Integrated Water Quality Model and Its Application in Baihe River Basin

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Abstract. The integrated watershed water quality model is an important tool for studying the water environment of the basin. This study explores several comprehensive watershed water quality models, analyzes the development history, structural principle, characteristics and application of the model. This paper preliminary applied SWAT model in the Baihe River Basin, Beijing, China to analyze the water quality changes. Finally, this study briefly analyzes the development trend of the basin comprehensive water quality model.

1. Introduction

In recent years, the domestic economy has developed rapidly, but various types of pollution have followed, especially water pollution. Water pollution can be divided into two types: point source pollution and non-point source pollution. Point source pollution refers to pollution caused by fixed sewage outlets, Non-point source pollution refers to water pollution caused by contaminants flowing from non-fixed locations to water bodies such as rivers and lakes by runoff under the action of precipitation and runoff. Compared with the two, non-point source pollution is more difficult to control, and the proportion of environmental pollution is also gradually increasing. Some studies have shown that non-point source pollution is the main cause of deterioration of water quality in important lakes such as Tai Lake, Chao Lake and Dianchi Lake [1]. In addition to nitrogen and phosphorus pollution sources, sediment is also one of the common sources of non-point source pollution in China [2].

Establishing a comprehensive water quality model for river basins is the most effective and direct research method for quantitative research, impact assessment and pollution control of non-point source pollution in river basins [3]. The model can not only quantitatively describe the pollutants in the basin, but also simulate the migration and transformation process of pollutants in the basin, and visualize the temporal and spatial distribution of pollutants in the basin, and provide decision-making basis for the management and management of water quality in the basin.

2. Model research progress

The development of the water quality model on the timeline can be divided into three phases, each of which develops as follows:

2.1 The initial stage

As of the 1960s, the water quality model mainly used oxygen balance as the research content, which is relatively simple and computationally intensive, such as the Streeter-Phelps model system, but the
model has low precision and cannot be applied to complex water bodies [4].

2.2 The development stage
From the 1970s to the 1980s, water pollution became more serious. From the 1970s to the 1980s, water pollution became more serious. A lot of research was carried out on pollutant transport laws and watershed management plans. The water quality model ushered in a period of great development, which is the most rapid development stage. Models at this stage are STORM, SWMM, ARM, HSPF, CREAMS, and so on. Compared with the initial stage, the water quality model of this period realized a complex hydrological and water quality coupling mechanism and realized continuous time series response analysis [5].

2.3 The improvement and maturity stage
Since the 1990s, the combination of water quality model and rapid development of computer information technology, GIS and RS has been rapidly developed [6], and the hydrological water quality simulation analysis of large-scale watershed has been realized. For example, the SWAT model developed by the US Department of Agriculture (USDA) is widely used in non-point source pollution simulation.

3. Main Watershed integrated water quality model and its application
This paper selects three Watershed integrated water quality models of SWAT, HSPF and MIKE models, and will focus on their development history, structural principles and characteristics as well as specific application cases.

3.1 SWAT model
The SWAT (Soil and Water Assessment Tool) model is a semi-distributed hydrological model based on watershed scale developed by USDA to strengthen integrated river basin management. The applied watershed scale ranges from several hundred square kilometers to hundreds of thousands of square kilometers. It was developed on the basis of the CREAMS hydrological model. It was renamed SWRRB after incorporating the EPIC crop growth module in the 1880s, and then merged with the river calculus module RO-TO to form the initial version of the SWAT model [7]. In 1994, combined with GIS, the SWAT model that is widely used at present is formed.

The SWAT model uses the spatial information provided by GIS and RS to simulate the physical and chemical processes such as hydrological elements and pollutants in a discretized manner using mathematical physics methods on a daily scale. In order to reduce the non-uniformity of the underlying surface of the watershed, the SWAT model divides the whole watershed into several sub-basins, and then divides the sub-basin into several hydrological response units (HRUs) according to geographical factors such as land use, soil type and slope. The above geographic elements in a hydrological response unit are all uniform. The model production flow calculation uses the SCS runoff curve number method, the sediment calculation uses the general soil loss equation MU-SLE method [8], and the nutrient transfer and transformation adopts the QUAL2E model. There are two types of data to be input into the model. One is meteorological data such as temperature, precipitation, relative humidity, solar radiation and wind speed. The second type is surface underlying data such as landuse and soil parameters.

At present, the SWAT model has been widely used domestic and abroad. Shrestha Sangam et al [9] quantified the individual and integrated impact of climate and landuse change in streamflows and nitrate nitrogen loadings in the Songkram River. Xu chang et al. [10] based on the SWAT model, the non-point source pollution model of the Zaoyang River Basin was constructed. Based on this, the total pollutant discharge control measures and load reduction schemes for water bodies in non-point source pollution control were proposed.
3.2 **HSPF model**

The HSPF (Hydrological Simulation Program - Fortran) model was developed by Robert Carl Johanson, the father of the HSPF model, in 1981, based on the SWM (Stanford Watershed Model) model. The HSPF model can not only simulate hydrological series for a long time, but also simulate surface area source pollution and point source pollution. It is an integrated water quality simulation software used widely for overseas applications [2].

The model mainly includes three modules: permeable module (PERLND), impervious module (IMPLND) and surface water module (RCHRES). Each module can be divided into several sub-modules according to functions, and each functional module is arranged according to a certain level to realize the migration and transformation of runoff and sediment, BOD, DO, nitrogen, phosphorus, pesticides and other pollutants and continuous simulation of load [11]. Like the SWAT model, HSPF also needs to input two types of data. The first category is continuous rainfall, evaporation, temperature, and sunshine. The second category is soil properties, vegetation cover, and topography. Compared with the SWAT model, the data quality required by HSPF is higher. Based on a powerful hydrological model and high-quality data, the HSPF model has high simulation accuracy and can simulate peak flow and low flow at different time scales (per minute, hourly or daily) [12].

The HSPF model is widely used abroad, but due to less domestic promotion, there are very few users. So Ra Ahn et al. [13] used the HSPF model in the Byulmi-cheon river basin in South Korea to assess the watershed scale effect of non-point source pollution loads caused by two different land use methods, tillage and no-till. Xing Kexia et al. [14] applied the HSPF model to simulate the non-point source pollution in the Dianchi Lake Basin. The results show that sediment is the primary pollutant of non-point source pollution. The main source of BOD is the point source, and the non-point source has a relatively small contribution. It is believed that the introduction of the HSPF model is conducive to solving the problem of quantification of non-point source pollution load in Dianchi Lake Basin.

3.3 **MIKE model**

Developed by the Danish Institute of Water Resources, the MIKE model is very powerful. It can not only simulate the water quality changes of water bodies such as river networks, lakes and sea areas, but also simulate the analysis of conventional water quality components. It can also analyze the changes of custom components in water bodies [4]. The MIKE model has many factors, so the calculation accuracy is very high, which limits its promotion and use to a certain extent. MIKE mode series software includes MIKE11, MIKE 21, MIKE FLOOD, MIKE URBAN, MIKEBAISIN, MIKE SHE, etc., which are widely used in practical engineering. Among them, MIKE11 and MIKE21 are widely used in the research of water quality, water flow and sediment transport.

MIKE 11 is a one-dimensional hydrodynamic model. The main modules are hydrodynamic (HD) modules, rainfall runoff (RR) modules, non-viscous sediment transport (ST) modules, convective diffusion (AD) modules, and water quality (ECO Lab) Modules, etc., where the hydrodynamic module (HD) is the most important module in MIKE11, it provides the basis for calculations for other modules. Xiong Hongbin et al. [15] carried out research on the MIKE11 model in Ying river, China, and improved water quality through measures such as water replenishment flow, hydration water quality, water replenishment location and water replenishment method. The results show that the method is feasible and provides a new method for river pollution control.

MIKE21 is a two-dimensional hydrodynamic model with the average vertical flow as the research object. The main module is also the most important hydrodynamic module. The model has powerful functions in two-dimensional numerical simulation and can be widely applied to simulation of rivers, lakes, estuaries and coastal currents and sediments [16]. Gong Xueliang et al. [17] and other applications applied MIKE21 to simulate the water quality in the upper lake of Nansi Lake, and analyzed the water quality change process in the upper lake of Nansi Lake under multiple scenarios, and obtained the water quality and water quality response relationship in the upper lake of Nansi Lake, which provided a theoretical basis for the improvement of water quality in Nansi Lake.
4. Development trend
At present, the Watershed integrated water quality models has been widely used in production and life to help people solve various types of water pollution problems, but there are still some problems that need to be improved. Firstly, the model uncertainty analysis stays at the level of individual research, and there is no universally applicable, systematic theory for the user's reference. If the theory is formed, the accuracy of the model application will be greatly improved. Secondly, the water environment pollution in different places is becoming more and more serious. The advantages of different models should be maximized. Therefore, the coupling between different models can be strengthened to better reflect the real water environment and carry out accurate water pollution control work!

5. Case Study—Taking the SWAT Model in Baihe River Basin as an Example

5.1 Research area
This paper selects the Baihe River Basin (40.4°-41.5°N, 115.4°-117.0°E) upstream of the Miyun Reservoir in Beijing as the study area. Considering many factors, the SWAT model was used to simulate the water quality changes in the basin from 1990 to 2010. Baihe river originated from Guyuan County, Hebei Province, with a total length of more than 280 km and a drainage area of over 9,000 km². It is one of the important reservoir rivers of Miyun Reservoir, therefore, the water quality of the Baihe River Basin directly affects the water quality of the Miyun Reservoir, and it is essential to control the water quality of the Baihe River Basin.

5.2 Model data source
The terrain data used in the SWAT model in this paper is ASTMTM2 DEM data at 30m resolution (https://earthexplorer.usgs.gov/); The soil data is the China Soil Dataset (v1.1) based on the World Soil Database (HWSD), and the land use data is the glc2000_lucc_1km_China.asc data product in the comprehensive land cover dataset in China, both of which are derived from the Cold Data Science and Technology Center of China(http://westdc.westgis.ac.cn/); The meteorological data is derived from the China Surface Climate Data Daily Value Dataset (V3.0) downloaded from the China Meteorological Data Network (http://data.cma.cn).

5.3 Establishing water quality model for Baihe River Basin
All data was processed and loaded to build the SWAT model of Baihe River Basin. The model running results and the runoff observed data from 1990 to 2010 are loaded in SWAP-CUP. The initial results of the simulated monthly scale runoff and observed are shown in Figure 1.

![Figure 1. Initial results of runoff monthly scale simulated and observed](image)

In the results, except for the individual monthly runoff simulation peaks that do not match the measured values, the peak trends of the simulated and observed runoff are basically the same. but the peak value of each month's simulated is much larger than the observed. At present, more than 10 parameters such as CN2 and GW_DELAY have been selected to verify the model. The results have been improved, but the parameters still need to be adjusted to provide a better basis for water quality simulation.
After the runoff simulation is completed, the simulation analysis of water quality such as sediment, nitrogen and phosphorus will be carried out, and the water quality changes in Baihe River Basin will be analyzed to provide services for better controlling the water quality of Miyun Reservoir.

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