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Simulation of a water ecosystem in a landscape lake in Tianjin with AQUATOX: Sensitivity, calibration, validation and ecosystem prognosis

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ABSTRACT

The parameters involved in AQUATOX of the relatively large lakes do not have widespread applicability in landscape lakes. To get a series of model parameters of landscape lakes, an AQUATOX model was developed for SH landscape lake in Tianjin. The parameter sensitivity analysis, calibration and validation were carried out in this study. Moreover, the model was applied to predict the changes of nutrient with different species in SH. The results of parameter sensitivity analysis indicated that the model is highly sensitive to the optimal temperature, maximum photosynthetic rate and respiration rate. The results from calibration and validation have revealed that the AQUATOX model did a good simulating for SH. Furthermore, the AQUATOX provided necessary information for management of SH. Based on the prognosis under different scenarios, the biomass of Bullhead and plants should be controlled to remain the water quality of SH in a good condition.

1. Introduction

In Chinese cities, most of the landscape lakes were artificial or half artificial, of which the water regulation and supplies, and ecosystem were mainly maintained artificially. And the area of most landscape lakes was less than 10,000 m^2, and the depth was about 0.4–2.0 m (Chen, 2014). The landscape lakes vulnerable to the surrounding environment and human daily activities, as a result of erupting eutrophication, reducing biodiversity, losing recreational and wasting a lot of water (Wang and Li, 2006; Zhong et al., 2010).

In recent years, computer technology comes into the rapid development period, and the impact of the lake water ecology model is becoming increasingly important on simulation of ecological changes and pollutants (Cao, 2006; Niu et al., 2013; Zhang, 2008). AQUATOX model is the water ecological mode described most extensive in the literatures. Rashleigh et al. (2009) described the food web dynamic characteristics of PCB in Lake Hartwell by AQUATOX, and used the measured data of fish biomass to calibrate the model. Morkoç et al. (2009) surveyed pollution load in Omerli and used AQUATOX model to simulate the changes of plants and nutrients under three specific scenarios. Park et al. (2008) applied the AQUATOX model to simulate ecosystem environmental fate and ecological effects of pollutants in lakes and other aquatic ecosystems, and obtained direct or indirect influence of various factors on the lakes. Cao (2006) carried out a water quality and ecological environment simulation with AQUATOX for studying eutrophication and water ecological processes, and partitioned Dongting Lake depending on the ecological functions. Yang et al. (2009) developed AQUATOX aquatic ecosystem model to simulate the seasonal changes of the algae and the changes of the water quality indexes in Dianshan Lake ecosystem, and analyzed factors affecting blue-green algae based on the model parameter calibration and validation. Chen et al. (2012a,b) determined the indexes needed to focus and control in the process of landscape lakes ecological restoration in north China HM ecological towns, and presented several restoration programs.

Currently AQUATOX model has been widely used in lake pollution control and water quality forecast, but the studies mainly focused on the relatively large lakes. Large difference between nature lakes and landscape lakes make the model parameters involved in the model do not have widespread applicability. It is essential to determine a series of parameters of landscape lakes in AQUATOX model for the urban landscape lake water quality control and function maintenance. The abilities of self-maintenance

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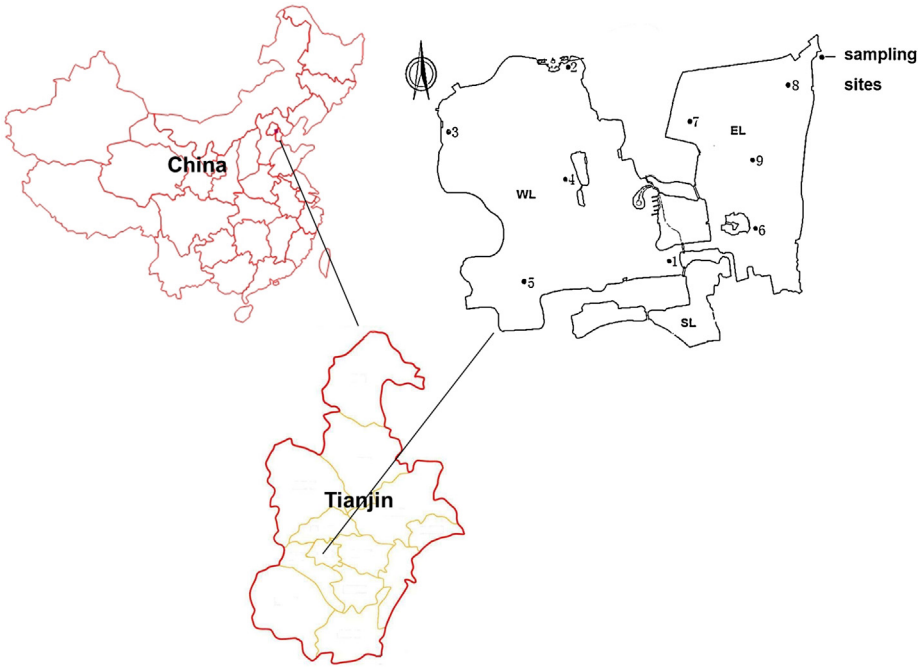

Fig. 1. Map of the study area including location of sampling sites.

and self-renewal are important aspects of lake ecosystem health (Hu et al., 2005; Rapport, 2000). Internal factors of lake ecological system, such as ecological system component composition, hydrodynamic conditions, nutrient concentration, pH, temperature and so on, have important influence on ecological health (Liu et al., 2004; Xu et al., 2001). Landscape lakes were vulnerable to outside interference for their own characteristics (Liu et al., 2009). In order to understand the influence degree of the interference to landscape lake, it is necessary to understand the ecological conditions in the natural evolution. The aim of this paper was to develop an AQUATOX model for SH landscape lake. The ecological status of the lake was simulated in the absence of influence from external factors. Optimization method was used to complete the parameter calibration. The model was applied to predict water quality of SH landscape lake to verify the feasibility of the method.

2. Model and methods

2.1. Description of the study area

The landscape lake named SH situated within the SH park of the city of Tianjin. SH landscape lake is a natural lake with artificial modification, area and depth of SH lake are larger and deeper than general urban landscape lakes. It is a typical landscape lake in China that is usually no water input and output, closeness, and maintaining water quality through self-purification (Chen, 2014; Gong et al., 2015; Peng et al., 2009; Wang and Li, 2006; Zhang, 2008). SH is composed of three lakes which are named East Lake (EL), West Lake (WL) and South Lake (SL) (Fig. 1). The area of the SH is 760,000 m^2, its max depth is approximately 5 m, and the shallowest is about 1.5 m.

SH landscape lake is located in the east of the Eurasian continent, near Bohai Bay, and is warm-humid continental monsoon climate (Wang et al., 2010). The area has four distinct seasons, the monthly average temperature is about 26 °C and minus 2 °C in the hottest July and coldest January, respectively (TMBS and SONBS, 2013). There is a long time of sunshine in the region; the annual sunshine time is approximately 2500–2900 h (TMBS and SONBS, 2013). The annual average frost-free period is about 210 d, and the shortest time is about 171 d and the longest time is about 267 d (TMBS and SONBS, 2013). The main wind is northwest in winter and south in summer when Pacific Subtropical high strengthens (Wang et al., 2010; Yang et al., 2014).

2.2. Analysis procedure

The analysis steps are as follows (Fig. 2):

a. sensitivity analysis, in order to select the most sensitive parameters;
b. calibration, to obtain suitable parameter values for SH;
c. validation, to evaluate the simulation accuracy of the model;
d. prognosis scenarios, to predict the changes in SH.

2.3. AQUATOX model

AQUATOX is an aquatic ecosystem models issued by EPA (United States Environmental Protection Agency, USEPA). AQUATOX is a general ecological risk model that evaluates the various factors direct or indirect effects on the current or future situation of waterbody (Chen et al., 2013; Morkoç et al., 2009). AQUATOX can simulate the fate of organic compounds, nutrients and other pollutants in the water environmental systems, as well as the impact on fish, invertebrates and aquatic plants, etc. AQUATOX includes five parameter libraries and contains a large number of model parameters. The model parameters provide relevant coefficients for the process functions. Users can use the default input parameters of the model itself, can also specify values in terms of the specific circumstances of simulated objects. AQUATOX can establish causal chain of biological response between water quality and bioavailability, and thus able to predict effects of chemical contaminants for aquatic ecosystems. AQUATOX simulation conceptual model of ecosystem is shown in Fig. 3 (US EPA, 2010).

2.4. Parameter sensitivity analysis methods

To analysis parameters sensitivity, the following approach may be applied: perturbation analysis, OAT (One-factor-At-a-Time), LH-