Water quality simulation of sewer plant discharge considering long-term and short-term conditions

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Abstract. The development of economy and society in China leads to a huge amount of wastewater discharge, which becomes a serious problem in most of Chinese cities. Therefore, the construction of sewer plant is more popular than before in lots of these cities. The wastewater discharge from the plant is then considered as a point source in most of the important rivers and channels. In this study, a typical wastewater treatment plant is introduced, a monitoring experiment is designed and executed to observe current river status. Additionally, a two-dimensional model is established to predict the water quality downstream of the plant. It is confirmed that the water quality will not significantly deteriorate, however, systematic control of wastewater discharge and protect of current river environment is still encouraged.

1. Introduction

Tongxiang is a northeast modern city in Zhejiang province, China. Though the river network system is highly developed in this city, it was a relatively water resources abundant region due to the low flow rate and unsatisfied water quality[1-3]. Nowadays, a new wastewater treatment plant is going to be constructed and operated in Tongxiang city[2,4,5]. Though the plant collects the wastewater from nearby towns, the sewer discharge from the plant will affect the water quality of the rivers and it is necessary to simulate and forecast the environmental effects from this point source. In this study, this new wastewater treatment plant is considered as a point source of wastewater discharge with the capacity of 140000m³/d. COD (Chemical Oxygen Demand) is considered as a typical pollutant, a field monitoring experiment is executed to collect the river water quality data of Changshan river in Tongxiang city, and a two-dimensional model is then utilized to predict the distribution of COD.

Figure 1. Location of Tongxiang wastewater treatment plant.
2. Methodology

2.1. Model configuration

In this study, a new wastewater treatment plant is considered as a point source of wastewater discharge, which locates close to Changshan river as shown in Figure 1. Changshan river is a 17.5km long, 60~80m wide river, the averaged water depth of this river is 3.9~4.5m approximately. A two-dimensional model is established in this study based on DELFT3D software in order to simulate and predict the water quality downstream of the wastewater treatment plant, basic equations of this two-dimensional model are given as[6-8]:

\[
\begin{align*}
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} &= -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + f_x, \\
\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} &= -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) + f_y, \\
\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} &= -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right) + S_x, \\
\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} &= -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right) + S_y.
\end{align*}
\]

Figure 2. Model setup of Changshan river (a) Monitoring sections, (b) Model grids.
Where \( x, y \) (m) are the Cartesian coordinates; \( u, v \) (m/s) are the horizontal velocity in \( x \) and \( y \) direction, \( p \) (kg/m s\(^2\)) is the pressure; \( \rho \) (kg/m\(^3\)) is the density, \( f \) (m/s\(^2\)) is the body force, \( C \) (mg/L) is the pollutant concentration, \( S \) (mg/L s) is the source term \([7,8]\). In total 10482 grids with 15–30m length and 8–15m width of each grid are configured in the model. Finer grids are usually used in the corner section of the river to improve the simulate accuracy. The model setup is shown in Figure 2(b).

### 2.2. Field monitoring

Since the historical data of Changshan river is insufficient, a field monitoring experiment is designed and executed in this study in order to collect up-to-date water quality and river status information, which is also able to be used in model verification and set as the background values in numerical model. Both the water velocity and water quality of Changshan river is monitored from May 24\(^{th}\) to May 25\(^{th}\), 2018. Four monitoring points including upstream, downstream, branch and verification section are distributed in Changshan river and its main branch accordingly, which are also shown in Figure 2(a). The water level and velocity data are monitored every 1.0 hour and the water quality samples are taken every 3 hours each day. In total 806 flow rate and water level data and 1566 water quality data are collected and used to verify the numerical model, which will be discussed later.

### 2.3. Model verification

Hydraulic model is firstly verified using the monitored water level data. During the verification, the upstream flow rate and downstream water level are both setup based on the field monitoring data, then, the water level comparison at the verification section is given as:

![Figure 3. Water level comparison between monitored and simulated data.](image)

Note: Water level refers to the Chinese national reference elevation (1985)

![Figure 4. Verification of water quality model (COD concentration).](image)
Since COD is considered as the main pollutant in Changshan river in the last several years, in this study, the water quality model is also verified based on the concentration of COD, the comparison section is similar with the one used in hydraulic model verification, and the verification of water quality model is given as Figure 4.

As shown in Figure 3 and Figure 4, both the hydraulic model and water quality model agree well with measured data, the maximum discrepancy in water level comparison is 1.1%, which appears at 14:00 on May 25th. While the maximum discrepancy of COD concentration is 8.1%, which appears at 12:00 on May 25th. Therefore, the hydraulic model and water quality model are acceptable and is able to predict the water quality downstream of the wastewater treatment plant.

3. Results and discussions

3.1. Simulation cases

Six different cases are set in this study based on different conditions. They are divided into two main groups, namely long-term discharge group and short-term discharge group, which are listed in Table 1.

| Group       | Case | Condition | Flow rate (m³/d) | COD(mg/L) | Discharge period |
|-------------|------|-----------|------------------|-----------|-----------------|
| Long-term   | 1-1  | Normal    | 140000           | 30        |                 |
|             | 1-2  | Unusual   | 140000           | 105       |                 |
|             | 1-3  | Malfunction | 140000        | 350       | Continue        |
| Short-term  | 2-1  | Normal    | 140000           | 30        | Emergency (72 hours) |
|             | 2-2  | Unusual   | 140000           | 105       |                 |
|             | 2-3  | Malfunction | 140000        | 350       |                 |

As shown in Table 1, the simulation cases in long-term group and short-term group have different discharge period, as for long-term group, the wastewater treatment plant will continually discharge, while for short-term group, emergency status will be considered with only 72 hours wastewater discharge. Additionally, the normal condition (100% treatment efficiency), the unusual condition (70% treatment efficiency), and the malfunction condition (0% treatment efficiency) are all set in both groups to show various wastewater discharge conditions.

3.2. Simulation results

The background conditions of numerical model are set based on the historical data and the field monitoring data of Changshan river, which are given based on previous research in the nearby districts as:

1) Upstream flow rate Q = 10.7 m³/s, downstream water level H = 0.95m.
2) Background COD = 17.4mg/L. Decay rate of COD = 0.11 d⁻¹.

Simulation time for all the cases are setup to one month, which is long enough to obtain steady state and minimize the effects from the initial condition. The prediction of COD concentration downstream of the wastewater treatment plant show differences due to the different wastewater discharge flow rate and COD concentration. Moreover, long-term discharge and short-term discharge also behave differently with time and space in the numerical results.
The simulation results of long-term group is shown in Figure 5, the comparison between case 1-1, 2-1 and 3-1 indicates that for different flow rate of the wastewater treatment plant, the COD concentration downstream of the wastewater treatment plant shows different characteristics. Case 1-1 shows the best water quality among all of the three long-term simulation cases since the wastewater discharge from wastewater treatment plant has the highest treatment efficiency and the COD concentration in wastewater is the lowest. Similarly, water quality downstream in case 1-2 simulation is better than case 1-3.

The simulation results of short-term group is shown in Figure 6, in which 4 different sections are selected to show the COD concentration varies after the short-term discharge. In total 2 downstream sections and 2 upstream sections are selected, downstream section 1 and section 2 are 1700m and 9000m respectively.
away of the wastewater treatment plant, respectively. While upstream section1 and section2 are 1100m and 4800 upstream from the wastewater treatment plant, respectively. It is clearly shown that the 2 upstream sections are seldom affected because of the water flow direction, but for the downstream sections, the spacial distance from the wastewater treatment plant becomes a key factor that leads to different COD concentration. The peak COD concentration at downstream section1 is almost 2 times of downstream section2 in all of the three simulation cases, which actually attributes to the dilution and transportation of COD in Changshan river. Additionally, since the period of short-term discharge is only 72 hours, the curves in Figure 6 show the COD concentration varies from the beginning to the end of the wastewater discharge. It is observed that the COD concentration goes down to the background value after 4 days when the wastewater reaches each section.

4. Conclusions
In this study, a sewer plant is considered as a point source in Changshan river. A field monitoring experiment is designed and executed to collect water quality data. A numerical model is setup to simulate different cases considering long-term and short-term discharge. Three discharge statuses such as normal condition, unusual condition and malfunction condition are all simulated. The simulation results indicate that for different discharge condition and period, the variation of COD concentration in Changshan river downstream of the wastewater treatment plant shows different characteristics. Better control and management of the plant is important to maintain water quality in Changshan river in the future.

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