Study of Donghu Lake Water Eutrophication Simulation Based on Mike21

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Abstract. In this paper, a water environment numerical model of donghu lake is constructed based on MIKE21. Firstly, the hydrodynamic numerical model of donghu lake is established by FM module. A nonlinear triangular grid computing domain was created in the research area, initial boundary conditions and wind-driven data were set and other hydrodynamic parameters were input. The actual water level and velocity data in the part of research periods in December 2017 were used for model calibration and verification. Calibration results: vortex viscosity coefficient is 0.29 and manning constant is 0.42m1/3/s. The result of hydrodynamic simulation is in line with the actual situation. On this basis, the water quality module WQ was coupled to simulate the water quality of donghu lake. The simulation period is from November 15 to December 17, 2017. The measured water quality data on December 17 were selected for model calibration and verification, and the errors of each verification point were counted. The calculated results show that the simulated MSE of chlorophyll a concentration is 19.60%, and the simulated MSE of orthophosphate phosphorus is 25.36%. The overall simulation accuracy is well, which can reasonably show the changes of main water quality indexes in donghu lake.

1. Introduction

The numerical simulation of water quality model can dynamically simulate the evolution mechanism of lake water quality and predict the change process of water quality with time [1], with low operating cost is controllable. It has been widely used in the water ecosystem study of river, lake and ocean. And a lot of research results have been obtained. It is an effective tool to study lake eutrophication.

Current representative water quality models include Dalft3D, WASP, MIKE and EFDC, which can be used as an important decision-making tool to control the eutrophication of target water body by constructing a reasonable and effective mathematical model of water environment based on the measured data of water quality and specific influencing factors [2-4]. The above model principles are all attempts to combine hydrologic, hydrodynamic processes with biochemical dynamic reactions of water quality. WASP can be applied to water quality simulation of all kinds of water bodies, but it is inferior to EFDC in three-dimensional hydrodynamic simulation. Although the source code for the EFDC model is publicly available and freely available, the encapsulated business model is expensive. It takes a long time to study deeply, and the large amount of data required is difficult to obtain. MIKE model includes water environment simulation and hydrological process simulation and prediction. The interface operation interaction is well designed, which can be seamlessly integrated with GIS, AutoCAD and other engineering applications. After a long time of practical application in China, it has been widely recognized.
2. Study Area
Donghu lake is located in the middle of Wuhan, east of Wuchang district. The center of the water surface is 30° 33′ 57″ N, 114° 23′ 48″ E. The coastline of the lake is tortuous with a total length of 121.7 kilometers. The multi-year average depth of donghu lake is 2.61 meters, and the maximum depth is nearly 6 meters. The lake has a total capacity of 85.35 million cubic meters, with a water area of 33.9 square kilometers, which is the largest area of the city in the first lake.

With the urban economic construction, donghu lake has formed a large amount of natural deposition, and the water system connection between the surrounding lakes has been artificially separated. As a result, the water exchange frequency and degree are too low, the water quality is gradually deteriorating, and the aquatic biodiversity is also decreasing. The water quality is mainly IV, V class, and some of them even reach inferior V class. In 1983, the donghu lake comprehensive treatment project was started, which mainly focused on sewage interception and sewage purification. From 2013 to 2017, the water environment state of donghu lake maintained a steady trend of development, basically maintaining the water quality of category IV. The mean status of eutrophication was between mild and moderate eutrophication.

3. Model building

3.1. MIKE21 model
The governing equations of the model are mass and momentum conservation governing equations of flows along average depth of shallow water in two dimensions, as shown in formula (1) ~ (3). The diffusion control equation of soluble pollutants is shown in formula (4).

\[
\frac{\partial \epsilon}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0 \quad (1)
\]

\[
\frac{\partial p}{\partial t} + u \frac{\partial p}{\partial x} + v \frac{\partial p}{\partial y} + gh \frac{\partial \epsilon}{\partial x} + fp - \Omega q - v \nabla^2 p - \lambda (hu_a) = 0 \quad (2)
\]

\[
\frac{\partial q}{\partial t} + u \frac{\partial q}{\partial x} + v \frac{\partial q}{\partial y} + gh \frac{\partial \epsilon}{\partial y} + fp - \Omega q - v \nabla^2 q - \lambda (hv_a) = 0 \quad (3)
\]

where \( \epsilon \) is the water level of free water surface; \( u \) and \( v \) are the x, y vertical mean velocity; \( P = h*u, \) \( q = h*v \) are the x, y components of single-width flow; \( g \) is the acceleration of gravity; \( f \) is the resistance coefficient; \( \Omega = 2\omega \sin \phi \) is for K coefficient, reflecting the earth's rotation of the eccentric force function.; \( \omega \) is the angular velocity of the earth's rotation; \( \phi \) is the latitude of the point; \( v \) is turbulence vortex viscosity coefficient; \( \lambda = C_\omega / \rho_\omega \) is the wind stress coefficient; \( \rho_\omega \) is air density; \( \rho_\omega \) is water density; \( \omega, u_a, v_a \) is the x, y wind speed and its components.

\[
\frac{\partial}{\partial t} (h c) + \frac{\partial}{\partial x} (u h c) + \frac{\partial}{\partial y} (v h c) + F h c - S = \frac{\partial}{\partial x} (h \lambda_x \frac{\partial c}{\partial x}) + \frac{\partial}{\partial y} (h \lambda_y \frac{\partial c}{\partial y}) \quad (4)
\]

where \( h \) is the water depth; \( c \) is the concentration of pollutants; \( u \) and \( v \) are the x, y horizontal velocity ; \( f \) is the linear attenuation coefficient; \( \lambda_x \) and \( \lambda_y \) is the x, y diffusion coefficient; \( S = Q_s(c_s - c) \), \( Q_s \) is the source and sink item traffic; \( c_s \) is the relative concentration of pollutants at source and sink.

3.2. Establishment of two-dimensional hydrodynamic water quality model of donghu lake
The MIKE 21 model contains a number of modules. Hydrodynamic module (Flow Mode, FM) and ECO Lab module are selected in this paper to establish hydrodynamic and water quality model to analyze the eutrophication status of donghu lake.

3.2.1. Model boundary and calculation region. Qingshan Port on the northwest side of the donghu lake and zengjia lane on the southwest side serve as water diversion gate. Dongsha lake channel and
The new ditch and jiufeng ditch are the lake outlet. The hydrodynamic boundary is set in this way.

The Mesh Generator in MIKE21 was used to establish an unstructured grid. In this paper, the unstructured triangular grid was used to divide the terrain area of the donghu lake (11823 trigonometric units, 6462 grid vertices). It shows in figure 1.

3.2.2. Initial data and input data. This simulation period is from 0 on November 15, 2017 to 0 on December 17, 2017. The main time step is 2h, 384 steps apart, 32d in total. The initial water level value was set as the perennial average water level value of donghu lake (19.15m). The initial flow rate was set at 0m/s. The time series record value of water level boundary mainly refers to Hubei rain information query system and Wuhan hydrology survey bureau's data bulletin. As the research period tends to winter, the open boundary is uniformly set as water level boundary treatment. In this study, some boundary points were interpolated using MIKE according to the average water level.

The pollutants in the donghu lake mainly come from the surrounding living areas, including point source pollution, non-point source pollution and endogenous pollution. According to the actual situation of each sub-lake of the donghu lake and its corresponding water quality index data during the simulation period, the point source pollution of the donghu lake was mainly generalized to 7 sewage sources, as shown in figure 2.

3.2.3. Model parameter calibration. This simulation is divided into two parts: hydrodynamic simulation and water quality simulation. The control parameter for hydrodynamic simulation is the friction of lake bottom (by changing the manning coefficient constant or eddy viscosity coefficient). The parameters to be controlled in water quality simulation are pollutant diffusion coefficient, pollutant degradation coefficient and nitrification reaction rate. The final model parameters were determined by calibrating the above parameters.

The control parameters are set according to historical experience [5]. The hydrodynamic water quality numerical model was run to obtain the main water pollution indicators (chlorophyll a and ammonia nitrogen) concentration and hydrodynamic flow field simulation results, as shown in figure 3.
Figure 3. Hydrodynamic and water quality simulation results

From the spatial distribution of simulation results, the hydrodynamic flow field simulation results agree with the lake boundary scheme. The overall spatial distribution of water quality parameter simulation results conforms to the actual investigation results (measured value on December 17). However, in the local area, only parts of the simulation results agree with the actual situation.

After comprehensive analysis, the control parameters of the coupling model need to be recalibrated. The final setting result is shown in table 1.

Table 1. Coupling model rate-setting parameter value

| Parameter name                                      | Parameter value   |
|-----------------------------------------------------|-------------------|
| Eddy viscosity coefficient                         | 0.29              |
| Manning constant                                    | $42 \, m^{1/3} \, / \, s$ |
| Coriolis force                                      | Automatic calculation by area latitude information |
| Transverse and longitudinal diffusion coefficients  | Average 9.2m$^2$/s |
| Ammonia nitrogen degradation coefficient (20 standard) | 0.045day$^{-1}$    |
| Orthophosphate degradation coefficient (20 standard) | 0.035day$^{-1}$    |
| BOD depletion coefficient (20 standard)             | 0.025day$^{-1}$    |
| Chlorophyll a attenuation coefficient (20 standard) | 0.015day$^{-1}$    |
| Nitrification rate (20 standard)                    | 0.035day$^{-1}$    |
With chlorophyll a as the reference, the simulation effect after the parameter calibration was analyzed. The comparison results were shown in figure 4. According to the analysis of the figure, the simulation rate setting effect is better and accords with the actual situation.

![Figure 4. Comparison of simulation results of chlorophyll a before (left) and after (right) parameter calibration](image)

3.2.4. Model validation. Data at the end of the simulation period were used in this study. The water quality measured on December 17 (Chl-a, nitrate, nitrogen, orthophosphate and phosphorus) was used to verify the simulation results. The result is shown in figure 5.

![Figure 5. Verification of simulation results after calibration](image)

According to the calculation, the average relative errors of chlorophyll a and orthophosphate are respectively 19.60% and 25.36%, which are less than 26%. The overall simulation results are well and consistent with the actual situation.

4. Conclusion
Using FM module and ECO Lab module of MIKE21 water flow model, the hydrodynamic and water quality mathematical model of donghu lake was constructed respectively. The parameters calibration and model verification were carried out on the hydrodynamic part by selecting the water level and velocity indexes, and good simulation results were obtained. Based on the measured data at the end of the simulation period in 2017, verification points of each sub-lake of the donghu lake were selected to analyze and verify the water quality model. The statistical results showed that the mean square error MSE of chlorophyll a, and orthophosphate was less than 26%. The overall accuracy meets the requirements, and the simulation results can meet the monitoring accuracy requirements.
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Conflicts of Interest
The authors declare no conflict of interest.

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