Assessing the Effectiveness of Low Impact Development by Bio-retention and Cistern System for Tianjin, Northern China

Niu Shuai and Zhang Sen

Abstract—**With the development of cities, environmental and ecological systems have been affected under certain damage and the change of water circulation system. In this paper, mainly two kinds of low impact development (LID) facilities are studied: bio-retention and cistern system. From their own characteristics, they were analyzed including application efficiency and landscape effect. The research shows that the landscape effect on bio-retention is better, and its effect on flood control is particularly prominent in the process of small-scale rainfall. Cistern system has relatively low manufacturing cost. Its setting is flexible, more runoff can be detained. And it has prominent and stable effect on water balance. These two facilities are fit able choices in urban planning and construction.**

Index Terms—**Low impact development, bio-retention, cistern system, urban development, water balance.**

I. Introduction

Urbanization represents the development level of a city. However, the over-quick urbanization process has brought a series of problems to the city [1]. Large population aggregation leads to the change of people's living pattern accordingly. The space in which people live is changed from the natural environment to the artificial. For the purpose of development, people change the original of nature with a variety of means and break ecological balance. The inherent ecological organization community is gradually disintegrated. The self-adjustment speed of ecological system is far behind the speed of city development. Ecosystem is being broken and the water cycle is also out of balance. The city will face severe problems of the lack of groundwater resources, the loss of rain water resources and flood disasters and so on [2].

LID is a hot topic that experts and scholars have been studying in the last decades. It means the concept of controlling and taking advantage of stormwater through some small-scale, decentralized facilities at the source using the simulation of natural hydrological conditions as the principle [3]. This is a new management method of rainwater. The schemes of LID have achieved great effect on the practice of many countries. LID will take advantage of many different landscape facilities to solve the problem of city stormwater [4]. These landscape facilities include bio-retention, green roofs, infiltration ditches and big tree planting schemes etc. Bio-retention has the ability to diminish the effects of urbanization by increasing interception an infiltration while reducing runoff and mitigating costs of stormwater management [5], [6]. In Berlin Joachim-Ringelnatz-Siedlung, each household in some communities has placed simple cistern system outside the building. This research is mainly about the comparison between bio-retention and cistern system. The analysis was conducted from their own characteristics, application efficiency, landscape effect and other aspects.

In this research, the storm water management model 5 (SWMM5) is used to evaluate the effect of facilities [7], [8]. The storm water management model (SWMM) was developed by U.S. Environmental Protection Agency in the 1970s [9]. SWMM is used to simulate the rainfall runoff of single rainfall event or long-term continuous rainfall runoff. SWMM can be used to load different LID facilities in the research area and set and commission parameters of different facilities, so as to make it convenient for the research on the effects of different LID facilities for water balance and flood control. It is relatively convenient for the comparison of results displayed [10].

The SWMM model can simulate and track a number of hydrological data of the rainfall including the water quality and quantity of runoff generated in every sub-basin at different time points. It can also simulate the flow, water quality, water depth and other conditions in every pipes and river channels [11]-[13]. It is confirmed in practice that SWMM is the right choice in research.

SWMM5 models the hydrological and hydraulic processes occurred in each LID facility by dividing the facility into three layers including the surface layer, soil or pavement layer and the storage layer [14], [15]. All the three layers have different storages and they function differently (Fig. 1) [16], [17]. For example, the bio-retention system has the storage on the surface layer (depression storage) accounting the effect of vegetation, storage in the void space of soil layer and the storage in the underlying gravel or crushed rocks layer(Note that the cistern system only has one layer). All these layers have different hydraulic conductivities or draining rate. The storage of a LID facility was a main factor which determined how much the rainfall could be captured and stored in the LID facility.

II. Procedure for Paper Submission

A. Bio-retention

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Bio-retention is a kind of rainwater filtration and permeation facility, as shown in Fig. 2. Its main function is to save, permeate and purify rainwater in lower terrain area through the effects of soil, taking advantage plants and microbial treatment and purification. Bio-retention has different names in different field such as rainwater garden, high flower bed, ecological retention zone or ecological tree pool.

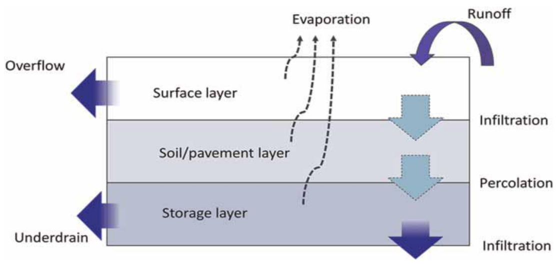

Fig. 1. Conceptual model of a LID process [source: USEPA 2012].

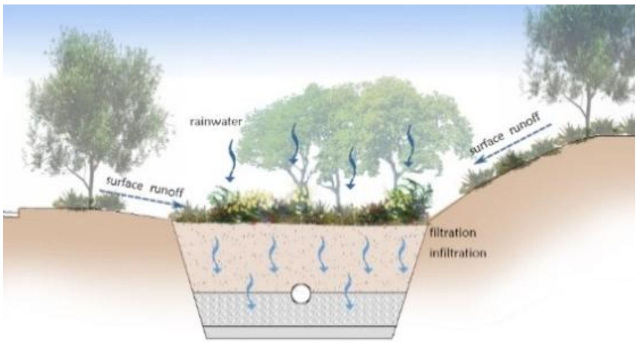

Fig. 2. Structure diagram of bio-retention.

Bio-retention is a relatively effective measure in the rainwater management. And, due to its imitation of natural landscape and natural rainfall infiltration process, it doesn’t only have the stormwater management function, but also has great effect on landscape aspect, shown as Table I. Bio-retention is similar to the miniature landscape of urban streets. The construction is cheap and its setting location and scale are both relatively flexible. Moreover, it has great ecological benefits and landscape functions. So it got highly positive evaluations and has been widely adopted in a large number of countries in Europe and the US.

The functions of bio-retention brought ecological benefits, economic benefits and social benefits and others:

1) To save runoff and supplements groundwater resources.
2) To reduce pollution
3) To reduce noises
4) To relive the urban heat island effect
5) To protect bio-diversity
6) To reduce energy consumption and save energy
7) To enhance the environmental landscape performance and become social places

TABLE I: PURIFICATION EFFECT OF BIO-RETENTION

Index	Removal rate
TSS	80%
TP	60%
TN	50%
Heavy metal	45%-95%
Causative agent	70%-100%

B. Cistern System

Cistern system is a container to collect rainwater which is also called rainwater pot or rainwater bucket. It is connected to the down-pipe of buildings and can be set by buildings on the ground or under the ground. Underground cistern system can save and collect rainwater of the same volume with the container and use again. The material of the cistern system is mainly wood, glass, metal or plastic. After processing and transformation, current cistern systems have beautiful modeling. They are easy to install and maintain. The manufacturing cost is also relatively cheap and suitable for setting combing with the courtyard.

The storage effect of cistern system is considerable. Take a building with a roof area of 110 square meters as an example. A cistern system of the capacity of 250L is configured at four corners of the building respectively. The storage amount is equivalent to the rainfall precipitation of 1 cm on the roof, i.e. the rainfall precipitation of a moderate rain. The rainwater obtained by the cistern system can be used for the irrigation of plants or be used as cheap non-potable water source after preliminary purification.

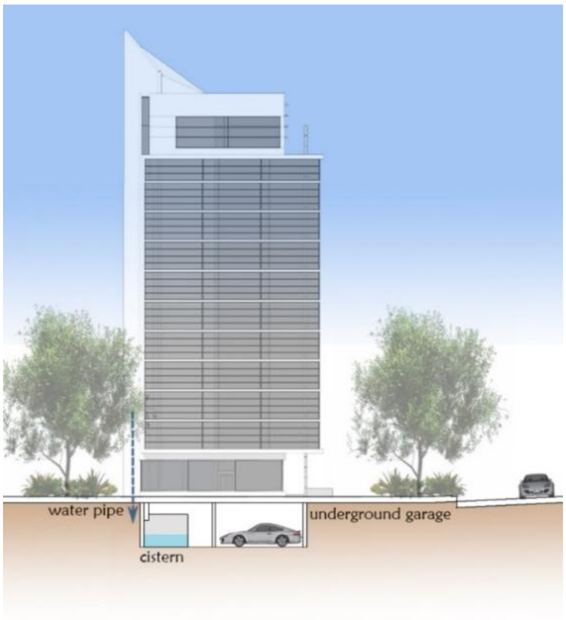

Fig. 3. Structure diagram of cistern system.

C. Comparison of Characteristics

TABLE II: CHARACTERISTICS OF THE SELECTED LID FACILITIES

project	appearance	advantages	scope of application
Bio-retention	The appearance is similar to flower beds. The plants are mostly shrubs and trees. Different shapes are set according to the terrain and landscape requirements	collect rainwater runoff, increase the infiltration ability, build natural landscape effect and recover the ecological system	street corners, parks, schools and around residences
Cistern system	Water tanks of large capacity. It is generally connected to the down-pipe of buildings	effectively collect the rainwater runoff on the roof, economical and convenient for management	around buildings, inside underground parking lot

Cistern system is frequently used inside of underground garages, shown as Fig. 3. The installation method is also to connect it with the down-pipe of buildings. Inside the underground garage, a medium-sized barrel water collection facility can be set up. A closed water storage space to collect the rainwater runoff transmitted by the down-pipe can also be formed by sealing up a parking space. Water outlet valve or tap is set at the proper spot in the water storage space. After natural precipitation or preliminary purification, the collected rainwater can be used as water source to clean cars and so on.

Table II lists the characteristics of the selected LID facilities.

D. Comparison of Flood Management Performance

In this study, in order to have a better comparison between bio-retention and cistern system in the application efficiency, SWMM5 model was used to simulate their effects on water balance and flood control in the process of rainfall. One district in Tianjin City of China was chosen as the research region. Its climate characteristics belong to the temperate semi humid monsoon climate. In the simulation, the rainfall data in 10 continuous years of Tianjin City was loaded. There were 261rainfall events identified in the 10-year rainfall records.

TABLE III: PARAMETERS SETTING OF TWO LID FACILITIES

LID practice	Modeling Parameters
Bio-retention	Thicknesses of the surface and storage layers were 20 and 500 mm respectively • 0.1 for vegetation factor • 0.45 for void ratio • 0.15 for slope
Cistern System	• Size of 10 m^3 for each cistern system • Drain delay of 24 hours for underdrain

According to the international standard with 25.4mm as the boundary, the rainfalls with a precipitation of ≥25.4mm are divided into heavy rains and the rainfalls with a precipitation of＜25.4mm are divided into light rains, which is the 1-inch rainfall usually used in the United States. The effect of two different facilities in different rainfall precipitations are studied respectively. After the simulation of SWMM software, the runoff value and peak flow and other data were exported. After the classification, comparison and calculation of the data, the following indexes were obtained: average runoff, change of total runoff, peak flow, change of peak flow, change of lag time and rainfall captured by LID on site.

Among them, average runoff is the average value of runoff in different sessions. This data can be exported directly by the simulation software. The change of total runoff is the ratio between the runoff change variable and the original average runoff after the loading of the two different types of LID facilities. Average runoff and change of total runoff are better evaluation indexes to measure the LID facilities in the control effect of water balance. The peak flow is the moment when the runoff is the highest in the process of rainfall. This value can also compare out the effect of different facilities directly by the simulation software. The change of lag time is the delay of the arrival time of the biggest rainwater runoff value after loading the LID facilities. Peak flow, change of peak flow and change of lag time are the main indexes to measure the effect of LID facilities in flood control.

The parameters setting of LID facilities are in Table III.

III. RESULTS AND DISCUSSIONS

From the Table Ⅳ, it can be seen that the average rainfall depth of light rains is 9.4mm, the average runoff is 3.392mm. The average rainfall depth of heavy rains is 42.7mm, the average runoff is 14.219mm. So, in the rainfall process of heavy rains, more runoff is generated. The runoff volume is significantly decreased after loading the LID facilities. The bio-retention is decreased by 9.1% and 4.8%, the cistern system is decreased by about 12.8% and 12.3%. After loading the two facilities respectively, the peak value is decreased and delayed. The most obvious is the behavior of bio-retention in light rains. The peak value is decreased by 41.645% and delayed by 21 minutes, which reduced the invasion of the flood peak. The cistern system also expressed certain flood control capacity in light rains, the peak value is decreased by 13% and delayed by 13 minutes. But, the behavior of cistern system in heavy rains is relatively general.

TABLE IV: SIMULATING RESULTS FOR RAINFALL EVENTS

Rainfall	LID practice	Average Runoff	Change of total runoff	Peakflow （$0.001m^3$/s/ha）	Change of peak flow (%)d	Change of lag time (min)	Ratio of runoff to precipitation	Rainfall captured by LID on site (mm)
＜25.4mm （Average rainfall 9.4mm）	NO LID	3.392 mm		0.328			0.36	
	Bio-retention	3.082 mm	9.1%	0.191	41.645	21	0.327	0.31
	Cistern System	2.956 mm	12.851%	0.317	13.004	13	0.313	0.436
≥25.4mm （Average rainfall 42.7mm）	NO LID	14.219 mm		9.483			0.333	
	Bio-retention	13.536 mm	4.803%	7.935	3.233	5	0.317	0.683
	Cistern System	12.468 mm	12.315%	9.069	0.548	3	0.292	1.751

In the aspect of water detention and storage volume, the behavior of cistern system in heavy rains is especially prominent. The water detention and storage volume is 1.751mm. From this it can be seen that cistern system has more optimal capacity of water detention and storage, which has close relation with its own structure and properties.

IV. CONCLUSIONS

By analyzing the data in the table, it can be seen that the average runoff and peak value set by under LID facilities are significantly decreased comparing with the values without the loading of any facilities. This means that both of bio-retention and cistern system played a positive role in the aspects of water balance and flood control in the process of rainfall. Seen from the rainfall precipitation, by comparison of the behavior of the facilities in heavy rains and light rains, it is clear that LID facilities have better impact on light rains, especially in the aspect of peak value control, they have great influence.

By comparing the performances of bio-retention and cistern system, it's obvious that the effect of cistern system in the aspect of water balance is better than bio-retention. But, in the aspect of flood control, the effect of bio-retention is more prominent. Comparing the two facilities in the aspect of water detention and storage, cistern system can store more runoff volume.

Generally speaking, bio-retention and cistern system are two LID facilities with their own characteristics. The design of bio-retention is usually combined with green-lands in cities, which promotes the landscape effect in cities to a large extent at the same time of controlling the stormwater. If LID is given more consideration to deal with the flood in cities bio-retention can be targetedly set in the city design. This can achieve the effect of decreasing the peak value and delaying the flood peak effectively. For cistern system, the setting method is to connect to the down-pipe of buildings. It can be set outside or inside the underground garages. The manufacturing cost is relatively low and the location is relatively flexible. It has great influence in the aspects of runoff control and the capacity of water detention and storage. This way can be massively adopted in city planning and construction.

There are many varieties of LID facilities. This study mainly performed the comparison analysis, between the two facilities of bio-retention and cistern system. Their capacities in performance, application and landscape effect were studied in order to provide the city designers a relatively facility performance index and basic information such as application scope so that the city stormwater problem can be effectively solved and city life quality can be improved. Because of the difference of market environments in different countries and cities, results have also big differences. This research lacks the study on the basic manufacturing cost of the two facilities and other issues. Therefore, it is proposed that it just applied in Tianjin City, we will do more research in the future, we believe it can be further improved.

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