Research and Prospect of Numerical Simulation of River Water Environment

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Abstract. Healthy water environment is the prerequisite for river resource utilization, social and economic development, new urbanization and healthy and happy river construction. Through the literature database retrieval statistics, summarizes the river water environment research to numerical simulation analysis, environmental quality improvement direction. The indicator system, evaluation method and significance of river ecosystem health assessment, and water ecological security assessment are introduced in detail. Finally, the types of river water environment numerical models are summarized, and the advantages and disadvantages of mainstream models and their application conditions and characteristics are compared and analyzed. In order to provide basic reference for river water environment numerical simulation machine watershed ecological environment protection and maintenance.

Keywords: river, water environment, numerical simulation.

1. Introduction

Rivers are the core resource for the development of a city’s civilization and an important foundation for the construction of happy rivers in the process of new urbanization. Changes in the quality of river water environment directly affect the health of its water ecosystem, the river landscape, and the ecological environment on both sides of the bank. With the advancement of new urbanization and the construction of a livable environment, pollutants discharged in the process of urban industry and agricultural production, land use changes, land ecological environment destruction, etc., these affect the water quality of the river, the distribution of water resources, and the aquatic biological habitat, and ultimately affect the quality of life of residents.

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2. Research status of river water environment

Searching the “River Numerical Simulation” and “River Water Environment” in the CNKI full-text database for statistical analysis, the literature on river water environment quality and numerical simulation is increasing, especially since 2007 the number of documents has been more than 100 articles per year (fig.1).

Statistical analysis was carried out by retrieving ‘river numerical simulation’ and ‘river water environment’ from CNKI full-text database. The literature on river water environment quality and numerical simulation was increasing, especially since 2007, the number of literatures was more than 100 per year (Fig.1). Numerical simulation of river water environment is widely used in water conservancy and hydropower engineering, geology, geophysics, environmental science and resource utilization, petroleum and natural gas industry, highway and water and land transportation. The main results come from well-known domestic universities such as China University of Geosciences (Beijing), Chang’an University, Hohai University, Chengdu University of Technology, Tianjin University, Ocean University of China, Tsinghua University, and other well-known universities in China, to evaluate the quality of river water environment and its health and well-being. As well as the evolution law of river water environment quality and ecological health assessment under different natural environmental characteristics.
Analyzing the frequency of keyword distribution in the literature on numerical simulation of river water environment (Fig.2). It’s found that the research focuses on numerical simulation of water environment and research on water environment quality, capacity and pollution mechanism. Numerical simulation, water environment and water environment capacity have the highest frequency. The numbers are 673, 167 and 103 respectively. Secondly, there are river water quality, watershed water environment, three-dimensional numerical simulation, Mountain Rivers, water environment pollution, model stability studies, and water flow characteristics. This shows that the research in the related fields of river water environment is based on the simulation side, water quantity and water quality change law and related mechanism principles, and continuous in-depth research on the applicability, application conditions and characteristics of the model itself. In this way, it can better simulate the temporal and spatial changes of water quality, water quantity, and water ecology of rivers with different characteristics, and the impact on the social economy and human settlement environment of the basin.

Figure 2. Frequency distribution of keywords in river water environment research

3. River water environment assessment research

3.1. River ecosystem health assessment

River ecosystem is an ecosystem composed of river basin water-land and socio-economic-natural environment. River ecosystem health is mainly concerned about the integrity of the ecosystem, and has been widely concerned by countries. The health of river ecosystem is mainly affected by the socio-economic development of the land under human activities, land use changes, river habitat, water quantity and quality, and changes in hydrological and meteorological conditions of the basin.

At present, the assessment of river ecosystem health mainly includes indicator biological method, comprehensive index method, mathematical model method and so on (Table 1). Among them, the indicator species method is to select fish, algae or benthic animals which are sensitive or tolerant to specific pollutants as indicator species to characterize the quality of river water ecological environment and pollution degree. In particular, macrobenthos generally have a wide range of activities, easy to capture and identify, relatively fixed activity sites, and relatively small interference with other organisms, and are widely used as indicative species [4, 5]. TBI (Trent Biotic Index) is a multi-metric biological index that evaluates the integrity and health of the ecosystem through a sensitive biological indicator system. IBI integrity index (Index of Biological) is widely used in the assessment of the impact of river water ecology and river basin non-point source pollution, urbanization, fishery, etc. on the ecological health of the river basin [6]. The mathematical model method is based on a large number of non-human-disturbed biological community and habitat background quality data under natural conditions, using river hydrology, water quality, aquatic organisms and other indicators to assess ecological health, combining habitat indicators with river
morphology and biological composition, and comprehensively assessing the health status of the river basin ecosystem [7, 8].

| Method                  | Principle                                                                 | Features                                                                 | Common methods                      |
|-------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------|-------------------------------------|
| Indicator biology       | The sensitivity and tolerance of aquatic organisms to water bodies        | Indicators are easily available, but the evaluation is not comprehensive | fish, algae, benthic animals         |
| Composite index method  | Compare control and survey, quantitatively analyze the integrity of aquatic organisms | It can be used to compare the health status of different river ecosystems, but requires a large amount of data and it is difficult to determine the comparison point | TBI Index, IBI Integrity Index, Biodiversity Index |
| Model simulation        | Based on numerical models, simulate and predict the health of aquatic ecosystems | Suitable for large-scale watersheds, but the model and its parameter selection require targeted research | RCE, ISC, RHP                       |

3.2. River water ecological security assessment

Scholars at home and abroad have applied grey clustering method, fuzzy comprehensive evaluation method, artificial neural network method, fuzzy matter-element analysis method and so on in the water ecological safety assessment work. Among them, the matter-element extension model method can better reflect the actual situation of the water body, and the improved entropy method can determine the corresponding index weight [9]. The river water ecological security assessment is based on the integrity of the river's physical, chemical and biological systems, and fully considers the impact of river waters and human activities on land areas as well as potential ecological risks. Water ecological security is mainly characterized from the aspects of pressure, filling, function and risk, including 9 elements such as land use in river basins, water resources, pollutant production and discharge, water ecological quality, habitat conditions, human activities, water environment quality, and ecological risks. An indicator system composed of 18 indicators evaluates the ecological safety of river water.

4. River water environment model

4.1. Classification of river water environment models

The water environment research institute involves large spatial scales, numerous pollutant components and complex environmental processes. It is only difficult to rely on experimental analysis or on-site monitoring. The establishment of mathematical models to achieve numerical simulation of the water environment has become a hot spot in this field. It is also the most economical to use mathematical tools and methods to solve water environment problems [10, 11]. Water environment model simulation prediction is an effective tool and indispensable basic work in water resources planning and management, water environment impact assessment, and water pollution comprehensive prevention and control, and it plays a very important role in water environment management. According to the spatial structure, calculation principle and simulation object of the river water environment model, it is divided into different types of numerical models [12]. According to the spatial structure, it can be divided into zero-dimensional, one-dimensional, two-dimensional and three-dimensional models. Among them, the simulation results of the 3D model are the most accurate, and the model has the widest application range, which can be used to solve the comprehensive problems of large-scale and complex rivers such as hydrodynamics, water quality, and water ecology. According to mathematical theory, it is divided into deterministic models based on combing equations, including stochastic models based on statistical analysis models, and planning models based on operations research.
4.2. Numerical model of river water environment

The research of numerical model of river water environment has gone through the stages of water quality research and hydrodynamic water quality model. Now point and non-point source pollution control and the scope of model application are more widespread. The earliest one-dimensional steady-state S-P model is only suitable for simple river water quality models, while the QUAL series models assume that materials in rivers migrate and diffuse through translation and dispersion, and can affect dissolved oxygen, organic phosphorus, ammonia nitrogen, water temperature, and degradable substances in the water. Simulate and analyze any combination of 13 water quality components. The WASP model can realize one-dimensional or multi-dimensional water quality simulation, analyze chemical oxygen demand, ammonia nitrogen, organic nitrogen and other water quality indicators, and simulate the migration and accumulation process of toxic substances and heavy metals in the water [13].

The MIKE series model is a watershed, hydrology, and water quantity and water quality model developed by the Danish Hydropower Research Institute. It is simple to run but has a high cost of use. Among them, the hydrodynamic model MIKE11 is based on the one-dimensional Saint-Venant equation, dynamically simulating changes in river water level and flow; for rivers, lakes, reservoirs, estuaries and coastal water environments, it can be realized by MIKE21 and MIKE31 models [14]. Delft 3D is currently the most advanced and widely used three-dimensional hydrodynamic-water quality model system. It supports surface format and adopts Delft calculation format to fully realize the conservation of mass, momentum, and energy. It can quickly, stably and accurately calculate the Flow of large-scale waters. Hydrodynamics, Waves, sediment, Waq, and Eco. The modules are dynamically coupled online, and can be seamlessly connected with ArcGIS, supporting multiple formats of graphics, images, and simulation, plug and play, and fully open (OMS) [15].

| Model | Applicable object | Application characteristics |
|-------|-------------------|-----------------------------|
| S-P   | rivers            | One-dimensional steady state. Simple waters. |
| QUAL  | rivers            | One-dimensional. Impact of multiple pollution loads under different conditions, and uncertainty analysis. |
| WASP  | rivers, estuaries, reservoirs, lakes | One-dimensional, two-dimensional, three-dimensional. Fast calculation speed, independent sub-module, can be used in combination with other models, able to simulate a variety of pollutants. |
| MIKE  | rivers, reservoirs, lakes, near coasts | One-dimensional dynamic, two-dimensional, three-dimensional. Suitable for complex water environment. |
| QUASAR| rivers            | One-dimensional. Suitable for river dissolved oxygen analysis. |
| EFDC  | rivers, lakes, near coasts | One-dimensional dynamic, two-dimensional, three-dimensional. Suitable for simultaneous calculation of point source and area source simulation. |
| PDM   | rivers            | Uncertain water quality model based on big data. |
| Delft 3D | rivers, lakes, near coasts | Two-dimensional, three-dimensional. Suitable for water flow, waves, ecology, sediment and riverbed landforms, etc., support surface format. |

5. Conclusion

(1) The research of river water environment focuses on numerical simulation, model development and optimization, water environment quality maintenance, environmental capacity estimation, and river basin water environment pollution mechanism research.

(2) River ecosystem health assessment and water ecological security assessment are both detailed assessments of the water environment of the river, aquatic organisms and their habitats, the natural environment of the water and land areas, and the social and cultural environment, and comprehensively assess the integrity and stability of the river ecosystem Sex and safety.
(3) There are various types of river water environment numerical models. For the development of numerical simulations, actual case applications, GIS and other mapping and image processing software applications, it can improve the accuracy and universality of the calculation results of the water environment numerical model.

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