Simulation of interception capacity of Nanhe initial rain storage tanks

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Abstract: River pollution sources are generally divided into point source, non-point source and internal source, non-point source pollution is mainly urban surface runoff. In this paper, the non-point source pollution model of SWMM in Nanhe region is constructed, and the water quantity and quality are verified by the measured data, and the verification results are in good agreement with the measured data. On this basis, the detention time and the interception amount of initial rain are analyzed. The results show that after intercepting the initial rainwater, the pollutants into the river are significantly reduced, and the lower the frequency is, the better the interception effect of the storage tank on the initial rainwater is. Comprehensive analysis shows that the overall removal rate of pollutants in each frequency of the four outlets of the storage tank can reach 37~39%.

1. Introduction
The initial rainwater runoff is an important cause of urban non-point source pollution. If this part of rainwater is not treated and directly discharged into the river, it will cause serious pollution to the river. Liu1 studied the regulation and storage capacity of Dianchi Lake by the thickness of initial rainwater, the volume and the effect of the regulation and storage pool. The results showed that after setting a 2000m3 regulation and storage pool, the annual discharge of overflow sewage was reduced by 55.7%, and the COD load reduction rate was 60.5%. Xiong2 used SWMM model to simulate the impact of storage tank on rule Lake Watershed in Nanchang city. The smaller the return period is, the greater the removal efficiency of pollutant load is. Jiang3 built a combined model of dual storage tanks with different scales under the condition of small recurrence rainfall, analyzed the interception effect of the two tanks on the initial rainwater runoff and the reduction of pollutant concentration, and found that the flow and velocity in the intercepting pipe had a positive correlation with the volume of the storage tank, showing an overall growth trend.

However, the development and use of the storage tank are restricted by the problems such as the closure flow and the difficulty in quantifying the closure water quality. Therefore, this paper establishes the SWMM model of non-point source pollution in the Nanhe River Basin, simulates the operation effect of the storage tank, and analyzes the interception of the initial rain of the storage tank on the basis of verification.
2. model establishment

2.1. overview of the study area
The Nanhe river basin covers an area of 27.68 km², belonging to the subtropical humid and semi humid monsoon climate zone. The flood level of the South River is influenced by the water level of the outer Qinhuai River, and the water level of the outer Qinhuai River is controlled by the regulation of the Sancha estuary sluice in non flood season. The area belongs to the north subtropical monsoon climate zone, with an average annual rainfall of 1027.5mm. However, the annual variation of precipitation is large, and the annual distribution is uneven. The flood season is 69 months, accounting for about 55% of the whole year, and the flood season rainfall is concentrated from June to July, accounting for 63% of the flood season rainfall. The main types of land use in the region are roads, greening and houses. The drainage system in the area is mainly the rainwater and sewage diversion system, and the rainwater is collected by the pipe network and discharged to the nearby water body. The main tasks of Nanhe comprehensive treatment project include: ecological dredging, source control and sewage interception, ecological treatment, drainage and water storage, flood control and drainage, waterfront space improvement. The main factors that affect the surface source pollution are pollution control and interception and primary rain reservoir. In this project, 54 small and medium-sized outlets and 6 large outlets on the right bank of Nanhe River were intercepted, and 4 new primary rain storage tanks were built: 1# Erganghan with 800 m³, 2# Yurun Square with 3500 m³, 3# Dingshuhan with 6900 m³, 4# Youzhihan with 6500 m³, and pretreatment tanks were added in Erganghan and Yurun Square.

2.2. return period of rainstorm
The formula of rainstorm intensity in Nanjing is used in the calculation, and the design rainfall intensity hydrograph of different frequency is obtained by Chicago rainfall pattern which is widely used at home and abroad. The latest rainstorm intensity formula in Nanjing and the rainfall pattern intensity formula in Chicago are as follows:

Rainstorm intensity formula:

\[
q = \frac{10716.7(1 + 0.837 \lg p)}{(t + 32.9)^{1.011}}
\]
Where: \( P \) -- Design Rainstorm return period (a); \( T \) -- rainfall duration (min), \( t = T_1 + T_2; \) \( T_1 \) -- surface water collection time (min); \( T_2 \) -- epidemic time in the canal (min).

In the city, the maximum flow that really determines the design scale of municipal drainage and water conservancy drainage is mainly determined by the storm peak of municipal drainage and water conservancy drainage design storm. Therefore, the relationship between the two design storm peaks can be found by comparing the two design storm peaks. Thus, the design rainstorm in the calculation is determined \(^4\). The rainstorm hydrograph of municipal drainage design is treated, and the 24-hour rainstorm hydrograph is used to accumulate the rainfall every 1 hour. The rainfall peak is compared with the rainstorm hydrograph of water conservancy design. The results are shown in Table 1.

| Frequency/year | Municipal rainfall peak / mm | Water conservancy rainfall peak / mm |
|----------------|------------------------------|-----------------------------------|
| 0.5            | 29.52                        |                                   |
| 1              | 39.46                        |                                   |
| 2              | 49.41                        |                                   |
| 3              | 55.22                        |                                   |
| 5              | 62.55                        |                                   |
| 10             | 72.50                        | 74.25                             |
| 20             | 82.44                        | 81.41                             |
| 50             | 95.58                        | 108.90                            |
| 100            | 105.53                       |                                   |

In Nanhe area, when the frequency is 10-year and 20-year return period, the municipal design rainstorm rain peak is basically the same as the water conservancy design rain peak, while when the frequency is 50 year return period, the municipal design rainstorm rain peak is much smaller than the water conservancy design rainstorm rain peak, and the water conservancy rain peak is equivalent to the 100 year return period of the municipal design rain peak. At present, the standard of drainage in Nanhe area is once in 20 years, and the matching frequency of municipal pipe network is once in 20 years.

### 2.3. model establishment

Finally, the model has 1123 catchment zones, 1166 nodes, 1179 pipe networks, 7 outlets and 4 storage tanks. The terrain data is generated by the terrain scattered point interpolation provided by the design institute. In SWMM model, the deterministic parameters are mainly calculated by GIS and other technologies, and the other parameters are mainly obtained by experience, model manual or experiment. The final hydrodynamic parameters are as follows:

| name                                      | Parameter value | name                                      | Parameter value |
|-------------------------------------------|-----------------|-------------------------------------------|-----------------|
| Manning coefficient of impervious zone    | 0.013           | Impervious area                           | 0.25            |
| Manning coefficient of pervious zone      | 0.24            | Maximum infiltration rate / mm / h        | 72.39           |
| Impervious area / mm                      | 1.5             | Minimum infiltration rate / mm / h        | 3.61            |
| Storage depth in permeable area / mm      | 2.5             | Permeability attenuation coefficient / D^1 | 8.46            |

The most sensitive parameters of SWMM water quality simulation are: the number of sunny days in the early stage \(^5\): according to the analysis of Jiangsu Academy of Environmental Sciences on Zhenjiang, Jiangsu Province, the number of sunny days in the early stage of this simulation is 9.25
days after comprehensive consideration. In addition, different land use types are closely related to the coefficient of pollutant accumulation function, and the land use types are mainly identified from satellite images. According to the user manual of SWMM model and related research[6-8], and mainly referring to the relevant research results of the study area[5], the parameters of cumulative correlation coefficient of pollutants in different land use types are adjusted according to the measured maximum concentration and concentration change trend of pollutants in the actual rainfall runoff, in which the semi saturated cumulative time is given in advance according to the actual situation and referring to the relevant literature. There is no further adjustment to the timing. According to the actual situation and related literature[9-10], the cleaning parameters are set as 0.0 for residential area, 1.0 for road and 0 for grassland. As the sweeping efficiency is assumed to be 70%, the final sweeping rate of various land use types is 0 for residential area, 0.70 for road and 0 for grassland.

3. Model validation

The project verifies the water quantity and quality of Nanhe non-point source pollution model based on the measured rainfall data on May 14, 2020.

3.1. Water quantity verification

It can be seen from the rainfall that the rainfall will gradually increase from 15:15 on May 14, 2020, but according to the field measurement, there is almost no flow in the rainwater well at 15:15, and there is a certain flow in the rainwater well at about 15:34. This is basically consistent with the calculation results of the model. The calculation results of the model show that the flow in the rainwater well is basically less than 0.01m$^3$/s before 15:15, and the flow is more than 0.03m$^3$/s around 15:30. Therefore, the model is reliable in terms of runoff generation and concentration time.

3.2. Water quality verification

Based on the water quality monitoring results of Nanhe rainwater well on May 14, 2020, the concentration hydrographs of TSS, COD, TP, TN and NH$_3$-N in the model were calibrated. From the calibration results in Figure 3, it can be seen that the trend of calculated pollutant hydrographs is consistent with that of measured ones, and the relative error of other points is basically within 30%,
except that the error of individual points of TSS and COD is more than 50%.

![Figure 3. calibration results of various pollutants](image)

### 4. Effect analysis of storage tank

#### 4.1. analysis of detention time

According to the statistics of outflow time and full storage time of each storage tank, the storage time under the design conditions of each storage tank (Table 3) is as follows: the storage time of Erganghan storage tank is 19 min, that of Yurun square storage tank is 30 min, that of Dingshuhan is 49 min, and that of grease culvert storage tank is 26 min.

| name          | Erganghan | Yurun Square | Dingshuhan | Youzhihan |
|---------------|-----------|--------------|------------|-----------|
| Outflow time (min) | 29       | 29           | 32         | 36        |
| Full storage time (min) | 47       | 57           | 85         | 61        |
| Storage time (min)    | 19       | 30           | 49         | 26        |

Taking Erganghan as an example, the change of total storage capacity of the storage tank shows that the maximum effective water depth of the storage tank reaches 5m after about 47 minutes, and the corresponding storage volume is $800\text{m}^3$. After adding the storage tank, the discharge of the Erganghan is 0 before the storage tank is full. After the storage tank is full, the discharge of the Erganghan increases rapidly.
4.2. Interception accounting of primary rain pollution

From the perspective of pollutant load into the river of each frequency: the trend of pollutant load into the river of each frequency before and after intercepting the initial rain is basically the same. When the rainfall frequency is less than 10%, the pollutant load into the river increases rapidly. When the rainfall frequency is more than 10%, the pollutant load into the river slows down. See Table 4 for pollutant load into the river of each frequency. In general, the lower the frequency is, the better the effect of source control and pollution interception is. For example, the removal rate of pollutants into the river can reach 61%–62% in case of 0.5-year rainfall, and 24–27% in case of 50 year rainfall. The average removal rate of pollutants into the river is 37~39% in comprehensive analysis. See Table 4 for details.

Table 4. removal rate of four pumping stations after intercepting the initial rain

| Frequency/year | COD  | TP  | TN  | NH3-N |
|----------------|------|-----|-----|-------|
| 0.5            | 62%  | 61% | 62% | 61%   |
| 1              | 46%  | 45% | 47% | 46%   |
| 2              | 40%  | 39% | 40% | 39%   |
| 3              | 37%  | 36% | 38% | 37%   |
| 5              | 35%  | 34% | 36% | 35%   |
| 10             | 31%  | 30% | 32% | 31%   |
| 20             | 29%  | 27% | 30% | 28%   |
| 50             | 26%  | 24% | 27% | 25%   |
| Average removal rate | 38% | 37% | 39% | 38% |

5. Conclusion

According to the topographic map, satellite image and pipe network information, the SWMM non-point source pollution model was constructed for the right bank of Nanhe River according to seven catchment areas, including 1123 catchment areas, 1166 nodes, 1179 pipe networks, 7 outlets and 4 storage tanks. The water quantity is verified by the measured data, and the results are in good agreement with the measured data.

In Nanhe area, when the frequency is 10-year and 20-year return period, the municipal design rainstorm rain peak is basically the same as the water conservancy design rain peak, while when the frequency is 50 year return period, the municipal design rainstorm rain peak is much smaller than the water conservancy design rainstorm rain peak, and the water conservancy rain peak is equivalent to the 100 year return period of the municipal design rain peak. At present, the standard of drainage in Nanhe area is once in 20 years, and the matching frequency of municipal pipe network is once in 20 years.

According to the outflow time and full storage time of each storage tank, the storage time of each storage tank is obtained as follows: the storage time of Erganghan storage tank is 19 min, the storage time of Yurun square storage tank is 30 min, the storage time of Ding Shuhan is 49 min, and the
storage time of grease culvert storage tank is 26 min.

From the perspective of pollutant load of each frequency: the trend of pollutant load of each frequency is basically the same before and after intercepting the initial rain. When the rainfall frequency is less than 10%, the pollutant load of each frequency increases rapidly. When the rainfall frequency is more than 10%, the pollutant load of each frequency increases slowly. In general, the lower the frequency is, the better the effect of source control is. After the construction of the storage tank, the average removal rate of pollutants into the river is 37~39%.

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