Environmental Engineering and Management Journal

June 2024, Vol. 23, No. 6, 1259-1269
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu
http://doi.org/10.30638/eemj.2024.102

"Gheorghe Asachi" Technical University of Iasi, Romania

NUMERICAL OPTIMIZATION STUDY OF THE NANFEI RIVER ECOLOGICAL WATER REPLENISHMENT PLAN

Haie Zhang[1]*, Pengyun Qi[2]

[1]*Anhui Hydropower Vocational Technical College, Hefei 230000, China*
[2]*Lake Ecological Environment Research Institute of Anhui, Chaohu Administration, Hefei 230000, China*

Abstract

This study investigates the effects of water quality improvements under various water replenishment conditions of the Nanfei River, aiming to identify an optimal scheme that maximizes ecological and environmental benefits. A numerical simulation that integrates water quantity and quality was used to model the Nanfei River. The calibrated and validated model simulated the water quality response in the river's main stream under different replenishment pathways and scales. Results show that high-quality water inputs from the Chuhe Main Canal significantly improve the river's water quality, with larger replenishment volumes enhancing this effect. The Banqiao River tributary, located upstream of the Nanfei's urban reach, provides the best overall ecological improvements to the main stream when replenished. Simultaneous inputs from the Ershibu and Dianbu Rivers improve tributary water quality but may negatively impact upstream improvements in the main stream. Therefore, coordination between systems is crucial for effective regulation. The study recommends prioritizing the replenishment of the Banqiao River for optimal water quality and ecosystem benefits.

Key words: ecological water replenishment, Nanfei river, numerical simulation, water resource scheduling

Received: January, 2024; Revised final: March, 2024; Accepted: March, 2024; Published in final edited form: June, 2024

1. Introduction

Rivers and lake systems are carriers of water resources, an essential part of the ecological environment, and a crucial support for economic and social development. Currently, China is promoting the construction of a national water network, comprehensively enhancing the capability to ensure water security (Al-Faraj and Scholz, 2014; Hirpa et al., 2018; Wang et al., 2022; Zhao et al., 2022). With economic development and urbanization, it is necessary to add ecological water replenishment measures on top of pollution source control. This improves water body mobility, increases the capacity and self-purification ability of the water environment, and enhances the effect of water environment improvement (Abdulhameed and Naif, 2023; Akinyemi et al., 2023; Boner and Furland, 1982; Borutska et al., 2023; Collivignarelli et al., 2018; Li et al., 2022; Li et al., 2023; Muis et al., 2024; Muoio et al., 2020; Obradovic and Vulevic, 2023; Oceng et al., 2023; Pramana et al., 2023; Wallingford, 2003; Wang et al., 2021a). Ecological water replenishment is an important means in comprehensive river channel management and a crucial method for ensuring ecological water use. It replenishes water to ecosystems that are impaired due to an inability to meet ecological water demands, aiming to solve the shortage of water resources in regional ecosystems and achieve a dynamic balance in the ecological environment (Gao et al., 2020; Greco et al., 2021; Richter et al., 1998). As the most important urban river in Hefei, the Nanfei River exhibits significant periodic variations in its water volume. Some sections severely lack ecological base flow during dry periods, urgently requiring ecological water replenishment. However,

* Author to whom all correspondence should be addressed: e-mail: 775734909@qq.com

due to constraints such as water sources, terrain, and water engineering, it is necessary to scientifically predict and assess whether water replenishment measures can produce the expected ecological and environmental benefits. In response to this, Xia (2017) proposed an ecological water replenishment strategy using water from the Yangtze River via the Sima Mountain Diversion Project from the perspective of water resource supply and demand balance. Wu (2015) used a steady-state analysis method to analyze the ecological water replenishment needs for improving the water environment of the Nanfei River. However, there is still a lack of quantitative analysis and research on the impact of different water replenishment routes and scales on the ecological environment of the Nanfei River. Existing replenishment plans lack scientific guidance in problem control and route allocation, making it difficult to achieve the best ecological benefits and leading to project waste.

Focusing on the quantitative evaluation of ecological water replenishment effects, scholars at home and abroad have conducted various types of research from the perspectives of the mechanism of river and lake replenishment on the aquatic ecological environment, planning assessment and engineering design, and water quality changes (Castelletti et al., 2008; Chen et al., 2022; Lai, 2019; Liu et al., 2019; King and Louw, 1998; Kuriqi et al., 2019; Pan et al., 2022; Wang et al., 2021b; Yang et al., 2022). In the actual design and optimized scheduling of ecological water replenishment projects, methods such as physical model experiments, field experiments, and numerical simulations are commonly used for analysis. Physical model experiments are less used due to site limitations and scale effects. Field experiments are costly and have long cycles, making it difficult to cope with multiple scenario conditions. Numerical simulation uses models based on physical processes to simulate, predict, and analyze actual-scale project planning and optimization design, offering cost-effective advantages (Nada et al., 2021; Pandolfi and Pettinari, 2020; Wang et al., 2021c), and has been applied in some rivers.

According to the actual situation of the Nanfei River Basin, the degree of urban ground hardening in the Nanfei River Basin has been increasing year by year, which has changed the underlying surface conditions of the basin. The inherent natural functions of the basin, such as stagnation, infiltration, storage and purification, have been weakened, and the ecological flow of the upstream river is scarce. At the same time, the main over-standard factors of Nanfei River are ammonia nitrogen and total nitrogen. How to realize ecological water replenishment and improve water quality and water environment quality is one of the key issues of current concern. This study, targeting the characteristics of the Nanfei River, constructed a water quantity and quality model for the river. Based on water transfer experiments, it quantitatively analyzed the impact of multi-point segmented ecological water replenishment on the main stream's water environment of the Nanfei River, and clarified the quantitative contribution of water replenishment routes and scales to the improvement of water quality in the Nanfei River. The research results can guide ecological water replenishment for the Nanfei River and also provide references for similar urban river ecological water replenishment studies.

2. Data and methods

2.1. Data sources

The Nanfei River, the mother river of Hefei City in Anhui Province of China, flows from northwest to southeast through the main urban area of Hefei and into Chaohu Lake (the fifth largest freshwater lake in China), with a total length of 70 km and a basin area of 1464 km². Basic data on hydrology, water quality, meteorology, and topography of the Nanfei River basin were obtained from observation and survey data from the Hefei Hydrology and Water Resources Bureau, Hefei Ecological Environment Bureau, Meteorological Bureau, and Natural Resources Bureau. Information on existing water conservancy project operation scheduling, point source, and non-point source pollution emissions of the main and tributary streams of the Nanfei River were obtained through field surveys.

2.2. Research scope

The scope of this study begins upstream at the water diversion points of Banqiao River, Ershibu River, and Dianbu River from the Chuhe Main Canal, passing through Banqiao River (about 23.5 km), Ershibu River (about 30.8 km), Dianbu River (about 42.1 km) along three routes to the main stream of the Nanfei River (about 41.07 km), and downstream to Chaohu Lake, as shown in Fig. 1.

2.3. Numerical simulation method

The MIKE 11 professional hydrodynamic software, a mature tool, was chosen to simulate the impact of ecological water replenishment on the water quantity and quality of the Nanfei River. A water quantity and quality model of the Nanfei River based on MIKE 11 was established and calibrated and validated using actual observational data.

2.3.1. Governing equations

MIKE11 hydrodynamic module is mainly used for flood forecasting and scheduling measures, canal / irrigation system design and scheduling, and estuary storm surge research. It is the most widely used commercial software in the world. It has the characteristics of stable calculation, high precision and strong reliability. MIKE 11 uses the vertically integrated conservation equations of mass and momentum, that is, the one-dimensional unsteady flow Saint-Venant equations, to simulate river hydrodynamics (Eqs. 1-2):

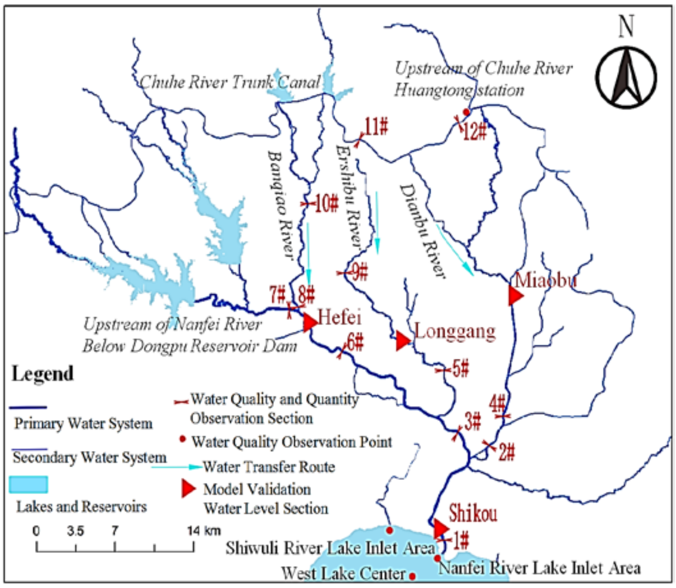

Fig. 1. Map of the study area

$$\frac{1}{B}\frac{\partial Q}{\partial x}+\frac{\partial H}{\partial t}=q_i \tag{1}$$

$$\frac{\partial u}{\partial t}+\frac{\partial u}{\partial x}+g\frac{\partial H}{\partial x}+g\frac{u|u|}{c^2R}=0 \tag{2}$$

where: B is the water surface width, Q is the cross-sectional flow, H is the water level, u is the average flow velocity, q_i is the lateral inflow, g is the acceleration due to gravity, C is the Chezy coefficient, R is the hydraulic radius, and x, t are the spatial and temporal coordinates, respectively.

The equations are discretized using the Abbott-Ionescu six-point implicit scheme (Fig. 2). This scheme alternately calculates flow or water level in sequence, known as Q-points and H-points. The Abbott-Ionescu scheme is characterized by good stability and high computational accuracy. The discretized linear equation set is solved using the chasing method.

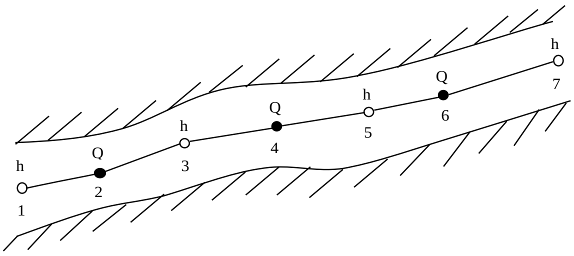

Fig. 2. Alternate layout of water levels and flow points in Abbott format

The water quality module is based on the hydrodynamic conditions generated by the hydrodynamic module to simulate the convection and diffusion processes of substances in the water body. A constant decay constant is set to simulate non-conservative substances, with the equation being (Eq. 3):

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}=\frac{\partial}{\partial x}(E_x\cdot\frac{\partial C}{\partial x})-KC \tag{3}$$

where: u is the average flow velocity, E_x is the diffusion coefficient, C is the substance concentration, K is the first-order decay coefficient for the simulated substance, and x, t are the spatial and temporal coordinates, respectively.

2.3.2. River network generalization

The hydrodynamic model is solved by difference method, and the differential is replaced by difference. It is required that the simplified river network should be used in the simulation calculation. The generalization of the river channel is to include the main river channel in the natural river channel into the calculation range under the premise of ensuring the water conveyance capacity and storage capacity of the river network. According to the principle of equivalence, the secondary river channel is merged into a single river channel or node to facilitate the calculation of water distribution. At the same time, in the process of modeling, the water area not included in the generalized river network is regarded as a ' small reservoir ' of equal area, and the lateral outflow form is used to consider the calculation of the outward diffusion of the river network, so as to make the mathematical model calculation more accurate and reasonable. The computational river network of the model is based on the actual river network and generalized using the principle of equivalence and the principle of unchanged storage volume (Fig. 3).

Lakes and reservoirs are summarized as nodes, generalized as zero-dimensional storage nodes, which are considered to have a storage effect on the flow and are adjustable storage nodes. If A_j is the surface area of the lake, then the water balance equation for such a storage node is (Eq. 4):

$$\Delta Q = \frac{d(A_j Z_j)}{dt} \tag{4}$$

2.3.3. Boundary conditions

Boundary conditions include external and internal boundary conditions. External boundaries are the endpoints in the model that do not connect with other river sections. These endpoints, serving as the inflow, outflow, or closed endpoints for the model's substance flow, all require boundary condition settings, including flow rate, water level, and closed endpoints. Without these settings, the model cannot compute.

Internal boundary conditions are set where there is inflow or outflow in a river section. The setting of internal boundary conditions is based on actual conditions. While not setting these conditions usually does not affect the model's operation, it does impact simulation results. Additionally, internal boundary conditions may change to external boundary conditions due to adjustments in model generalization, thus needing to match the model. The model's external boundary conditions include the upstream inflow of Banqiao River, Ershibu River, Dianbu River, and the upstream inflow and downstream water level of Chaohu Lake at the Nanfei River, totaling five points; see Table 1 for details. Internal boundary conditions mainly include 11 points such as the main discharge inflow, replenishment point inflow, and main wastewater treatment plant effluent discharge, etc. See Fig. 3 and Fig. 4 for the main boundary condition settings.

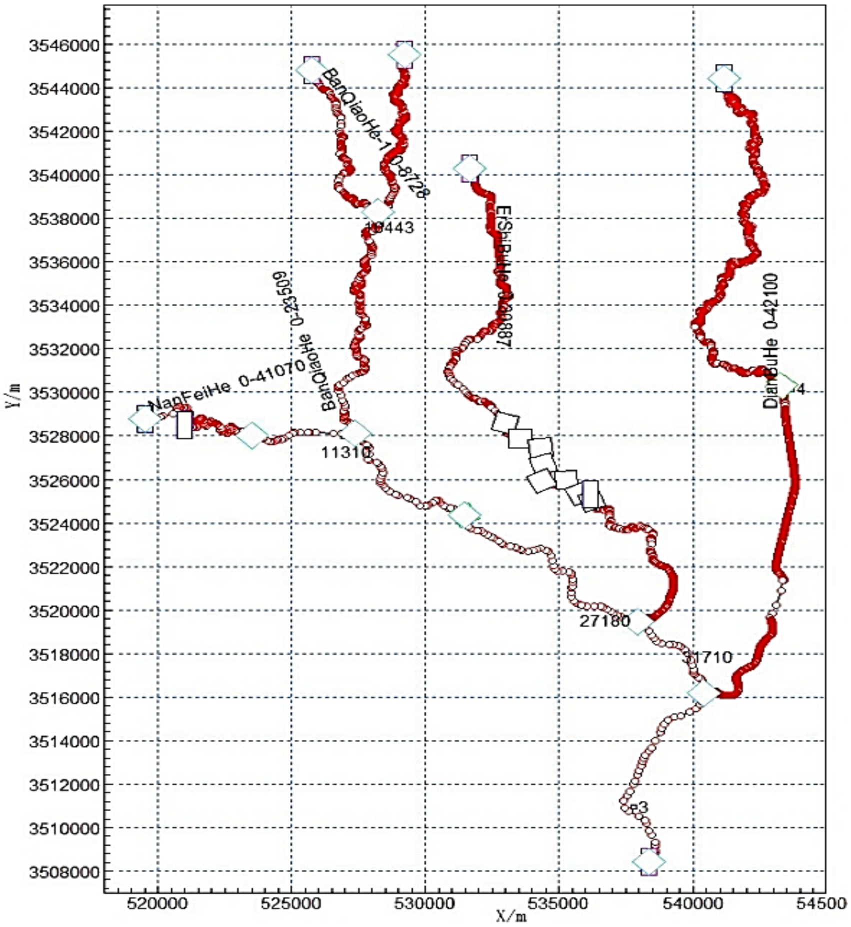

Fig. 3. Generalized map of river network

Table 1. Setting of external boundary conditions of the model

<table>
<tr><th>River Section</th><th>Hydrodynamic boundary</th><th>Water quality boundary</th><th>Remarks</th></tr>
<tr><td>Upstream Nanfei River</td><td>Closed boundary</td><td>/</td><td>No downstream discharge from Dongpu Reservoir</td></tr>
<tr><td>Upstream Banqiao River</td><td>Flow open boundary</td><td rowspan="4">COD, NH_3-N, TP, TN</td><td rowspan="3">Calibration period flow rate uses actual measured flow process; computation uses the current maximum diversion flow rate; ecological replenishment water is river water, using the actual measured water quality concentration of Chuhe Main Canal as the water quality boundary</td></tr>
<tr><td>Upstream Ershibu River</td><td>Flow open boundary</td></tr>
<tr><td>Upstream Dianbu River</td><td>Flow open boundary</td></tr>
<tr><td>Downstream Nanfei River</td><td>Water level open boundary</td><td>Uses the measured water level from the ecological water replenishment experiment</td></tr>
</table>

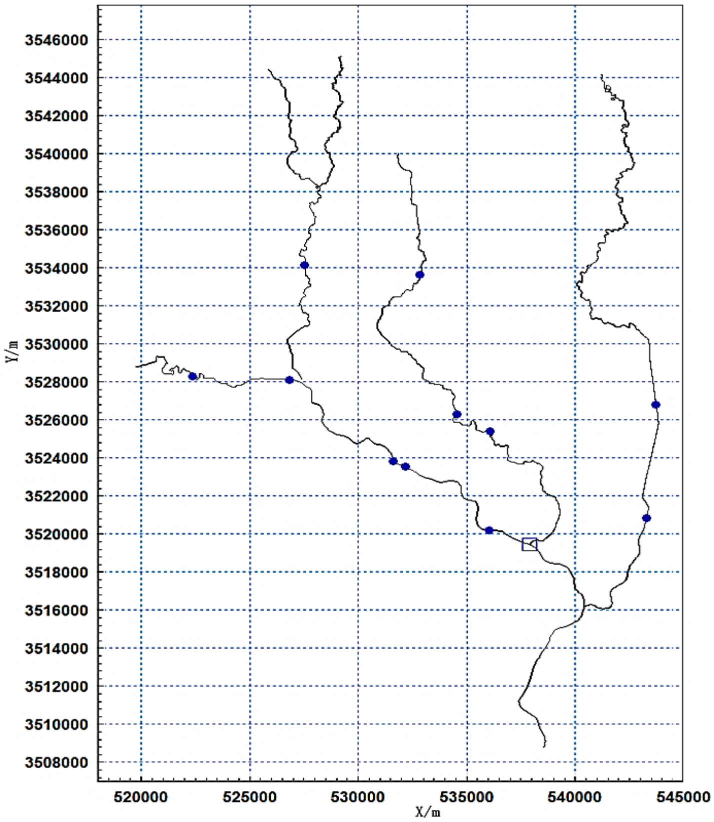

Fig. 4. Internal model boundaries

2.4. Replenishment plans

(1) Replenishment routes

The source of water for the replenishment project in this study comes from the Yangtze River, routed through the existing Wujiang Station, First Level Station, Second Level Station, and Third Level Station at the Sima Mountain to the Chuhe Main Canal. From the Chuhe, water is replenished to the Nanfei River via Dianbu River, Ershibu River, and Banqiao River. There are multiple connections between the Chuhe Main Canal and the Nanfei River system. To avoid disturbing the high-quality water sources of Dongpu and Dafangying urban areas, three replenishment routes are available: ① through Dianbu River into the main stream of Nanfei River; ② through Ershibu River into the main stream of Nanfei River; ③ through Banqiao River into the main stream of Nanfei River.

(2) Replenishment volume

The volume of water replenishment is a crucial parameter relating to the extent of ecological water replenishment's impact on water quality along the river, downstream sections, and Chaohu Lake. For ease of implementation, to gather experience and achieve emergency benefits, considering the pumping station and canal water diversion capabilities and the irrigation requirements of the Sima Mountain irrigation area, and taking into account the current flow capacity of the replenishment rivers, the total flow of ecological water replenishment is set at 7 m^3/s, lasting approximately 5-10 days.

(3) Replenishment water quality

The quality of replenishment water will directly affect the improvement of the Nanfei River and its tributaries. The better the quality of the replenishment water, the more evident the improvement effect on the polluted river water; conversely, if the quality of replenishment water is worse than that of the Nanfei River, the replenishment will be meaningless and instead increase the pollution load of the Nanfei River. The quality of replenishment water depends on the water quality of the source and the collection of sewage in the river network during the replenishment route.

Based on the above replenishment principles, the following four replenishment plans are set (Table 2).

3. Results and discussion

3.1. Model calibration

The model calibration was based on the water quantity and quality observation data from the ecological water replenishment experiment conducted from October 14 to 22, 2019.

3.1.1. Hydrodynamic model calibration

Through the calibration and validation of model parameters, the model simulations were made to closely match the actual measurements. Calibration and validation of the model are crucial processes to ensure its reliability. The calibration parameter for the hydrodynamic model is the roughness coefficient. By setting different roughness values for different river sections, the simulated water levels were made to fit well with the observed water levels. After calibration analysis, the roughness values for the river sections are shown in Table 3.

(1) Water level verification

By analyzing the water level processes at various sites and conducting quantitative analysis, the model's computational accuracy was assessed. The simulated water levels were quite satisfactory. During the simulation period, the average error at three evaluation sites ranged between 2 cm and 7 cm, and the correlation coefficients between simulated and observed values were all above 0.98. The results are shown in Table 4.

(2) Flow verification

The evaluation of flow rate calibration results during the water transfer period is shown in Table 5. The absolute error at the Fanhua Avenue cross-section was the largest, at 1.5 m^3/s. Considering the total flow rate of 23.5 m^3/s, the relative error was 6.4%. The results for other comparison cross-sections were all within 1.1 m^3/s, indicating overall good performance. The Ershibu River and the Logistics Avenue Bridge cross-sections entering the Nanfei River mouth showed relatively large errors, attributed to the lack of corresponding upstream measured flow during the water transfer period, leading to inaccurate boundary inflow in the model.

3.1.2. Water quality model calibration

Based on the measured data from water transfer, the model was calibrated for the concentrations of pollution loads entering the river, attenuation coefficients, and diffusion coefficients, ensuring the trends of the measured and simulated values were consistent and the absolute errors remained within a certain range. Calibration results of water quality parameters is shown in Table 6.

3.2. Numerical simulation of ecological water replenishment effect

Using the constructed numerical model for the ecological water replenishment experiment, simulations were carried out for various ecological water replenishment schemes of the Nanfei River, considering the actual conditions of the water replenishment experiment, and simulating water replenishment for 8-10 days to analyze the effects of each scheme.

Table 2. Setting of water refill conditions

Plan	***Water refill volume/($m^3 \cdot s^{-1}$)***		
	Banhe River	***Dianbu River***	***Ershibu River***
1	7	0	0
2	5	0	2
3	5	2	0
4	3	2	2

Table 3. Results of roughness determination

River	***Name in model***	***Distance/m***	***Roughness***
Banqiao River	BanQiaoHe	0	0.032
		23509	0.032
Small Banqiao River	BanQiaoHe-1	0	0.032
		8728	0.032
Ershibu River	ErShiBuHe	0	0.035
		30887	0.035
Dianbu River	DianBuHe	0	0.031
		42100	0.031
Nanfei River	NanFeiHe	0	0.027
		7230	0.027
		7231	0.032
		17848	0.032
		17849	0.03
		41070	0.03

Table 4. Evaluation results of water level determination

Site	***Water level/m***			***Correlation coefficient***
	Observed average	***Simulated average***	***Absolute error***	
Hefei Station	10.30	10.35	-0.05	0.99
Longgang Station	12.87	12.85	0.02	0.98
Dianbu Station	11.82	11.75	0.07	0.98

Table 5. Assessment of river flow rate during water transfer period

Site	***River flow rate during water transfer period/($m^3 \cdot s^{-1}$)***		
	Observed average	***Simulated average***	***Absolute error***
Dongfang Avenue Bridge	7.5	7.8	-0.3
Yanhe East Road Bridge	7.9	9.0	-1.1
Dangtu Road Bridge	11.4	10.5	0.9
Fanhua Avenue	23.5	22	1.5
Logistics Avenue Bridge	0.6	1.3	-0.7
Ershibu River into Nanfei River Mouth Bridge	0.7	2.2	-1.5

Table 6. Calibration results of water quality parameters

Site No.	***Measured average/($mg \cdot L^{-1}$)***				***Simulated average/($mg \cdot L^{-1}$)***			
	COD	***Ammonia nitrogen***	***Total phosphorus***	***Total nitrogen***	***COD***	***Ammonia nitrogen***	***Total phosphorus***	***Total nitrogen***
A	18.2	0.33	0.078	2.1	18.1	0.27	0.088	3.2
B	16.2	0.49	0.090	4.0	18.7	0.52	0.100	3.5
C	15.1	1.07	0.120	4.9	17.1	1.34	0.090	4.2
D	16.5	2.48	0.130	7.2	17.2	2.39	0.120	5.4
E	27.4	0.53	0.190	7.2	18.2	0.65	0.190	6.8
F	16.4	2.28	0.130	7.1	17.4	2.25	0.150	6.1
Site No.	***Absolute error/($mg \cdot L^{-1}$)***				***Relative error/%***			
	COD	***Ammonia nitrogen***	***Total phosphorus***	***Total nitrogen***	***COD***	***Ammonia nitrogen***	***Total phosphorus***	***Total nitrogen***
A	0.1	0.06	-0.01	-1.1	0.5	18.2	-12.8	-52.4
B	-2.5	-0.03	-0.01	0.5	-15.4	-6.1	-11.1	18.8
C	-2.0	-0.27	0.03	0.7	-13.2	-25.2	25.0	14.3
D	-0.7	0.09	0.01	1.8	-4.2	3.6	7.7	25.0
E	9.2	-0.10	0	0.4	33.6	-17.8	0.0	5.6
F	-1.0	0.03	-0.02	1.0	-6.1	1.3	-15.4	14.1

Note: A-Dongfang Avenue Bridge 10#; B-Yanhe East Road Bridge 8#; C-Dangtu Road Bridge 6#; D-Fanhua AvenueBridge 2#; E-Logistics Avenue Bridge 9#; F-Ershibu River into Nanfei River Mouth Bridge 3#.

3.2.1. Changes in Chemical Oxygen Demand (COD)

For the four river water transfer schemes, the Yanhe East Road section on the Banqiao River and the Dangtu Road Bridge section on the Nanfei River showed a significant decrease in concentration after water transfer, from a background concentration of 20 mg/L down to 17 mg/L. The concentration differences under different water transfer flow rate schemes were not significant. Changes in Chemical Oxygen Demand (COD) are shown in Fig. 5.

3.2.2. Changes in ammonia nitrogen

After water transfer at the Yanhe East Road section, the ammonia nitrogen concentration decreased from 0.7 mg/L to within 0.2 mg/L, showing a significant improvement. At the Dangtu Road section, the ammonia nitrogen concentration reduced to around 0.5 mg/L after water transfer. Changes in ammonia nitrogen are shown in Fig. 6.

3.2.3 Changes in total phosphorus

For the four river water transfer plans, after water transfer at the Yanhe East Road section, the total phosphorus concentration could decrease to around 0.05 mg/L; after water transfer at the Dangtu Road Bridge, the total phosphorus concentration ranged between 0.05 to 0.1 mg/L. Changes in total phosphorus are shown in Fig. 7.

3.2.4 Changes in total nitrogen

After water transfer at the Yanhe East Road section, the total nitrogen decreased from a background concentration of 4.5 mg/L to between 1.0 to 1.5 mg/L; the concentrations at the Dangtu Road Bridge varied significantly between different schemes, with a minimum of 1.5 mg/L and a maximum of 3.5 mg/L. Changes in total nitrogen are shown in Fig. 8.

3.3. Result Analysis

(1) At present, ecological water replenishment is mainly studied by hydrodynamic model or multi-objective optimization model. Wu et al. (2020) constructed a hydrodynamic model of Poyang Lake based on the MIKE21 module, and set different working conditions for simulation to analyze the impact of the construction of water conservancy projects on the utilization of water resources in the basin.

Kong et al (2021) established a coupling model of MIKE11 and SWMM, and complemented the advantages of the two models to evaluate urban rivers from two aspects : hydrodynamic and water quality. Based on the MIKE11 module, this paper constructs a hydrodynamic model to obtain the empirical relationship of multiple objectives, and solves the multi-objective optimization model to obtain a more feasible ecological water replenishment scheme.

(2) In this paper, the numerical model of ecological water replenishment test of Nanfei River is constructed. Based on the observation results of water replenishment test and river terrain data, combined with natural runoff and river pollution, MIKE simulation software was selected to develop, calibrate and verify the hydrodynamic and water quality model of ecological water replenishment in Nanfei River.

Using the measured hydrological and water quality data of the ecological water replenishment test, the calibration and verification of the model was completed. Based on the water level data of Hefei station, Longgang station and Dianbu station, During the simulation period, the average error at three evaluation sites ranged between 2 cm and 7 cm, and the correlation coefficients between simulated and observed values were all above 0.98. and the water level simulation results are ideal. Based on the water quality data of each key site, the water quality calculation results of the model are verified.

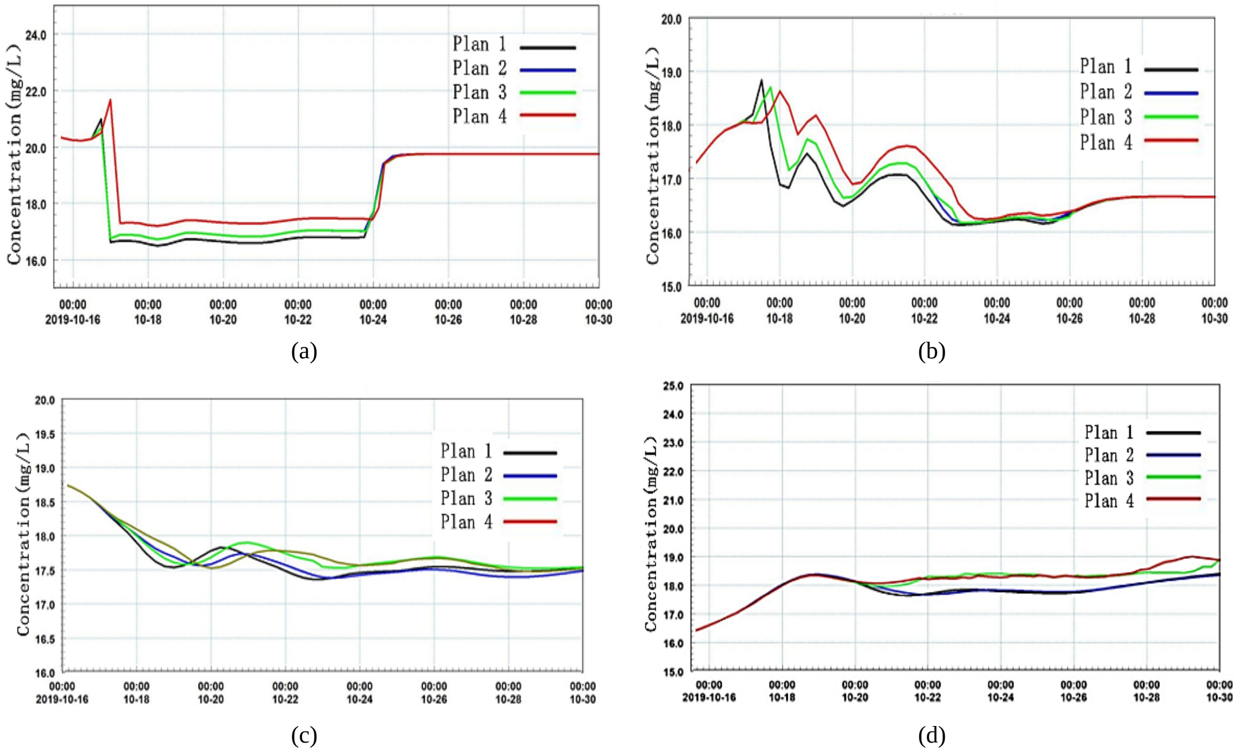

Fig. 5. COD change process of typical section after water transfer: (a) Yanhe East Road Bridge 8#; (b) Dangtu Road Bridge 6#; (c) Fanhua AvenueBridge 2#; (d)Shikou1#

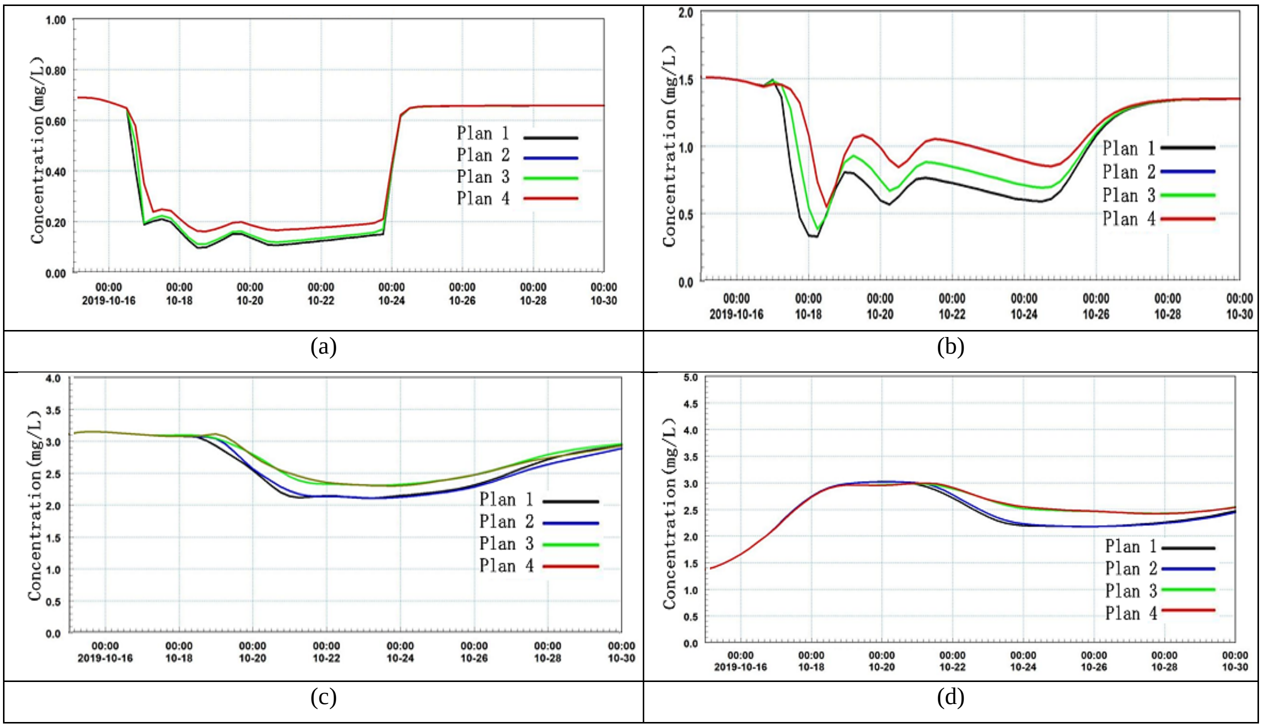

Fig. 6. Ammonia nitrogen change process of typical section after water transfer: (a)Yanhe East Road Bridge8#; (b)Dangtu Road Bridge 6#; (c)Fanhua AvenueBridge 2#; (d)Shikou1#

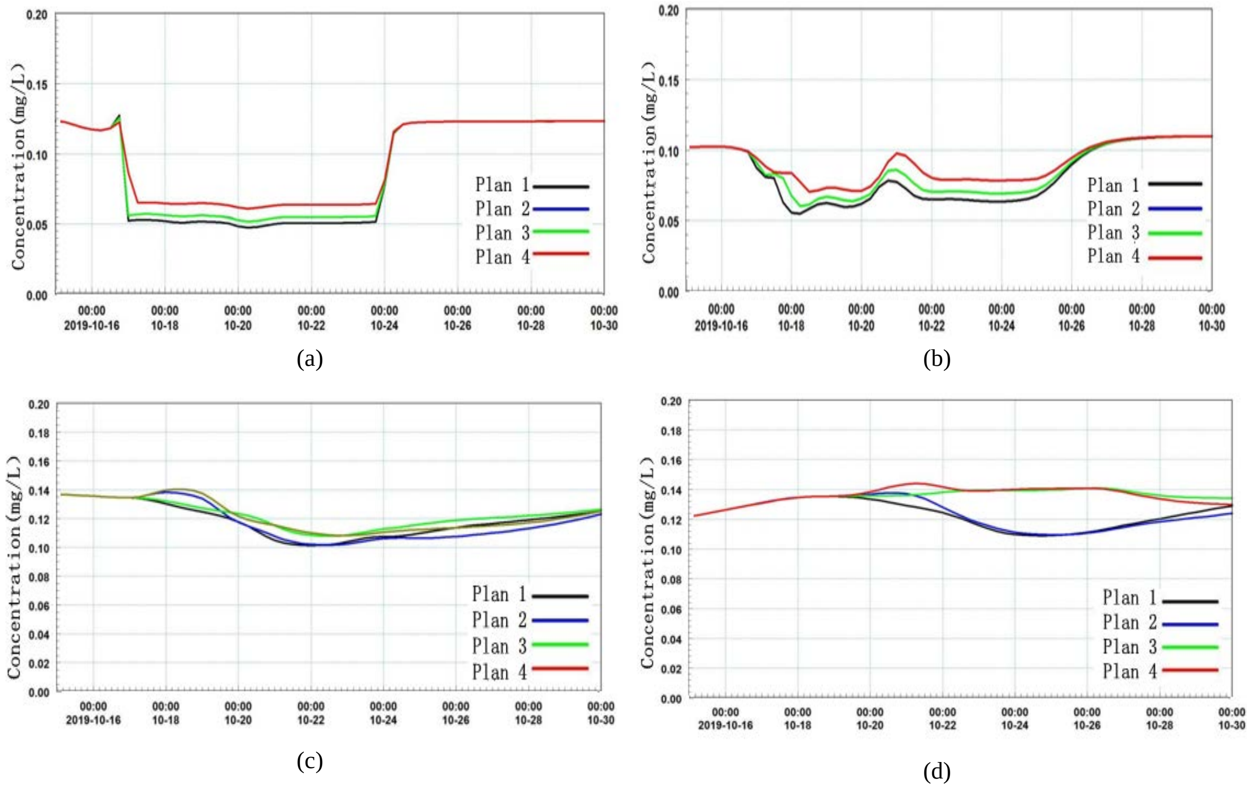

Fig. 7. Total phosphorus change process of typical section after water transfer: (a)Yanhe East Road Bridge8#; (b)Dangtu Road Bridge 6#; (c)Fanhua AvenueBridge 2#; (d)Shikou1#

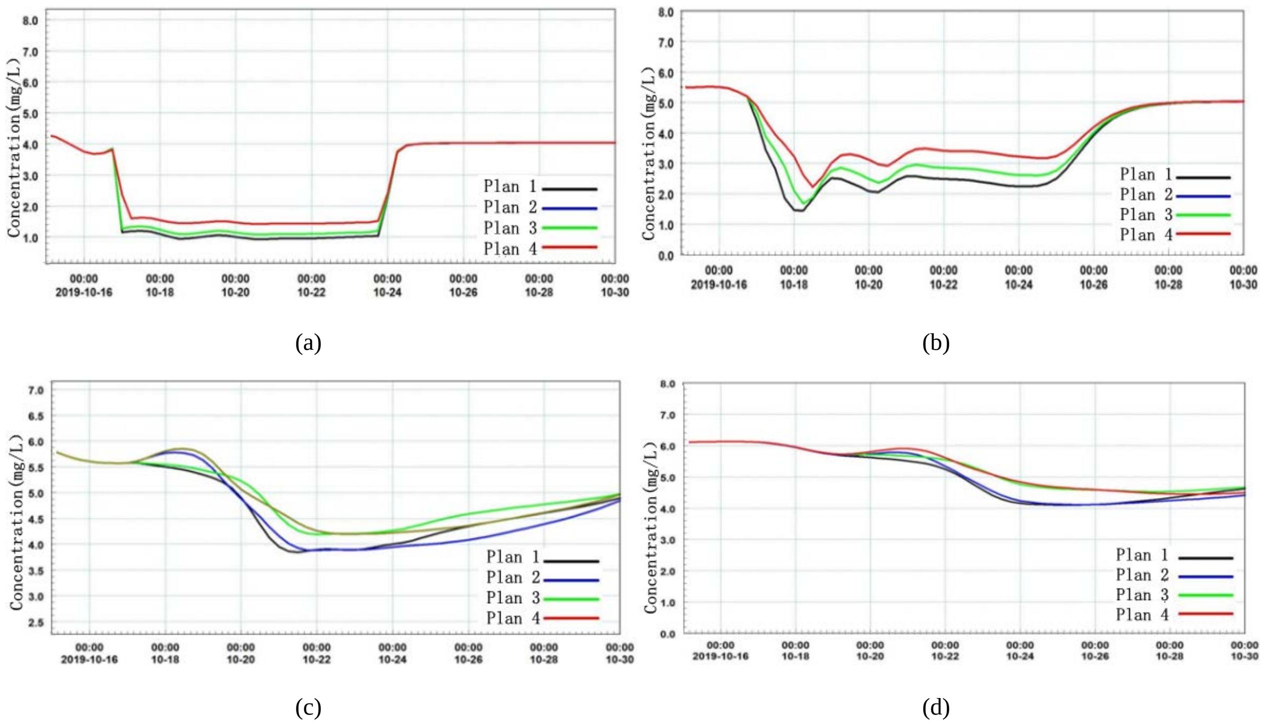

Fig. 8. Total nitrogen change process of typical section after water transfer: (a) Yanhe East Road Bridge8#; (b) Dangtu Road Bridge 6#; (c) Fanhua AvenueBridge 2#; (d) Shikou1#

In general, the simulated values of chemical oxygen demand, ammonia nitrogen, total phosphorus and total nitrogen have small errors with the measured values.

(3) Comparisons of the four water replenishment schemes showed that each had a certain improvement effect on water quality at the cross-sections. For instance, after water transfer, the concentrations of COD at the Yanhe East Road section and the Dangtu Road Bridge section significantly

decreased, from a background concentration of 20 mg/L down to 17 mg/L.

Further analysis revealed that Plan 1 showed the most rapid overall response in water quality (although there were periodic declines in total nitrogen and total phosphorus at some sections, the best water quality improvement was still achieved during the replenishment period), and water quality fluctuations were smaller during the middle and later stages of replenishment, indicating that Plan 1 was the most effective in ecological improvement under the same volume of replenishment.

4. Conclusions

(1) Under the predetermined conditions of the water replenishment source, the choice of replenishment routes and the size of the replenishment flow significantly impact the ecological effectiveness of the replenishment. Based on the numerical simulation of ecological water replenishment in the Nanfei River, using the calibrated Nanfei River water quantity and quality coupled numerical model, it is possible to quantitatively analyze the actual impact of various replenishment schemes on water quality in different downstream river sections.

(2) Plan 1, which concentrates the replenishment flow in the Banqiao River, shows the most significant improvement in water quality at the downstream Yanhe East Road section, and also has a good improvement effect on the Dangtu Road Bridge section of the Nanfei River. The ecological water replenishment of Scheme 2 has the next best effect on improving water quality, while Schemes 3 and 4 are relatively less effective.

(3) Plan 1 achieves the best water quality improvement under the same volume of replenishment. It is recommended that future water replenishment efforts should pay attention to the coordination among water systems and primarily implement the Banqiao River replenishment scheme.

References

Abdulhameed I.M., Naif R.I., (2023), Optimization of rainwater-harvesting dam placement in Iraq's western desert: A GIS and mathematical modeling approach, *Journal of Civil and Hydraulic Engineering*, **1**, 38-48.

Akinyemi B.T., Ogundele O.D., Afolabi A.B., (2023), Advancements in sustainable membrane technologies for enhanced remediation and wastewater treatment: a comprehensive review, *Acadlore Transactions on Geosciences*, **2**, 196-207.

Al-Faraj F.A., Scholz M., (2014), Assessment of temporal hydrologic anomalies coupled with drought impact for a transboundary river flow regime: the Diyala watershed case study, *Journal of Hydrology*, **517**, 64-73, https://doi.org/10.1016/j.jhydrol.2014.05.021.

Boner M.C., Furland L.P., (1982), Seasonal treatment and variable effluent quality based on assimilative capacity, *Journal (Water Pollution Control Federation)*, **54**, 1408-1416.

Borutska Y., Vashchyshyn M., Zhurba I., Leskiv H., Taranenko H., Panteleiev M., (2023), State environmental impact management in ecological tourism development, *International Journal of Design & Nature and Ecodynamics*, **18**, 1247-1254.

Castelletti A., Pianosi F., Soncini-Sessa R., (2008), Water reservoir control under economic, social and environmental constraints, *Automatica*, **44**, 1595-1607, https://doi.org/10.1016/j.automatica.2008.03.003.

Chen L.M., Chen L.G., Li T.L., Lu H., (2022), Comparative analysis of ecological water replenishment scheduling schemes for urban wetland parks, *Water Resources Protection*, **38**, 162-167.

Collivignarelli M.C., Abbà A., Sorlini S., Damiani S., Crotti B.M., (2018), From the application of water safety plan to the achievement of the ISO 22000:2005 standard: A case study, *Environmental Engineering and Management Journal*, **17**, 2361-2372, https://doi.org/10.30638/eemj.2018.234.

Gao W., Li J.C., Yan C.A., (2020), Optimization allocation model and application of ecological water replenishment in multi-water source rivers, *Yangtze River*, **51**, 75-81.

Greco M., Arbia F., Giampietro R., (2021), Definition of ecological flow using IHA and IARI as an operative procedure for water management, *Environments*, **8**, 77, https://doi.org/10.3390/environments8080077.

Hirpa F.A., Dyer E., Hope R., Olago D.O., Dadson S.J., (2018), Finding sustainable water futures in data-sparse regions under climate change: Insights from the Turkwel River basin, Kenya, *Journal of Hydrology: Regional Studies*, **19**, 124-135, https://doi.org/10.1016/j.ejrh.2018.08.005.

King J., Louw D., (1998), Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology, *Aquatic Ecosystem Health and Management*, **1**, 109-124.

Kong Y., Sun W., Li X.L., Xia Y.G., Xu H., Yang X.L., (2021), Building and application idea of SWMM-MIKE 11 coupling model in sponge river construction, *Water Resources Protection*, **37**, 74-79.

Kuriqi A., Pinheiro A.N., Sordo-Ward A., Garrote L., (2019), Flow regime aspects in determining environmental flows and maximizing energy production at run-of-river hydropower plants, *Applied Energy*, **256**, 113980, https://doi.org/10.1016/j.apenergy.2019.113980.

Lai X.J., (2019), Research progress on integrated simulation of watershed water environmental processes, *Progress in Geography Science*, **8**, 1123-1135.

Li P., Ran Y.L., Li X.M., Han Z., Zhang Y., Zhang L.Y., Du Z.J., Wu X.M., (2023), Thermal equilibrium analysis of small-to-medium river ecosystems in northern China under multi-factor coupling and decision-making for ecological restoration, *International Journal of Heat and Technology*, **41**, 1291-1300.

Li W.D., Min Y., Shi S.C., Tang R., Zhong L., Yin Y.Y., (2022), Research on ecological water replenishment measures for urban water networks in the plain area of Taihu Basin, *Yangtze River*, **53**, 75-81.

Liu Y., Fan Z.W., Xie C., et al., (2019), Design and on-site verification of the free-flowing water scheme for the main urban area of Yunbei in Changzhou City, *Journal of Hydraulic Engineering*, **177**, 10-17.

Muis I., Agustang A., Maru R., Adam A., (2024), Exploring social, physical, and mental risks of ecological modernization through dam construction: A case study of PT. Vale Indonesia's mining activities, *International Journal of Sustainable Development and Planning*, **19**, 385-390.

Muoio R., Rossi L., Santianni D., Caretti C., Lubello C., Ferretti E., (2020), Development and implementation of a water safety plan for the drinking water supply system of Florence, Italy, *Environmental Engineering and Management Journal*, **19**, 1813-1822, https://doi.org/10.30638/eemj.2020.173,

Nada A., Zeidan B., Hassan A. A., Elshemy M., (2021), Water quality modeling and management for Rosetta Branch, the Nile River, Egypt, *Environmental Monitoring and Assessment*, **193**, 603, https://doi.org/10.1007/s10661-021-09357-8

Obradovic V., Vulevic A., (2023), Water resources protection and water management framework in western balkan countries in drina river basin, *Acadlore Transactions on Geosciences*, **2**, 24-32.

Oceng R., Andarani P., Zaman B., (2023), Quantifying plastic waste and microplastic contamination in african aquatic systems: An imperative for sustainable waste management, *Acadlore Transactions on Geosciences*, **2**, 94-112.

Pan R.Y., Jiang X., Pan L., Huang X.R., (2022), Study on ecological water replenishment based on water quality-water quantity-water source coupling model, *Water Saving Irrigation*, **2022**, 58-63.

Pandolfi G., Pettinari J. (2020). Nature-based solutions for flood management: A study conducted in Labaro - Prima Porta District, Rome, Italy, *Environmental Engineering and Management Journal*, **19**, 1835-1846, https://doi.org/10.30638/eemj.2020.176.

Pramana A., Sukendi, Putra R.M., Agrina A., (2023), Assessing ecological and socio-economic attributes in sustainable management of solid medical waste in urban environment, *International Journal of Sustainable Development and Planning*, **18**, 977-983.

Richter B.D., Baumgartner J.V., Braun D.P., Powell J., (1998), A spatial assessment of hydrologic alteration within a river network. *Regulated Rivers: Research & Management*, **14**, 329-340, https://doi.org/10.1002/(SICI)1099-1646(199807/08)14:4<329::AID-RRR505>3.0.CO;2-E.

Wallingford H.R., (2003), Handbook for the assessment of catchment water demand and use, Project Report. HR Wallingford Ltd/DFID, On line at: https://eprints.hrwallingford.com/498/.

Wang F., Wang X.P., Zheng Z.Q., Jiang R.F., Ren Y., (2021a), Research on ecological water replenishment in a tidal river network based on hydrodynamic and water quality simulation, *Water Supply and Drainage*, **57**, 223-228.

Wang F.F., Qing X.X., Yu S.J., (2021b), Optimal allocation of ecological water replenishment projects in rivers, *Hydrology*, **41**, 48-52.

Wang H.W., Zhou X.M., Liu X.Y., Fu X.Y., Zhao H.S., (2021c), Production-living-ecology nexus of land-use functions in the mountainous areas: A case study of Chongqing, China, *International Journal of Sustainable Development and Planning*, **16**, 1071-1080.

Wang X., Wang G., Tian W., Li C., Yang Y., (2022), Characterizing long-term water quality variation with multivariate statistical methods: a case study in the two tributaries of Yellow River, China, *Environmental Engineering and Management Journal*, **21**, 1117-1125.

Wu P.J., Duan M., Chen J., Ye Q., Ji, Y., (2020), Influence of Poyang Lake water control project dispatching on water resources utilization in Poyang Lake, *Yangtze River*, **51**, 101-106.

Wu S., (2015), Discussion on the demand of ecological water replenishment for water environment improvement in Nanfei River, *Jianghuai Water Resources Science and Technology*, **2**, 20-22.

Xia W.B., (2017), Study on ecological water replenishment to Nanfei River by Sima Mountain Diversion Project, *Jianghuai Water Resources Science and Technology*, **4**, 27-28.

Yang Z.M., Li S., Li T.R., Sun X.J., Sun Q.C., Jiang H., (2022), Analysis of ecological water replenishment for the Beijing section of the Yongding River, *China Water Resources*, **2022**, 76-78.

Zhao H.T., Xuan W., Li L.Y., (2022), Promoting high-quality development of follow-up projects after the South-to-North Water Transfer and accelerating the construction of the national water network main framework and major arteries-Interview with Li Guoying, Party Group Secretary and Minister of the Ministry of Water Resources, *China Water Resources*, **2022**, 1-3.