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# Water Quality Parameter Modeling and Eutrophication Evaluation for Lakes and Reservoirs Based on WASP

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***ABSTRACT:*** *Environmental protection has attracted more attention because of its great significance to economy and people's livelihood. In order to well analyze the water quality, appropriate parameter model and eutrophication evaluation method are indeed necessary. Water quality parameter model could reflect the change rules and mutual relations of various water quality parameters, which lays a powerful foundation for water quality analysis. In this paper, the WASP eutrophication module was adopted to implement the water quality parameter modeling for lakes and reservoirs. Parameter calibration and varying flow setting were applied to improve the model accuracy. With the historical monitoring data of Beihai Lake, comparison between the estimated and measured values of parameters were given, and results showed a good accordance, which proved the effectiveness and practicality of the proposed method. Moreover, according to the water condition in Beihai Lake, suitable eutrophication evaluation standard was chosen to evaluate the water quality status of Beihai Lake, providing a scientific reference for water environment management.*

***Keywords:*** *WASP; eutrophication module; water quality parameter modeling; eutrophication evaluation*

## I. INTRODUCTION

Environmental protection has attracted more attention because of its great significance to economy and people's livelihood. With the rapid development of modern society, discharge of industrial and domestic sewage is increasing day by day, and eutrophication of lakes and reservoirs is becoming more and more serious. Generally speaking, eutrophication is caused by excess nitrogen, phosphorus and other inorganic nutrients in the water, where nitrogen and phosphorus are the main reasons for the eutrophication of slow flow water, such as lakes, reservoirs and bays [1]. At present, percentage of lakes with different degree of eutrophication are about 53%, 28%, 53% and 28% in Europe, Africa, North and South America respectively, and 54% Asia-pacific region lakes have eutrophication problem [2]. Therefore, solving eutrophication economically and effectively has become an urgent problem to be solved.

In order to improve the eutrophication situation, an appropriate mathematical model is required to reflect the characteristics of the system, which could be helpful for eutrophication evaluation and provide scientific reference for environment management. The famous water quality models involve Steeter-Phelps model system, multivariable QUAL—I water quality model, unsteady QUAL—II water quality model and comprehensive WASP water quality model [3-5]. WASP water quality model is an almighty model that can simulate the pollutants transfer and diffusion for various kinds of surface water, including rivers, lakes, estuaries and seas [6]. The main features of WASP model include the Windows-based development environment, ability to generate the data format which WASP can identify, the high efficiency treatment module for eutrophication and organic pollutant, and the intuitive computation results [7].

Based on the previous research on eutrophication in lakes and reservoirs, combining with integrated consideration of water quality, WASP model was adopted to analyze water quality parameters and evaluate eutrophication situation. Beihai Lake was taken as case study to verify the effectiveness of the proposed modeling method, and eutrophication evaluation was implemented thereafter.

## II. WASP WATER QUALITY MODEL

### 2.1 Overview

WASP is a comprehensive water quality model developed by the United States Environmental Protection Agency (EPA), which can be used to explain and predict water quality pollution caused by nature and men, and simulate hydrodynamics, rivers of one dimensional unstable flow, lakes and estuaries of three-dimensional unstable flow, conventional pollutants (including dissolved oxygen, biological oxygen consumption, nutrients and algae pollution) and toxic pollutants (including organic chemicals, metals, and sediments) migration and transformation rule in the water [8]. WASP is consisted of the hydrodynamic model program DYNHYD5 and the water quality simulation program. Among them, EUTRO module can be used to predict the changes of the dissolved oxygen, chemical oxygen demand (cod), carbon, chlorophyll a, nitrate, organic nitrogen and orthophosphate in the rivers and lakes. And then TOXI is a dynamic model of migration and accumulation of organic compounds and heavy metals in all kinds of water, which can predict changes of the dissolved and chemical adsorption in the rivers and lakes [9]. The following focuses on the eutrophication of EUTRO module.

### 2.2 Eutro module of eutrophication

EUTRO module can simulate water quality variables including dissolved oxygen, chlorophyll a, ammonia nitrogen, nitrate nitrogen, organic nitrogen, inorganic phosphorus, organic phosphorus, and carbon biochemical oxygen demand (cod) of eight state variables, and the interact relationships of them can be represented by four reaction systems, namely, the nitrogen cycle, phosphorus cycle, dissolved oxygen and phytoplankton dynamics process. The mutual relationships between the variables of EUTRO module are shown in Fig 1.

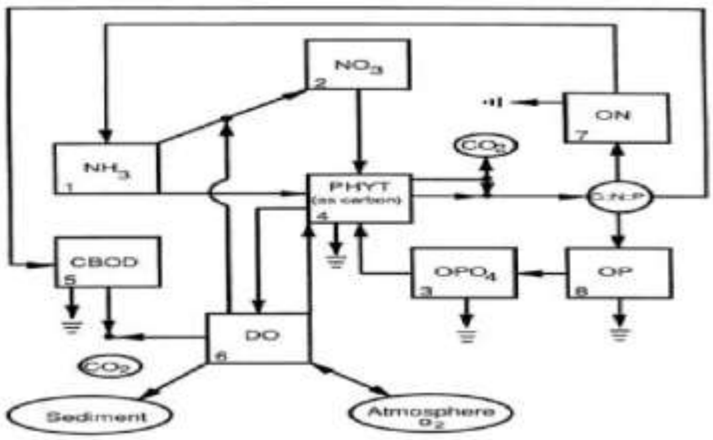


**Fig 1.** Mutual relationships between the variables of Eutro module

The basic equation of Eutro module is a translation – diffusion mass transport equation, which can describe the time and space variation of any water quality index. For any infinitely small water, the mass balance of the water quality indicators can be expressed as:

$$\frac{\partial}{\partial t}(AC) = \frac{\partial}{\partial x}\left(-UAC + EA\frac{\partial C}{\partial x}\right) + AS_T \quad (1)$$

In the formula, U is velocity (m/s), C is concentration of different water quality index (mg/L), E is the river diffusion coefficient ($m^2/s$), A is cross-sectional area ($m^2$), $S_T$ is the total leakage source item, which indicates the kinetic reaction rate, positive is source, and negative is leakage[g/(m3.d)] [10].

### 2.3 The basic process of simulating water quality status by WASP

First, river (lake) network is generalized, divided into several sections, according to the geological features and the surrounding artificial environment factors. The generalized river (lake) network should basically reflect the hydraulic characteristics, and its carrying capacity and storage capacity should be close to the actual condition or almost the same.

Second, it is necessary to determine various input parameters of the model, such as environmental parameters, including name and type of the model, time and step length, information of control body (basic information, parameter information, initial concentration, dissolution ratio); transformation parameters, containing the model parameters with spatial variation, constants and dynamical functions; transmission parameters, referring to the network connection structure between the control body, flow rate and the numbers of exchange domain; the boundary parameters of the model, where the boundary conditions and pollution loads are contained.

Finally, make use of WASP to simulate the water quality status, output and analyze the results. The process of simulating water quality status by WASP is shown in Fig 2.

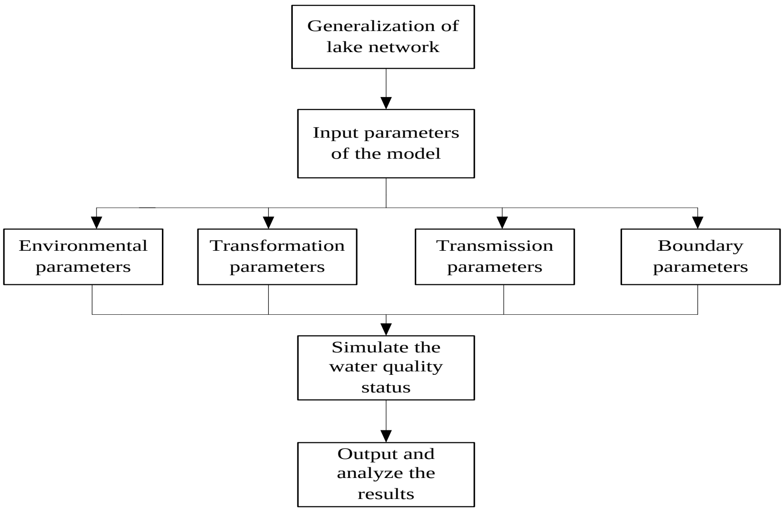


**Fig 2.** The process of simulating water quality status by WASP

## III. ANALYSIS ON WATER QUALITY of LAKES AND RESERVOIRS Based On Wasp

Taking Beihai Lake in Beijing as an example, the dissolved oxygen, chlorophyll a, ammonia nitrogen, total nitrogen and total phosphorus in the lake are simulated by WASP, in which nitrate nitrogen and inorganic positive phosphate are replaced by the total nitrogen and total phosphorus respectively.

### 3.1 Generalization of lake network

According to the geological characteristics and surrounding man-made environment factors of Beihai Lake, it is generalized into three sections , and then calculate the water volume of each section and the characteristic distance to adjacent partitions. Within the three sections, the first and third section are connected to Zhonghai and Qianhai Lake respectively, and some buildings can be found near the second section.
Data needed in the simulation mainly contain: (1) length, width, flow velocity and flow of each section; (2) boundary concentration of water quality variables; (3) time series of water temperature, light and wind speed values.

### 3.2 Calibration of input parameters

Considering the model is mainly for the eutrophication analysis, the EUTRO module was chosen. The time step is set to 0.9. The initial concentration is in accordance with the first measured data, and then input flow, boundary concentration, light, water temperature and other parameters information successively. Through experimental research, the parameter values for Beihai Lake are obtained by using trial method for several times, as shown in table 1.

**Table 1.** The WASP parameter values of Beihai Lake

| Name | Value of Beihai Lake | Value range of model |
|---|---|---|
| Nitrification rate at 20℃ | 0.11 | 0-10 |
| Temperature correction coefficient of nitrification rate at 20℃ | 1.07 | 0-1.07 |
| Half saturation coefficient of oxygen limited | 2 | 0-2 |
| Denitrification rate at 20℃ | 0.09 | 0-0.09 |
| Temperature correction coefficient of denitrification rate at 20℃ | 1.035 | 0-1.04 |
| Half saturation coefficient of oxygen limited | 0.1 | 0-0.1 |
| Growth rate of Phytoplankton at 20℃ | 1 | 0-3 |
| Temperature correction coefficient of growth rate of Phytoplankton at 20℃ | 1.068 | 0-1.07 |
| Respiratory rate of phytoplankton at 20℃ | 0.125 | 0-0.5 |
| Temperature correction coefficient of respiratory rate of phytoplankton at 20℃ | 1.045 | 0-1.08 |

| | | |
|---|---|---|
| Oxygen restoration rate at 20℃ | 1.028 | 0-10 |
| Temperature correction coefficient of oxygen restoration rate at 20℃ | 0.9 | 0-1.03 |
| Sediment oxygen demand | 4 | 0.2-4.0 |

### 3.3 Results of simulation

In order to reflect the eutrophication condition in the central part of Beihai Lake, the second section was chosen for analysis. With the parameters stated in the previous subsection, a model that describes the time and space variation of different water quality parameters was successfully built. Fig 3-7 showed simulated and measured values of these parameters, which are dissolved oxygen, ammonia nitrogen, total nitrogen, total phosphorus and chlorophyll a concentration respectively.

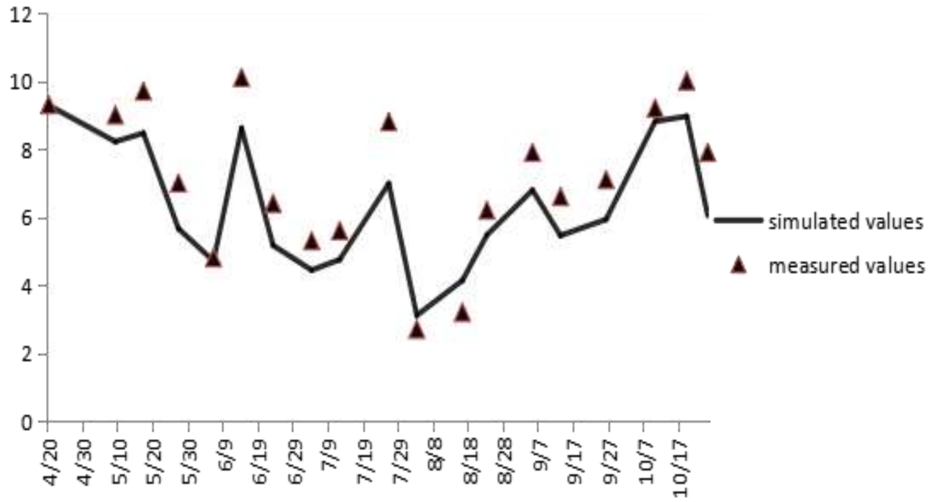


**Fig 3.** Comparison between simulated and measured values of dissolved oxygen concentration

It can be seen from fig 3, from the end of April, with the increase of temperature and precipitation, concentration of dissolved oxygen fluctuates. However, in the middle of July, along with the arrival of the rainy season, precipitation together with point source and non-point source pollution, and the pollution from restaurant near the lake, caused declination of water quality and plummeting of dissolved oxygen. After the rainy season, slight fluctuation and improvement appears.

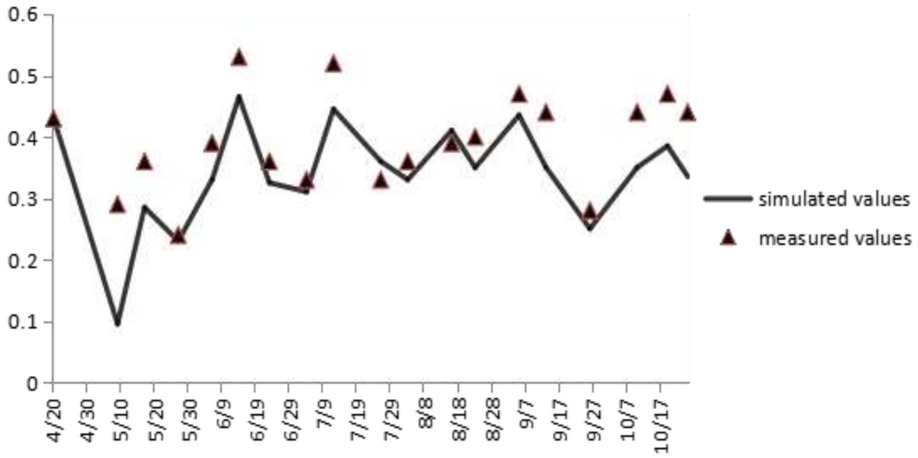


**Fig 4.** Comparison between simulated and measured values of ammonia nitrogen concentration

The average error value of ammonia nitrogen concentration between simulated values and the measured values is 14.6%, reflecting a good consistency of the result. The reason of the error may be that in the process of ammonia nitrogen simulation, not only the simple physical settlement and dissolution were involved, but also plankton, dissolved oxygen, light and other factors were considered in the process of chemical equilibrium.

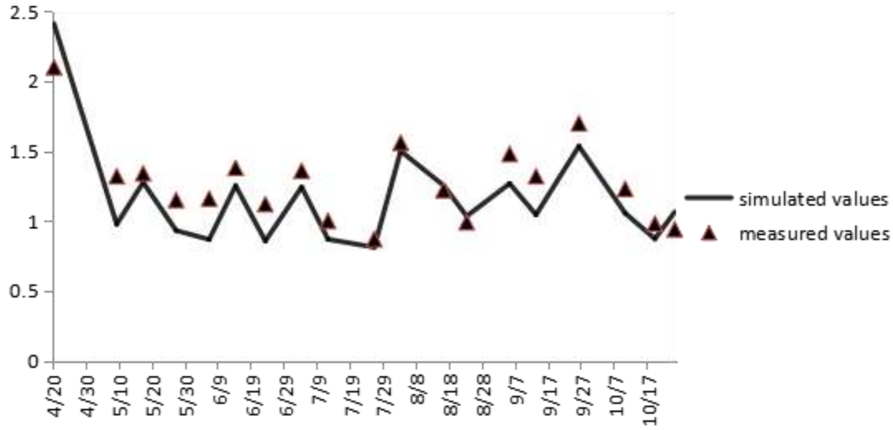


**Fig 5.** Comparison between simulated and measured values of total nitrogen concentration

As can be seen from fig 5, from May to July, total nitrogen concentration is relatively stable, while it starts to fluctuate during August to October, which may be due to the impact of the season and the different rainfall.

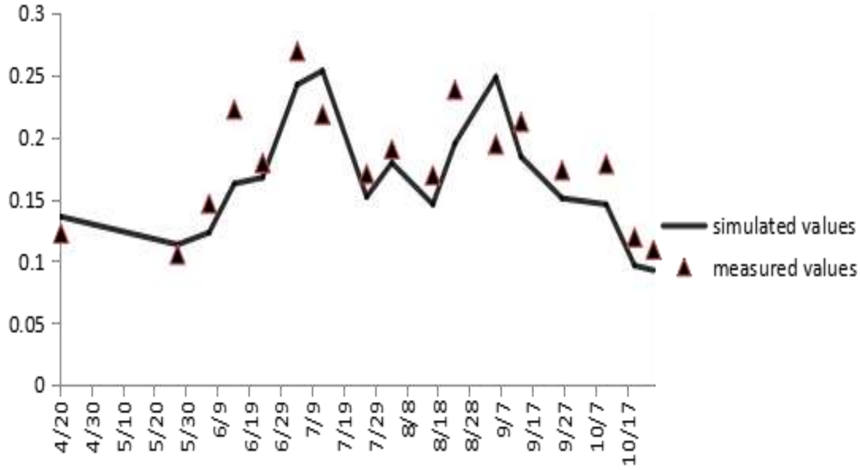


**Fig 6.** Comparison between simulated and measured values of total phosphorus concentration

As is shown in fig 6, starting from June, total phosphorus concentration has increased, which may be caused by the point source pollution from the construction nearby when the tourist season arrived.

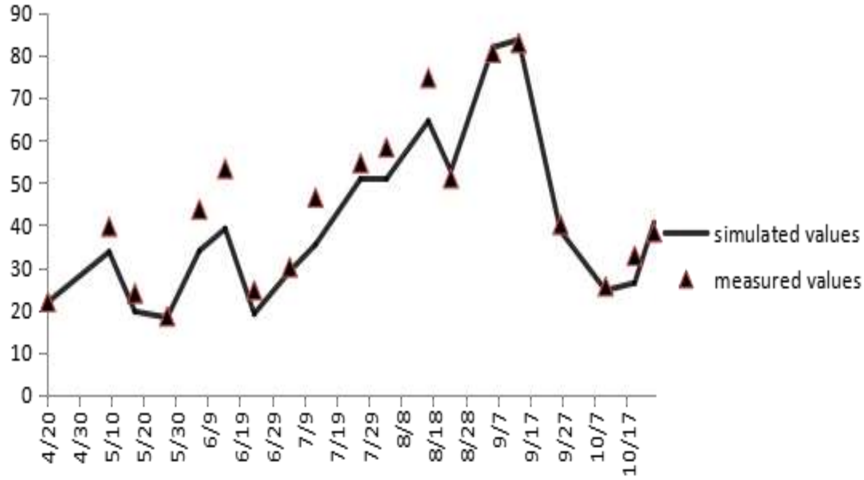

**Fig 7.** Comparison between simulated and measured values of chlorophyll a concentration

According to the result in fig 7, from the beginning of July, due to the increase of nitrogen and phosphorus concentration, as well as the rise of water temperature, the algae accumulation stage becomes obvious, and the significant increase of chlorophyll a concentration just appears, which makes the lake show a trend of eutrophication.

Through the comparison between the simulated values and measured values of the targeted water quality parameters, it shows that the average relative error value is within 15%, which represents the simulation results agree well with the measured data, and confirms the validity and practicability of this method.

## IV. EUTROPHICATION EVALUATION FOR WATER BODY

The section above is the modeling process for the Beihai Lake using the historical monitoring data. Based on this, with some new water quality monitoring data of Beihai Lake, accuracy of the model was further verified, and applicability of the model was improved. Using the same system information, the unit control body data, parameters, constants, and the time functions of model, the new boundary condition was given as input to generate results for the new time period. The results show that the average relative error value between the simulated values and the actual value is within 14.5%, which is in good accordance, and the model accuracy was improved further. Then the eutrophication evaluation was carried out.

The evaluation methods of water eutrophication can be divided into water quality parameters method, biomarker parameters method, nutrition index method and fuzzy mathematics method [11]. At present, there is no unified standard of eutrophication evaluation at home and abroad. Common methods include the S.Jorgensen lake trophic type standard, R.V.VollenWei-der load standard, Hangzhou Xihu Lake eutrophication evaluation standard, Taihu Lake eutrophication evaluation criterion and Wuhan Donghu Lake eutrophication evaluation standard. According to the actual water status in Beihai Lake, water quality parameters such as the concentration of nitrogen, phosphorus and chlorophyll a, and hydrology parameters were adopted to evaluate eutrophication. Here Taihu Lake eutrophication evaluation criteria was introduced as the evaluation standard, and detailed indicators are shown in table 2.

**Table 2.** Taihu Lake of eutrophication evaluation criteria

| Evaluation parameters / Eutrophic type | Physical and chemical indicators of water quality | | |
|---|---|---|---|
| | Total nitrogen (mg/L) | Total phosphorus (mg/L) | Transparency (m) |
| Extreme oligotrophy | 0.01 | 0.0004 | 48 |
| Oligotrophy | 0.02 | 0.0009 | 27 |
| Mesotrophy | 0.31 | 0.023 | 2.4 |
| Entrophy | 1.2 | 0.1 | 0.73 |
| Severe eutrophy | 4.6 | 0.56 | 0.22 |

According to the monitoring data of Beihai Lake, the average concentration of the total nitrogen is 1.2mg/L, the average total phosphorus concentration is 0.15mg/L, and the transparency is 0.5m. Referring to the Taihu Lake eutrophication evaluation criteria, Beihai Lake is in a eutrophication status.

## V. CONCLUSION

The WASP water quality model was applied to study the eutrophication of Beihai Lake in Beijing, and the results are consistent with the measured data. The water quality analysis model of Beihai Lake was established with the calibrated parameters, and average relative errors of the parameters are within 15%. Based on the model derived in WASP, combined with Taihu Lake eutrophication evaluation criteria, the eutrophication state of Beihai Lake was obtained. The model has practical guiding significance for water management, and pollution reduction scheme can be set according to the analysis for different seasons, so as to improve the water quality of different lakes.

## ACKNOWLEDGEMENTS

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