In order to prevent flooding and restore the natural hydrologic cycle, there is increasing interest in LID-decentralized rainwater management techniques and facilities [14].

LID facilities were designed for the decentralized rainwater demonstration district (1.8×10^6 m^2) of AsanTangjung New Town (central Korea) in 2011. The LID facilities will be installed in 2015. Many vegetation swales, infiltration trenches, urban constructed wetlands, etc. will be installed in streets, parks and green spaces of the district. This study was conducted to analyze the flood reduction effect on the watershed of LID design demonstration district of AsanTangjung.

2. Materials and methods

2.1. SWMM5 model

The SWMM5 model was applied in this study. SWMM5 was developed by the U.S. EPA for simulating the hydrological effect of LID facilities. This model can be applied to urban watersheds and sub-basins with artificial drainage systems. Single and continuous rainfall events can be calculated and rainfall interval can be set randomly. The time interval of rainfall occurrence can be adjusted arbitrarily. Runoff is caused by rainfall and outflow, and a non-linear storage equation is used for the analysis of surface runoff in this model.

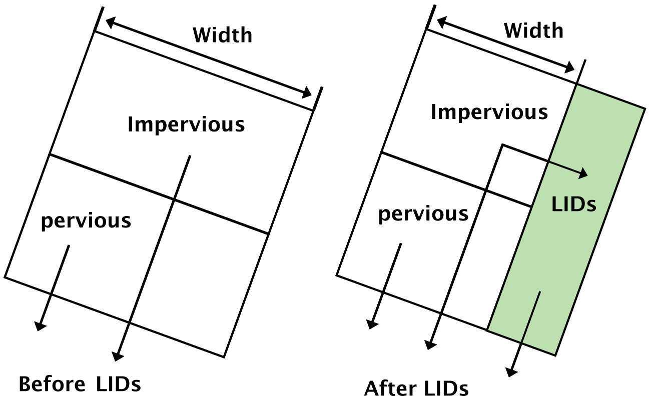

Fig. 1. Conceptualization of the surface runoff of SWMM5-LID (EPA).

Fig. 1 conceptualizes the surface runoff of SWMM5-LID. In the previous versions of SWMM, two equations, namely, Horton and Green-Ampt were used to calculate the infiltration rate [8]. In the latest version, however, Soil Conservation Service Center Equation (SCS-CN) was introduced.

2.2. LID design demonstration district

The Korean government and Korea Land and Housing Corporation designated this area as a LID-decentralized rainwater management demonstration district in 2009 and 2010. Various LID facilities will be installed in the LID design demonstration district of AsanTangjung. The runoff of this district flows into the Jangjae Stream below Park C. Site map and land use planning are shown in Fig. 2. In the construction plan of the LID decentralized rainwater management demonstration district, 1448 places will be installed. The facilities in the district will be applied in order to reduce non-point source pollution and to improve retention, infiltration and evaporation. Fig. 2 shows the application of facilities in the LID decentralized rainwater management district. Several LID facilities were planned to be installed depending on land use, soil characteristics and road configuration in roads, parks and green spaces. The site was divided into 15 basins, in which 60 urban constructed wetlands, 463 lateral infiltration ditches, 845 infiltration swales, and 80 vegetation swales will be installed. Infiltration swales and vegetation swales will be installed in parks and buffer greens. Small urban constructed wetlands will be installed in the planting strips of roads. Lateral infiltration ditches will also be used in areas without planting strips and green spaces [12–14].

Fig. 2. Overview of the LID-decentralized rainwater management demonstration district.

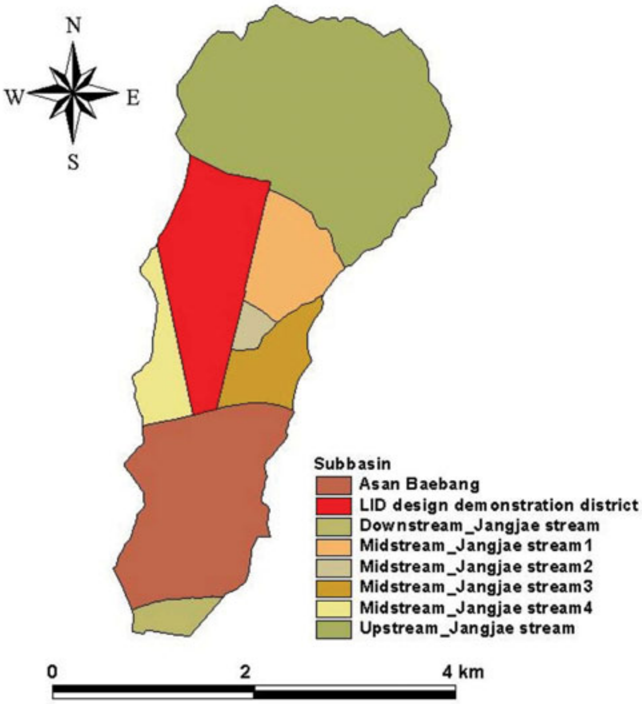

Fig. 3. Subbasins of the Jangjae Stream watershed.

2.3. Building and calibration of SWMM5 model

Data required in SWMM were watershed areas, slopes, imperviousness, roughness coefficient and CN values. Also, several data about channels such as their shape, maximum depth and length were used.Subbasinsof the Jangjae Stream are shown in Fig. 3. In this study, we used Geographic Information System (GIS) to analyze data about the stream such as slope, soil characteristics and land use. The measurement points of flood flow in the stream are shown in Fig. 4 [14]. Calibration and verification were carried out for accuracy and reliability using the measured data and the trial and error method in the Jangjae Stream.

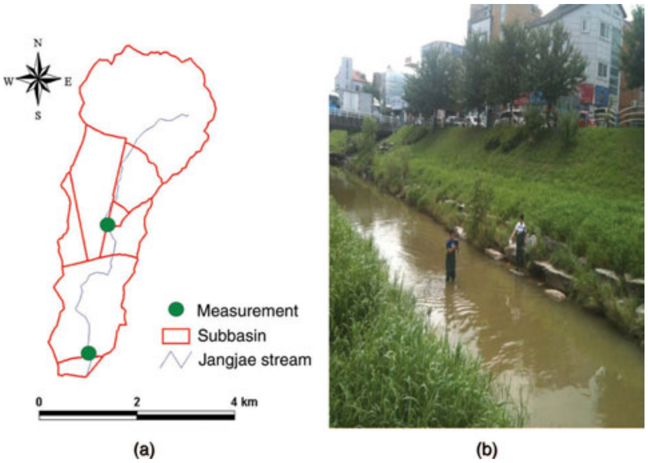

Fig. 4. Flood flow measurement points in the Jangjae Stream: (a) Flow measurement points; (b) View of flow measurement.

Table 1 shows the results of each measurement and simulation. Overall, the simulated results and measured values seem to correspond with each other. The relative error of the results was less than 14%. Given the flow rate measurement errors, the result of model calibration is considered relatively satisfactory.

3. Results and discussions

This study calibrated the SWMM5 model using data on the watershed, channel characteristics, and actual measurements before developing the LID rainwater

Table 1
Relative errors of simulated results and measured values

Date and Time		Midstream of Jangjae Stream (below Park C of LID design demonstration district)			Downstream of Jangjae Stream		
		Simulated (m^3/s)	Measured (m^3/s)	Relative error (%)	Simulated (m^3/s)	Measured (m^3/s)	Relative error (%)
7-7-2011	12:00	0.340	0.392	13.3	–	–	–
	13:00	–	–	–	1.137	1.158	1.8
	16:00	0.673	0.671	0.3	1.173	1.138	3.1
14-7-2011	13:00	0.707	0.744	5.0	–	–	–
	16:00	–	–	–	9.730	9.407	3.5
10-8-2011	13:00	0.680	0.708	4.0	–	–	–
	14:00	0.590	0.618	4.5	–	–	–
	15:00	0.450	0.433	3.8	–	–	–
11-8-2011	12:00	0.450	0.472	4.7	–	–	–
	13:00	0.450	0.458	1.7	–	–	–
	14:00	0.450	0.460	2.2	–	–	–

management demonstration district of AsanTangjung. Using the calibrated model, we analyzed flood reduction effects on the watershed resulting from developing of the LID rainwater management demonstration district of AsanTangjung. For this study, we used weather data for around 38 y from January 1973 to August 2011 collected from the Cheonan City Observatory near the district. Using the weather data, we performed continuous simulation of urban runoff in order to analyze impacts on the Jangjae Stream from the development of the district and the installation of LID facilities.

In order to examine the flood reduction effect by the installation of LID facilities, we selected and analyzed the 1st, 2nd and 3rd flood events among actual rainfalls that had occurred during the 38 y. Table 2 shows the dates of the 1st, 2nd and 3rd flood events and the observed rainfalls in those events. Figs. 5–7 are the hydrographs of these flood events before and after development, and after the installation of LID facilities. Table 3 shows that there was a flood reduction effect of around 56–64 % on the Jangjae Stream after the installation of LID facilities compared to that before installation.

Moreover, we analyzed the reduction effect of LID facilities in the watershed based on probable precipitations by return period. That is, we determined the reduction effect of LID facilities in case of probable extreme heavy rains. Using weather data for around 38 y from 1973 to 2010 collected from the Cheonan City Observatory, we analyzed probable precipitations. Floods of return period 50, 80, and 100 y were

Table 2
1st, 2nd and 3rd largest flood events

Flood event	Date	Rainfall (mm)
1st	August 9, 1995	273.5
2nd	September 17, 2005–September 18, 2005	215.0
3rd	August 23, 1995–August 24, 1995	203.5

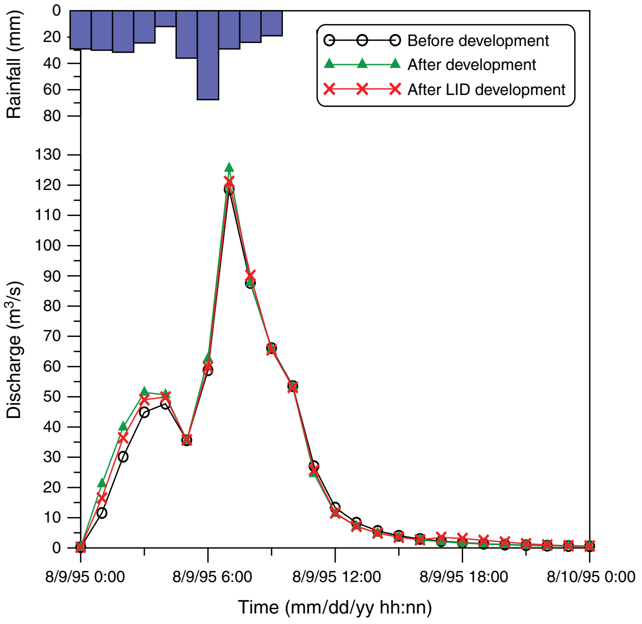

Fig. 5. Hydrograph of the 1st flood event in the Jangjae Stream watershed (Aug. 9, 1995).

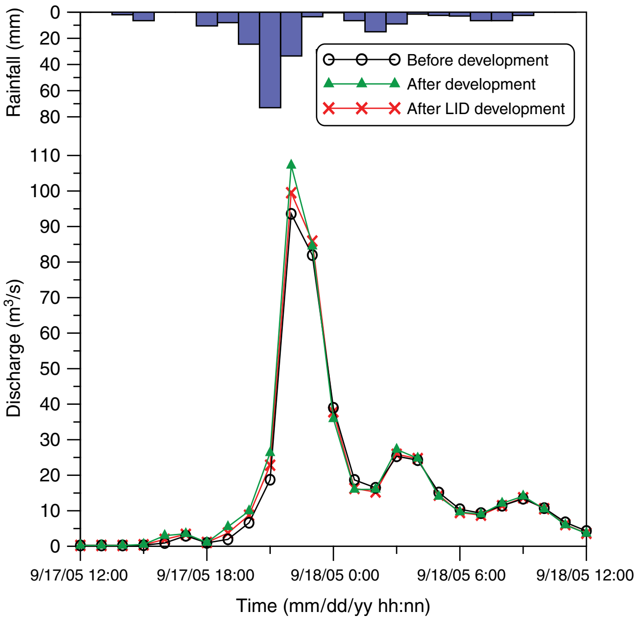

Fig. 6. Hydrograph of the 2nd flood event in the Jangjae Stream watershed (Sept. 17–18, 2005).

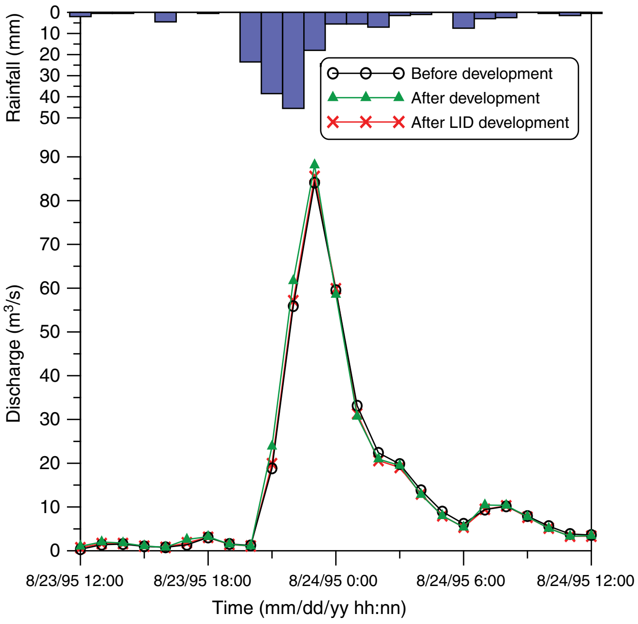

Fig. 7. Hydrograph of the 3rd flood event in the Jangjae Stream watershed (Aug. 23–24, 1995).

simulated, which can have the biggest impact on LID facilities and the Jangjae Stream. For the rainfall distribution in the watershed of Jangjae Stream, we applied HUFF distribution, and analyzed the third quadrant of the most frequency and the fourth quadrant of the maximum flood in the watershed. Table 4 shows the results of flood runoff simulation including flood discharge and flood reduction effect before and after development and after the installation of LID. Figs. 8–9 are the results of runoff simulation of return period 50 y. In general, the flood reduction effect was around 7–15% after the installation of LID facilities compared to that before the installation.

Table 3
Flood reduction effects of runoff simulation on flood events

Flood event	Flood peak (m³/s)			Flood reduction effect (%) [(A-L)/(A-B)]
	Before development (B)	After development (A)	After setting LID (L)	
August 9, 1995	118.58	125.51	121.21	62.0
September 17, 2005	93.57	107.23	99.52	56.4
August 23, 1995	84.09	88.13	85.53	64.4

Table 4
Flood reduction effects of runoff simulation on probable precipitations

Huff distribution	Return period (year)	Flood peak (m³/s)			Flood reduction effect (%) [(A-L)/(A-B)]
		Before development (B)	After development (A)	After LID installation (L)	
3rd quadrant	50	116.43	133.87	132.53	7.7
	80	127.95	145.38	143.93	8.3
	100	133.60	150.94	149.82	6.5
4th quadrant	50	144.15	162.56	159.72	15.4
	80	157.77	177.05	174.59	12.8
	100	164.45	184.11	182.18	9.8

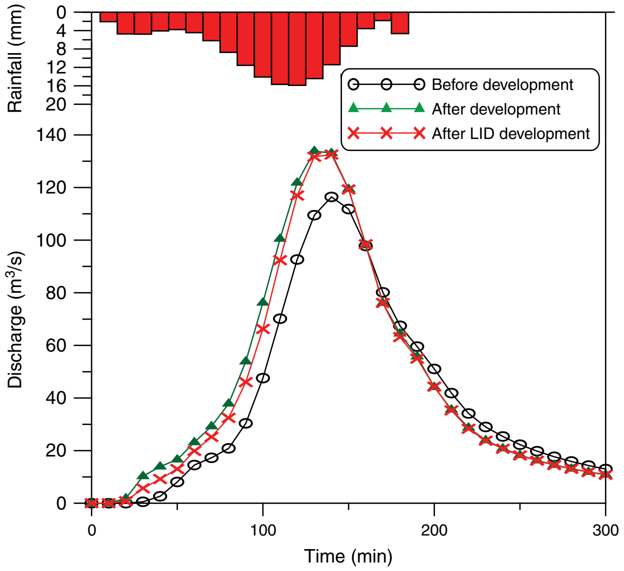

Fig. 8. Hydrograph of return period 50 y (3rd quadrant).

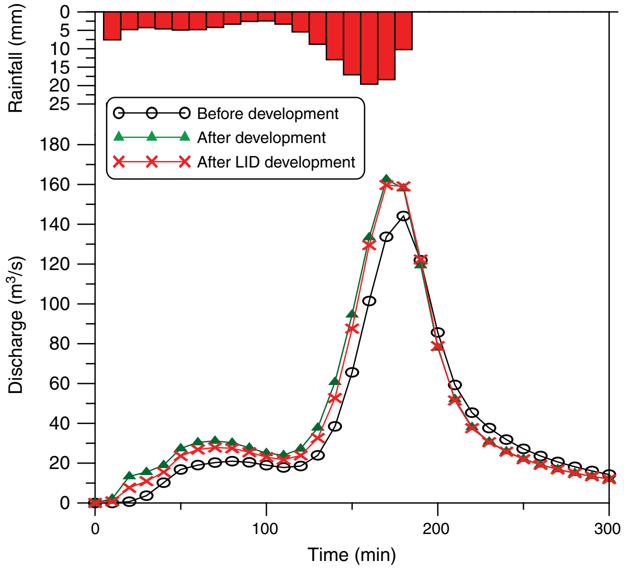

Fig. 9. Hydrograph of return period 50 y (4th quadrant).

4. Conclusions

Using data (from 1973 to 2011) of the Cheonan Observatory in the watershed of the Jangjae Stream, we performed continuous simulation on urban runoff before and after the development of the AsanTangjung rainwater management demonstration district and after the installation of LID facilities. In order to examine the flood reduction effect of LID facilities, we used the 1st, 2nd and 3rd largest flood events. In the results of simulation using the 1st, 2nd and 3rd flood events, the flood reduction effect after the installation of LID facilities was around 56–64% compared to that before the installation.

Using rainfalls corresponding to return period 50, 80, and 100 y among probable precipitations obtained from analyzing data (from 1973 to 2011) of the Cheonan Observatory in the watershed, we simulated flood discharge of the third quadrant and fourth quadrant of Huff. In the results, when rainfalls of return period 50, 80, and 100 y happen, the respective flood reduction effects would be around 7–8% in case of the third quadrant and around 10–15% in case of the fourth quadrant. The installation of LID facilities brought a flood reduction effect of around 7–15% compared to that before the installation. This is far lower than the effect of the installation of LID facilities in actual heavy rain events. That is, the flood reduction effect of LID facilities was higher for real rainfalls in the past.

These results mean that the LID-decentralized rainwater management and the plan of LID facilities may have an effect on flood control. That is, this means that LID rainwater management is one of various methods for flood reduction. Of course, the estimated flood reduction effect of planned LID facilities should be adjusted through monitoring after the installation of facilities.

The results of this study suggest that LID should be discussed as a new method of urban flood control in future land use, sewer and stormwater management planning. Moreover, SWMM5 is expected to contribute to the quantitative analysis of improvement effect on urban water cycle and reduction effect on non-point source pollution through LID rainwater management.

Acknowledgements

We would like to express our gratitude for the assistance of research expenses (Development Plan for Water-cycle Green City in Asan New Town 1, Analysis on Flood Reduction using LID 1) from LHI of Korea Land and Housing Corporation. Also, this paper was supported by the Korea Ministry of Environment as "The Eco-Innovation Project: Non-point source pollution control research group".

References

[1] K.H. Hyun, J.I. Oh, J.B Park, J.N. Kim, K.Y. Jung, K.M. Lee, Y.H. Kim, J.J. Choi and S.W. Jin, Rainwater pollutant load and runoff reduction by natural rainwater management Facilities, Huri Focus, 32 (2008).
[2] E. Chouli, E. Aftias and J.-C. Deutsch, Applying storm water management in Greek cities: learning from the European experience, Desalination, 210 (2007) 61–68.
[3] Prince George's County, Low impact development design strategies: an integrated design approach. Maryland, 1999.
[4] B. Griffiths-Sattenspiel and W. Wilson, The carbon footprint of water.Stream Network, Portland, OR, USA, 2009.
[5] T.G. Lee and Y.H. Han, Estimation of proportion to decentralized rainwater management needed in apartment complex development, Journal of the Korea Institute of Ecological and Environment, 6(3) (2006) 27–34.

[6] K.H. Hyun, S.S. Ahn, J.J. Choi and S.Y. Park, The effect of a decentralized rainwater management system in Korea apartment complex, Water Pract. Technol., 3(2) (2008).

[7] K.H. Hyun and J.M. Lee, Impacts on water-cycle by land use change and effects of infiltration trenches in A New town, Journal of the Korean Society of Water and Wastewater, 24(6) (2010) 691–701.

[8] J.-M. Lee, K.-H. Hyun, Y.-S. Lee, J.-G. Kim, Y.-B. Park and J.-S. Choi, Analysis of water cycle effect by plan of LID-decentralized rainwater management using SWMM-LID model in a low-carbon green village, LHI Journal of Land, Housing, and Urban Affairs, 2(4) (2011) 503–507.

[9] S. Watanabe, Study on storm water control by permeable pavement and infiltration pipes, Water Sci. Technol., 32(1) (1995) 25–32.

[10] E. Warnaars, A.V. Larsen, P. Jacobsen and P.S. Mikkelsen, Hydrologic behaviour of stromwater infiltration trenches in a central urban area during 23/4 y of operation, Water Sci. Technol., 39(2) (1999) 217–224.

[11] Y. Jia, N. Guangheng, K. Yoshihisa and S. Tadashi, Development of WEP model and its application to an urban watershed, Hydrological Processes, 15 (2001) 2175–2194.

[12] Korea Land and Housing Corp., Basic plan of AsanTangjung land development project, 2010.

[13] J.-M. Lee, S.-W. Bae, K.-H. Hyun, Y.-J. Lee and Y.-G. Lee, Analysis of flood reduction effect of LID rainwater management demonstration district in AsanTangjung using SWMM5, 2011 Fall Joint Conference of Korean Society of Water and Wastewater and Korean Society on Water Quality, (2011) 277–278.

[14] J.-M. Lee, K.-H. Hyun, J. Choi, Y. Park and Y. Gong, Building and calibration of SWMM5 model of flood reduction effect of LID rainwater management demonstration district in Asan-Tangjung, 2011 Fall Joint Conference of Korean Society of Water and Wastewater and Korean Society on Water Quality, (2011) 805–806.