Study on dynamic water environmental capacity of the river network in Wenhuang plain based on the hydrodynamic and water quality coupling model

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Abstract. The calculation of water environment capacity (WEC) is the basis of pollution control, and it is of great significance to the formulation of water environment quality management scheme meanwhile. Due to the precipitation varies with seasons, WEC has an obvious temporal dynamic feature, that is ignored in the traditional method under a single fixed hydrological condition design hydrological condition. Thus, on the basis of the hydrodynamic and water quality coupling model, the trial-and-error method was adopted to investigate the traditional and dynamic (by month) WEC of NH3-N of Wenhuang plain of Zhejiang Province in this paper. The result shows that WEC had a relatively large fluctuation during the year, of which the value was distinctly lower in dry season and the peak was present in June. It can be concluded that the dynamic algorithm was more in line with the actual circumstances compared with the traditional method.

Keywords: Wenhuang plain; Dynamic water environmental capacity; Hydrodynamic and water quality coupling model; NH3-N

1. Introduction
It is the rapid urbanization that has brought population concentration, economic development and development intensity increase in China's eastern coastal areas. Unfortunately, it also led to the increasingly serious deterioration problem of water environment that has overloaded for a long time. In order to ensure the water quality to meet the requirements of the water functional zone, the relevant departments put forward the total emission control system where the water environmental capacity exactly plays a very important role [1]. Water environmental capacity (WEC) refers to the maximal permissible quantity of pollutants per unit time of the given water areas and hydrological conditions on the premise of specified pollutant emission pattern and water quality targets, reflecting the pollution carrying capacity of the water [2-4]. This is somewhat similar to "Environmental capacity", "Assimilative capacity", "Total maximum daily loads (TMDL)", etc. typically used in Europe and America [5]. As expected, WEC of a particular water area is affected by many factors such as hydrological conditions, water quality targets, temperature, pollutant characteristics and sewage
discharge modes, etc. However, if other influence factors are relatively stable, WEC is highly sensitive to the hydrological factors, among which the discharge has the greatest impact. Generally, WEC figured out by traditional method is a stable threshold value without any change throughout the year owing to the constant design hydrological condition that is the monthly average flow rate at low water with 90% guaranty. In a sense, it is unfavorable to govern water environment scientifically and suit the refined environmental management needs according to the local conditions. Therefore, it is of great research value to calculate the dynamic WEC by taking the change of hydrological conditions into account.

There is a really complex river net composed of numerous canals in Wenhuang plain of Zhejiang Province, but with an insufficient water mobility and a fragile self-purification capacity. In recent years, a series of water pollution control projects have effectively improved the water quality, but definitely still not enough to water quality targets of water functional zone [6-7]. In this paper, through establishing the hydrodynamic and water quality coupling model, we worked out the traditional and dynamic WEC of Wenhuang plain using the trial and error method respectively, that would provide a strong technical support for preventing water pollution and improving water quality in the study area.

2. Study area

The Wenhuang plain is located on the southeast coast of China with an area of about 2358km², surrounded by the main stream of Jiaojiang river, the East China sea and Yueqing bay (Figure 1). The relevant administrative regions mainly include the urban district of Taizhou city, Wenling city and Linhai city. The precipitation is significantly influenced by monsoon season and typhoon in the study area, so it has an evident seasonal variation and great variation between years. It is mainly focus on May to September accounting for about 60-70% of the whole year. The water network of the study area is composed of Yongning River, Jiazhi River, Dongguan River, Nanguan River, Jinqing River, Hongjia River, Qinglong River, Yitiao River, Mucheng river, Dongyue River, Huaman River, etc. According to water resources bulletin of Taizhou city in 2018, the study area is divided into 19 water functional areas by water quality management target, only 8 of which was up to standard with a compliance rate of 42%, and the main exceeding standard factor was NH₃-N.

Figure 1. Location and water system of Wenhuang plain.
3. Hydrodynamic and water quality coupling model
MIKE11 is a one-dimensional calculation model coupled the hydrodynamic with water quality mainly by hydrodynamic module (HD) and Advection-Dispersion module (AD) [8-9]. The flow movement and contaminant transport process in the river network is able to be simulated following the principles of hydraulic boundary and the open-close of the water control projects.

3.1. Model generalization
The river network was simplified through identifying the main rivers and water control projects in the study area, shown as Figure 2.

![Figure 2. Generalization of river network in the study area.](image)

3.2. Calibration and verification
According to the research of Yue Q H and Zhou F [6-7], the bed roughness is between 0.025 – 0.035 and the degradation coefficient of NH₃-N is between 0.04 – 0.10 d⁻¹ in the study area. What we should do next is just to select an appropriate period to validate the model parameters. In addition, Nash efficiency coefficient (NSE) was selected as the criteria to judge the hydrodynamic and water quality coupled model, the value of which must be less than 1 (Formula 1). If NSE approaches 1, the model is of good quality and high reliability; If NSE approaches 0, it indicates that not only the simulation results are on average close to the measured ones, but also the model is credible overall despite the big error in the simulation process; If NSE is far less than 0, the model is incredible. Referring to the research of Gong X L, Chen C J et al., when NSE is greater than 0.85, it can be considered that the credibility of the model meets the calculation requirements [10-11].

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NSE = 1 - \frac{\sum_{t=1}^{T}(Q_0^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_0^t - \bar{Q}_0)^2}
\]

Where \( t \) is the step time, \( Q_0^t \) is the measured value at time \( t \), \( Q_m^t \) is the simulated value at time \( t \), \( \bar{Q}_0 \) is the average measured value.

3.2.1 Verification period. The verification period is determined to be from May 1 to June 30 in 2018, as during which the data of rainfall-runoff and drainage of sluice are recorded continuously. It will
apparently assist the calibration and verification of HD module. In addition to rainfall, the river flow in the study area also includes sewage disposal from domestic, agricultural, industrial consumption and urban runoff, etc. Besides, the specific data of sewage discharge and pollutant concentration are available in the environmental protection department.

3.2.2 Verification of HD module. The water level data of hydrometric station Luqiao was selected for hydrodynamic verification, and the result was shown in Figure 3. It is evident that the simulated values achieved a high level of compliance with the measured ones, where NSE=0.903, greater than 0.85, satisfying the calculation requirements.

![Figure 3. Comparison of measured and simulated water level of station Luqiao.](image)

3.2.3 Verification of AD module. Now that the verification of HD module has fulfilled, the monitoring data of water quality of 5 sections including Xijiang, Hongjia, Pengjie, Zhuqiao and Ruoheng were chosen to verify the Advection-Dispersion (Table 1). It can be seen that the simulated values are quite near to the monitoring ones. And the NSE is equal to 0.891, greater than 0.85, which fulfills the calculation requirements.

Through above calibration and verification, we come to conclusions that the channel roughness (n) is 0.03, the dispersion coefficient (D) is 5 m².s⁻¹, and the degradation coefficients (K) is 0.06~0.08 d⁻¹ in the study area.

| Table 1. Comparison of measured and simulated concentration of NH₃-N of monitoring sections. |
|----------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Sections | Monitoring data [mg L⁻¹] | Simulated data [mg L⁻¹] | Error | Monitoring data [mg L⁻¹] | Simulated data [mg L⁻¹] | Error | Monitoring data [mg L⁻¹] | Simulated data [mg L⁻¹] | Error | Monitoring data [mg L⁻¹] | Simulated data [mg L⁻¹] | Error |
|----------|-----------------|-----------------|-----|-----------------|-----------------|-----|-----------------|-----------------|-----|-----------------|-----------------|-----|
| Xijiang | 0.75            | 0.70            | 4%  | 1.45            | 1.55            | 7%  | 1.23            | 1.12            | -9% | 0.75            | 0.70            | -9%  |
| Hongjia | 2.87            | 2.93            | 2%  | 2.74            | 2.82            | 3%  | 2.31            | 2.41            | 4%  | 2.03            | 1.97            | -3%  |
| Pengjie | 3.28            | 3.18            | -3% | 5.24            | 5.55            | 5%  | 3.47            | 3.58            | 3%  | 3.10            | 2.98            | -4%  |
| Zhuqiao | 4.30            | 5.56            | 9%  | 6.78            | 7.32            | 8%  | 3.71            | 3.42            | -8% | 3.77            | 3.95            | 5%   |
| Ruoheng | 4.76            | 5.14            | 8%  | 4.31            | 3.88            | -10%| 4.79            | 4.36            | -9% | 2.11            | 1.96            | -7%  |

4. Calculation and discussion

4.1. Water quality target
The division of water environment function zoning of Zhejiang province (2015) indicates that the water quality targets of most waters in the study area are class IV, except a few is class III. The target concentrations of NH₃-N of the monitoring sections are determined by functional zones where they are located, shown as Table 2.

Table 2. Target value of NH₃-N concentration of monitoring sections.

| Number | Sections | Target level of NH₃-N mg.L⁻¹ |
|--------|----------|----------------------------|
| 1      | Xijiang  | 1.0                        |
| 2      | Hongjia  | 1.5                        |
| 3      | Pengjie  | 1.5                        |
| 4      | Zhuqiao  | 1.5                        |
| 5      | Ruoheng  | 1.5                        |

4.2. Traditional algorithm
We applied the P-III frequency curve to analysis the daily runoff time series data from 1961 to 2017 in the study area, and figured out the monthly average flow rate at low water with 90% guaranty was 4.0 m³.s⁻¹ that would be taken into the calculation model as the boundary condition. Then, it was calculated that the average monthly WEC of NH₃-N was 9.4×10³t and the annual WEC of NH₃-N was 112.8×10³t by trial-and-error method.

4.3. Dynamic algorithm
When the water environment function zoning and sewage discharge pattern are relatively fixed, the hydrologic condition is the main factor that affects the WEC because of the uneven distribution of precipitation throughout the year. Therefore, the dynamics of the WEC calculation is primarily commanded by the change of river flow. Then, we also used the P-III frequency curve to analysis the same time series data and figured out the average flow rate with 90% guaranty of every month from January to December (Table 3). Finally, taking them into the calculation model as the boundary condition, the WEC of NH₃-N of each month was calculated after trials (Table 3). And we came to the result that the annual WEC of NH₃-N was 350.1×10³t by adding the monthly ones.

Table 3. Dynamic monthly WEC of NH₃-N of the study area.

| Month | Flow rate with 90% guaranty m³.s⁻¹ | WEC of NH₃-N 10³t |
|-------|----------------------------------|------------------|
| 1     | 1.7                              | 3.8              |
| 2     | 3.4                              | 7.9              |
| 3     | 10.3                             | 24.8             |
| 4     | 10.2                             | 24.5             |
| 5     | 15.0                             | 37.0             |
| 6     | 38.6                             | 98.0             |
| 7     | 22.8                             | 57.0             |
| 8     | 16.4                             | 40.7             |
| 9     | 11.5                             | 27.8             |
| 10    | 7.6                              | 18.1             |
| 11    | 3.2                              | 7.4              |
| 12    | 1.4                              | 3.2              |
| Sum   |                                  | 350.1            |
4.4. Analysis and discussion
The comparison of the traditional and dynamic WEC of NH$_3$-N (Figure 4) shows that:

(1) The result confirmed a positive correlation between the WEC of NH$_3$-N and river discharge, that was the larger the flow the greater the WEC. Besides, due to different design water inflow, the dynamic WEC of NH$_3$-N was usually quite greater than the traditional one in terms of the annual total quantity.

(2) The dynamic algorithm is better at reflect the fluctuation of the WEC throughout the year, of which the trend is highly consistent with the change of river flow. The WEC in the flood season is greater than that in non-flood season and reaches the peak in June, accounting for about 28% of the annual total quantity. It is suggested that the emissions of pollutants in the flood season could be properly increased in a sense, while it should be controlled strictly in the non-flood season to achieve the same water quality goals.

![Figure 4. Comparison of the traditional and dynamic WEC of NH$_3$-N.](image)

5. Conclusion
The traditional WEC is a rather fixed threshold value without any change during the whole year that is unable to keep pace with the fine-grained environmental management. In hence, we set up the hydrodynamic and water quality coupling model and applied the trial-and-error method to calculate the dynamic monthly WEC chosen the Wenhuang plain as the study area. In the process, the average flow rate with 90% guaranty of each month from January to December was determined by using the P-III frequency curve to analysis the daily runoff time series data from 1961 to 2017. It is concluded that the dynamic algorithm has an advantage over the traditional one: it is used to reflect the variation of the WEC in actual state objectively. Under the same water quality target, the pollutant discharge amount in the flood season could be properly expanded, while it should be controlled strictly in the non-flood season. It will further provide technical support for controlling pollution to improve the water quality in Wenhuang plain.

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