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Assessing temporal and spatial variability of algal bloom in Three Gorges Project reservoir----Application of an unstructured-grid three-dimensional coupled hydrodynamic-water quality model

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Abstract: Patterns of temporal and spatial variability of algal bloom in Three Gorges Project (TGP) reservoir and the tributary Xiangxi River (XXR) were examined using SELFE, an unstructured-grid, three-dimensional, hydrodynamic-water quality model. Dynamics of phytoplankton biomass characterized by chlorophyll *a*, nutrients including organic and inorganic nitrogen and phosphorus, dissolved oxygen (DO) , suspended and bottom sediments were modeled using an expanded and revised version of Water Analysis Simulation Program (WASP) which was fully coupled to SELFE model. The coupled model was driven by surface wind force, heat fluxes, oxygen exchanges at water-air interface, solar radiation and boundary conditions fluxes from Changjiang River (CJR) and XXR. The model was calibrated and verified by two time series of field observed data of algal blooms in TGP over the periods from September to October in 2007 and from June to July in 2008. The model results indicate that the stratified layers can form in the confluence zone between XXR and CJR because of water temperature three-dimensional distribution and also the water and nutrients interchange and backflow into the tributary XXR will influence the algal bloom process. The interactions between suspended and bottom sediment with nutrients and phytoplankton through adsorption and light attenuation were also considered. The developed model will provide a new tool to study the aquatic environmental problems in TGP.

Keywords: Three Gorges Project reservoir; Xiangxi River; Ecosystem modeling; SELFE; WASP

Introduction

The Three Gorges Project (TGP) is the biggest hydropower project in the world. TGP, a river reservoir with a storage capacity of $393 \times 10^9 \text{ m}^3$, is located in the upper course of the Yangtze River. The gorge presents a narrow and deep shape, with long water retention time and seasonal temperature stratification. Thus, TGP affects the hydrodynamic conditions of the river course or its tributaries. In recent years, with significant economic development and rapid population growth, large amounts of non-point source pollutants from agricultural production, as well as industrial and local phosphorus mining production, have been discharged around and into the TGP reservoir area. Furthermore, many small hydropower projects have been built in the upper reaches of Xiangxi River (XXR), a tributary of the Yangtze River in the TGP reservoir area. These projects intercept water and sediment runoff and affect benthic diatoms. Prior to the construction of the TGP, algal blooms, which result from massive phytoplankton reproduction, did not occur in the XXR. However, algal blooms began to occur frequently since the commencement of construction of the TGP in 2003. Such occurrences negatively affect the water ecosystem and lives of the locals. Thus, algal blooms have received great attention from environmental authorities and researchers.

Mathematic models can provide information on the variations in temporal and spatial biological processes, and a number of numerical models have been used to study water quality and ecosystem problems. Some well-established three-dimensional (3D) ecological models including WASP 6 ([Wool et al, 2001](#)) have been developed and applied to simulate water quality variations in river, lake, estuary, and ocean environments. However, these models are developed in structured mesh mode, which does not adapt well to the complex boundaries of natural rivers or oceans and requires tedious preprocessing. Thus, an unstructured mesh model was developed based on the SELFE model ([Zhang et al., 2008](#)). An ecological model must cover the basic physical, chemical, and biological processes of an aquatic ecosystem as well as the effects of sediment on the water quality processes. Hence,

the unstructured mesh model is expanded here to simulate the interaction system of hydrodynamic conditions, temperature, light intensity, nutrients, sediment, dissolved oxygen (DO), and phytoplankton.

The current study aims to develop a 3D unstructured mesh ecological model based on SELFE model to investigate the XXR algal bloom in 2007 and 2008. Flow information, such as velocities, water surface elevation, and eddy viscosity parameters, was obtained from SELFE model. In the model, the parameters for nutrient adsorption–desorption by SS, bed release, light intensity, temperature, and phytoplankton were calibrated and verified by field data. The results may not only help planners establish effective water quality management policies but also improve the local ecosystem sustainability of the TGP reservoir area.

1 Basic Theory of Water Quality Model

The model was developed based on SELFE framework, which is a widely used oceanic model ([Zhang et al., 2008](#)). The developed model aims to simulate the temporal and spatial variations in suspended sediment, DO, nutrients including organic and inorganic Phosphorus and Nitrogen as well as phytoplankton, the bottom mud layer influencing the nutrients and phytoplankton cycling in water column was also considered. The model scheme generally followed the WASP ([Wool et al., 2001](#)) model and included algorithms that represent phytoplankton dynamics, DO, SS, as well as nitrogen and phosphorous cycles, the conceptual framework of the coupled model can be referred to Fig.1, and the reader can get the detailed modules information and the theory from literatures ([Li et al., 2012](#), [Li et al., 2014](#)).

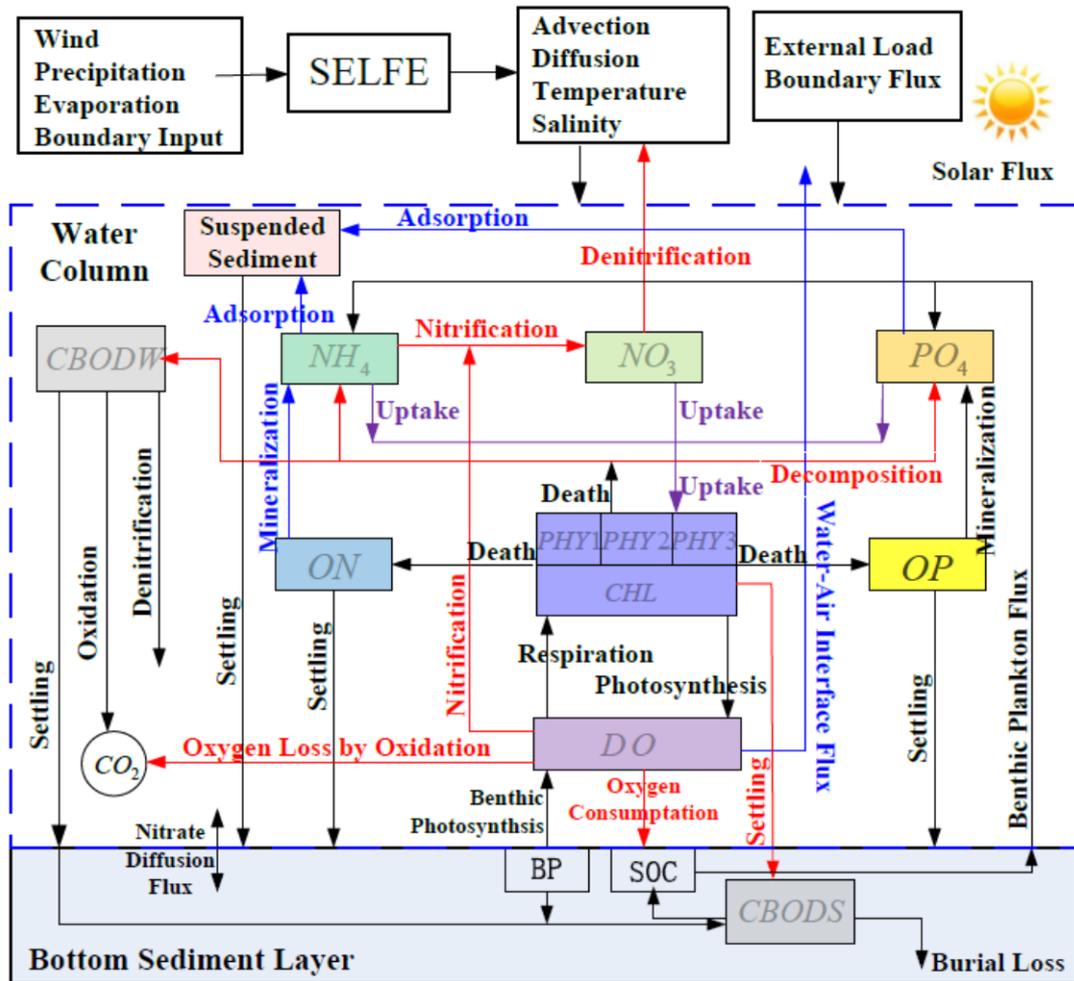


Fig.1 Conceptual Framework of the coupled hydrodynamic-water quality model (Adapted from WASP6)

2 Modeling Area

XXR located in Hubei Province of China and flows across Xingshan and Zigui Counties between 110.47° to 111.13° E and 30.96° to 31.67° N. The XXR has a length of 94 km length, a catchment area of 2939 km^2 , and is among the Yangtze River tributaries. The Xingshan and Jianyangpin Stations are controlled hydrological stations with an average annual discharge of $47.4 \text{ m}^3 \cdot \text{s}^{-1}$ and $10.0 \text{ m}^3 \cdot \text{s}^{-1}$, respectively (Fig. 1). The local hydrodynamic condition has a close relationship with the main stream flow of the Yangtze River. For example, both backflow mixing and the vertical exchange occur during the water impoundment and water release processes of the TGP reservoir. Thus, the nutrients, sediment, and phytoplankton near the XXR mouth interact with those of the main stream flow of the Yangtze River.

The computational domain of the XXR, including the Gaolan River tributary,

was discretized with 15,282 horizontal triangle elements and 21 vertical “pure S-layers” (Fig.3). The hydrodynamic calculation time step was set to 60s and the mass transportation (including nutrients, DO, SS, and phytoplankton) calculation time step was also set to 60 s. The XXR algal blooms occurred in 2007 and 2008. A total of 11 in situ observation stations were set along the river course to measure the nutrient (TP and TN), SS, DO, and chlorophyll concentrations in the water surface as well as biochemical and meteorological data for the two algal blooms (Fig. 2). The inlet boundary conditions of the XXR and Gaolan River were set to the discharge level during the algal bloom, and the outlet boundary at the XXR mouth was set to the operational water level of the TGP reservoir. The TN, TP, SS, DO, and chlorophyll concentrations on the first day of the algal bloom were defined as the initial calculation conditions.

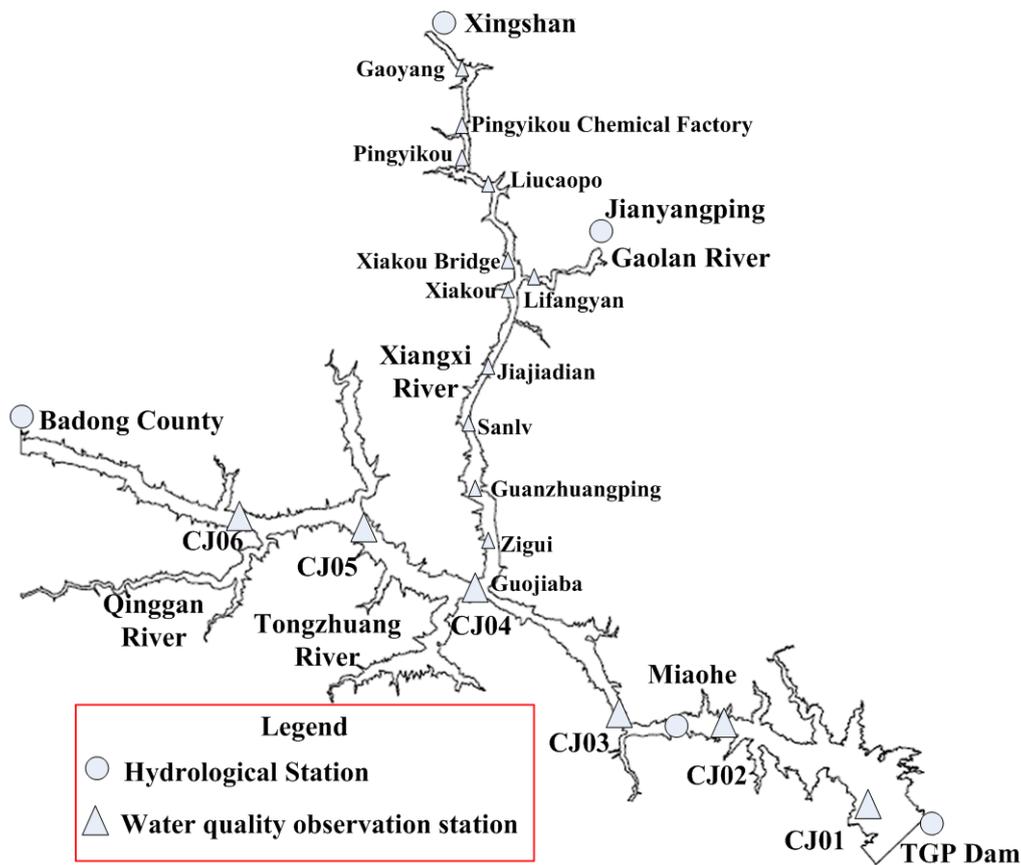


Fig. 2 Schematic map of Three Gorges Project reservoir and the field observation

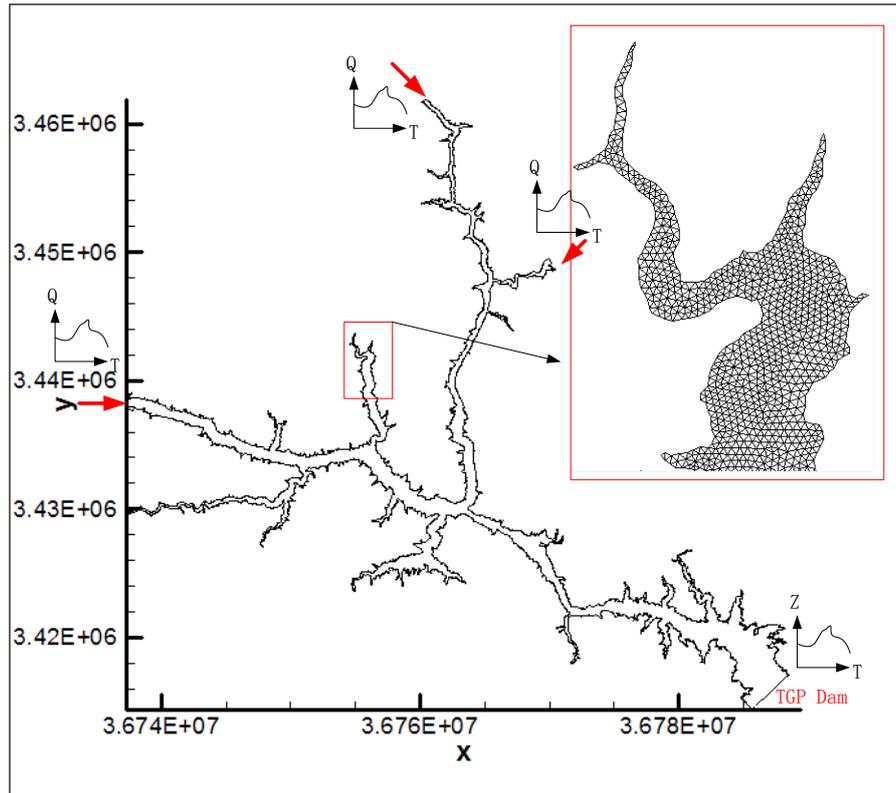


Fig.3 Mesh and boundary conditions for modeling

3 Modeling the Changjiang mainstream and tributaries

The coupled model was calibrated using daily field measurement data, and the analysis of the water samples was obtained between September 2007 and October 2007 (Zhu Kongxian., 2013). For calibration runs, the velocity field was calculated from SELFE runs. The eco-dynamic model parameters were repeatedly adjusted to obtain a reasonable reproduction of field data. Some of the model parameters were referred from previous literature. Some parameters were directly obtained from experiments and field measurement. All adopted parameter values were in the range reported in literature (Wool et al., 2001).

The current study compared the surface measurements with the modeling results at the surface layer. Figs. 4 and Fig. 5 show the modeling and measurement results for Xiakou and Gaoyang Stations, respectively. The simulated TP, TN, chlorophyll, and the dissolved phosphate (PO_4) concentrations are consistent with the measured values after considering adsorption–desorption by SS. The chlorophyll concentrations at the water surface are obviously higher than those at the bottom of the river because of

light shading caused by the water, SS, and phytoplankton. The spatial distribution of TP upstream was greater than that downstream because of the phosphorus mining around Baisha and Gufu Rivers. By contrast, the spatial distribution of TN had no distinct characteristics.

In general, the modeling results of chlorophyll reasonably reproduced the rapid algal bloom process. Furthermore, the modeling results provided acceptable magnitudes for the water quality constituents. However, the model did not satisfactorily reproduce local temporal variations in the field measurements along the whole river course, especially near the river mouth. These differences may have resulted from the different data used, that is, the field measurements were obtained daily whereas the simulation time step was 60 s. The eco-dynamic processes in the XXR system are also too complex to be fully understood through the current numerical studies.

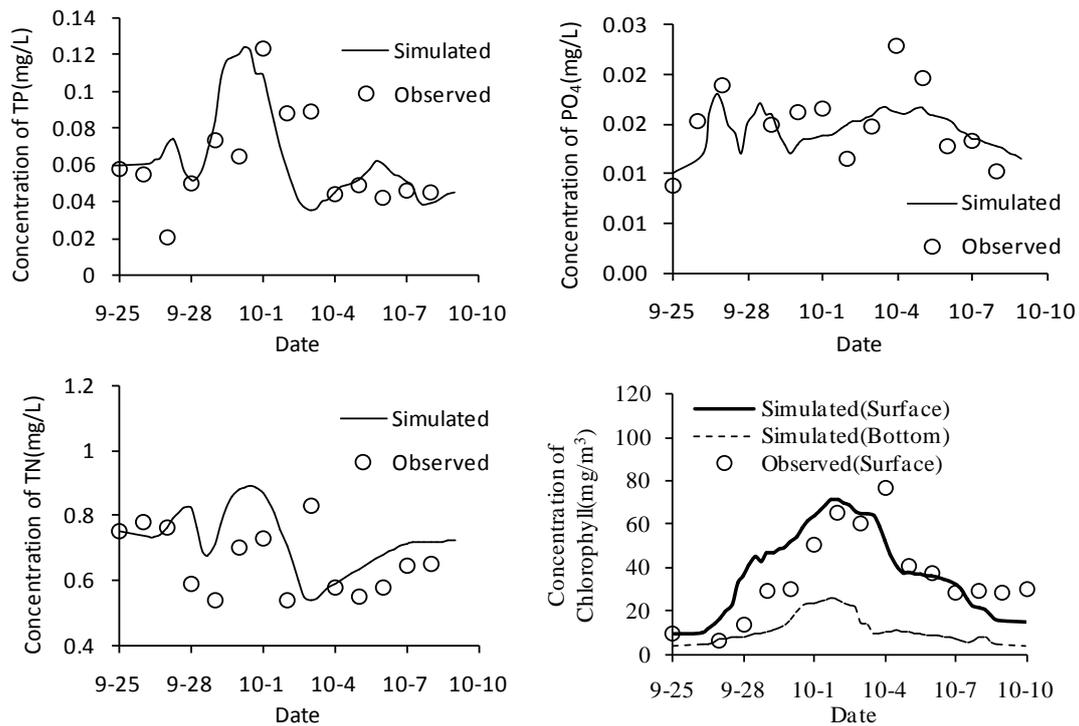


Fig. 4 Concentrations of phosphorus, nitrogen and chlorophyll at Xiakou Station (calibration)

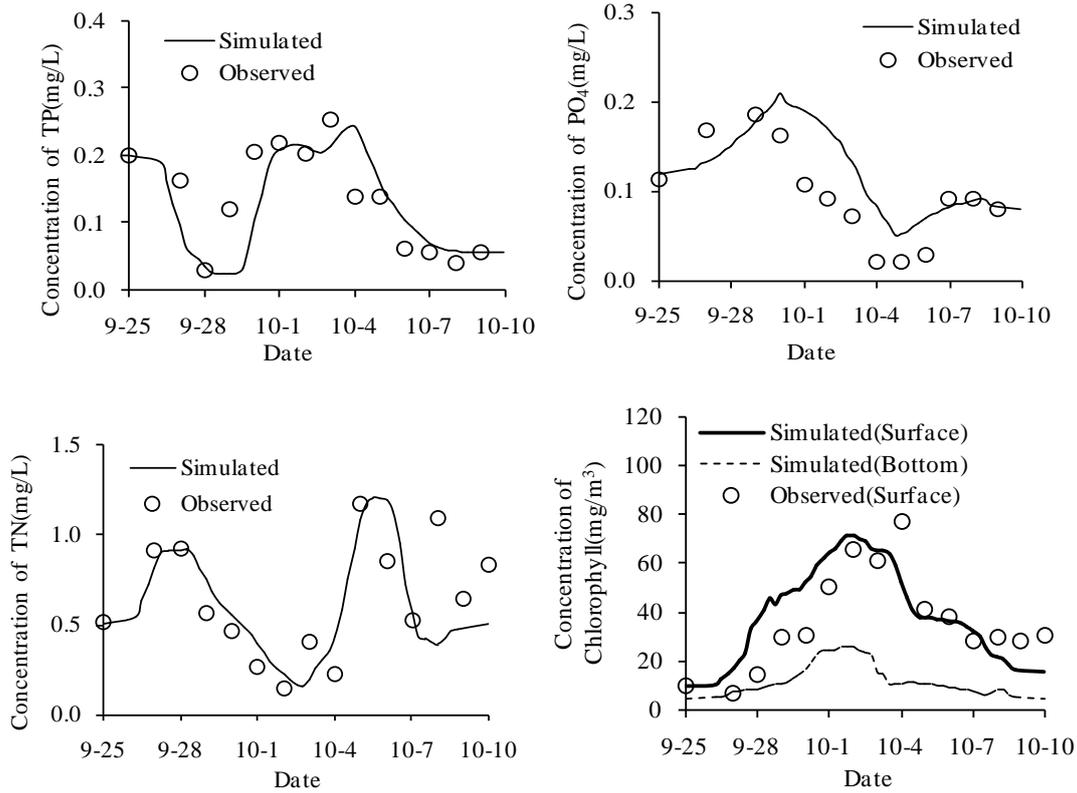


Fig. 5 Concentrations of phosphorus, nitrogen and chlorophyll at Gaoyang Station (calibration)

5 Conclusion

The current study presents a 3D unstructured mesh numerical model for simulating the concentrations of water quality constituents, SS, DO, and chlorophyll in the XXR, where sediment-related processes are important. The model framework was based on water quality WASP model. Some sediment-related processes were reasonably considered in the model. The nutrient adsorption and desorption by sediment was considered. The Langmuir equation was adopted to calculate the dissolved and particulate nutrients rather than the simple linear assumption between the particulate and dissolved nutrient concentration in the WASP model. To determine the bed release rate of nutrients, the effects of pH, temperature, DO concentration, and nutrient concentration gradient across the water-sediment interface were considered. In many models, the effect of SS on the light attenuation coefficient was not considered. In the unstructured mesh model, the effect was considered and validated based on field observations. The effect of hydrodynamic conditions on phytoplankton

growth was also considered in the model to simulate river algal bloom.

The unstructured mesh model was more adaptive to the complex boundary of rivers than structured mesh models such as CCHE3D (Chao et al., 2006). The model was successfully applied to the study of XXR algal blooms. Realistic trends and magnitudes of nutrients and phytoplankton concentrations were obtained from the numerical modeling and generally agreed with the field observations.

The model was also used to analyze the sensitivity of the XXR chlorophyll concentration to the inlet discharge (flow velocity) and SS and nutrient concentrations. XXR algal blooms could be controlled by increasing the discharge and sediment release from the upper reach because primary productivity is limited by flow velocity and SS shading. Chlorophyll concentration was somewhat less sensitive to TP concentrations and insensitive to TN concentrations. However, phosphorus pollution control is also important for preventing algal blooms.

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References

- [1] Chao X. B., Jia Y. F., Charles M. C. et al., Development and Application of a Phosphorus Model for a Shallow Oxbow Lake. *Journal of Environmental Engineering, ASCE*. 2006. 1498-1507.
- [2] Li Jian, Jin Zhongwu, Yang Wenjun. Numerical modeling of the Xiangxi River algal bloom and sediment-related process in China. *Ecological Informatics*, 2014, 22: 23-35.
- [3] Li Jian, Li Danxun, Wang Xingkui. Three-dimensional unstructured mesh eutrophication model and its application to Xiangxi River, China. *Journal of Environmental Sciences*, 2012, 24(9): 1569-1578.
- [4] Wool T. M., *Water Quality Analysis Simulation Program (WASP) Version 6 User's Manual*. US Environmental Protection Agency, Atlanta, GA. 2001.
- [5] Zhang Yinglong, Antonio M. Baptista. SELFE: A semi-implicit Eulerian-Lagrangian finite-element model for cross-scale ocean circulation. *Ocean Modelling*. 2008. 21:71-96.

[6] Zhu Kongxian. Studies on photoplankton community dynamics and eutrophication in the Three Gorges Reservoir. Doctoral dissertation of Chinese Academy of Sciences, 2013.