Simulation and Application on Storm Flood in Dongguan City Based on SWMM

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Abstract—For today's increasingly serious problem of urban rainstorm waterlogging, a rainstorm and flood model is established based on SWMM, which selects Guancheng District, Dongguan City, as a relatively closed region. Under the simulation of the design storm return period P=1a, we compared the simulation results with the actual flooding areas. It proved that the model had certain reliability. Then, we analysis the location of the main bottlenecks point and the possible factors leading to overflow, such as, the percentage of impervious area on the ground, pipe diameter and pipe roughness. According to the results, the main reason of the node overflow is that the pipe diameter is too small. Based on the results of section optimization, we carried on the second simulation. It showed that the pipe sections optimized the design could satisfy the drainage requirements of the design storm return period P=2a. The research methods and results in this paper could provide a reference to help related management department discovering and solving the problem of water, so as to reduce the losses caused by rainstorm to the city.

Keywords-urban; waterlogging; SWMM; overflow; flooding

I. INTRODUCTION

Since China's reform and opening up, with the accelerating urbanization process, many places have completed the transition from small villages and towns to the city. Urban modern integrated transport system and various types of municipal infrastructure have been gradually built, the city carrying capacity is growing. However, in terms of urban infrastructure, due to urban development and construction of drainage is not synchronized, urban drainage system problems gradually appear, the problems of urban rainstorm waterlogging become more and more seriously which affect the urban life and the development of the city[1, 2].

In order to realize effective and scientific management of urban storm flood, the establishment of rainstorm and flood model has important significance for the city to find out the causes of hydrocephalus and develop urban waterlogging countermeasures[3, 4, 5]. In this paper, a urban storm flooding model at Guancheng district, Dongguan City is built based on the rainstorm runoff management model (Storm Water Management Model, SWMM), which is developed by the United States Environmental Protection Agency (EPA)[6,7,8], for different design storm simulation scenarios to identify the flooding spots and find out a variety of possible reasons for analysis and simulation, so as to advance the corresponding measures on this basis and provide scientific basis for urban flood control and drainage construction.

II. SWMM INTRODUCTION

SWMM was developed in 1971, with the support of the U.S. Environmental Protection Agency first. It's widely used in urban storm flood, combined sewers, drains and other drainage systems analysis and design since its initial development in the world[9, 10].

The latest version, SWMM 5.0, can edit input data for the study area, the simulation of hydrological, hydraulic, water quality, and the results can be displayed in various forms. In addition, this model can simulate not only on a single rainfall dynamically, but also for the runoff generated by continuous rainfall, water quantity and quality changes after importing drainage network system. Furthermore, flow rate, water depth and velocity at nodes, pipes and other drainage buildings can also be simulated and displayed.

III. FLOOD MODEL BUILDING

A. Introduction of the study area

Selected Guancheng District, Dongguan City, a relatively closed drainage area as the research object, shown in Fig .1. Its total area is approximately 3.5km2, where is southwest to Qifeng Road, northwest to the Rosa Road, east to the Dongcheng Middle Road. Average annual rainfall of the study area is 1770.2mm; most of the rainfall is concentrated in the April to September, accounting for 83.8% of the annual rainfall. The main types of land use are construction land, roads, parks and green space, etc. Drainage network in the region is relatively complicated, mainly by the early construction of the Combined Sewage, pipes or tanks during the community's construction or renovation and rainwater drainage pipe on municipal roads. The flooding area is shown in Fig .1 as the red zone.

B. Model generalization

According to the basic data in Guancheng District, Dongguan City, such as topographic maps, satellite images, drainage network diagrams and land use types, through the sub-catchment division of the study area, drainage network system generalized, parameter debugged, we build a flood model on the basis of SWMM.

Figure 1. Study area and flooding area

1) Division of the catchment area

The total area of the catchment area identified in this paper is about 3.5km2. According to the slope of the ground, the distance from the drain point, the catchment is divided into a total of 1049 sub-catchments, shown in Fig .2. Each sub-catchment area corresponds to an outlet (which can be a drain outlet point or another sub-catchment area), water imports into the drainage network through the drain outlet, and exports out from the study area eventually.

2) Generalization of the drainage network system

After the analysis of the terrain and the drainage network flow, determining the outlet of the study area is located in the northwest corner at the Dongmen Road. Due to the complexity of underground pipe network, we only neglected part of the pipes, which are at a shorter length or located at the start of the pipeline, when generalized the drainage network system. Pipe network mainly distributes along the main roads, and drainage network is generalized ultimately as follows: 1 outlet, 2844 nodes and 2943 pipelines, shown in Fig .2.

3) Model parameter settings

Model parameters can be divided into two categories: "Measurement parameters", which you can get by measuring, and "Calibration parameters", which need to be optimized. Among them, the measurement parameters include: the area of the sub-catchment, impervious rate (calculated by land use type), average slope (calculated by topographic map), the bottom elevation and the depth of the node, the length and the slope of the pipeline, etc; the calibration parameters include: the manning coefficient in the pervious and impervious sub-catchments, depression storage quantity, and the manning coefficient of the pipe.

Reference to relevant information[9], selected parameters according to the related characteristics of the study area: infiltration by Horton mode, the maximum permeability is 103.81 mm/h, the minimum permeability is 11.44 mm/h, the infiltration rate is 8.46 /h, the manning coefficient at impervious area is 0.013 while pervious area is 0.24, the depression storage quantity at impervious area is 2.5 mm while pervious area is 5 mm, the manning coefficient of the pipe is 0.012.

Figure 2. Generalization of the sub-catchment and the drainage network system

C. Rainfall simulation scenario setting

In the model, rainfall should be input by the actual rainfall, but it can also assume certain scenarios based on flood control standards when it's in the absence of the measured data. Due to the lack of rainfall data, rainfall was calculated according to the formula of storm intensity. The rainstorm intensity formula in Dongguan City is:

$$q = \frac{2094.861 \times (1 + 0.506 LgP)}{(t + 8.875)^{0.633}} \tag{1}$$

Where: q is design storm intensity, $L/s \cdot ha$; t is rainfall duration, $\min$; P is design return period, a .

The type of rainfall pattern chooses Chicago rainfall pattern, which is widely used both at home and abroad[11]. Based on the rainstorm intensity formula in Dongguan City, build a design hyetograph by design rainfall return period for 1 year. In this rainfall pattern, the rainfall during any period is equal to the design rainfall. If the formula for the storm is $a = A/(t+b)^n$, the rainfall pattern can be expressed as:

Before the peak:

$$I = \frac{A}{\left(\frac{t_1}{r}+b\right)^n}\left(1-\frac{nt_1}{t_1+rb}\right) \quad (2)$$

After the peak:

$$I = \frac{A}{\left(\frac{t_2}{1-r}+b\right)^n}\left[1-\frac{nt_2}{t_2+(1-r)b}\right] \quad (3)$$

Where: a is the average rainfall intensity lasted in t, $mm/\min$; I is the instantaneous rainfall intensity, $mm/\min$; t_1 is the duration before the peak, $\min$; t_2 is the duration after the peak, $\min$; r is the relative position of the peak of the rain; A , n , b are the parameters for rainstorm formula.

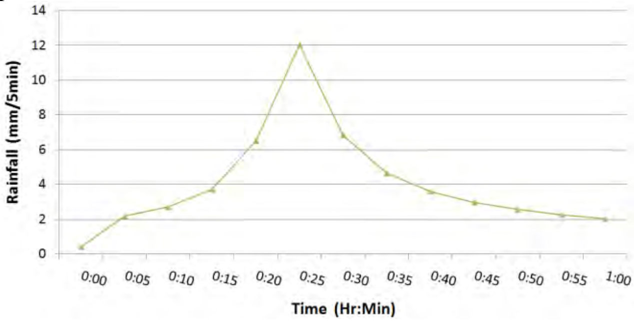

Figure 3. the rainfall line of P=1a

Many domestic and international data indicate that most of the values were between 0.3 and 0.5, this paper is taken as 0.367. The rainfall duration is taken as 60 min. The rainfall line, whose design storm return period is P = 1a, is shown in Fig .3.

IV. RESULTS ANALYSIS

A. Model validation

In order to ensure the reasonableness of the model, it is necessary to compare the calculated results with the actual flooding spots. Select the simulation results, whose design storm return period is P = 1a, to compare with the actual flooding area, the results show that the nodes whose overflow time is longer than 20 min are almost located within the actual flooding area. It indicates that the flooding results simulated by the model and the actual situation are relatively consistent, so that the simulation results are basically reliable.

B. Identify bottlenecks point

In this paper, the design storm return period is P = 1a, the rainfall duration is 60 min, and the simulation time is 3 h, because rain water runoff into the pipe from the surface and to the outlet of the catchment would deplete some time. Simulation results show that, about 4.1% of the nodes overflow more than 10 min, 2.4% of the nodes overflow more than 20 min, while the node HS02003125 overflows lasted 56 min; 53.5% of the nodes haven't overflowed, while the other have taken place in different levels of the overflow.

After the nodes overflow, water stored at the top of nodes first, until the water in the pipes receded, it will re-enter into the discharge pipes. Therefore, in practice, if the node overflow time is too long, streets or low-lying place will be easy to form waterlogging. It also indicates that the flood is over the running load, and the drainage's capacity can't meet the requirements.

As can be seen from the simulation results, the study area has five major flood regions. Node WS03000922 to node WS06066279 and the pipes which connect these nodes are the main bottlenecks at Dongcheng Road. In this paper, we discuss some measures to improve the bottlenecks overflowing based on these nodes and pipes. The bottlenecks nodes at Dongcheng Road are shown in Table 1.

TABLE I. THE BOTTLENECKS NODES AT DONGCHENG ROAD

Node	Time Flooded/min	Time of Max Occurrence/ Hr : Min
WS03000922	0.66	0:30
WS03000923	0.01	0:24
WS03000925	0.01	0:17
WS03000927	0.35	0:30
WS03000928	0.01	0:16
WS03000929	0.06	0:16
WS03000931	0.66	0:30
WS03000932	0.15	0:30
WS06066274	0.01	0:17
WS06066276	0.18	0:17
WS06066278	0.69	0:30
WS06066279	0.01	0:18

C. Explore measures to improve the bottleneck section of overflow

Factors affecting the overflow nodes are: the percentage of impervious area, the sub-catchment's depression storage capacity, Manning roughness coefficient at the pervious area and impervious area, the pipe's diameter, the pipe's roughness coefficient, the pipe's slope and so on. But the main influencing factors are the percentage of impervious area, the pipe's diameter, and the pipe's roughness coefficient.

Select node WS03000922 ~ node WS06066279 and their connected pipes as the research object to analysis the three main factors that affect the overflow. Explore the effects of different factors in a single change of conditions to improve the overflow of the nodes. As in the case of changing the model parameters, the bottleneck section of each node and the overflow of the connected pipes have the same trend, therefore, select the changes of the overflow at the intermediate node WS03000927 to instead of the bottleneck of the overflow condition to analyze.

1) The overflow effect by the percentage of impervious area

By changing the percentage of impervious area at the local bottleneck section, the simulation results of the node WS03000927 are shown in Fig .4. Before improvement, the percentage of impervious area at the local bottleneck section is 51.59%~92.18%, and the overflow time of the node WS03000927 is 28 min. If the percentage of impervious area reduces 30% to increase the pervious area, the overflow time of the node WS03000927 will be shortened 3 min; else if the percentage of impervious area reduces 50% to increase the pervious area, the overflow time of the node WS03000927 will be shortened 4 min.

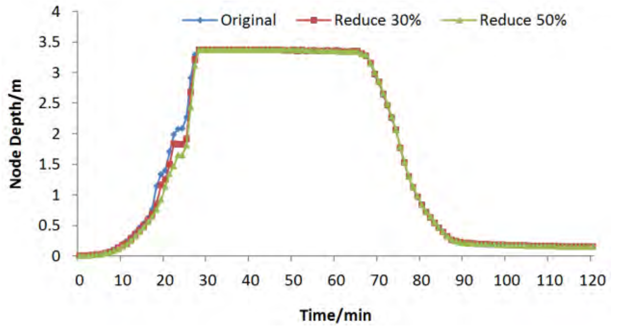

Figure 4. Node depth under the different percentage of impervious area

2) The overflow effect by the pipe's diameter

The diameter of the pipe, which connects to the overflow nodes, is 600 mm. Change the pipe's diameter at the bottleneck section, the results are shown in Fig .5 after the simulation. It shows that the overflow time will be shortened to 13 min if the pipe ' s diameter at the bottleneck section is replaced from 600 mm to 700 mm; and the overflow time will be shortened to 3 min if the pipe's diameter at the bottleneck section is replaced from 600 mm to 800 mm. Obviously, Changing the pipe's diameter at the bottleneck section can shorten the overflow time effectively, and reduce the incidence of urban waterlogging.

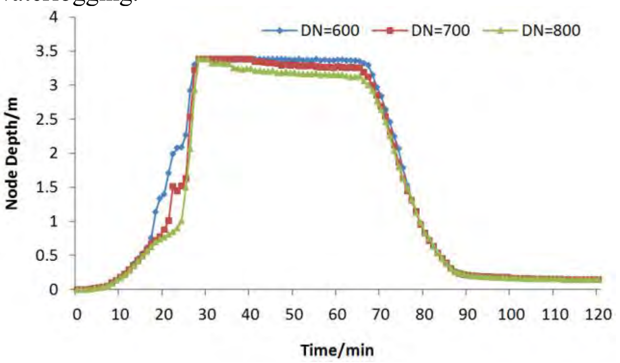

Figure 5. Node depth under the different diameter of pipe

3) The overflow effect by the pipe's roughness coefficient

The pipes near node WS03000927 are concrete pipes. According to the relevant information, under the conditions of using the steel template, good construction quality, and smooth seams, the roughness coefficient of the pipes with no plaster surface layer and the reinforced concrete pipes is between 0.012 ~ 0.015. The overflow time of node WS03000927 was 28 min when the pipe's roughness coefficient was 0.012; the overflow time increased to 33 min when the pipe's roughness coefficient was 0.014; if the material of the pipes changes from concrete to steel, whose roughness coefficient is 0.011, the overflow time will shorten to 23 min. The results of the overflow under different roughness coefficient of the pipe are shown in Fig .6. Changing the pipe's roughness coefficient can increase the flow rate and shorten the overflow time, but changing the local pipe's roughness coefficient to improve the effect of the overflow is not obvious.

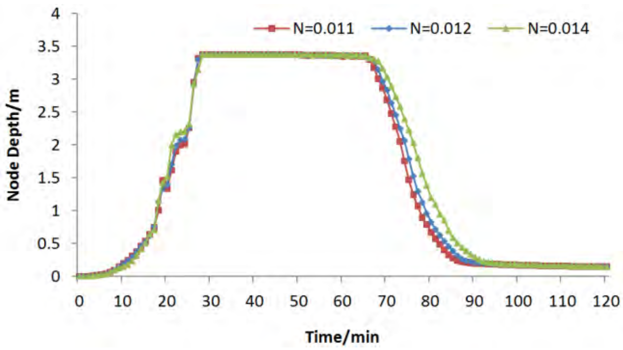

Figure 6. Node depth under the different roughness coefficient of pipe

D. Optimization measures and effects

The overflow time affects by the percentage of impervious area, the pipe's diameter, the pipe's roughness coefficient, and many other factors. The above simulation results of the influence of different factors on the node overflow suggest that, the main cause of node overflow for a long time is the pipe's diameter is too smaller. The overflow effects by changing the percentage of impervious area only consider the local sub-catchment near the bottleneck sections, but it will be better if increase the scope of the pervious area and improve rainwater infiltration capacity. So, for the improvement of the local flooding problems in the bottleneck sections, optimization measures considered mainly from the increase in the diameter of the pipe, i.e. the pipe's diameter at the bottleneck section is replaced from 600 mm to 800 mm, the overflow time of node WS03000927 was reduced from 28 min to 3 min, it can reduce the incidence of urban waterlogging effectively.

E. Simulation under the design storm return period P=2a

After optimization design of the pipes, check its drainage capacity whether could meet the requirement of drainage under the design storm return period P=2a. As the same as above, select the changes of the overflow at the intermediate node WS03000927 to instead of the bottleneck of the overflow condition. Designing rainfall process is shown in Fig .7. The total rainfall is 60.15 mm, which has increased by 7.92 mm when P = 1a. The peak intensity of the rain is 13.86 mm/5min, which has increased by 1.84mm/5min when P = 1a. And the average rainfall intensity is 4.63 mm/5min. Seen from the simulation results in Fig .8, the initial overflow time when P = 2a advance about 1 min, and the overflow time lasts 5 min, which is 2 min longer than the time when P = 1a. No rainwater will be on the road and cause flooding, so the pipe sections to optimize the design can basically meet the drainage requirements of the design storm return period P = 2a.

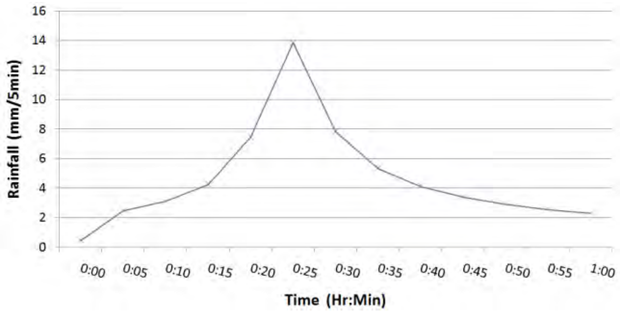

Figure 7. the rainfall line of P=2a

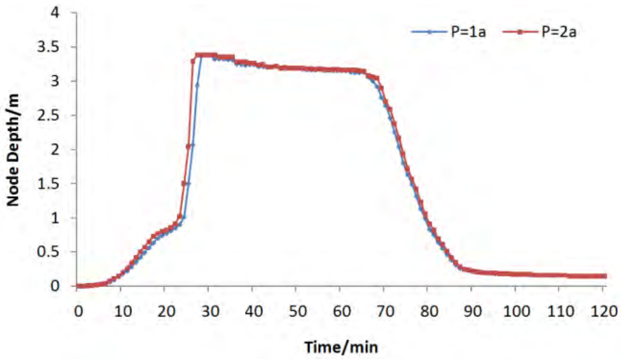

Figure 8. Node depth under the different storm return period

V. CONCLUSIONS

Urban flooding damage, which forms by high intensity rainfall, becomes more and more serious at the urban area, where its population is dense, the number of building is growing and the pervious area becomes less. The economic losses caused by it cannot allow to be ignored.

Based on Guanchang District, Dongguan City as an example, we construct a rainstorm and flood model. By comparison with the actual flooding area, prove the rationality of the model. When the design storm return period is P = 1a, 2.4% of the nodes overflow more than 20 min, where is the main area of waterlogging. Based on the analysis of the overflow effects under different factors, it is concluded the main reason that the bottleneck sections caused by the overflow is the pipe's diameter is too small, the water in the pipes can't flow free, so that the overflow time lasts too long. According to the simulation results, optimize the bottleneck section. The pipe's diameter at the bottleneck section is replaced from 600 mm to 800 mm, the overflow time of node WS03000927 was reduced from 28 min to 3 min. So, the optimization effect is remarkable.

After the bottleneck section optimization design, run the model under the design storm return period P=2a. The simulated results show that the pipe sections to optimize the design can basically meet the drainage requirements of the design storm return period P=2a.

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REFERENCES

[1] Deng P D. Urban Stormwater Cause Analysis and Countermeasures[J]. Water & Wastewater Engineering. 2011(12): 37-40. (In Chinese)

[2] Zhang W, Li S M, Shi Z N. Formation Causes and Coping Strategies of Urban Rainstorm Waterlogging in China[J]. Journal of Natural Disasters. 2012(05): 180-184. (In Chinese)

[3] Zhao D Q, Tong Q Y, Wang H Z, *et al*. Application of SWMM in Urban Storm Drainage Network Modeling[J]. Water & Wastewater Engineering. 2009(05): 198-201. (In Chinese)

[4] Liu J, Xu X Y. Application of Urban Stormwater Model Used in Tianjin[J]. Haihe Water Resources. 2001(01): 9-11. (In Chinese)

[5] Chen L Q. SWMM Applicability Research in Urban Drainage Planning and Design[J]. Water & Wastewater Engineering. 2010(05): 114-117. (In Chinese)

[6] Meierdiercks K L, Smith J A, Baech M. L., *et al*. Analysis of urban drainage network structure and its impact on hydrologic response[J]. Journal of the American Water Resources Association (JAWRA), 2010,46(5):932-943.

[7] Chang C H, Wen C C, Lee C S. Use of intercepted runoff death for storm water runoff management in industrial parks in Taiwan[J]. Water Resource Manage, 2008,22:1609-1623.

[8] Peterson E W, Wicks C M, Assessing the importance of conduit geometry and physical parameters in karst systems using the storm water management model (SWMM)[J]. Journal of Hydrology, 2006,329:294-305.

[9] Rossman L A. Storm Water Management Model User's ManualVersion 5.0[EB/OL].http://www.epa.gov/ednnrmrl/models/swmm/epaswmm5_user_manual.pdf.

[10] Jorge G, Larry A R, Jennifer D. Storm Water Management Model: Applications Manual[EB/OL].http://www.epa.gov/ednnrmrl/models/swmm/epaswmm5_apps_manual.pdf.

[11] Cen G P. Research on Rainfall Pattern of Urban Design Storm[J]. Advances in Water Science. 1998(01): 42-47. (In Chinese)