Coupling simulation of non-point source pollution and 2-D water quality in Nanhe River

Ziming Wang¹, *, Rui Fu², Dongying Wang³, Xingjian Zhang², Xijun Lai⁴

¹Zhejiang Institute of Hydraulics & Estuary (Zhejiang Institute of Marine Planning & Design), Hangzhou 310020, China
²Nanjing Yuhuatai District Water Affairs station, Nanjing, 210012, China
³Nanjing Water Planning and Designing Institute Co. Ltd., Nanjing, 21001, China
⁴Nanjing Institute of Geography & Limnology, Nanjing, 210008, China

*Corresponding author: E-mail: wangziming1301@126.com

Abstract: With the rapid growth of urban population and stable growth of GDP in China, non-point source pollution has become an important reason for the deterioration of urban water pollution, which seriously threatens the security of urban ecological environment. In this paper, the coupling model of non-point source pollution and two-dimensional water quality of SWMM in Nanhe region is constructed, and the coupling model is verified, and the verification results are in good agreement with the measured data. The results show that the improvement of water quality of Nanhe River by ecological treatment is limited; the load of pollutants into the river and the maximum concentration of pollutants in Nanhe River can be effectively reduced by source control and sewage interception; under the design conditions, the water quality index will be difficult to reach and recover to the original level after short-term rainfall, so it is necessary to maintain the water quality. When the diversion flow is 3 m³/s and 5 m³/s, the Nanhe River can basically return to the level before rainfall in one day.

1. Introduction

Two dimensional hydrodynamic water quality model is widely used in rivers, lakes and reservoirs¹⁻⁵. However, the model only considers point source pollution, but lacks consideration of source pollution. SWMM model has been widely used in the calculation of urban waterlogging⁶⁻⁷ and urban non-point source pollution⁸⁻¹⁰. Therefore, the coupling of SWMM model and river network water quality and quantity can effectively solve the problem of insufficient generalization of two-dimensional water quality and quantity coupling model for non-point source pollution, and provide an effective means to solve the problem of urban flood and comprehensive control of river network water quality and quantity. The coupling model can calculate the river water quality and quantity. So as to provide a scientific basis for improving the river water environment and playing an important role of water conservancy projects. Based on SWMM non-point source pollution model and two-dimensional water quantity and quality model, this paper coupled urban non-point source pollution with two-dimensional water quantity and quality model, and applied the model with Nanhe water quality to provide support for better comprehensive treatment of Nanhe river.

2. Domain

Nanhe River belongs to Qinhuai River Basin. The upstream is connected with Qinhuai New River,
where Lianhua sluice is set. The downstream is connected to outer Qinhuai River at Saihong bridge, and Nanhe sluice is built at 1.25km away from Saihong bridge. The total length of the river is about 9.35km. According to the East and West Bank, the inflow of Nanhe river basin is divided into two parts. The east bank is basically the catchment of hilly area, with a catchment area of 6.10 km², which is distributed in belts. Most of the areas have been developed and constructed into urban built-up areas. The flood generated by rainstorm flows directly into Nanhe River, while the West Bank is the catchment of polder area, which is pumped into Nanhe river through drainage pump station. The South River flows into the Qinhuai River from the west bank near Saihong bridge in Nanjing, and a sluice is built near the downstream estuary. Its flood is affected by the inflow from the catchment area, the flood of the Qinhuai River and the flood backwater of the Yangtze River. The comprehensive water environment improvement project of Nanhe river is divided into dredging, sewage interception, bank slope reconstruction, ecological management, water diversion and storage, waterfront space improvement, etc. It is expected to play a role in improving the water environment quality of Nanhe River after full implementation.

3. Construction of coupling model

3.1. SWMM non-point source pollution model
This study covers the right bank of Nanhe river, the SWMM non-point source pollution model has 1123 catchment zones, 1166 nodes, 1179 pipe networks, 7 outlets and 4 storage tanks. The terrain data are generated by terrain scatter interpolation.

![Figure 1. SWMM model of Nanhe area](image)

3.2. Two dimensional hydrodynamic water quality model
The research scope of this project is lianhuazha and Saihong bridge. The mixed quadrilateral and triangular grids are used in the model, with a total of 5656 grids and 6372 nodes. The boundary conditions of the model are the flow boundary of Lianhua sluice in the upstream, the water level boundary of Saihong bridge in the downstream, the Xinhe pumping station, Erganghan, Yurun square, Dingshuhan, Youzhihan, Gongnong pumping station and Jihecun pumping station. The model scope is shown in Figure 2 below, and the model grid is shown in Figure 2 below.
3.3. SWMM coupled with 2D model

In order to determine the pollution load of the model more accurately, the SWMM is weakly coupled with the two-dimensional water quantity and quality model when analyzing the implementation effect of the Nanhe River environmental treatment project. The SWMM model provides the river inflow and pollutant load under different frequency conditions for the two-dimensional model, and evaluates the implementation effect of the treatment project through the two-dimensional water quantity and quality model.

In the coupling model, SWMM is Pyswmm model based on Python language, and the two-dimensional model is Nanhe water environment dynamic model based on two-dimensional unsteady flow and its material transport and degradation process. Finally, the two are coupled by Python language.

4. Model validation

4.1. Hydrodynamic verification

The velocity distributions of Yikang street and Nanhe Sluice at 10:00 am and 4:00 pm on December 1, 2019 were selected. It can be seen from Figure 3 that the maximum measured velocity in the middle of Yikang street is about 0.4m/s, and the minimum velocity on both sides is about 0.1m/s, which gradually decreases from the middle to both sides, basically consistent with the velocity distribution calculated by the two-dimensional model; it can be seen from Figure 3 that the maximum measured velocity in the middle of Nanhe sluice is about 0.1m/s, which gradually decreases from the middle to both sides, basically consistent with the velocity distribution calculated by the two-dimensional model.
4.2. Water quality verification
Taking the measured water quality and quantity on September 8, 2020 as the boundary condition to verify the Nanhe model, the discharge of Lianhua sluice(p1) in the upstream is 3m$^3$/s, and the water level of Saihong bridge(p11) in the downstream is 7.0m. The water quality at the boundary adopts the measured water quality at Lianhua sluice and Saihong bridge. The other outlets do not consider the entry of pollutants. The comparison between the calculated water quality results and the measured water quality is shown in Figure 5 below. The verification results show that the trend of calculated values and measured values of each measuring point is basically consistent. Except for the calculated values and measured values of NH$_3$-N at Xin'anjiang bridge(p7), Mengdu street(p8) and Saihong bridge(p11), the errors of the other measuring points are basically within 10%.

5. Result analysis
5.1. Impact of ecological management on water quality
The impact of ecological treatment on the water quality of Nanhe river is mainly reflected in the increase of the degradation coefficient of pollutants. The schematic diagram (partial) of the two-dimensional model and the ecological treatment area of Nanhe River is shown in Figure 5. Generally speaking, the impact of ecological management on Nanhe river is small, and its impact
mainly concentrated in the areas with ecological management, while for the areas without ecological management, its impact on water quality is small. For example, within 10 hours of calculation, the COD value in the area with ecological treatment changed from 19.344 mg/L to 18.402 mg/L, the TP value changed from 0.195 mg/L to 0.192 mg/L, the NH$_3$-N concentration changed from 0.967 mg/L to 0.939 mg/L, and the COD value changed from 19.33 mg/L to 19.328 mg/L in the area without ecological treatment.

Figure 5. Nanhe ecological management area and its model generalization (partial)

5.2. Influence of source control and sewage interception on water quality

For example, the peak concentration of COD is reduced from 53.04mg/L to 36.66mg/L; the peak concentration of TP is reduced from 1.61mg/L to 1.36mg/L; the peak concentration of TN is reduced from 4.24mg/L to 2.20mg/L; the peak concentration of NH$_3$-N is reduced from 2.32mg/L to 1.64mg/l. However, the degradation rate of pollutants is slow after entering the Nanhe River, and the pollutants tend to be stable in the late stage of rainfall, so it is difficult to further reduce the pollutant concentration.

Figure 6. impact of ecological treatment on water quality
Figure 7. Changes of COD concentration river before and after source control and sewage interception

Figure 8. Change of NH$_3$-N concentration before and after source control and sewage interception
5.3. Influence of diversion and storage on water quality
After water diversion and storage, the water quality of Nanhe river is obviously improved, especially the water quality concentration at each outlet is significantly lower than that without water diversion. With the increase of diversion flow, the pollutant concentration in Nanhe River decreases faster. Taking the location of the Erganghan as an example, the discharge sewage has a great impact on the upstream and downstream of Erganghan without water diversion. After water diversion, the concentrations of COD, TP and NH$_3$-N around the Erganghan are significantly reduced, and the water quality is significantly improved.

![Figure 9. change of pollutant concentration in Erganghan before and after water diversion](image)

The results show that the diversion of water can cut the peak of pollutants obviously and reduce the concentration of pollutants rapidly. Taking the discharge outlet of Erganghan as an example, after 1, 3 and 5 m$^3$/s diversion, the peak of COD concentration is 53.044 mg/L, 35.190 mg/L and 29.24 mg/L respectively; the time for water body to recover to the original river level is 5.85 h, 4.25 h and 3.7 h respectively; the peak of TP concentration is 1.608 mg/L, 1.127 mg/L and 0.824 mg/L respectively; the time for water body to recover to the original river level is 7.1 h, 4.7 h and 4.05 h respectively.

6. Conclusion
According to the water environment characteristics of Nanhe River after the project regulation, the coupling model of non-point source pollution and two-dimensional water quantity and quality was used to analyze the water environment of Nanhe river.
Source control and interception can effectively reduce the load of pollutants into the river and the maximum concentration of pollutants in the South River, but without water diversion, the degradation speed of pollutants is slow only relying on the self purification capacity of the South River, and the water quality index will be difficult to reach and recover to the original level after rainfall.

Generally speaking, the impact of ecological management on Nanhe river is small, and its impact mainly concentrated in the areas with ecological management, while for the areas without ecological management, its impact on water quality is small. For example, within 10 hours of calculation, the COD value in the area with ecological treatment changed from 19.344 mg/L to 18.402 mg/L, the TP value changed from 0.195 mg/L to 0.192 mg/L, the NH3-N concentration changed from 0.967 mg/L to 0.939 mg/L, and the COD value changed from 19.33 mg/L to 19.328 mg/L in the area without ecological treatment.

Under the design conditions, water diversion is needed to maintain or improve the water quality of Nanhe River after short-term rainfall. The water quality of Nanhe River can be improved by continuously diverting water for 1-5 flows. The larger the amount of water, the faster the water quality will be improved. When the water diversion is 1m$^3$/s, it is difficult for some water quality indexes of Nanhe River to return to the original level within 24 hours after rainfall. When the water diversion flow is 3m$^3$/s and 5m$^3$/s, Nanhe River can basically return to the level before rainfall in one day.

Reference

[1] Qian Ling, Liu Yuan, Chao Jianying. Research status and development trend of water quality and quantity joint regulation in China [J]. Environmental science and technology, 2013,36 (S1): 484-487
[2] Peng Zhuoyue, Zhang Lili, Yin Junxi, Wang Hao. Research progress and Prospect of joint operation of water quality and quantity [J]. Water conservancy and hydropower technology, 2015,46 (04): 6-10
[3] Zhang Xiang, Li Liang, Wu Shaofei. Risk analysis of joint operation of water quantity and quality in Huaihe River [J]. Chinese scientific paper, 2014,9 (11): 1237-1242
[4] Song Gangfu, Shen Bing. Ecological based joint operation model of urban river water quantity and quality [J]. Journal of Hohai University (NATURAL SCIENCE EDITION), 2012,40 (03): 258-263
[5] Xu GUI Quan, song de fan, Huang Shi Li, Chu Jun Da, Xu Hui CI. Water quantity and quality model of tidal river network and its numerical simulation [J]. Journal of applied foundation and Engineering Science, 1996 (01): 94-105
[6] Wang Ziming, Cha Liangyu, Wang Bin. Coupling research and application of two-dimensional surface hydrodynamic model and SWMM [J]. Zhejiang water conservancy science and technology, 2019,47 (04): 1-4
[7] Cong Xiangyu, Ni guangheng, Hui Shibo, Tian Fuqiang, Zhang Tong. Simulation analysis of rainstorm and flood in typical urban area of Beijing based on SWMM [J]. Water conservancy and hydropower technology, 2006 (04): 64-67
[8] Zhao Lei, Yang fengle, Yuan Guolin, Wang Junsong, Zhu Yongguan. SWMM model simulation of rainfall runoff and water quality in Mingtong River Basin of Kunming City [J]. Acta ecologica Sinica, 2015,35 (06): 1961-1972
[9] Wang Wenwen. Hydrological effect simulation evaluation of low impact development model based on SWMM [D]. Peking University, 2011
[10] Cao Yunxia, Zhang Gongsu, Wei Mingjie. Calculation of flood control and drainage in Beijing urban area using American storm water management model [J]. Hydrology, 1993 (06): 19-24