Application of storm water management model to designing the sponge city facilities in the Athletes Village of Military World Games in Wuhan

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Abstract: This study discusses application of the storm water management model (SWMM) to designing the sponge city facilities in the Athletes Village of Military World Games in Wuhan in October 2019. The SWMM was used to simulate the runoff processes and reduction efficiencies of the sponge city facilities. The runoffs of the sponge city facilities were compared with those of traditional drainage system for the design rainfall of 35.2mm and the rainfalls with different recurrence periods. The results show that the hign density sponge city facilities could meet the requirements for 80% of annual runoff control rate, SWMM can determine the scales of the sponge city facilities and effectively simulate the hydrological processes for different layout schemes. The simulation model is also helpful to making optimization of the sponge city facility layout.

Keywords: Storm water management model, sponge city, residential area, simulation, design

1. INTRODUCTION

With the acceleration of urbanization process, the natural attributes of urban areas are weakened, and the original hydrological cycle process is disturbed, which result in frequent urban waterlogging and deterioration of urban water environment [1]. General Secretary of the Communist Party of China (CPC), Xi Jinping, pointed out in the *Central Urbanization Work Conference* in December 2013 that priority should be given to the limited rainwater storing on site in enhancng urban drainage system and drainage by use of natural forces, and natural retention and storage, natural infiltration and natural purification of the sponge city should be built [2]. In response to the call of Xi Jinping, the central government began the pilot work of the sponge city construction in April 2015. Wuhan will held the 7th World Military Games in October 2019, and it is one of the pilot cities of the sponge city construction selected in April 2015. Wuhan government requires that new large-scale infrastructure must be built in consideration of the sponge city facilities. Therefore, the sponge city facilities shall be constructed in the playing fields and Athletes Village of the 7th World Military Games.

There are many similarities between the sponge city facilities in China and the low-impact development (LID) facilities in the United States of America (USA). Most of hydrological calculations of the LID facilities in USA are carried out by the storm water management model (SWMM) developed by the US Environmental Protection Agency. Due to lack of suitable hydrological models for LID facilities in China, Liu et al. adopted SWMM to determine the scale and sections of the LID facilities of the Longmuwan project in Sanya, Hainan Province in 2011 [3]. The calculation method of minute distribution of rainfall necessary for input conditions of SWMM was also proposed on basis of hourly rainfall, and it can be used to calculate the scale of the LID facility when the LID sites lack minute distribution of rainfall [4].

This paper addresses the application of SWMM to determine the sponge city facilities in the Athletes Village of the 7th Military World Games, analyzes the response of sponge city facilities under rainfalls with different recurrence periods.

2 OVERVIEW OF THE ATHLETE VILLAGE AND DESIGN GOALS OF THE SPONGE CITY FACILITIES

2.1 Outline of the Athletes Village

The 7th World Military Games Athletes Village is located near the Huangjiahu Lake, Jiangxia District, Wuhan. The natural environment is very good with 2700m long lake shoreline. According to field survey in March 2016, the project site is fan-shaped and the land area is 27.8 ha with fan radius of 550 - 700m. The geomorphy is the Changjiang III terrace, the site elevations change greatly. The ground elevations are between 18.7m and 33.2m, and the maximum height difference is 14.5m. The original terrain is generally high on the east and low on west, and the north-south landscape is undulating. There are warehouse in the site on north and east sides, which parallels to the Huangjiahu Avenue, the site elevation is about 27.5m, the other parts are farmland, woods and fish ponds. Therefore, designers should give full play to the terrain and geographical advantages of the project site in designing the sponge city facilities, make the runoffs before and after development almost the same by innovative design.

30 resident buildings are planned to be built for the athletes, and per capita living space reaches 21 m^2. The design concept of the sponge city would be implemented in this project, which reflects the forefront of the ecological construction and livable value.

Fig. 1. General layout of the playing fields and Athletes Village

2.2 Design goals of the sponge city facilities

According to the requirements of *the Special Plan of Wuhan Sponge City* and *the Planning and Design Guide of Wuhan Sponge City*, the climate, topography, natural environment and geological conditions of the project site, the design objectives of the sponge city facilities in the Athletes Village are determined as follows [5,6]:

1) The annual runoff control rate is set as 80% and the design rainfall is 35.2mm, which is larger than 75% that recommended by *the Planning and Design Guide of Wuhan Sponge City*;

2) For the rainfall with 50 years recurrence period, the runoff and peak discharge after the sponge city facilities are constructed are less than 2/3 of the ones by traditional drainage pipelines, and the runoff coefficient on the project site with the sponge city facilities is less than 0.5;

3) The storm water shall be utilized; and

4) Most of the traditional drainage pipelines will not be constructed except for the drainage pipes

along the main roads.

3 SIMULATION MODEL AND CALCULATION CONDITIONS

3.1 LID control module of SWMM

SWMM is a dynamic precipitation-runoff model that is used to simulate a single precipitation event or a long-term runoff and water quality. The runoff module comprehensively deals with the precipitation, runoff and pollution load in each sub-basin. SWMM for the hydrological calculation of the LID facilities is its LID control module, which can simulate the hydrological process of the following 7 LID facilities: 1) Permeable pavement, 2)Raingardens, 3) Green roofs, 4) Street planters, 5) Cisterns, 6) Infiltration trench and 7) Vegetative swales. The planners and designers can combine LID facilities with traditional drainage pipelines and sewage pipelines to calculate the efficiency of stormwater management and pollution removal [7].

3.2 Calculation conditions and layout of the sponge city facilities

The hydrological processes of the sponge city facilities were calculated for the design rainfall of 35.2mm and the rainfalls with 2-year, 5-year, 10-year, 20-year and 50-year return periods listed in Table 1 [8].

Table 1. Rainfalls for different return periods in Wuhan

Occurrence Period (Year)	2	5	10	20	50
Rainfall (mm)	57.3	72.6	102.5	117.6	137.5

In order to effectively utilize the sponge city facilities, the low density and high density sponge city facility layouts as shown on Fig. 2 and Fig. 3 are simulated by SWMM, and the calculated results were compared with the ones of the traditional drainage pipeline layout. The low density sponge city facility scheme was arranged as follows:

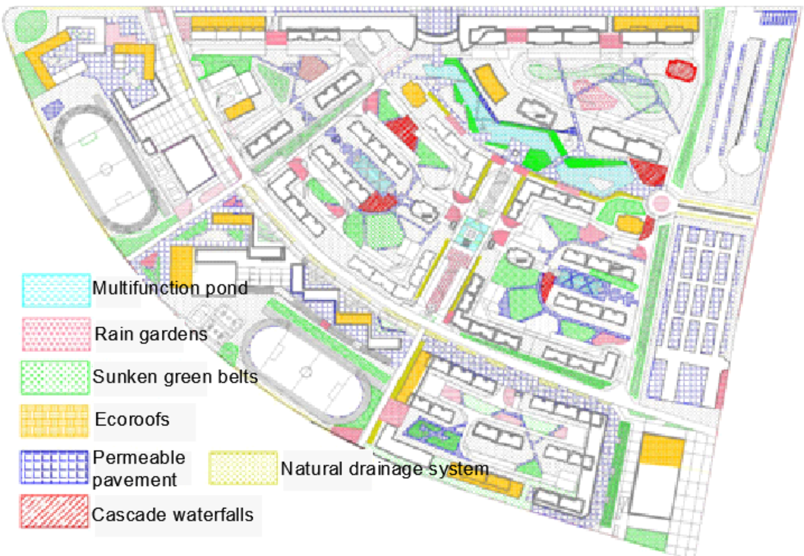

Fig. 2. Layout of low-density sponge city facilities

1) Natural drainage systems: The natural drainage systems were arranged along the roads to convey the runoff to the Huangjiahu Lake;

2) Cascade waterfalls: The cascade waterfalls were designed in the green belts in consideration of different elevation topography;

3) Raingardens: The raingardens were arranged near buildings and around the natural drainage systems;

4) Permeable pavements: The permeable pavements were designed for part of roads;

5) Sunken green belts: A part of green belts and green space were designed as sunken green belts;

6) Ecoroofs: A part of the roofs of the commercial and resident buildings were designed as ecoroofs which do not irrigate and fertilize; and

7) Multifunction ponds: A part of the existing ponds were reformed as multifunction ponds for flood control and landscape.

The total area of the sunken green belts, raingardens, natural drainage systems, cascade waterfalls and multifunction ponds accounts for 20.3% of the landscaping land; 40.3% of the roads were designed as permeable pavements, and the ecoroofs account for 17.8% of the roofs of the buildings in the project site.

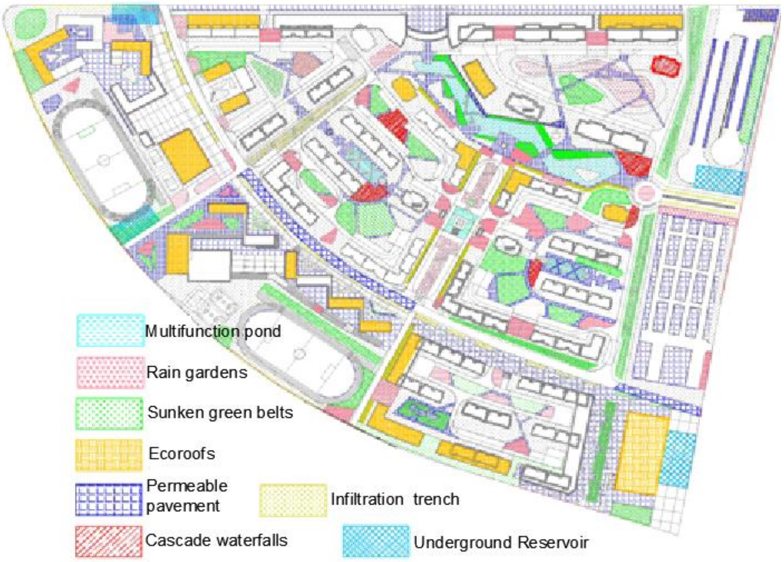

Fig. 3. Layout of high density sponge city facilities

On basis of the low-density sponge city facilities, the high-density sponge city facilities were arranged by increasing 500 m^3 underground tank, 2.14ha raingardens, 1.8ha permeable pavement and 6.83ha ecoroofs.

4 CALCULATED RESULTS

Fig. 4 shows the hydrographs of different development modes for design rainfall of 35.2mm. It can be found that the runoff of the high density sponge facility layout is basically equal to zero, it means that the high density sponge facility layout can meet the design goal of the annual runoff control rate of 80%.

Table 2 to Table 4 give the calculated runoffs, peak discharges and runoff coefficients of undeveloped status, traditional pipeline development scheme, low density sponge city facility development scheme, and high density sponge city facility development scheme for the rainfalls with different return periods. Fig. 5 shows the hydrographs of different development modes in the case of rainfall with 50-year return period.

As compared with the traditional development, the runoff reduction rates of the low density sponge city facility scheme are 44.42%, 42.2%, 39.82%, 38.88% and 37.9% for 2, 5, 10, 20 and 50 year rainfall events; and the peak discharge reduction rates are 57.14%, 54.48%, 49.94%, 49.24% and 48.06%, respectively. Compared with the traditional development, the runoff reduction rates of the high density sponge city facility scheme are 58.43%, 56.72%, 54.25%, 53.46% and 52.53% for 2, 5, 10, 20 and 50 year rainfall events; and the peak discharge reduction rates are 68.12%, 66.01%, 62.20%, 61.63% and 59.8%, respectively. Two sponge city facility schemes meet the goals of runoff and peak discharge less than 2/3 of those of traditional pipeline development. In addition, the reduction rates of the runoffs and peak discharges decrease with the increase of the recurrence period of rainfall.

The runoff coefficient of the high density sponge city scheme is close to the one of the undeveloped status, and it is equal to 0.39 for 50 years rainfall, which is far less than that of the traditional pipeline development.

Considering the requirements for 80% annual runoff control rate and the reduction effects of the sponge city facilities, high density sponge city facility scheme is finally recommended as the plan of the sponge city construction in the Athletes Village of the 7th World Military Games.

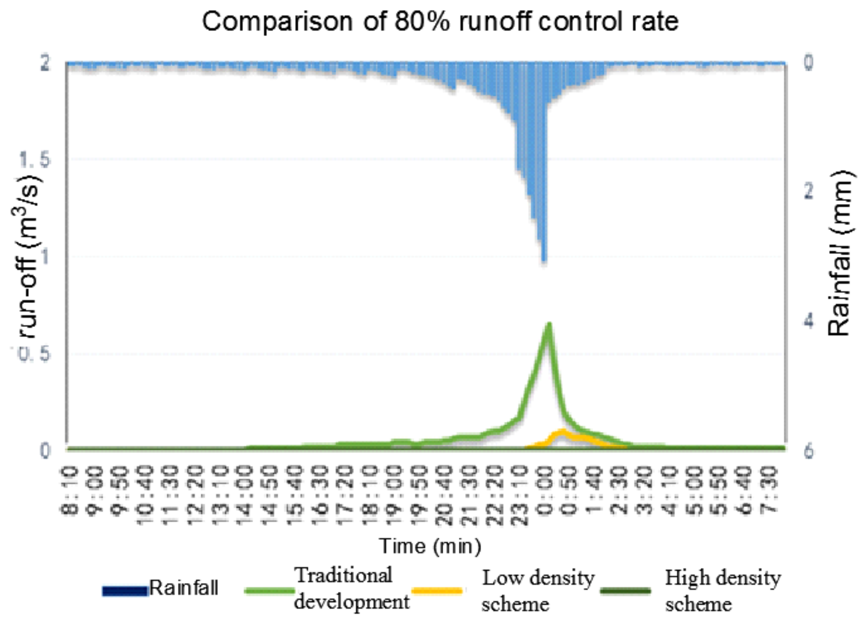

Fig. 4. Hydrographs for design rainfall of 35.2mm

Table 2. Comparison of the runoffs of different development modes（m^3）

Return period	2 years	5 years	10 years	20 years	50 years
Undeveloped status	3946.8	5502.0	8655.0	10354.8	12640.2
Traditional development	11271.0	15075.6	22203.6	26062.8	31204.8
Low density scheme	6264.0	8713.2	13363.2	15930.6	19378.8
High density scheme	4685.4	6524.4	10157.4	12130.2	14817.0

Table 3. Comparison of the peak discharges of different development modes (m^3/s)

Return period	2 years	5 years	10 years	20 years	50years
Undeveloped status	1.30	1.89	2.85	3.45	4.36
Traditional development	4.83	6.59	8.89	10.58	12.86
Low density scheme	2.07	3.00	4.45	5.37	6.68
High density scheme	1.54	2.24	3.36	4.06	5.17

Table 4. Comparison of the runoff coefficients of different development modes

Return Period	2 years	5 years	10 years	20 years	50years
Undeveloped status	0.24	0.27	0.30	0.32	0.33
Traditional development	0.70	0.74	0.78	0.80	0.83
Low density scheme	0.39	0.43	0.47	0.49	0.50
High density scheme	0.29	0.32	0.35	0.37	0.39

5 CONCLUSIONS

SWMM was used to simulate the hydrological processes of the sponge city facilities in the Athletes Village of the 7th World Military Games in Wuhan. The runoffs, peak discharges and runoff coefficients of undeveloped status, traditional pileline development scheme, low density sponge city facility development scheme and high density sponge city facility development scheme were analyzed for the design rainfall and the rainfalls with different return periods. The results show that SWMM can effectively predict the hydrological changes for different development modes, and it is good tool to make the layout and optimization of the sponge city facilities.

The sponge city facilities have obvious reduction effects of runoffs and peak discharges than the traditional pipeline development, and they can enhance the onsite flood control capacity.

The reduction effects of the sponge city facilities for small rainfalls are better than those for heavy storms. The runoff reduction effects of the sponge city facilities increase with the area increase.

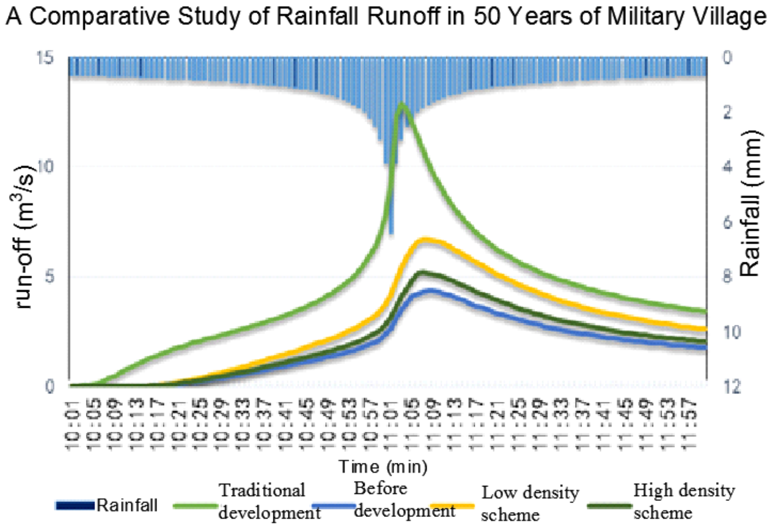

Fig. 5. Hydrographs for rainfall with 50 years return period

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