Simulation of Urban Storm Water Runoff Control Based on Big Data

Yunzhu Liu¹, Jinbao Cao¹

¹Nanchang Institute of Technology, Nanchang, 330044

*Corresponding author e-mail: 2459241930@ncit.edu.cn

Abstract. The acceleration of urbanization has brought about rapid economic development, but at the same time, it has also brought some damage to the ecological environment. The proportion of hardened area of the ground is higher and higher, and the rainwater runoff pollution caused by rainfall is more and more serious. In order to follow the sustainable development strategy, and for the more stable and high-speed economic development, the control of rainwater runoff pollution is urgent. The purpose of this paper is to simulate the urban storm water runoff control and find the most suitable scheme for storm water runoff pollution control. Because the simulation of SWMM is more accurate than other models, it can directly reflect the situation of rainwater runoff pollution, so the model selected for rainwater runoff in this paper is SWMM, and then build the model, through the collection and collation of the basic data of the study area, the generalization of the sub catchment area and drainage network is completed. Through the analysis of the characteristics of the study area, the rainwater garden and permeable pavement are determined as the scheme to control the rainwater runoff in the study area. Finally, the SWMM model is used to simulate the control effect of rainwater garden and pervious pavement on rainwater runoff pollution control. The experimental results show that the storm water garden can effectively control the impact of SS scouring effect on the environment, significantly reduce the discharge of SS, and significantly reduce the peak concentration of SS, and its ability to control SS increases with the thickness of the surface plant layer. The control ability of rain permeable brick pavement to SS increases with the increase of surface porosity, that is, the control effect of SS is the best when the porosity is 20%.

Keywords: Big Data, Storm Water Runoff, Control Simulation, Storm Water Management Model

1. Instruction
The city has become the center of politics, economy, culture and education in China, and the masses have flocked to the city to seek better development opportunities [1]. In the process of rapid development of urbanization, people have caused great damage to the ecological environment [2]. The consequence of high urbanization is that asphalt concrete replaces the original silt soil on the surface, resulting in a sharp increase in hardened ground and a sharp decrease in the permeability of underlying surface,
followed by a significant increase in rainwater runoff, which cannot effectively control the occurrence of waterlogging in the originally designed urban rainwater system; what's more, rainwater runoff pollution is also accompanied in the rainfall runoff process. This will have a huge impact on the urban water environment and human health. Specifically, the pollution factors such as vehicle exhaust and animal manure gathered on the surface will flow into the drainage system with the rainwater runoff, and finally flow to the urban water system, causing great harm to the urban ecosystem [3-4].

In order to reduce the damage of urban rainwater runoff pollution to the ecological environment, many scholars have studied this phenomenon and proposed solutions [5]. For example, through continuous efforts and using data analysis technology, researchers have found solutions to use hydraulic water quality model to simulate urban rainwater system and find technical measures; international advanced technology SWMM can effectively evaluate the control effect of different schemes on urban rainwater runoff pollution, and simulate lid through SWMM. The control effect of lid measures on rainwater runoff pollution is analyzed, which can not only comprehensively show the performance characteristics of lid measures, but also provide reference for lid measures in the actual application process [6-7].

Based on big data technology, this study simulated the urban rainwater runoff pollution control in a specific research area [8]. First, select the rainwater runoff pollution control model SWMM to make a brief introduction; then build the SWMM model to set the meals of the model; finally, based on the SWMM model, simulate the effect of rainwater garden and permeable pavement on rainwater runoff control, and analyze and evaluate the two schemes respectively [9-10].

2. Study on pollution control model of rainwater runoff

(1) Introduction to SWMM Model.

Rain and flood management model (SWMM) is a software developed by the national environmental protection agency in the 1970s. It can simulate the whole process of rainfall runoff fully, which is shown as the dynamic demonstration of the output results: the whole process color animation simulation of rainwater transfer facilities such as catchment sub region and pipeline flow can be carried out according to the time series. The software also adds the low impact development (LID) module, which can fully simulate and predict the runoff and pollution reduction effect of different research areas after adopting lid measures.

(2) The principle of SWMM.

SWMM is composed of several modules, such as runoff, transportation, expansion transportation, storage / treatment, water storage. To realize the simulation of rainfall runoff process, a lot of theories of hydromechanics and water quality environmental engineering are needed. In SWMM model, the theories can be divided into three categories: the principle of hydrodynamics flow generation and confluence; the principle of pollutant accumulation and scour in water quality and environmental engineering.

1) Flow generation principle.

When the infiltration capacity of the ground is less than the rainfall intensity, runoff will be formed on the surface and even the waterlogging will be caused. In order to simulate the runoff accurately, it is necessary to analyze the infiltration of the ground. There are three functions in SWMM which can be used for the analysis of ground infiltration, which are green infiltration model, runoff infiltration curve model and Horton infiltration model.

① Green infiltration model.

The principle of green infiltration is to divide the soil into two states, water saturation and unsaturated according to the actual situation, and can reflect the dry and wet interface between the two states. The specific function expression is as follows:

\[ f = k_s(1 + \frac{i_t}{z_r}) \]  

(1)
Where \( f \) is the infiltration rate of soil, \( k_s \) is saturated water conductivity, \( i \) is the thickness of saturated layer, is the capillary water pressure of wet front.

2. Runoff infiltration model.
   The principle of runoff infiltration curve model is to simulate the infiltration capacity of rainwater in the process of rainfall by using the process function of accumulated rainfall and residual capacity consumption. The model is suitable for the simulation of rainwater infiltration in the study area of large watershed. The specific function expression is as follows:
   \[
   Q = \left( \frac{R - 0.2S}{R + 0.285} \right)^{10} \tag{2}
   \]
   Where \( q \) is runoff (m\(^3\)/s), \( R \) is rainfall (mm), and \( S \) is the comprehensive parameter of underlying surface. The comprehensive parameters of the underlying surface are related to the slope of the underlying surface, groundwater level, land use type, etc., and can be solved according to the dimensionless parameter \( CN \), as shown in the following formula:
   \[
   S = 25.4 \left( \frac{1000}{CN} - 10 \right) \tag{3}
   \]

3. Horton infiltration model.
   The model is an empirical formula derived from a large number of observation data, and it is adopted by some scholars because of the less data of soil parameters.
   2) Principle of confluence.
      Confluence refers to the process of runoff generated on the underlying surface under certain rainstorm intensity during the process of rainfall runoff. In undeveloped land, runoff will converge from higher terrain to lower area; in the developed land (city), runoff will flow from ground to drainage outlet through pipelines after surface confluence. Therefore, the land block confluence process after development includes ground confluence and pipeline convergence flow two processes.
   3) Principle of lightning strike and scour of pollutants.
      In sunny or cloudy days, there will be a lot of pollutants on the surface, and a large amount of accumulated surface pollution will cause the surface pollution with the runoff transfer. In order to simulate the runoff pollution process in rainfall runoff accurately, SWMM simulates the total amount of pollutants accumulated on the surface in non rainfall days by using the pollutant accumulation function, and simulates the process of pollutant transportation with runoff after runoff is formed by rainfall. SWMM can simulate the runoff quality of rainwater through two plates of pollutant accumulation and scour.

3. Construction of SWMM model

3.1. generalization of study area
   The study area adopts the diversion drainage system. The generalization of rainwater system in the study area is based on the following two assumptions: ① the rainfall is uniform in the whole area, that is, the rainfall intensity at each point is equal; ② the whole area is divided into several sub catchment areas, and the rainwater in each sub catchment area flows into the pipe network node nearby. According to the terrain of the study area and the situation of rainwater into the pipeline, the whole community is divided into 60 sub catchment areas. The rainwater pipe network is generalized into 88 nodes and 77 sections of pipeline, and the diameter of rainwater pipeline is between 600 ~ 1800mm.

3.2. model parameter setting
   (1) Flow generation model.
      Green Ampt model accords with the objective law, and soil can be divided into two states: water saturation and unsaturated state according to the actual situation when rainwater is infiltrated, so it has high simulation precision. So green Ampt model is used as the production flow model in this study. In
this study, the soil water transport rate in green Ampt model is 63mm/min, the capillary head height of wet front is 230mm, the initial soil moisture loss value is 0.43; the surface roughness of the catchment area is 0.5 and the impervious surface roughness in the catchment area is 0.013; the permeable ground in the catchment area is stored as 5.3mm, the impervious surface of catchment area is 2.1mm; the percentage of impervious surface without depression storage is 62%.

(2) Confluence mode.
In this study, the nonlinear reservoir model is used to study the rainwater confluence process.

(3) Hydraulic model.
The dynamic wave can simulate the complex situation of backwater and diversion, and the simulation results have high precision. Therefore, the hydraulic model of this study adopts the dynamic wave calculation method.

3.3. sensitivity of SWMM parameters
The dynamic simulation process of rainfall runoff by SWMM is mainly realized by hydrological hydraulic plate and water quality plate. The former can be operated independently, while the latter can only be operated on the basis of the former. Therefore, this study will first analyze the parameter sensitivity of the hydrological and hydraulic plate, and then calibrate the sensitivity parameters of the plate; then analyze the sensitivity parameters of the water quality plate on the basis of the calibrated hydrological and hydraulic plate, and finally get a reliable regional model through the calibration of the water quality sensitivity parameters. In this study, when analyzing the sensitive parameters of SWMM, the initial parameters are perturbed with a fixed step size of 5% (i.e. $\Delta = 5$).

3.4. calibration of SWMM parameters
In this study, the artificial trial and error method is used to solve the optimal solution set of SWMM sensitivity parameters. SWMM first The most sensitive parameter in the model is optimized in its value range, and the first calibration value of the parameter is determined according to the results of the model when other sensitive parameters remain unchanged; then the second sensitive parameter is changed and combined with the first calibrated parameter value, and the second calibration value of the most sensitive parameter is determined when other parameters remain unchanged. The calibration values of the first and second sensitive parameters are the combination of the first and second sensitive parameters; repeat the above process until the combined calibration values of all sensitive parameters are determined.

4. Control analysis of different schemes on rainwater runoff

4.1. rain garden
According to the relevant references, the parameters of rainwater garden used in this study are: the thickness of plant surface is 300 mm, the roughness coefficient is 0.5, and the surface slope is 0.3; the thickness of soil in soil layer is 300 mm, the porosity is 46%, the water production capacity is 0.25, and the withering point is 0.15; the thickness of aquifers in aquifers is 700 mm, and the void ratio is 75%.

The area of rainwater garden should be 2% ~ 10% of the catchment area. In order to determine the value, the Darcy wave frequency method is used to calculate the area of bioretention facilities required by each catchment area in the study area. The formula is as follows.

$$A_f = \frac{(WQ_v \ast d_f)}{(k \ast t_r \ast (h_{avg} + d_f))}$$  (4)

Where $A_f$ is the area of bioretention facilities, is the thickness of biological growth soil layer in rainwater garden, k is the infiltration coefficient of plant growth soil layer, is the average water depth, is the drainage time of water in the study area; $WQ_v$ is the water quality flow, and the calculation formula is as follows:

$$WQ_v = A_T \ast P \ast \frac{R_v}{100}$$  (5)
According to formula (4) and formula (5), the area of rainwater garden facilities in each sub catchment area is determined as shown in Table 1.

Table 1. Area of rainwater garden facilities

| Sub catchment area | Catchment area (M2) | Surface area of rainwater garden (M2) | Proportion (%) |
|--------------------|---------------------|---------------------------------------|---------------|
| X1                 | 14400               | 765                                   | 5.31          |
| X2                 | 16550               | 920                                   | 5.56          |
| X3                 | 22100               | 1140                                  | 5.16          |
| X4                 | 26500               | 1250                                  | 4.72          |
| ...                | ...                 | ...                                   | ...           |
| X60                | 17300               | 956                                   | 5.53          |

To sum up, the total area of bioretention facilities in the study area is 11.8 ha, accounting for 5.5%.

Analysis of the effect of rain garden with different thickness of plant layer on the control effect of SS peak reduction rate.

The thickness of the plant surface of rain garden is usually 200-300 mm, so the thickness of the plant surface is 200, 250 and 300mm respectively when other design parameters are unchanged. The effect of rain garden with different thickness of plant layer on SS is shown in Table 2.

Table 2. Effect of different thickness of plant surface rainwater garden on SS control

| Return period | 200mm | 250mm | 300mm |
|---------------|-------|-------|-------|
| 0.5a          | 23.1  | 23.2  | 23.5  |
| 1a            | 21.2  | 21.2  | 21.2  |
| 2a            | 20.2  | 19.8  | 20.5  |
| 5a            | 12.8  | 15.3  | 16.5  |

Figure 1. Control effect of SS reduction rate

According to Figure 1, the control capacity of rainwater garden to SS increases with the thickness of surface plant layer, as shown in the figure, when the thickness of plant layer is 300mm, the peak reduction rate of SS is the highest.
4.2. permeable pavement
The specific parameters of permeable pavement used in this study are as follows: the height of revetment in the surface layer is 5 mm, the manning coefficient of surface is 0.01, and the surface slope is 3 °; the thickness of pavement in the pavement layer is 300 mm, the porosity is 20%, and the surface impervious ratio is 20%; the water storage depth in the aquifer layer is 90 mm, the void ratio is 0.5, and the permeability is 430 mm/h. The layout area of pervious pavement and bioretention facilities in the study area is the same, occupying 5.3% of the total area.

Analysis on control effect of SS removal rate of permeable brick pavement with different porosity
According to the requirements of relevant documents, the porosity of permeable brick pavement is generally less than 20%, so the surface porosity is 10%, 15% and 20% respectively with other design parameters unchanged. The control effect of different thickness of plant surface rainwater garden on SS is shown in Table 3.

| Return period | SS removal rate |
|---------------|-----------------|
|               | The porosity is 10% | The porosity is 15% | The porosity is 20% |
| 0.5a          | 34.2            | 34.4              | 34.8              |
| 1a            | 32.6            | 32.2              | 32.9              |
| 2a            | 31.6            | 31.4              | 31.7              |
| 5a            | 24.5            | 25.6              | 25.8              |

![Figure 2. Control effect of SS removal rate](image)

It can be seen from Figure 2 that in terms of reducing the total SS load, the reduction rates of the three are basically the same in the range of P = 0.5 ~ 2A; however, when P = 5a, the reduction rate of 20% porosity is significantly higher than that of the other two porosity, which is due to the higher porosity of scenario C, which can quickly infiltrate more rainwater runoff and SS into the ground. Overall, the order of SS peak concentration control ability is: porosity 20% > porosity 15% > porosity 10%.

5. Conclusion
The main work of this paper is to determine SWMM model as the simulation model of rainwater runoff control, and the effect of two methods of simulating rain garden and pervious pavement on pollution control. Through experimental research, it is found that both of these schemes are of great help to pollution control. And the control effect of these two schemes is obvious with the increase of porosity.
Due to the limited time and experimental conditions, there are many deficiencies in the treatment and details of some problems. In view of the shortcomings of this simulation study, the following suggestions are put forward. In this study, the method of artificial error test is used to determine the parameter rate of SWMM model. Although the method is widely used and simple, the accuracy of SWMM can only be accepted by the rate determination results. Therefore, in order to make SWMM model achieve high precision in the future research process, we can use artificial genetic algorithm, ant colony optimization algorithm and other methods with high model fitting accuracy to determine the parameters of SWMM model.

References
[1] Angrill S, Petit-Boix A, Morales-Pinzon T, et al. Urban rainwater runoff quantity and quality – A potential endogenous resource in cities? [J]. Journal of Environmental Management, 2017, 189(MAR.15):14-21.
[2] Kwak, D., H. Kim, and M. Han. "Runoff Control Potential for Design Types of Low Impact Development in Small Developing Area Using XPSWMM." Procedia Engineering 154(2016):1324-1332.
[3] Li, Y., et al. "Seeking urbanization security and sustainability: Multi-objective optimization of rainwater harvesting systems in China." Journal of Hydrology 550(2017):42-53.
[4] Huybrechts D, Verachtert E, Aa S V, et al. Polluted rainwater runoff from waste recovery and recycling companies: Determination of emission levels associated with the best available techniques [J]. Waste Management, 2016, 54(aug.):74-82.
[5] Romania, Alicia. Assessment of the relation between atmospheric precipitation and rainwater runoff for various urban surfaces [J]. Journal of Water & Land Development, 2017, 32(1):87-94.
[6] Zhang, L., et al. "Rainwater storage/infiltration function of rain gardens for management of urban storm runoff in Japan." Landscape and Ecological Engineering 15.4(2019):421-435.
[7] Liu M X, Dai S P, Zhou T Y, et al. [Capacity of extensive green roof to retain rainwater runoff in hot and humid region.] [J]. Ying yong sheng tai xue bao = The journal of applied ecology, 2017, 28(2):620.
[8] Kamei-Ishikawa N, Yoshida D, Ito A, et al. Cesium and strontium loads into a combined sewer system from rainwater runoff [J]. Journal of Environmental Management, 2016, 183:1041-1049.
[9] Zhao L, Hou R, F Wu, et al. Effect of soil surface roughness on infiltration water, ponding and runoff on tilled soils under rainfall simulation experiments [J]. Soil & Tillage Research, 2018, 179:47-53.
[10] Kwak D, Kim H, Han M. Runoff Control Potential for Design Types of Low Impact Development in Small Developing Area Using XPSWMM [J]. Procedia Engineering, 2016, 154:1324-1332.