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Multi-Objective Optimal Design of Detention Tanks in the Urban Stormwater Drainage System: LID Implementation and Analysis

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Abstract Under the influences of climate change and rapid urbanization, extreme rainfall events become more and more intensive and the urban flooding issues have been frequently faced in many cities in the world. Previous practical and scientific experiences have demonstrated that appropriate utilization of detention facilities and low impact development (LID) devices for urban region design could be important and effective ways to the flooding control and drainage service management of an urban stormwater drainage system (USDS). This paper investigates the optimal design and application of detention tank network and LID devices for achieving these multiple objectives in the USDS. The framework and method of LID-based multi-objective optimal design of detention tanks in USDS is first developed in this study, and a practical case in SA city of China is then taken for the application. The results of this study confirm the feasibility and validity of the proposed methodological framework for the LID-based multi-objective optimal design of detention tanks in the USDS. Specifically, both total investment costs and flooding risk have been greatly reduced by the optimal implementation of the detention tank and LID measures. Meanwhile, the results indicate that the LID devices may have global effect to the flooding control and the detention tanks can be locally efficient to reduce the flooding risk. Finally, the findings of this study are discussed in the paper for their practical implications to the practical design and management of USDS.

Keywords Cost-effective analysis · Detention tank · Low impact development (LID) · Multi-objective optimization (MOO) · Urban stormwater drainage system (USDS)

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1 Introduction

With the background of global climate change and rapid urbanization, extreme rainstorm events are increasing in intensity and frequency worldwide, which has caused significant economic losses as well as social and environmental problems (IPCC 2014; Zhou 2014). Flooding risks and drainage disasters have become more and more severe in current urban stormwater drainage system (USDS) (Chen et al. 2011; Li et al. 2015; Duan et al. 2016). The United Nations Office for Disaster Risk Reduction (UNISDR) reported over 100 urban flooding disasters per year worldwide during 1980 ~ 2008 and these events have resulted in more than 6700 deaths. More specifically, the analysis of worldwide flooding data from 1975 to 2001 by Jonkman (2005) shows that on average, 12 deaths resulted from each severe flooding event due to urban drainage problems with a total number of over 70 floods recorded in the past three decades.

For example, a flooding disaster due to severe rainstorm occurred in January 2011 in Brisbane, Australia, with causing 24 deaths (van den Honert and McAneney 2011). In July 2012, similar flooding tragedy happened in Beijing, China with over 1.6 million residents influenced and 79 lives lost in this irreversible event (Wang 2012). From a regional perspective, in the Pearl River Delta (PRD) of China, the annual rainfall in 2013 was reported at over 2800 mm, which was nearly 20 % higher than the mean value of 1981 ~ 2010 (Chan et al. 2010). To address these challenges in this region, the Hong Kong Government has committed over HK$ 10 billion from 2008 ~ 2018 to improve the capacity of current USDS. Meanwhile, the "Blue-Green Cities" research project was launched in 2013 in UK (EPSRC 2013), and the similar strategic plan of "Blue-Green Infrastructure" was proposed in 2014 by the Hong Kong Government (DSDHK 2016)m with aim to achieve sustainable USDS. Under this background, an effective design and management of the USDS becomes necessary and urgent to meet such crucial challenges.

Through various practical applications and experience, there are many ways that could provide an improvement and/or rehabilitation of the drainage capacity for existing USDS under extreme conditions such as rainstorms. Amongst these different methods, previous experiences in both theory and practice have evidenced that the stormwater detention tank was found to be a feasible and effective way to achieve such purpose (Tung 1988; Weiss et al. 2006; Li et al. 2015), especially for those cities and regions with limited ground utility space and complex urban development and configurations (e.g., heavy traffic and intensive residence) (Mays and Bedient 1982; Travis and Mays 2008). However, these applications also demonstrated that the design, operation and management of the detention tank network in USDS could be affected by many practical factors such as financial investment, physical limitation, existing system condition, utility function and public influence, as well as local development strategies (Yeh and Labadie 1997; Ramos et al. 2013; Oxley and Mays 2014). A recent study by Li et al. (2015) has developed a general framework that addresses the multi-objective optimization (MOO) based design and operation of detention tanks in USDS by considering the hydraulic and economic conditions as well as local design criteria and urban development strategy. Their practical case study revealed the feasibility and applicability of the developed methodological framework and optimization method in that study. Thereafter, the uncertainty analysis for the MOO-based design of the detention tanks was conducted in an extended study of Duan et al. (2016). The case study in that work indicated the potential influence of the physical system and economic conditions to the design results. From this perspective, it is necessary to examine the influence of local conditions and advanced application tools of the USDS for better design, operation and management of USDS, which is within the scope of this paper.

The low impact development (LID) of USDS, which is also termed as sustainable urban drainage systems (SUDS), water sensitive urban design (WSUD), green infrastructure (GI) or sponge city (SC) in the literature, is found to be another useful and important measure that could provide potential solution to the urban flooding control under extreme rain storm conditions (Elliott and Trowsdale 2007; MHURDC 2014). The principle of the LID-based USDS is to fully develop and effectively utilize a set of site devices or facilities that are designed to reduce the runoff and associated pollutants from the site at which they are generated in the USDS, and thus to reduce or prevent the impact of urban development (Vogel et al. 2015). Such LID devices may include structural measures such as wetlands, ponds, swales, rainwater tanks, bio-retention devices and filter strips, and also functional materials such as reduced impervious area, cluster building, permeable pavement and green roofs (CIRIA 2000; Rossman 2004; Zhang and Hu 2014). From the design experience and application practice, it is necessary to note that typical LID designs are usually based on the combination and incorporation of more than one type of the aforementioned devices or techniques to provide integrated and optimal effect of the LID-based USDS design, operation and management. Despite of the progress made so far for the LID techniques and practices, a series of fundamental and applied questions still remains open for the general utilization and development of such techniques, which actually requires further and systematic investigations through extensive theoretical and practical programs (Vogel et al. 2015). Specifically, the local design criteria and operation conditions have become the critical and urgent questions for the effective design and resilient management of the LID-based USDS, which is dealt with in this study.

In this paper, the two important measures of stormwater detention tanks and LID devices are incorporated into the framework of MOO-based design for USDS, which is thereafter verified and used for the cost-effective analysis of a practical USDS subject to different local design criteria and system conditions. With the results obtained from the practical case study, the effectiveness and contributions of the designed detention tank network and different types of LID devices considered in this study are examined and analyzed for the urban flooding control and drainage system management. Finally, the results and findings of this study are discussed for the practical implications to the design, operation and management of USDS.

2 Models and Methodology

2.1 Numerical Simulation Model

The one-dimensional (1D) Saint-Venant model for transient open channel flows is used in this study for the investigation of hydrological-hydraulic process in the USDS, which are expressed as follows (Rossman 2004):

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial H}{\partial x} + gA\left(S_f + h_L\right) = 0 \quad (2)$$

where x is distance along the conduit; t is time; A is cross-sectional area; Q is flow rate; H is the pressure head; S_f is the friction slope; h_L is the local energy loss per unit length of conduit; and g is the acceleration of gravity. To better integrate different local design criteria and conditions, as well as to incorporate the LID controls into the analysis, the Storm Water Management Model (i.e., SWWM5.1) developed by U.S. Environmental Protection Agency (USEPA), is adopted in this study for the numerical simulation based on Eqs. (1) and (2) (Elliott and Trowsdale 2007; Obropta and Kardos 2007; Li et al. 2015; Duan et al. 2016). The SWMM-based hydrological-hydraulic simulation process is then lumped into the LID-MOO-based design framework that is developed in the following study.

2.2 MOO-Based Cost-Effective Analysis Model

The multiple objective functions for the cost-effective analysis of the LID-based detention tank design can be expressed as follows:

(1) Objective 1 – total cost of designed detention tank network (f_1):

$$f_1 = \sum_{i=1}^{N} [a(S_i \cdot H_i)^c + bS_i + g(S_i)] \tag{3}$$

where N is the total number of the designed detention tanks in USDS; c is the exponential index representing the urban economic scale factor; a and b are coefficients; $g(S_i)$ is launching cost of each detention tank which can also be considered as an additional cost for initializing the detention tank construction; S_i and H_i are the cross-sectional area and depth of the designed tank. The reference values for the economic coefficients (a, b, c, g) are dependent on the economic level of the city under investigation and their values are provided in Li et al. (2015) for the case study in this paper.

(2) Objective 2 – total cost of designed LID devices (f_2):

$$f_2 = \sum_{j=1}^{M} \left[d\left(A_j\right)^e + h\left(A_j\right)\right] \tag{4}$$

where M is the total number of the types of LID devices used in USDS; A_j is the occupied catchment area of the designed LID devices; d, e are economic scale factors; and h = RMB 10,000 in this study. Similarly to the detention tank design, the economic coefficients of d and e are highly related to the construction cost of the relevant LID devices for the given USDS, which will be provided in the case study in this paper.

(3) Objective 3 – total flooding risk of the system design (f_3):

$$f_3 = R(S_1, S_2, \cdots S_N, A_1, A_2, \cdots A_M) \tag{5}$$

where R is hydrological-hydraulic performance function with the design scenario of N detention tanks and M LID devices in the focused USDS, which is obtained from the simulation results based on the SWMM tool.

In summary, the cost-effective analysis of the MOO-based USDS design is aimed to, minimize

$$f_1 + f_{2,} f_{3,} \tag{6}$$

subject to:

(a) hydrological-hydraulic process, which are modelled by SWMM in Eq. (1) and Eq. (2);

(b) initial and boundary conditions of the USDS, including the initial runoff and system discharge conditions (e.g., river, treatment plant, existing storage facilities, etc.), as well as the hydrological environment (e.g., rainfall intensity and design return period);
(c) local design criteria and conditions:

[1] the design range of the cross-sectional area of each tank S_i and each LID device A_j for practical construction conditions,

$$0 \le S_i \le S_{max} and \ A_{min} \le A_j \le A_{max}, \tag{7}$$

where S_{max} is the maximum cross-sectioanl area of the detetion tank; A_{min} and A_{max} are the maximum and minimum areas for constucting the LID device respectively;

[2] the minimal total volume of the detention tank network in USDS,

$$\sum_{i=1}^{D} V_i \ge V_{min} \tag{8}$$

where V_{min} is the minimal volume to provide enough capacity for the detention of initial rainfall to avoid possible pollution;

[3] the number of different types of LID devices for each sub-catchment (L_i),

$$0 \le L_i \le L_{max}, \tag{9}$$

where L_{max} is maximum number of the types of LID devices for each sub-catchment due to the limitation of construction in USDS;

[4] the restriction of inundation-prone nodes for the USDS design,

$$T \ (S_1, S_2, \ \dots, \ S_N) \ = \ 0, \tag{10}$$

where T is the total number of inundation-prone nodes under the application of N detention tanks, which can be obtained from SWMM simulation results;

[5] the restriction of the risky flooding nodes for the USDS design,

$$W \ (S_1, S_2, \ \dots, S_N) \ = \ 0, \tag{11}$$

where W is the number of risky flooding nodes under the application of N detention tanks, which can also be obtained in the results of SWMM model;

[6] the restriction for the construction locations of the designed detention tanks,

$$Z \ (I_L, K_L, Y_L) = 0, \tag{12}$$

where Z is the number of designed detention tanks in the USDS; I_L, K_L and Y_L are the locations with key traffic hubs (e.g., railway stations), important public utilities (e.g., power stations), and existing detention facilities respectively.

Particularly, the details about the definitions and classifications of different flooding nodes in above restriction conditions [4, 5] for the risk analysis of USDS can refer to Li et al. (2015) and Duan et al. (2016). Meanwhile, the following four types of LID devices (i.e., M = 4) are considered in this study for a preliminary investigation of the effect of LID approach (see Fig. 1: (i) bio-retention tank (Fig. 1a); (ii) small-scale rain garden (Fig. 1b); (iii) permeable pavement (Fig. 1c); (iv) green roof (Fig. 1d). The parameters of each LID device applied for this investigation are presented in Table 1 later in the case study part of this paper. It is also worthwhile to point out that, in the following case study of this preliminary research work, the application of above different types of LID devices are based on the local urban construction condition and design criteria of the specific USDS (e.g., MHURDC 2014; CURCNC 2015; Li et al. 2015; Duan et al. 2016). Considering that the focused USDS in this study is located in the developed urban region, the LID devices are designed and planned in each sub-catchment along the main streets and roads where the drainage pipelines are installed. Moreover, the obtained results are mainly used to analyze the influence of the used LID devices to the MOO-based design in bot aspects of advantages and disadvantages for the studied USDS.

2.3 LID-MOO-Based Design Framework

On the basis of previous studies (e.g., Li et al. 2015; Duan et al. 2016), the modified Particle Swarm Optimization (NPSO) scheme has been successfully applied to solve the MOO problem of the USDS design. In this study, this efficient scheme is adopted further for the LID-MOO-based USDS design based on the cost-effective analysis model above in Eq. (6) through Eq. (12). The application framework of the LID-MOO-based design is described in the flowchart shown in Fig. 2. It is necessary to note that, based on the NPSO-based computation, the final results obtained for the MOO-based USDS design in this study are consisting of a series of optimal and quasi-optimal solutions (e.g., the top 5 % for the objective function fitness), so that they can be comparatively analyzed and determined by the decision-makers.

3 Case Study and Results Analysis

The developed LID-MOO-based design framework in Fig. 2 is verified for its feasibility and efficiency through a practical USDS case study in the SA city of China, which was extracted

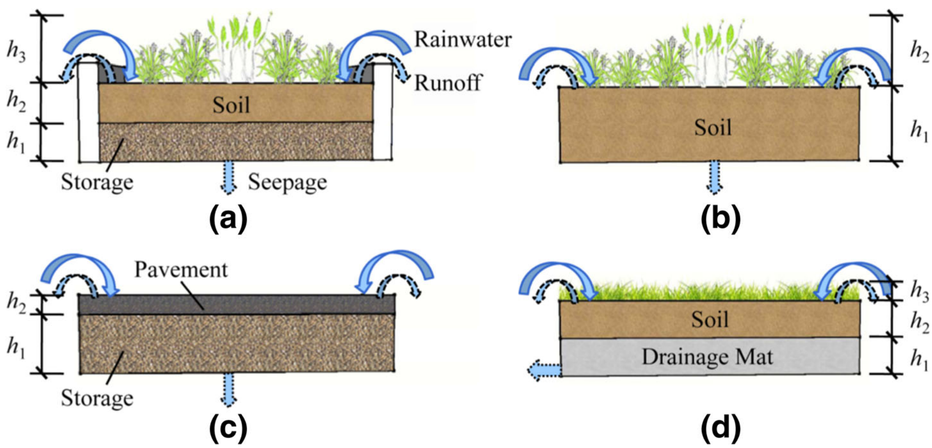


Fig. 1 Different types of LID devices used for the analysis: **a** bio-retention tank; **b** rain garden; **c** permeable pavement; and **d** green roof

Table 1 The settings of different LID devices in Fig. 1 for this study ("NA" = not applicable)

LID type	Layer height (mm)			Other parameters			
	h_1	h_2	h_3	Fraction (%)	Seepage rate (mm/h)	Permeability rate (mm/h)	Conductivity rate (mm/h)
(a): bio-detention tank	300	300	300	10	12.5	NA	12.5
(b): rain garden	300	300	NA	10	NA	NA	12.5
(c): permeable pavement	300	100	NA	NA	12.5	2500	NA
(d): green roof	150	100	50	10	NA	NA	12.5

from the previous research works (i.e., Tao et al. 2014; Li et al. 2015; Duan et al. 2016). The system information is described briefly for clarification and the results and analysis are performed later in this section.

3.1 Description of the Studied USDS

The USDS used for analysis located in the SA town of China is shown in Fig. 3, consisting of 127 sub-catchments, 95 main drainage conduits (with diameters > = 400 mm), two pump stations, two

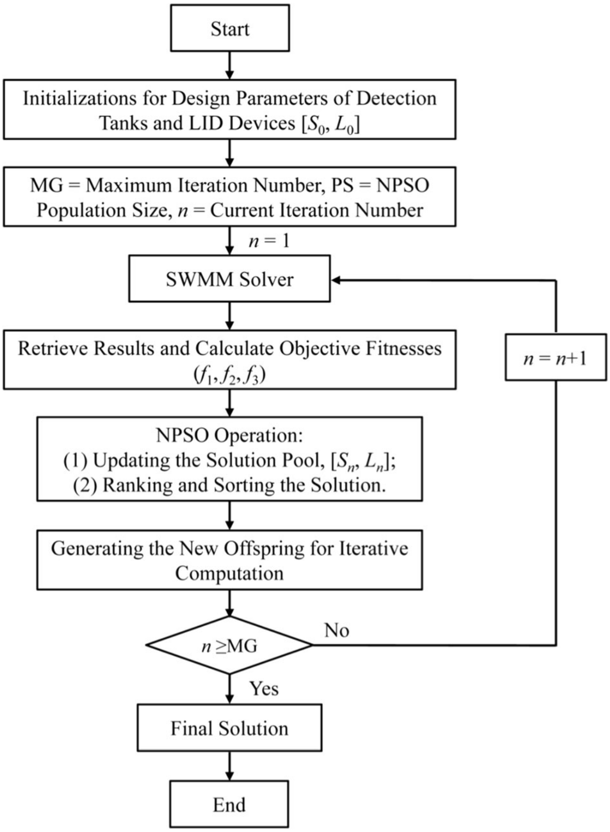


Fig. 2 Flowchart of the LID-MOO-based USDS design framework

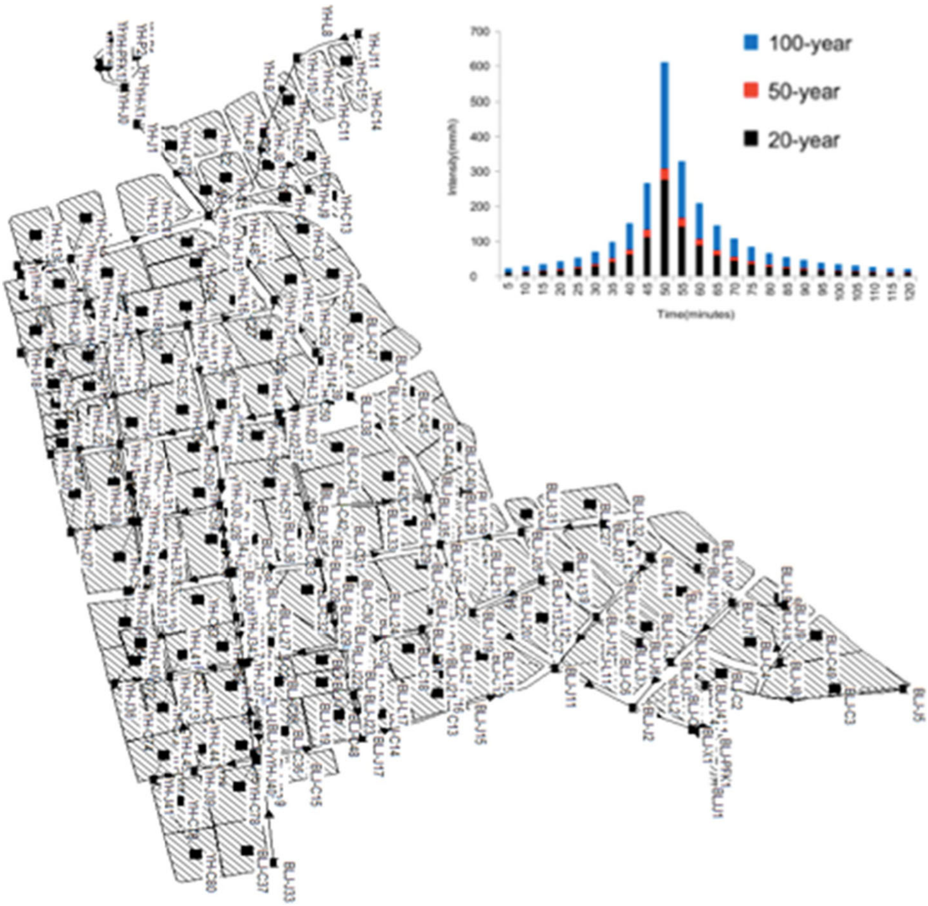


Fig. 3 The schematic of the catchments and drainage networks for the studied USDS

outfalls to the nearby river and two exiting detention tanks. Despite that three different design return periods of rainfall intensity (i.e., 20-year, 50-year and 100-year) were inspected in the former study (see Fig. 3), that of 20-year is adopted in this study for an illustration. During the hydrological-hydraulic simulations based on the SWMM tool, the stormwater drainage process with 8-h duration in this USDS is considered and used for the flooding risk analysis, with a typical reporting time of 15 s (Tao et al. 2014; Li et al. 2015; Duan et al. 2016).

Furthermore, the economic coefficients in Eq. (3) and Eq. (4) are necessary for the quantitative cost-effective analysis, which are estimated based on the local economic reports and relevant design guidelines (e.g., CDOWE 2014) in this study as follows: a = 2000; b = 500; c = 0.69; d = 1000; e = 0.5; g = 50,000; h = 10,000. The practical dimension ranges of the detention tank and LID devices for optimal design are set as (CDOWE 2014; MHURDC 2014; CURCNC 2015): S_{max} = 8000 m^2; V_{min} = 8500 m^3; A_{min} = 0.05A_{sc} m^2; A_{max} = 0.50A_{sc} m^2 with A_{sc} being the area of sub-catchment. During the MOO-based design process, the LID devices are planned in each sub-catchment along the main streets with drainage pipelines under the above design conditions. For illustration, the main configured parameters of the used LID devices are listed in Table 1, which are mainly estimated based on the available design manuals in China (MHURDC 2014; CURCNC 2015). Other settings of these adopted LID devices refer to the suggested values in SWWM (James et al. 2010). It is also necessary to note that different settings of these economic coefficients may affect the design results in this study. However, the objective of this application is to demonstrate and verify the developed LID-MOO-based methodological framework in this study and thus to analyze the influence of the LID consideration to the USDS design in practice. Therefore, these estimated values of the economic coefficients are mainly obtained from the previous studies of Li et al. (2015) and Duan et al. (2016) and used for the analysis throughout this research work.

3.2 Results by LID-MOO-Based Design Method

By following the proposed method and procedure in Fig. 2, the optimal design results of the studied USDS by considering both the detention tanks and LID devices are shown in Table 2. Specifically, the first four optimal/quasi-optimal solutions are extracted and used herein for the analysis. Meanwhile, the corresponding design results by considering the detention tanks only from the previous study (Li et al. 2015) are also listed in the table for comparison. This successful application has demonstrated the feasibility and validity of the proposed method and framework for the MOO-based design of USDS by implementing the different measures of detention tanks and LID devices.

The comparative results in Table 2 clearly reveal the improvement of the design results for both total costs and risks. Particularly, with less (solutions no. 1 and no.3) or very similar (solutions no. 2 and no. 4) total cost, the resulted flooding nodes by implementing the LID devices are much less than original design without LID (i.e., with detention tanks only). The optimal results also indicate that both measures (detention tank and LID) could have important effects on the flooding control in this USDS. Meanwhile, with including the LID implementation, the required detention tanks for the whole USDS are much less than the original design scheme. From this comparison, it is demonstrated that the implementation of LID devices together with other measures such as detention tanks in this study could greatly enhance the security of the USDS system (i.e., reduction of flooding nodes) under same/similar investment cost conditions. Therefore, it is useful and significant to develop and implement appropriate LID devices in the USDS, at least for the real-life case of interest in this study, so as to achieve the sustainable design and management of USDS.

3.3 Influence and Contribution of LID-Based Design

To further explain and explore the influence of the LID implementation to the MOO design of USDS, it is necessary to extract the detailed drainage process from the obtained results and compared with original design scheme in Li et al. (2015). For illustration, one of the typical

Table 2 The design results with and without LID measures (*wo/* = without; *w/* = with)

Solution rank no.	Cost (million RMB)		No. of flooding nodes		No. of detention tanks	
	wo/ LID	*w/* LID	*wo/* LID	*w/* LID	*wo/* LID	*w/* LID
1	86.07	73.66	0	0	68	37
2	70.92	72.23	7	2	58	25
3	73.76	60.42	4	4	58	13
4	62.27	64.95	14	1	50	13

and critical flooding nodes in the system is traced for its discharging process with time, and similar trends have been found for other critical and flooding nodes in the system. On the basis of optimal solution no. 1 in Table 2, the extracted results of discharge curves at this specific node under the conditions with and without LID implementation are plotted in Fig. 4. For reference, the result of the case without detention tanks and LIDs obtained in Li et al. (2015) is also plotted in the figure.

The comparison of the two results in Fig. 4 shows the implemented detention tanks and LID devices could reduce greatly the peak discharge during the drainage process. Specifically, the peak discharge at this selected critical location has been decreased from originally over 6.8 m^3/s without detention tanks and LIDs to about 6.3 m^3/s with detention tanks only, and to about 4.9 m^3/s with both detention tanks and LIDs. Moreover, it is estimated from Fig. 4 that about 5076 m^3 and 7475 m^3 of the water volume have been reduced during the drainage event by the measures of detention tanks and LIDs respectively. Actually, the LID devices may cause the delay of the discharge with certain extent so that there is less chance for the instantaneous confluence of peak flows at the specific node from different catchments. This delay effect of the LID devices is clearly evidenced from the results in Fig. 4, where the results peak flows are shown more frequently but with smaller magnitudes (i.e., the discharge oscillations in the figure) in the whole discharge duration than the original design scheme.

To analyze the contribution of the LID implementation, the distribution of the LID devices in the studied USDS is retrieved from the optimal solution no. 1 and qualitatively shown in Fig. 5. This distribution result reveals clearly the relative importance and contribution of the LID devices to each catchment. Overall, it can be concluded that the LID devices may become essential and useful measure to the regions (catchments) where the detection tanks are not allowed to be designed and constructed according to the local design criteria (e.g., Eq. (12)). Meanwhile, the optimal results indicate that it is more important and efficient to implement LID devices along the branched drainage pipelines (upstream catchments), while it is more practical and economic to construct detention tanks along the main discharge pipelines in the USDS.

Accordingly, the individual contribution of each LID device in Fig. 1 to the total LID effectiveness is calculated according to the respective percentage of the occupancy of total catchment area and the statistical results are shown in Fig. 6. The result implies that, under the same economic condition given in Eq. (4), the bio-retention tank is the most effective LID measure with largest catchment area occupancy percentage (32 %), followed in sequence by green roof (29 %), permeable pavement (21 %) and rain garden (18 %). This is mainly due to: (1) the different drainage detention effects of these LID devices; and (2) the land-use

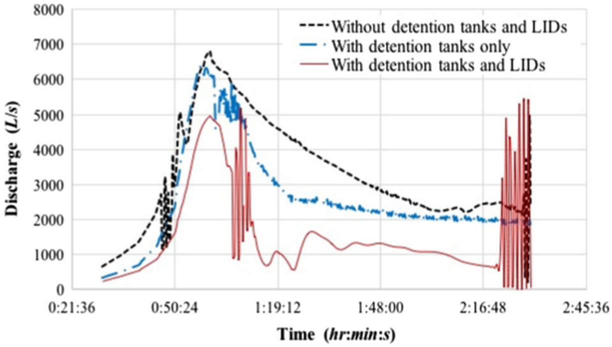
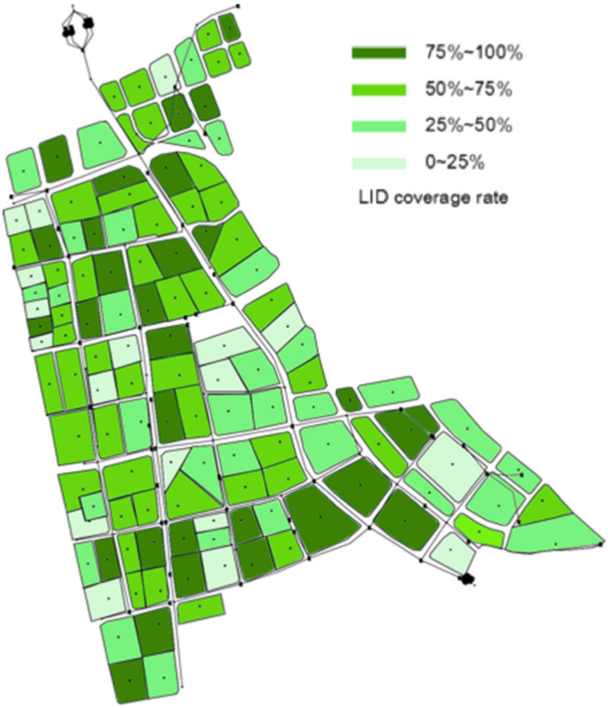


Fig. 4 The discharge process at a critical flooding node in the system based on solution no. 1

Fig. 5 The distribution of the LID measure in the USDS based on optimal solution no. 1

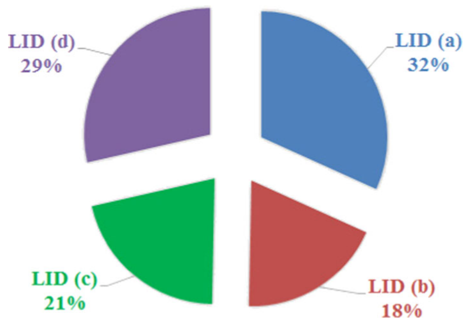


characteristics of high-dense buildings in this newly developed region of this studied city. Specifically, in this high-dense building region, the LID devices of green roof and small bio-detention tank become more feasible and effective, while the rain garden will be less suitable for its space requirement. However, it is also noted that, the suitability and possibility of implementing each LID device in different drainage catchments has not yet been included in this design process, which needs further information from the studied USDS.

4 Results Discussion and Practical Implications

The application results of the real-life case in this study demonstrate the importance and benefits of the LID devices in the optimal design of USDS. In practice, it is important to

Fig. 6 Individual contribution of each LID device used in the studied USDS, with LID **a** – bio-detention tank; LID **b** – rain garden; LID **c** – permeable pavement; LID **d** – green roof



consider the combination of different measures under the specific local design conditions for the sustainable design and management of USDS, which is consistent with the findings and discussions in the literature (e.g., Elliott and Trowsdale 2007; Zhang and Hu 2014; Vogel et al. 2015). For this purpose, the results and findings of this study may provide feasible design and evaluation method/tool as well as useful information for the sustainable design and management of USDS.

On one hand, based on the design information and background of the studied case herein, the LID measure is found to be more economic and efficient tool than others in the MOO-based design of USDS. For example, under the condition of given total investment cost, the flooding risk has been greatly reduced compared to original scheme of detention tanks only. From this perspective, the LID implementation could become useful supplement and alternative to the USDS design in addition to other traditional measures such as detention tanks.

On the other hand, the design results of the studied USDS also show that the measure of LID devices has to be applied as a global implementation so that it can become more effective to the system. For example, the number of the LID-implemented catchments is much more than that of the required detention tanks in the system. Specifically, to achieve the optimal design (e.g., solution no. 1 in Table 2) for the studied system, all of the drainage catchments require different LID implementations with different extents (Fig. 5). Moreover, the suitability and possibility of different LID devices for the specific USDS is worthwhile to be included in the design process based on further field survey and relevant local policy investigation. On this point, it is practical to include the local design conditions for implementing globally the LID devices for the MOO-based optimal design of USDS.

It is also noted that the uncertainties in the practical USDS may have potential influences to the MOO design results (e.g., Duan et al. 2016). According to the previous work experience (e.g., Elliott and Trowsdale 2007; Vogel et al. 2015), different uncertainties commonly exist in the implementation process of the LID devices, including the rainfall intensity and distribution, urban permeability properties, drainage and storage conditions, economic situation of studied region, and decision maker's strategy (Tung 1988; Xu and Tung 2008; Duan et al. 2016). Meanwhile, the impacts of the LID devices on the hydrologic-hydraulic drainage process need more investigations in the aspects of experimental tests and numerical modelling. Consequently, further studies are necessary for developing and improving the theory and practice of the LID implementation for the USDS in the future work.

5 Conclusions

This paper studies the multi-objective optimal design of urban stormwater drainage systems by implementing the measures of detention tanks and LID devices. The methodological framework and application procedures are firstly developed for the MOO-based design of USDS by including the local design criteria and two above-mentioned sustainable design measures. A real-life USDS case is then applied to validate the developed framework. The obtained results confirm the feasibility and validity of the proposed method and procedure, which could provide a useful tool for the practical design purpose.

The comparison of the design results for the situations with and without LID devices indicates the importance and benefits of the LID implementation to reducing the system flooding risk and/or total investment cost. Meanwhile, it is evidenced that the used two measures may provide different influences and contributions in the USDS for its sustainable development and management. Specifically, the LID devices may have global effect to the flooding control and the detention tanks can be locally efficient to reduce the flooding risk. The results analysis and discussion of this study also imply the necessity and importance of combining different measures in practical design process for achieving more sustainable USDS.

Finally, it is also necessary to point out that, on the basis of this study, the inclusion of uncertainty analysis and further development of LID theory and practice are required to be explored for achieving sustainable design and management of USDS in the future work.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Statement We declare herein that our paper is original and unpublished elsewhere, and that this manuscript complies to the Ethical Rules applicable for this journal.
Dr. HF Duan, on behalf of all the authors in the paper.

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