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A vertical-compressed three-dimensional ecological model in Lake Taihu, China

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Abstract

A three-dimensional ecological model on the basis of the analyses of environmental characteristics is set up for Lake Taihu, one of the largest shallow lakes in China. The hydrodynamic processes, nutrient cycling, chemical processes and biological processes are integrated in the model. Model state variables include: water current, surface displacement, nutrients of nitrogen and phosphorus, as well as their different forms such as ammonia nitrogen, nitrate nitrogen, phosphate phosphorus, etc., biomasses of macroplankton, phytoplankton, zooplankton and fish, and also the nutrient levels of macroplankton and phytoplankton. A nutrient budget and sediment transformation are also coupled in the model. The data from January 17, 1997 to January 18, 1998 are use to calibrate the model. The model results have shown good agreement with the observations. It implies that the model could be used for the lake environmental management and research for examining the processes and determining the water quality. The reasons of deviations between the modelled results and the observed values are also discussed. There are six factors that explain the deviations of the modelled results from the observed values and they can be grouped into two sets. One set of problems is associated with the standard deviation introduced by sampling and analyses. The second set of problems can be solved by introduction of processes lacking in the present model (resuspension, phytoplankton transportation mode under the wind with low speed, shifts in species composition and varied size of phytoplankton and zooplankton). The latter two processes should be included in the model at a later stage by integration of a structurally dynamic approach into the three-dimensional model.

Keywords: Three-dimensional ecological model; Phytoplankton; Nitrogen; Phosphorus; Lake Taihu

1. Introduction

Lake Taihu is among the five largest fresh water lakes in China. There are 38 cities and 34.2 million people surrounding the lake. Gross Domestic Produc-

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tion in the lake drainage area is about one-seventh of the total GDP of China. Lake Taihu provides the necessary water resource for agriculture, industry and drinking water. It plays, therefore, an extremely important role in the area for economical and social development.

An increasing amount of pollutants has been discharged into the lake directly and indirectly due to the economical and social development since the 1980s. Consequently, the lake ecosystem has deteriorated. Frequent algal blooms take place in the lake. In the summer of 1990, the algal bloom was distributed in the entire Meiliang Bay and lasted more than one week, causing 118 industrial plants to stop working and people to lack drinking water in Wuxi city. Algae blooms have badly influenced the development of economy and society and does harm to people's health. Consequently, considerable scientific research has been devoted to the lake to characterize algal bloom and it's jeopardizing the water quality. In order to successfully manage the lake water quality and to prevent algae bloom, it is necessary to know why, when and where algal blooms occur. Eutrophication in Lake Taihu is a comprehensive problem, which involves nature, society and economy. Systematic answers to the above questions cannot be obtained only by observations on site and experiments in a laboratory. It is necessary to supplement the observations and experiments with an ecological model, which is better to integrate the available information about the lake and answer the above-mentioned questions. A good model would be able to guide the management and to indicate how water quality could be improved.

The purpose of this study is to develop an ecological eutrophication model for characterizing the space–time distribution of algal bloom in Lake Taihu. The model should be applicable for a proper water quality management and give guidance on how to improve the lake water quality.

Since Lake Taihu is a large shallow lake with an area of 2338 km^2, the annual average water depth of 1.9 m and maximum of 2.6 m, it has different water quality in different areas due to its size. Consequently, the mean value of many parameters in the whole lake is not equal to the corresponding parameters in the outflow. This implies that Lake Taihu cannot be considered as a well-mixed water body. Therefore, the ecological model, we develop, considers the horizontal uneven distribution and divides the lake into many cells. Although many models on the hydrodynamics and water quality of Lake Taihu have been developed since the 1980s (Wu and Pu, 1989; Wang, 1987; Ma and Cai, 1997; Liu, 1993), most of them are two-dimensional models that have revealed the characters of the vertically averaged water circulation and the transportation of matter which is vertically well-mixed. However, they cannot describe the vertical distribution of the water current since the dominate currents are wind-driven current in most cases. They are unable to show the transportation of matter which is uneven vertically distributed (Hu and Qin, 2002).

Since the dominate species of phytoplankton are *Microcystis* in most months of a year, phytoplankton biomass is usually unevenly distributed in the vertical direction due to its vertical movement to more solar radiation. The phytoplankton biomass uneven vertical distribution and the uneven distribution of solar light imply that the phytoplankton production is varied in different layers. Consequently, the nutrient uptake by the phytoplankton will also have differences in different layers. This will also mean different nutrient concentrations in different layers. So, the ecological model should consider these differences. Therefore, different three-dimensional models have been established on the lake hydrodynamics and water quality over the last 20 years (Hu et al., 1998a,b,c; Jiao, 1986; Zhu and Cai, 1998; Pang et al., 1998; Liang and Zhong, 1994). In Jiao's (1986) three-dimensional model, he discussed hydrodynamics and sediment transportation. Zhu and Cai (1998) discussed the hydrodynamics and the spatial distribution of algae in a rectangular area without considering the phytoplankton growth dynamics. Liang and Zhong (1994) only discussed a hydrodynamic characterization by using his three-dimensional model. Pang et al. (1998) discussed hydrodynamics by using a three-dimensional model, but he just used two-dimensional model when he considered algal distribution and algal growth. Hu et al. (1998a,b,c) further discussed in depth the difference between two-dimensional hydrodynamic model results and three-dimensional hydrodynamic model results by using a three-dimensional hydrodynamic model. As stated previously, the three-dimensional hydrodynamic model should be used when uneven vertical distributions of state variables are considered. The ecological model presented in this paper is based on a three-dimensional hydrodynamic model. It integrates the nutrient cycling