

Article

Estimation of Reclaimed Water Utilization Benefits in a Typical Coastal River Network

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Abstract: Nowadays, reclaimed water is widely acknowledged as a convincing alternative to fresh water resources, with it also recognized as an important material in water diversion projects around the world. As a typical coastal area, Taizhou city, located in southeast China, is close to the East China Sea. In this study, the benefits of reclaimed water utilization in a water diversion project are estimated, and both field monitoring and numerical simulation are executed to demonstrate the improvements in the local plain river network water quantity and quality. The highly developed domestic society and economy have led to a huge contradiction between water supply and demand. As a result, the coastal plain river network in Taizhou city is always plagued by low flow velocity and poor water quality. The utilization of reclaimed water in Taizhou city has been proven to be efficient and effective for the local development and environment in this study, and it will be a good tool for the coastal plain river network in improving both the water quantity and quality in the future for those cities close to the shore area.

Keywords: reclaimed water; diversion project; field monitoring; numerical model; benefits estimation



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1. Introduction

Recently, the utilization of reclaimed water has become popular around the world, especially in water diversion and distribution projects in coastal plain river networks [1–5]. Indeed, reclaimed water is an unusual water resource that is purified to meet specific water quality standards [6–9]. When considering river networks close to coastal areas, the utilization of reclaimed water makes it not only possible to alleviate the shortage of freshwater resources in those areas but also optimize the allocation of local water resources [5,7,10–14]. The utilization of reclaimed water has also played a positive role in the restoration and protection of local ecosystems [13–18].

The coastal plain river network is usually crucial to the domestic economy and society since most coastal cities combine both natural landscapes and human activities. As a result, freshwater sources are usually insufficient in coastal plain river network areas [17,18]. Agriculture and industry are usually highly developed in these areas [19–21]. Hence, sustainable management is essential to balance the development between human society and the domestic environment. In fact, due to the limitations of the coastal plain river network, it is generally plagued by the issues of insufficient water quantity and poor water quality. In order to solve these problems, the utilization of reclaimed water is widely acknowledged as a reliable and efficient tool to solve the domestic water quantity and

quality problem [22–25]. Namely, the hydrodynamics of the coastal plain river network can be improved, and the self-purification capacity of the river network can also be upgraded by utilizing reclaimed water [24–29].

In this study, reclaimed water is considered an efficient tool to alleviate both the water quantity and quality problems of a typical coastal plain river network. The field monitoring and numerical model are executed together in this study in order to show the different statuses of the selected coastal plain river network. Various cases of reclaimed water diversion are simulated using the numerical model, and the effects of the domestic reclaimed water diversion project are compared and analyzed in this study to show the advantages of reclaimed water utilization.

2. Field Monitoring and Materials

Taizhou city is located on the eastern coast of Zhejiang Province, as shown in Figure 1. The river network in Taizhou city is complicated, though most of the rivers are of low velocity. Indeed, the government of Taizhou city has paid considerable attention to the local water environment for decades, and different kinds of water environment treatment methods have been applied for the purpose of water quality improvement. However, the water quality of the coastal plain river networks in Taizhou city is still unable to meet the stipulated requirements, and the domestic water environment still needs to be consolidated.



Figure 1. The location and river network of Taizhou city.

As shown in Figure 2, the Taizhou coastal river network reclaimed water diversion and distribution project is composed of three different sewage and reclaimed water treatment plants, namely the Jiaojiang sewage treatment plant, the Luqiao Urban sewage treatment plant, and the Luqiao Coastal sewage treatment plant. Additionally, more than 3000 km of the pipeline project is also an important component of the domestic reclaimed water diversion system in this city.

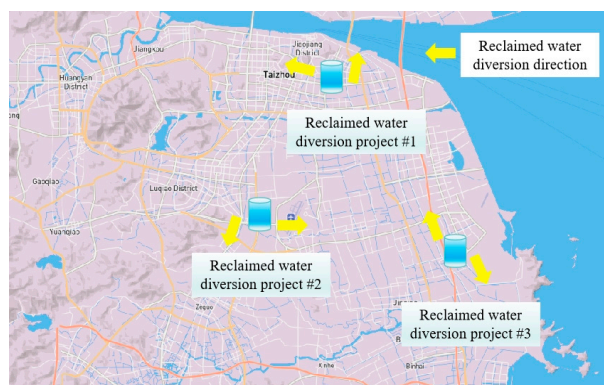


Figure 2. The local reclaimed water diversion projects.

From the perspective of the local agriculture and industry demand, the ecological flow of the river network can not be guaranteed. Firstly, the water resources in the southern area of Taizhou city, which includes the Jiaojiang, Luqiao, and Wenling districts, are relatively lacking. The domestic drinking water supply system relies on the Changtan reservoir, while most of the agricultural and industrial water is taken from the plain river network. The water resources per capita in these areas are lower than 60% of the average water resources per capita in Taizhou city. Secondly, the ecological flow is insufficient, especially in the dry season, since the supply and demand of water resources are unbalanced. Moreover, the flow discharge reduction of the large- and medium-sized reservoirs also leads to a serious water resource shortage problem in Taizhou city. Thirdly, the utilization of reclaimed water is still inadequate to meet the water demand requirements, and the capacity of the river's self-purification is also poor.

The local government has constructed two automatic monitoring stations in the river network of Taizhou city, which are located in the Batou gate section and the Yantou gate section. As shown in Figure 2, the Batou gate section is located east of the Nanguan River, which is acknowledged as the upstream water quality control section of Taizhou city, while the Yantou gate section is located in the northeast region of the river network, which is acknowledged as the downstream section of Taizhou city. In order to clarify the water quality of the river network in Taizhou city, the monthly water quality monitoring data of the above two sections from 2019 to 2021 were collected and analyzed in detail in this study. Three ordinary pollutants were selected to show the water quality of the river network, which are widely accepted and used in water quality research, namely, COD_{Mn} (Permanganate), $\text{NH}_3\text{-N}$ (Ammonia Nitrogen), and TP (Total Phosphorus). The annual water quality variation in 2021 was examined in this study to show the recent water quality status of the river network in Taizhou city. The annual water quality variation of the Batou gate section and the Yantou gate section is shown in Figure 3.

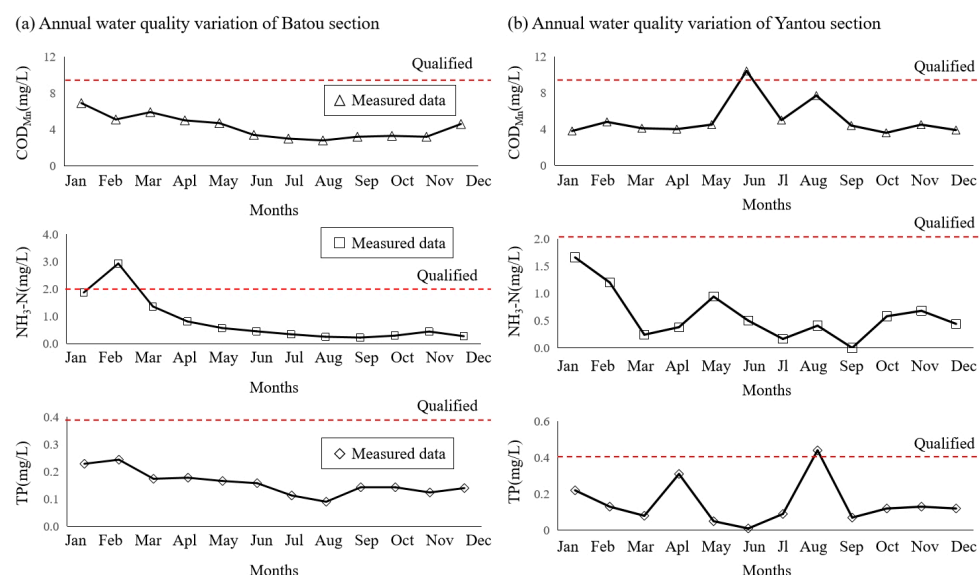


Figure 3. The annual water quality variation of the Batou gate section and the Yantou gate section.

Generally, the water quality of both sections is fine. For the Batou gate section, the concentration of COD_{Mn} is lower than 8 mg/L and the concentration of TP is lower than 0.4 mg/L, whereas the concentration of $\text{NH}_3\text{-N}$ is not as good as the previous two factors. For the Yantou gate section, the concentration of COD_{Mn} exceeds 10 mg/L in June, and the concentration of TP exceeds 0.4 mg/L in August, whereas the concentration of $\text{NH}_3\text{-N}$ was consistently lower than 2.0 mg/L during 2021. Actually, the coastal plain river network of

Taizhou city suffers from poor hydrodynamic conditions and low regional water quality due to the shortage of ecological flow. In addition, the domestic sewage and rural non-point sources are the key factors that affect the regional water quality and lead to a weak water self-purification capacity. Thus, it is critical for the local environment to find an efficient regional water source that is suitable for improving both the water quantity and quality of the local river network. In this study, reclaimed water becomes the best choice for Taizhou city as the regional circulation water source to achieve the aim of accelerating the water flow and upgrading the water quality of the coastal plain river network.

3. Numerical Model

In this study, a hydraulic and water quality coupling model of the Taizhou coastal plain river network is constructed considering the configuration of the regional reclaimed water diversion project in the study area. This coupling model consists of 81 rivers, 456 sections, 6 water diversion discharges, and 12 sluices, weirs, or dams.

3.1. Hydraulic Model and Water Quality Model

The hydraulic and water quality coupling model generalized in this study for simulating the Taizhou coastal river network is shown in Figure 4.

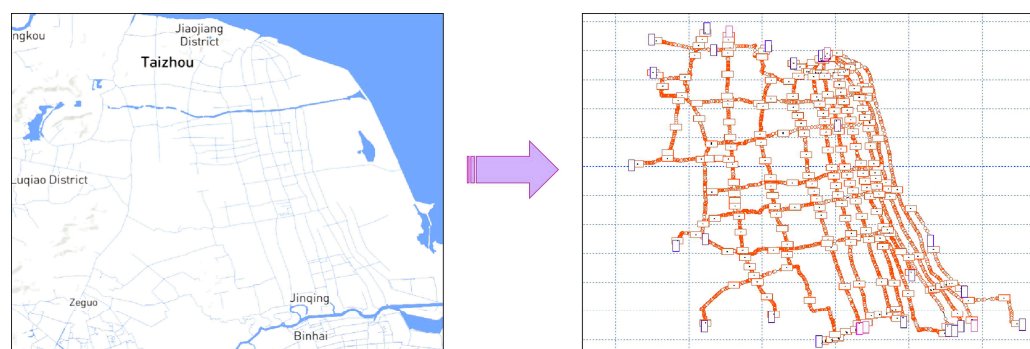


Figure 4. Numerical model configuration.

1. Hydraulic model

The one-dimensional governing equations of the unsteady hydraulic model are given as follows [28,30–32]:

$$\frac{\partial Z}{\partial t} + \frac{1}{B} \frac{\partial Q}{\partial X} = q \quad (1)$$

$$\frac{\partial Q}{\partial t} + 2u \frac{\partial Q}{\partial X} + Ag \frac{\partial Z}{\partial X} = u^2 \frac{\partial A}{\partial X} - g \frac{Q|Q|}{C^2 R} + q_i(u - u_0) \quad (2)$$

where Z is the average water level (m); B is the water width (m); q is the flow rate of the specific section (m^3/s); Q is the total flow rate (m^3/s); A is the area of the cross-section (m^2); u is the section average velocity (m/s); C is the Chezy coefficient; q_i is the tributary flow (m^3/s); and g is the acceleration of gravity (m/s^2).

2. Water quality model

The water quality model was established based on the one-dimensional convection–diffusion model, and the linear degradation of pollutants was also included. The water quality model is given as follows [33–35]:

$$\frac{\partial AC_1}{\partial t} + \frac{\partial QC_1}{\partial x} - \frac{\partial}{\partial x} \left[AD \frac{\partial C_1}{\partial x} \right] = -AKC_1 + C_2q \quad (3)$$

where C_1 is the pollutant concentration; C_2 is the point source concentration, q is the flow rate of the point source; A is the area (m^2); D is the diffusion coefficient (m^2/s); and K is the degradation rate (s^{-1}). The other coefficients are the same as the hydrodynamic model. The convection–diffusion equation is solved using the implicit finite difference scheme in this study [21,27,34].

The initial conditions are given as static conditions for both the hydraulic and water quality model. The flow rate and water level in the model are set as constants, and the pollutant concentrations are also given as constants at the beginning of the simulation, while the boundary conditions are given as Dirichlet boundary conditions. For the hydraulic mode, the upstream boundary condition is set using the flow rate, and the downstream boundary condition is set using the water level. For the water quality model, both the upstream and downstream boundary conditions are given as the pollutant concentration.

During the simulation, the hydraulic and water quality models were simulated simultaneously due to the complex conditions of the coastal plain river network. The data obtained from the field monitoring experiment were used to verify and calibrate the existing model, which is also helpful in increasing both the efficiency and accuracy of the numerical model itself. Additionally, different cases of reclaimed water utilization were simulated and analyzed based on the numerical model, which can aid the domestic government in optimizing the reclaimed water diversion project.

3.2. Model Verification

Field monitoring data were obtained and used in this study to verify the hydraulic and water quality model. As indicated in the model setup, the upstream conditions were set using the flow rate, while the downstream conditions were set using the water level. Both the upstream and downstream boundary conditions were set based on the field monitoring data, as shown in Figure 5.

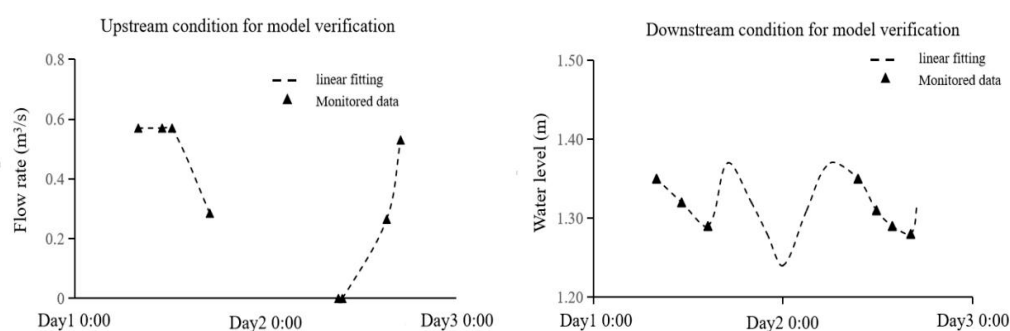


Figure 5. Upstream and downstream boundary condition setup for model verification.

During the simulation, the water flow and water quality were calculated simultaneously; the degradation coefficients of COD (Chemical Oxygen Demand), $\text{NH}_3\text{-N}$, and TP were set to 0.11 d^{-1} , 0.09 d^{-1} , and 0.08 d^{-1} , respectively.

In this study, both the hydraulic model and water quality model were verified in different sections of the coastal plain river network. The upstream and downstream boundary conditions were set based on the field monitoring data with a linear differential fitting process, as shown in Figure 5. The comparison sections were selected considering the spatial configuration, namely, the Hongjiachangpu section, the Qinglongpu section, and the Santiaohe section. Moreover, the comparison periods for the water quality model were selected at 12:00 each day.

The simulation time of model verification coincides with the field monitoring date. Three different internal sections of the Taizhou coastal river network were selected to verify the hydraulic and water quality model. The simulated and monitored data of water

level and water quality were compared and analyzed in the Hongjiachangpu section, the Qinglongpu section, and the Santiaohe section of the local river network.

1. Verification of the hydraulic model

As shown in Figure 6, the verification results of the hydraulic model are acceptable. In the three different sections, the calculated water level of the model shows good agreement with the measured water level. The maximum discrepancy between the measured water level and the calculated water level of the Hongjiachangpu section is as low as 3.8%. The maximum discrepancy between the measured water level and the calculated water level of the Qinglongpu section is as low as 7.2%, while the maximum discrepancy between the measured water level and the calculated water level of the Santiaohe section is as low as 4.5%. The water level comparisons in these three sections are in good agreement. In addition, the Taizhou plain river network is affected by the tidal bore of the Jiaojiang River, which leads to significant tidal flow characteristics. The water level data calculated through model verification also show a certain degree of fluctuation in water flow, which is quite similar to the tidal flow characteristics. In summary, the hydraulic model verification results are acceptable, which shows the ability of the present hydraulic model to reflect the water flow characteristics of the Taizhou coastal plain river network.

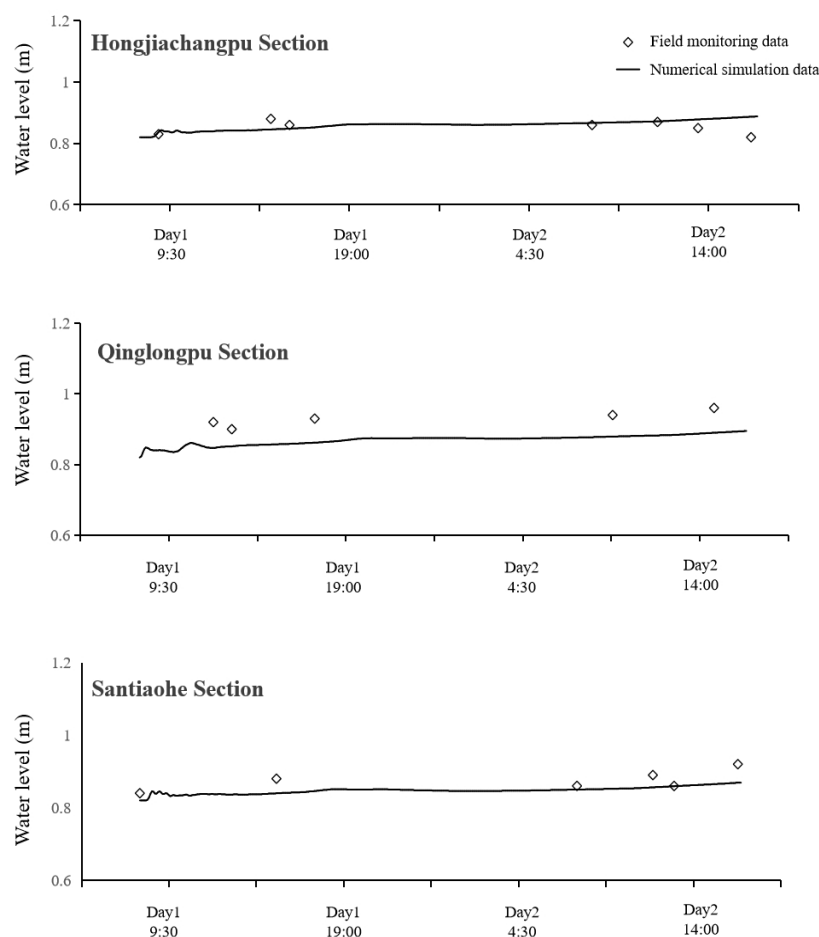


Figure 6. Hydrodynamic model verification in the three different sections.

2. Verification of the water quality model during the dry season

As shown in Figure 7, the discrepancy between the simulated and measured data is acceptable, although the discrepancy at some specific comparison times is slightly greater. Among all of the comparison sections, the averaged water quality discrepancies in the

Hongjiachangpu section are tiny, with all of them being less than 10%, while the averaged water quality discrepancies in the Santiaohe section are the greatest. From the perspective of water quality indicators, the COD concentration shows good agreement between numerical results and the field monitoring data, while the simulated results of $\text{NH}_3\text{-N}$ and TP are relatively lower than the field monitoring data, as shown in Figure 7. Generally, the maximum discrepancy in COD concentration in the three sections is 34.8%, which appears in the Qinglongpu section. Meanwhile, the comparison of $\text{NH}_3\text{-N}$ and TP concentrations in the Hongjiachangpu section is also good; the discrepancies in each pollutant concentration are less than 20%. However, there is a 38% difference between the simulation results and the field monitoring data of $\text{NH}_3\text{-N}$ concentration in the Qinglongpu section, and there is a 60% difference between the simulation results and the field monitoring data of the $\text{NH}_3\text{-N}$ concentration in the Santiaohe section, which is relatively large. In total, during water quality model verification, considering 18 samples from different periods and sections, the discrepancies of 0.2% to 60% in the pollutant concentration were obtained. Almost 80% of the comparison samples show convincing results. Though it is doubtful that the coastal plain river network of Taizhou city will be affected by rainfall, point and non-point source pollution, the water quality model verification results are still credible.

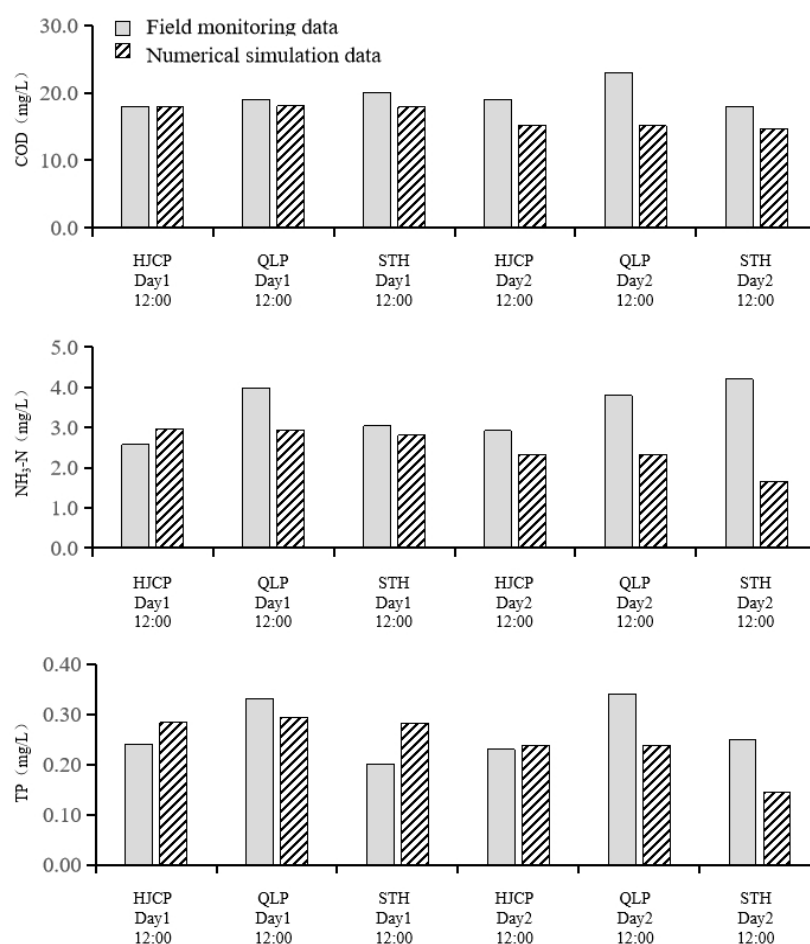


Figure 7. Water quality model verification in the three different sections.

4. Simulation of the Reclaimed Water Diversion Project

In order to fully demonstrate the improvement in both the water quantity and quality in the local plain river network of Taizhou city by using reclaimed water, key factors, such as the treatment standard of the sewage treatment plant, the reclaimed water flow rate, and the spatial configuration of the water diversion project, were all included and considered.

Eventually, a total of nine groups of water diversion and distribution simulation cases were formulated in this study, as shown in Table 1.

Table 1. The simulation cases refer to the reclaimed water diversion project in Taizhou city.

Sim Cases	Reclaimed Water Configuration	Concentration of COD	Concentration of NH ₃ -N	Concentration of TP
1-1	Current case	/	/	/
2-1	Wastewater	300	30	5
2-2	Wastewater	300	30	5
2-3	Wastewater	300	30	5
3-1	High-quality reclaimed water, 20% load	30	1.5	0.3
3-2	High-quality reclaimed water, 40% load	30	1.5	0.3
3-3	High-quality reclaimed water, 60% load	30	1.5	0.3
3-4	High-quality reclaimed water, 80% load	30	1.5	0.3
3-5	High-quality reclaimed water, 100% load	30	1.5	0.3
4-1	Low-quality reclaimed water, 20% load	60	8	1.0
4-2	Low-quality reclaimed water, 60% load	60	8	1.0
4-3	Low-quality reclaimed water, 100% load	60	8	1.0
5-1	Reclaimed water plus wetland, 20% load	20	1	0.2
5-2	Reclaimed water plus wetland, 60% load	20	1	0.2
5-3	Reclaimed water plus wetland, 100% load	20	1	0.2
5-4	Reclaimed water plus wetland, 200% load	20	1	0.2

4.1. Multi-Scheme Simulation and Analysis of Reclaimed Water Diversion and Distribution in the Nanguan River and the Qinglongpu River

According to the design plan of the domestic reclaimed water diversion project, the diversion and distribution outlets of the reclaimed water are configured in the Nanguan River and the Qinglongpu River in Taizhou city. Based on the construction report of the domestic reclaimed water diversion project, it can be confirmed that the water diversion and distribution outlets of the Nanguan River are located about 250 m upstream of the cross section of the Nanguan River and Qinglongpu River. When the reclaimed water diverts into the Nanguan River, it will flow downstream into the Nanguan River and Qinglongpu River and benefit both the water quantity and water quality in these rivers. Another water diversion and distribution outlet is located in the Qinglongpu River, which is 400 m downstream of the outlet of the Nanguan River. The reclaimed water diverted from this outlet is completely used to supply the water flow in the Qinglongpu River.

As shown in Figure 8, it can be seen that the water level comparison between case 1-1 and case 3-4 shows specific differences in all of the comparison sections, including Hongjiachangpu, Qinglongpu, and Santiaohe, which are located variably on the coastal plain river network of Taizhou city.

Firstly, the Hongjiachangpu section is located in the middle of the Taizhou coastal plain river network, which is actually far away from the three reclaimed water diversion discharge outlets. As clearly shown in the above figure, its water level did not change too much during the comparison; the water level simulated in case 1-1 is slightly lower than the water level simulated in case 3-4. It was also confirmed that since the Hongjiachangpu River is a relatively wide river in the Taizhou coastal river network with a width of 80–120 m, the water flow is usually sufficient compared with that of small-sized rivers. The scale of the river itself and the relatively sufficient water flow also result in a limited water level rise caused by the reclaimed water diversion compared with the current non-diversion simulation case. Indeed, when comparing case 1-1 and case 3-4, the water level rise caused by the reclaimed water diversion in the Hongjiachangpu section is only about 0.01 m. Although the simulation results show an overall limited increase in water level, they also show a positive effect of reclaimed water diversion in the coastal plain river network in Taizhou city.

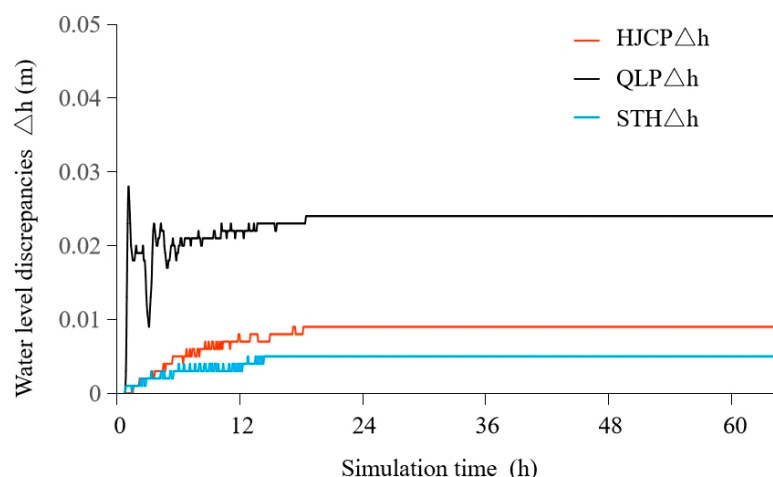


Figure 8. Comparison of water levels based on the reclaimed water diversion project in the three sections.

Secondly, the Santiaohe section is located upstream of the reclaimed water diversion discharge outlet close to the Yantou gate, which is a provincial water quality monitoring section. Indeed, the Santiaohe section is nearly 50 m away from the reclaimed water diversion discharge outlet; however, the water level comparison between case 1-1 and case 3-4 does not show a significant difference. The reclaimed water diversion project improves the water quality of the Yantou gate because the river water flows northward at this section, and eventually, all of the water flows into the Jiaojiang River. Hence, as shown in Figure 8, the rise in water level in the Santiaohe section is only 0.006 m from the comparison between case 1-1 and case 3-4. Though the improvement in water quantity in the Santiaohe section is tiny, the water quality improvement is significant through the implementation of the reclaimed water diversion project, which will be analyzed later in this study.

Thirdly, the Qinglongpu section is located downstream of the reclaimed water diversion discharge outlet. Actually, the Qinglongpu River itself is small, with an estimated river width from 20 m to 40 m. Due to its small scale, the Qinglongpu River has a high risk of disruption during the dry season. The designed flow rate of the reclaimed water from the local sewage plant is about $0.9 \text{ m}^3/\text{s}$, which has a significant effect on the ecological water supply in the Qinglongpu River. According to the simulation results, the water level comparison between case 1-1, without water diversion, and case 3-4, with the reclaimed water diversion, is quite different. It can be concluded that in the dry season, the reclaimed water diversion project is beneficial in improving the water level of the Qinglongpu section, which is 0.024 m higher than the non-diversion scenario, with a 3% increase in water level. Hence, the reclaimed water diversion is able to improve the ecological flow of the Qinglongpu River and effectively reduce its risk of disruption. In fact, the water quantity and quality are both satisfactory in the Qinglongpu River due to the sufficient reclaimed water diversion from the years 2022 and 2023.

4.2. Optimization Configuration Scheme of Yantou Gate Section Water Quality Improvement

Reclaimed water is widely used for the ecological flow supply in the Taizhou coastal plain river network and has become critical nowadays since it provides sufficient water flow instead of fresh water. As shown in the field monitoring and simulation data, the positive effect of the reclaimed water diversion project has been confirmed, and the reclaimed water plays an important role in domestic social and ecological development. It was also noted that the reclaimed water can be further purified by the ecological wetland close to the Yantou gate section before entering the Santiaohe River. The water quality of the diverted

reclaimed water becomes better than the water flow in the Santiaohu River itself. As a good alternative water source to the river network, the reclaimed water has proven effective in improving the water quality of the Yantou gate section in recent years. And because of its relatively stable diversion flow rate, it also has a positive improvement effect on the water quality stability of the Yantou gate section, which is valuable in alleviating the water quality fluctuation in the Yantou gate section, especially at a certain period of time when it is impacted by a sudden water pollution accident.

The reclaimed water used for the ecological water flow supply in the Taizhou coastal plain river network is critical nowadays since it provides a sufficient alternative water source. It was also noted that the reclaimed water is further purified by the ecological wetland close to the Yantou gate section before entering the Santiaohu River; the quality of the diverted reclaimed water becomes much better than the water flow in the Santiaohu River itself. As a good alternative water source for the river network, the reclaimed water has played an efficient role in improving the water quality of the Yantou gate section in recent years. And because of its relatively stable diversion flow rate, it also has a special improvement effect on the water quality stability of the Yantou gate section, which is also valuable in alleviating the water quality fluctuation of the Yantou gate section when it is impacted by a sudden water pollution accident.

The optimal configuration of water quality improvement for the Yantou gate section was set up by comparing the simulation results among simulation groups 1 to 4, focusing on the water quality improvement effect with different simulation conditions. At the same time, as a provincial control section, the Yantou gate section is the focus of this study to show the effect of the reclaimed water diversion project. Furthermore, as indicated before, an ecological wetland is located in front of the reclaimed water diversion outlet, which is also helpful in purifying the reclaimed water quality. Indeed, the concentrations of COD, $\text{NH}_3\text{-N}$, and TP are anticipated to degrade due to the reclaimed water diversion. The multi-purpose optimization configuration for improving the water quality at the Yantou gate section is then executed based on the hydraulic and water quality coupled model.

In this study, the Chinese national environmental quality standard was introduced, in which the good condition for river and lake water flow refers to the pollutant concentration, such as $\text{COD} < 30 \text{ mg/L}$, $\text{NH}_3\text{-N} < 1.0 \text{ mg/L}$, and $\text{TP} < 0.2 \text{ mg/L}$. From the historical data analysis, the Yantou gate section usually has sufficient water flow since it has not been disrupted for decades. Therefore, the multi-purpose simulations in this study paid most attention to the water quality in the Yantou gate section; the comparison between the different simulation groups and cases is shown in Figures 9–11.

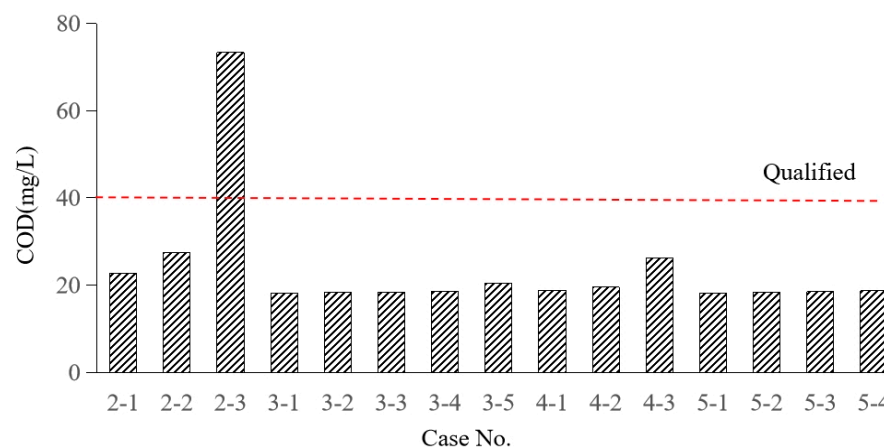


Figure 9. Comparison of COD concentration among the different simulation cases.

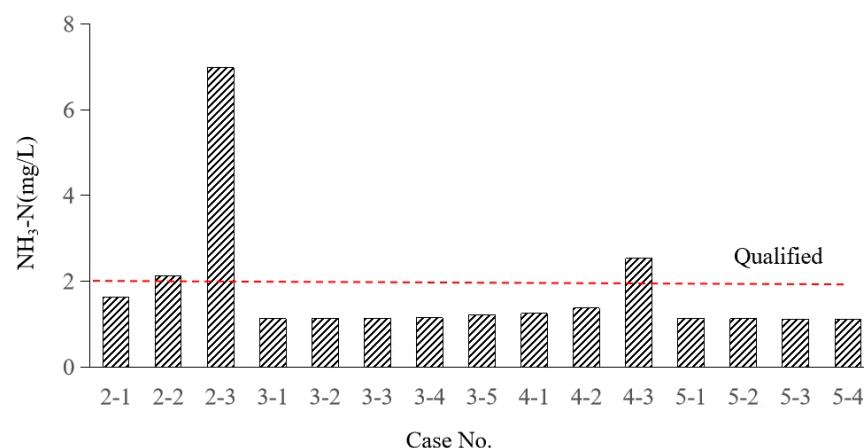


Figure 10. Comparison of NH₃-N concentration among the different simulation cases.

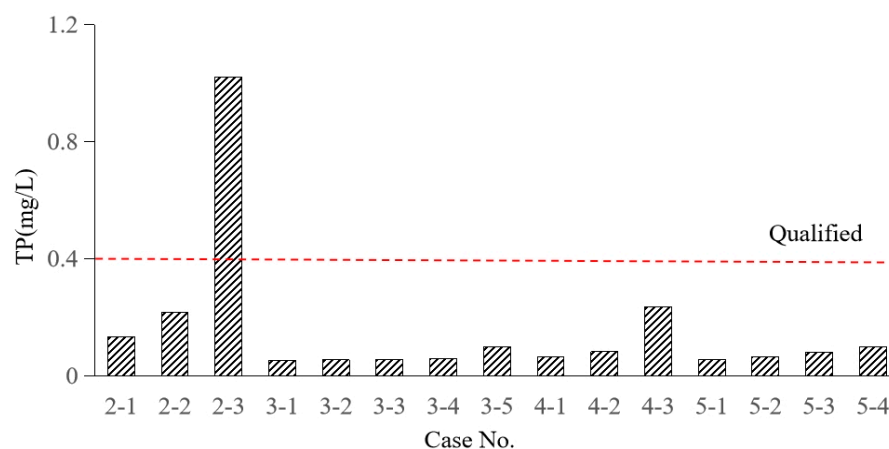


Figure 11. Comparison of TP concentration among the different simulation cases.

From the above three figures, it can be concluded that the water quality improvement by utilizing the reclaimed water in the Yantou gate section is significant. The concentration of reclaimed water pollutants in all of the simulation cases in Group 2 is relatively high; thus, the concentrations of COD, NH₃-N and TP in the Yantou gate section exceed the green level, which means that the COD concentration is greater than 20 mg/L, the NH₃-N concentration is greater than 1.0 mg/L, and the TP concentration is greater than 0.2 mg/L; all of them are unsatisfactory, especially for case 2-3. The concentration of COD reached 71 mg/L, the concentration of NH₃-N reached 6.9 mg/L, and the concentration of TP reached 1.03 mg/L during the simulation of case 2-3.

It above comparison figures confirm that the construction and operation of the local sewage treatment plant and the reclaimed water diversion project provide an excellent, high-quality water source for the Yantou gate section. From the water quality comparison between simulation group 2, group 3, and group 4, a higher reclaimed water quality results in better simulation data and vice versa. It was also noted that the concentration of COD, NH₃-N, and TP is still unsatisfactory for case 4-3, with it not being possible to meet the water quality requirement of the Yantou gate section.

As shown in Figure 3, the simulation cases in group 3 are recognized as uniform reclaimed water diversion project numerical cases, in which the concentrations of COD, NH₃-N, and TP in the reclaimed water are 30 mg/L, 1.5 mg/L, and 0.2 mg/L, respectively. In comparison, the flow rate of the reclaimed water diversion project varies from 10,000 m³/d to 150,000 m³/d, namely, approximately 0.116 m³/s to 1.736 m³/s. From the simulation results, the reclaimed water diversion project has improved the fluidity of the Yantou gate section in the Santiaohu River, although the water level has not risen too much.

However, the concentration of $\text{NH}_3\text{-N}$ in the Yantou gate section is still not satisfactory due to the high $\text{NH}_3\text{-N}$ concentration from reclaimed water.

Finally, the function of the ecological wetland is distinct. If the weather is good, the wetland function is apparent, and the flow rate of the ecological wetland is also stable; thus, the reclaimed water diversion effect is always good on those days in good weather. The simulation results of group 5 also show an excellent reclaimed water diversion effect. In the cases of a high reclaimed water flow rate, namely case 5-3 and case 5-4, the water quality indicators of the Yantou gate section, including COD, $\text{NH}_3\text{-N}$, and TP, are all in good condition. Even in the cases of a low reclaimed water flow rate, namely, case 5-1 and case 5-2, the water quality of the Yantou gate section can still be guaranteed, although it is slightly worse than the water quality calculated in case 5-3 and case 5-4. However, the concentration of $\text{NH}_3\text{-N}$ is slightly higher compared with the Chinese national environmental quality standard.

From Figures 12 and 13, it can be seen that in the Yantou gate section, the water quality indices obtained from different reclaimed water diversion simulation cases are quite similar because the conventional water flow of the river channel is sufficient. As indicated before, the Yantou gate section is located at the end of the Santiaohe River, which is the confluence of the Santiaohe River and the Jiaojiang River. Hence, it is widely known as an important provincial control section, and the concentration of the three main pollutants in this section has a positive relationship with the water quality of the reclaimed water diversion project. Generally, the better the reclaimed water quality, the lower the pollutant concentration in the Yantou gate section.

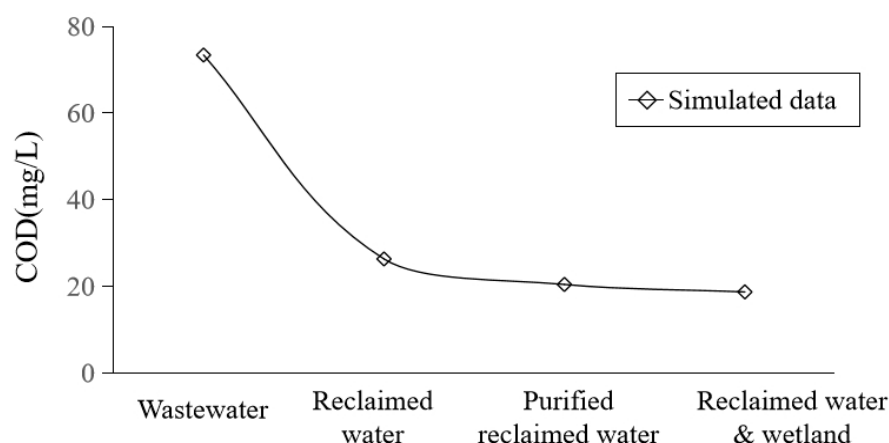


Figure 12. Variation in COD concentration in the Yantou gate section for the different cases.

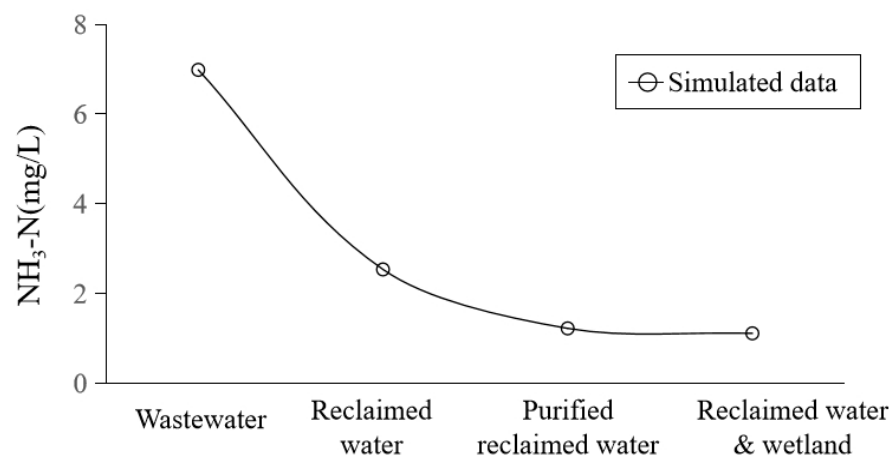


Figure 13. Variation in $\text{NH}_3\text{-N}$ concentration in the Yantou gate section for the different cases.

5. Conclusions

In this study, the utilization of reclaimed water in the coastal plain river network in Taizhou city was monitored and simulated. Both the field monitoring and numerical model were executed in order to manifest the positive effect of the reclaimed water diversion project, which has three main discharge outlets in the river network. In total, 5 different groups and 16 cases were configured for the numerical model simulation. Three typical pollutants, namely, COD, NH₃-N, and TP, were all included in the simulation in order to show the advantages of the reclaimed water diversion project. The reclaimed water usually has a good water quality compared with the river network water quality; hence, the results confirmed the positive effect in the different comparison sections, such as the Qinglongpu section and the Yantou gate section.

The simulation results show that in all comparison sections, the water level rises from 0.006 m to 0.024 m based on the variable reclaimed water diversion flow rate. If the comparison section is close to the diversion discharge outlet, the correlated water level rises significantly and vice versa. As an important provincial control section, both the water level and water quality comparison are assessed in the Yantou gate section to show the effect of the reclaimed water diversion project. The water quantity and quality are in good condition, which confirms the advantages of the reclaimed water as an alternative water source for the coastal plain river network in Taizhou city. The results obtained in this study indicate that the utilization of reclaimed water is convincing for Taizhou city to improve the environmental conditions of its plain river network. It is also anticipated that the reclaimed water will become a good tool for these Chinese coastal cities to deal with environmental problems. Moreover, it is proposed that the benefits of reclaimed water utilization can be extended to different types of coastal cities or have broader applicability since most Chinese eastern coastal cities suffer from water shortages and water quality problems.

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