Analysis of the ecological water diversion project in Wenzhou City

Haibo Xu¹, Lei Fu¹,³ and Tong Lin²

¹ Zhejiang Institute of Hydraulics & Estuary, Hangzhou, China, 310020;
² Wenzhou Municipal Water Resources Bureau, Wenzhou, China, 325009.
³ fl19840802@126.com

Abstract. As a developed city in China, Wenzhou City has been suffered from bad water quality for years. In order to improve the river network water quality, an ecological water diversion project was designed and executed by the regional government. In this study, an investigation and analysis of the regional ecological water diversion project is made for the purpose of examining the water quality improvements. A numerical model is also established, different water diversion flow rates and sewer interception levels are considered during the simulation. Simulation results reveal that higher flow rate and sewer interception level will greatly improve the river network water quality in Wenzhou City. The importance of the flow rate and interception level has been proved and future work will be focused on increasing the flow rate and upgrading the sewer interception level.

1. Introduction
Wenzhou City has been suffered from bad river network water quality for tens of years [1-3], therefore, the regional government’s attention has been paid on the ecological water diversion project in order to improve the river network water quality [3-5]. In the late 2016, the government of Wenzhou City organized an experiment of the ecological water diversion project in order to analyze the current river network water quality. In this study, the experimental data is collected and investigated. Numerical study is also executed, the effects from the water diversion flow rate as well as the sewer interception level are both considered. Based on this study, future ecological water diversion project can be designed and a better river network water quality of Wenzhou City is anticipated.

Figure 1. Water diversion project in Wenzhou City.
Generally, in this study, firstly, the data collected from the experimental monitoring sections has been paid most of the attentions. Secondly, a numerical model is established to predict the improvement of the water quality in the future with different water diversion flow rates and sewer interception levels. At last, suggestions for the future work is proposed for the purpose of further improve the river network water quality.

2. Investigation of ecological water diversion project

2.1. Monitoring sections

The experiment is based on the ecological water diversion project in Wenzhou City. Therefore, during the experiment, the flow rate is similar with the current ecological water diversion project. In total 17 sections are configured as shown in figure 2, both upstream and downstream of the main water diversion rivers are involved. Hence, the water quality from the water diversion source to the outflow of the water diversion river can be monitored during the experiment.

![Figure 2. Monitoring sections in Wenzhou City.](image)

2.2. Experimental results: River network

The flow rate of the water diversion project did not change during the experiment, which means the flow rate of the experiment is the same as the current ecological water diversion project. Hereafter, the Chinese “Environmental Quality Standards for Surface Water” is introduced in order to quantify the water quality in all 17 sections of the river network in Wenzhou City during the experiment.

| Water quality | I | II | III | IV | V |
|---------------|---|----|-----|----|---|
| DO (Dissolved Oxygen) | 7.5 | 6 | 5 | 3 | 2 |
| COD<sub>Mn</sub> | 2 | 4 | 6 | 10 | 15 |
| NH<sub>3</sub>-N | 0.15 | 0.5 | 1 | 1.5 | 2 |
| TP | 0.02 | 0.1 | 0.2 | 0.3 | 0.4 |

*Note: “Environmental Quality Standards for Surface Water” (GB3838-2002) is a Chinese Standard for evaluating the water quality of surface water.*
The experimental results show that the current river network water quality in Wenzhou City is severe. Almost 83% of the monitoring sections show inferior level V water quality, only 2 sections show level III water quality, which is only 12% of all the sections. The pie chart of the water quality in Wenzhou City is shown in figure 3. Due to the fact that most of the sections are still on inferior level V, the water environment and protection in Wenzhou City is still a key consideration in the future and the improvement of the ecological water diversion project is also anticipated, which will be discussed in the numerical simulation in this study.

**Figure 3.** Water quality of monitoring sections.

2.3. Experimental results: Spacial distribution

Additionally, the spacial water quality distribution of Wenzhou City is also considered and analyzed. As shown in figure 4, the sections near the source of the water diversion project, which lie in the southwest of Wenzhou City, have better water quality than the other sections. On the other hand, the sections away from the water diversion source have worse water quality, most of which are inferior level V. It is confirmed that the water quality will be better if the monitoring sections are closer to the water diversion source because of the good water quality near the source region.

**Figure 4.** Spacial distribution of river network water quality in Wenzhou City.

Moreover, the water quality in the main river of the ecological water diversion project is shown in figure 5. The water quality is decreasing from upstream to downstream of the main river, different pollutants’ concentration in figure 5 show the same tendency, the concentration of COD\textsubscript{Mn} increased by 40%, the concentration of NH\textsubscript{3}-N increased by 100%, and the concentration of TP increased by 10%, while the concentration of DO decreased by 50% from upstream to downstream of the main water diversion river.

In summary, experimental data indicates that under the circumstance of the current ecological water diversion project, the river network water quality of Wenzhou City is still not satisfied since
most of the monitoring sections did not comply with the requirement of level III water quality as shown in table 1.

![Water quality variation from upstream to downstream.](image)

**Figure 5.** Water quality variation from upstream to downstream.

### 3. Numerical modeling

#### 3.1. Methodology

Since the current water quality is not satisfied, a one-dimensional numerical model is utilized in order to further simulate the river network water quality in Wenzhou City. Based on different water diversion flow rates and sewer interception levels, a one-dimensional numerical model is established using Saint-Venant equation, the governing equations are given as [6-8]:

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

$$\frac{\partial Q}{\partial t} + 2u \frac{\partial Q}{\partial X} + Ag \frac{\partial Z}{\partial X} = u^2 \frac{\partial A}{\partial X} - \frac{Q|Q|}{C^2 R} + q_i (u - u_o)$$  \hspace{1cm} (2)

$$\frac{\partial AC_p}{\partial t} + \frac{\partial QC_p}{\partial X} - \frac{\partial}{\partial X} \left( AD \frac{\partial C_p}{\partial X} \right) = -AKC_p + C_2 q$$  \hspace{1cm} (3)

where $Z(x, t)$ is the water level (m), $Q(x, t)$ is the flow rate (m$^3$/s), $A(x, t)$ is the river sectional area (m$^2$), $u(x, t)$ is the velocity (m/s), $C$ is the Chezy coefficient, $q_i$ is the branch’s flow rate (m$^3$/s), $C_p$ is the pollutant concentration (mg/L), $D$ is the diffusion coefficient, $K$ is the degradation coefficient, $C_2$ is the source concentration (mg/L) [8-11]. Model verification and calibration are executed in the next section with comparing the current model results and experimental data.
3.2. Model setup and comparison sections

**Table 2.** Numerical cases considering different flow rates and sewer interception levels.

| Case | Description | Water diversion flow rate (m$^3$/s) | Sewer interception level                   |
|------|-------------|------------------------------------|-------------------------------------------|
| 1    | Current     | 8.67                               | Low level (Present)                        |
| 2    | Short-term  | 8.67                               | High-level (Planned)                      |
| 3    | Mid-term    | 9.13                               | High-level (Planned)                      |
| 4    | Long-term   | 21.78                              | High-level (Planned)                      |

**Table 3.** Simulation results of different cases (Based on NH$_3$-N concentration, mg/L).

| Sections | Fengmen | Sanxi | Qingfen | Puzhou | Yongqiang |
|----------|---------|-------|---------|--------|-----------|
| Experiment | Concentration (mg/L) | 10.21 | 3.69 | 6.00 | 4.98 | / |
|          | Water quality level | Inferior V | Inferior V | Inferior V | Inferior V | / |
|          | Improvement | / | / | / | / | / |
| Current | Concentration (mg/L) | / | 3.04 | 5.08 | 5.70 | 5.86 |
|          | Water quality level | / | Inferior V | Inferior V | Inferior V | Inferior V |
|          | Improvement | / | / | / | / | / |
| Short-term | Concentration (mg/L) | / | 2.06 | 2.05 | 2.33 | 2.94 |
|          | Water quality level | / | Inferior V | Inferior V | Inferior V | Inferior V |
|          | Improvement | / | 41.36% | 67.24% | 78.76% | 52.36% |
| Mid-term | Concentration (mg/L) | / | 1.22 | 1.26 | 1.41 | 1.86 |
|          | Water quality level | / | IV | IV | IV | V |
|          | Improvement | / | 65.20% | 79.80% | 87.14% | 69.89% |
| Long-term | Concentration (mg/L) | / | 0.98 | 1.03 | 1.14 | 1.50 |
|          | Water quality level | / | III | IV | IV | IV |
|          | Improvement | / | 72.01% | 83.56% | 89.60% | 75.69% |
The current flow rate of the ecological water diversion project is only 8.67 m$^3$/s, which is obtained from the regulation report of the water diversion project in Wenzhou. However, in the future, the flow rate will increase to 9.13 m$^3$/s, and moreover, 21.78 m$^3$/s in 2030, which will indeed greatly improve the river network water quality. While the sewer interception level in 2030 will also be different from it is in 2016. Hence, in this study, four cases are simulated including the current water diversion situation, which is given as:

The simulation case 1 is the current case, which actually simulates the current ecological water diversion project. The model setup of case 1 is the same as the experiment in this study, therefore, case 1 can be also used for the model verification. Case 2 to Case 4 are the short-term, mid-term and long-term simulation cases, which consider different water diversion flow rates and sewer interception levels. The simulation results at five different sections as well as the experimental data are listed in table 3.

3.3. Results and comparisons

The comparison at five sections between experimental data and simulation case 1 (current case) in table 3 confirms the capacity of the numerical model in predicting the water quality in the river network of Wenzhou City, although some discrepancies are still obtained. While the comparison among current case, short-term case, mid-term case and long-term case reveals the effects from different water diversion flow rates and sewer interception levels.

Obviously, a conclusion can be made that a high water diversion flow rate will greatly improve the river network water quality. As shown in table 3, the current case and short-term case did not show good water quality, all of the comparison sections simulated by current case and short-term case show inferior level V water quality. However, when the water diversion flow rate increases to 9.13 m$^3$/s for the mid-term case and 21.78 m$^3$/s for the long-term case, the river network water quality becomes much better. Generally, a larger flow rate will lead to a better river network water quality.

Moreover, the sewer interception level is also paid attention. As also shown in table 3, the only difference between the current case and short-term case is the sewer interception level. For the current case, the sewer interception level is low, which means that the sewer interception is the same as the current status in Wenzhou City, while the short-term case has a high sewer interception level, which means 100% sewer interception is used for the short-term case. The comparison between current case and short-term case show at least 41.56% improvement of NH$_3$-N concentration in all the comparison sections, therefore, the sewer interception is also important in the future if a better water quality is anticipated.

4. Conclusion

In this study, an investigation and analysis of water diversion project in Wenzhou City is executed based on experiment and numerical simulation. The analysis of the current status of the river network water quality in Wenzhou City is made based on the experimental data at 17 different sections, the result reveals that under the current circumstance, the water quality of Wenzhou City is not satisfied.

In order to further investigate the relationship between the river network water quality and the water diversion flow rate as well as the sewer interception level, numerical modeling is also introduced in this study. In total four cases are simulated, the comparison among these simulation cases leads to the conclusion that higher flow rate and higher sewer interception level will greatly improve the river network water quality. Therefore, future work should be focused on increasing the flow rate and upgrading the sewer interception level for the ecological water diversion project in Wenzhou City.

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