Design and Application of Automatic Monitoring System of Water Environment Using GIS

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Abstract: in order to achieve more effective management and monitoring of water environment, an automatic monitoring system is designed for the water environment of Heihe River Basin in Zhangye through GIS (geographic information system). The EFDC (environmental fluid dynamics code) model is used to establish the automatic monitoring model of water environment, and the annual average data of permanganate index of Yingluoxia, Gaoya hydrological station, and Liubaqiao in Heihe River Basin from 2015 to 2019 are used to fit and verify the water quality model. The trend suggests that the simulated data of the three observation points are close to the measured data. The fitting degree reveals that the R index of fitting curve of Liubaqiao is 0.793, while that of Yingluoxia, and Gaoya hydrological station is higher than 0.8, with good fitting degree. The average relative error between the simulated value and the measured value of permanganate index (mg/L) is small, the change trend is basically consistent, and the prediction error is small. The model is successfully established and applied to the automatic monitoring and early warning system of total phosphorus index.

1 Introduction

The development of the automatic water environment monitoring system is faced with numerous problems, such as ineffective information construction, backward base station and communication devices, insufficient infrastructure upgrading, etc. In order to cope with these problems, a stable and reliable system, and an extensible real-time data release platform [1] are required to provide early warning information regarding the flood control and draught relief, and increase the time and space for the countermeasures. An automatic monitoring and management system, which can more effectively manage the river and pollution sources in the whole drainage basin, should be built to realize the real-time, intuitive and dynamic management and expression of automatic monitoring data, thus providing a powerful data support and decision-making basis for the environment management work, such as the analysis, research, and judgment of water environmental conditions in the river basin [2]. The automatic water environment monitoring and management system of drainage basis is a real-time visualization platform, from which the administrative department can not only acquire the hydrological and spatial information of the river basin but also can timely obtain the water quality information in the visual space [3,4].

This system is of service-oriented architecture. Based on the demand for the water environmental management,

the automatic monitoring system was designed for the water environment in Heihe River Basin of Zhengye City via the geographic information system (GIS), the environmental fluid dynamics code (EFDC) model was used to establish an automatic water environment monitoring model, and the overall framework and logical structure of the automatic water environment monitoring and management system in the river basin were designed, followed by the system functional design, early warning workflow design of water environment, analysis of database system composition, and the interactive relationship between different system parts, etc., in an effort to provide a data support for the water quality analysis, hydrodynamic simulation of water quality, early warning and disposal of emergencies in the water body.

2 Method

2.1 Technical principles of GIS system platform

The GIS system is an electronic information technology system that acquires, saves, manages, retrieves, analyzes, displays, and describes the geological information data related to the spaces on the whole or partial earth surface [5]. Through the real-time sampling of various satellite sensors, and the data transmission in the distributed network, the water environment-related data are acquired into the system management center, and the real-time

monitoring points of the water body are displayed on the GIS platform. A preliminary data analysis of the acquired mass water environment data can be implemented to realize the automatic and scientific information management for the real-time monitoring of water environment data, provide early warnings, and facilitate the prevention & control of the abnormalities [6].

2.2 Overall framework of automatic water environment monitoring system

The automatic water environment monitoring system is a comprehensive management system, which is used to analyze and manage the fundamental data such as hydrological and geological conditions, and pollution status in the river basin [7]. Besides the common functions that the GIS system has, such as inquiry, browsing, statistics, analysis, plotting, and output, this system should also include water quality analysis of water environment, hydrodynamic simulation of water quality, early warning & disposal analysis of emergencies, and recording of emergency handling process, etc.

The data layer takes charge of constructing unified environmental spatial data standards and related technical specifications, integrating all kinds of environmental geographic space information and water environment-themed information, and building a unified and standard geographic space information resource library for the water environment in the river basin. The model layer will

establish the scientific and reasonable major pollution source and sectional water quality co-monitoring model, water quality model, and hydrodynamic model, predicts and evaluates the water quality via various mathematical models, and provides a decision-making basis for the automatic water environment monitoring, and data analysis and processing. Based on the data layer and model layer, the application layer takes full advantages of the hydrological, geographical, and water environment data at the data layer, and the mathematical models at the model layer, in order to manage and serve the water environment in the river basin at a higher level.

2.3 System database design

In this study, the database of the automatic water environment monitoring system was divided into the six main information sheets: area, area node, display node, sensor, display point information, and node information. The attribute data of the automatic river basin monitoring and management system included pH, water temperature, dissolved oxygen, permanganate index, total phosphorus, contents of trace metal elements, etc. In the logical layering process of different data objects, different methods will be used to realize the classified management, and the user needs to make choices according to different needs. The relational graph of the data sheets in the automatic water environment monitoring system is presented as follow:

Figure 1. Relational Structure of System Data Sheets

2.4 Water environment modeling

As a 3D mathematical model for surface water quality developed by Virginia Institute of Marine Science at the College of William and Mary, the EFDC model is applicable to over 100 water bodies, including river, lake, reservoir, wetland, estuary, and coastal area, and it can support the environmental assessment and management, and satisfy the related legal requirements. The EFDC model, which is the latest hydrodynamic model, has developed into a technically vindicable hydrodynamic model most widely used in the world [8], where the physical characteristics of the water body are expressed with stretching or sigma vertical coordinates, Descartes or curve, and orthogonal horizontal coordinates. Besides the average motion equation of turbulent flow on the 3D vertical still water free surface for the density-variable fluid, this model also solves the turbulent kinetic energy, turbulence scale, salinity, and temperature dynamic coupling transport equation. The EFDC model allows to dry and wet the areas at superficial layer through the conservation plan of mass. The physical principles and calculation scheme of the EFDC model are equivalent to the widely used Blumberg-Mellor model in many aspects. The EFDC model can simulate the changes of water and water quality components in the complex geometric and dynamic water body (e.g. river, layered estuary, lake, and coastal area), and analyze the motion equation for the basic variable of the turbulence—vertical hydrostatic force—in the 3D coordinate system. The coordinate system is orthogonal with curvilinear figure in the horizontal plane, and it is stretched to follow the bottom terrain and the free surface displacement in the vertical direction, with its vector aligned at the gravity [9]. The Being able to simulate the wetting and drying cycles, the EFDC model includes a near-field mixing zone model, which is completely coupled with the distant-field migration of the variables—salinity, temperature, sediments, pollutants, and eutrophication. Besides, it also contains a hydraulic structure, which receives the radiation stress field from the wave refraction-diffraction model to simulate the sediment transport process of the river and water body [10].

The hydrodynamic model can reflect the different hydrological characteristics of different water bodies, where the variables output by the hydrodynamic module can be directly coupled with the water quality module, pollutant migration module, etc. as the driving conditions for the matter transport. The basic equation of the hydrodynamic model is as below:

$$W \frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = Q \quad (1)$$

$$\frac{\partial q}{\partial t} + \frac{\partial uq}{\partial x} + S \frac{\partial z}{\partial x} + \frac{n_{1d}^2 q^2}{S r^{4/3}} = 0 \quad (2)$$

where x is length of river channel (m); t is time (s); S is cross-sectional area of river channel (m²); W is river width (m); h is depth of water body (m); z is height of water body (m); q is total flow quantity in the river

channel (m³/s); Q is lateral flow quantity in the river channel (m³/s); u is average flow velocity on the cross section (m/s); r is radius of river channel (m); n_{1d} is channel roughness.

The model is an enhancement of the hydrodynamic method, including vegetation resistance, wetting & drying, hydraulic structure, interaction at wave flow boundary layer, and wave induced current, so it can realize the precise modeling of the water body system and nearshore waves, and induce the transport effect between wave flow and sediment. All elements are integrated through the calculation to create an efficient and seamless tool for the sake of hydrodynamic, sediment transport, and water quality modeling.

2.5 Model verification

The relatively complete water environment data and the corresponding pollutant discharge data in typical recent years were selected, and the relative error between simulated value and measured value was calculated to verify the effectiveness of the simulation result. The reasonableness research of the model simulation was perfected through the water level verification, verification of index parameters for the monitoring section, etc. The error statistical approach was firstly selected to generate each statistical report in the model verification.

$$A = |E - T| \quad (3)$$

$$R = |E - T| * 100\% \quad (4)$$

$$\theta = \frac{(E_1 - T) + (E_2 - T) + \dots + (E_n - T)}{n} = \sum \frac{A_i}{n} \quad (5)$$

$$\theta' = \frac{|E_1 - T| + |E_2 - T| + \dots + |E_n - T|}{n} = \sum \frac{|A_i|}{n} \quad (6)$$

$$\Delta = \sqrt{\frac{(E_1 - T)^2 + (E_2 - T)^2 + \dots + (E_n - T)^2}{n}} = \sqrt{\sum \frac{A_i^2}{n}} \quad (7)$$

where A is absolute error; R is relative error; θ is average error; θ' is absolute average error; Δ is root mean square error; E is simulated value; T is measured value; A_i is the difference value between simulated value and measured value.

3 Results and Discussion

3.1 Model verification results

The plotting and statistical analysis were implemented after the data input, and the statistical values of model-calculated data and measured data were viewed and calculated through the model. The model data could be compared in the model using the data chains like time sequence and vertical section model. The calculated data-measured data comparison chart could be drawn by

loading the simulated data and reading the measured data, the correlation graph between the model data and the existing data could be plotted, the fitting degree was displayed, and the simulation was confirmed by combining the error analysis. The model fitting was conducted using the annual average data index—permanganate index (mg/L)—at sectional monitoring points of Yingluo Strait, Gaoya Hydrological Station, and Liuba Bridge in Heihe River Basin from 2015 to 2019, and the results are displayed in the following figure:

Figure 2. Fitted Index Curve at Sectional Monitoring Point of Yingluo Strait

Figure 3. Fitted Index Curve at Sectional Monitoring Point of Gaoya Hydrological Station

Figure 4. Fitted Index Curve at Sectional Monitoring Point of Liuba Bridge

The data fitting curve of annual average value of

permanganate index (mg/L) at three sectional monitoring points in Heihe River Basin of Zhangye City from 2015 to 2019 was presented in the above figure. From the trend, the simulated data of three monitoring points were all approximate to the measured data; the R index (degree of fitting) of Liuba Bridge was 0.793, and those of sectional monitoring points in Yingluo Strait and Gaoya Hydrological Station were both higher than 0.8, indicating good degree of fitting. The average relative error between simulated value and measured value of annual average permanganate index (mg/L) was small, their variation trends were basically consistent, and the visually inspected error was not large, so the water environment monitoring model was successfully established.

3.2 Application of water environment monitoring system

The water environment-related data were selected in the water environment monitoring system, including pH, water temperature, dissolved oxygen, permanganate index, total phosphorous, and contents of trace metal elements. The water environment status was acquired by calculating the comprehensive index. After the comprehensive water environmental assessment model program was loaded and invoked, the monitoring data could be inquired by taking the information like time and monitoring point as the conditions, Java language was used for the data retrieval and invocation in the back-end database, the inquired information data were then fed back to the evaluation module, the system would automatically input the monitoring information into the mathematical evaluation model, and the analysis results would be returned to the display interface. The following figure displays the monitoring and early warning model of the total phosphorous index of three sectional monitoring points in Yanluo Strait, Gaoya Hydrological Station, and Liuba Bridge.

Figure 5. Monitoring Model of Total Phosphorus Index at Three Sectional Monitoring Points

4 Conclusion

The automatic monitoring system was designed for the water body in Heihe River Basin of Zhangye City via the GIS system, an automatic water environment monitoring

model was established using the environmental fluid dynamics code (EFDC) model, the water quality model was verified through the fitting process with the annual average permanganate index at three sectional monitoring points—Yingluo Strait, Gaoya Hydrological Station, and Liuba Qiao in Heihe River Basin—from 2015 to 2019, and the results showed that the simulated data were approximate to the measured data at all of the three monitoring points. Hence, this system provides a data support for the water quality analysis, early warning & disposal of emergencies, etc.

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About the author

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References

1. Guo P F, Wen Z Y, Zhou Y et al. Design of remote water quality monitoring system based on Raspberry Pi. *Journal of Chongqing University of Technology (Natural Science)*, 2018, 32 (04): 186-192.
2. Zhao Y H, Guo X W, Cao X et al. Automatic Water Pollution Monitoring GIS System Design of Henan Province. *Journal of Henan University: Natural Science*, 2019, 49 (5): 559-566.
3. Wang J L. Employment of PLC ladder diagram in automatic monitoring system for water environment. *City Stories*, 2018, 000 (002): 706-706.
4. Du J, Song P C. Applied research on automatic water quality monitoring system for surface water in China. *Environmental Science and Management*, 2020, v.45; No. 267 (02): 119-123.
5. Yue J H, Wang T, Ren Y Q et al. WebGIS-based geographical information system development and application. *Microcomputer Applications*, 2018, 034 (012): 40-42.
6. Rao M. WebGIS-based geographical information system development and application analysis. *China CIO News*, 2019, 000 (005): 48.
7. Wang X L. Discussion about application of GIS system in water supply line management. *China CIO News*, 2019, 301 (01): 85.
8. Zhang J P, Wu Y, Tian Z B et al. Water temperature simulation of Lake Erhai based on EFDC model. *Journal of Environmental Engineering Technology*, 2020, 010 (003): 368-376.
9. Wang D, Zhang S L, Guo D Y. Simulation of dam-break flood evolution of Qinghe Reservoir based on EFDC model. *China Rural Water and Hydropower*, 2020 (7): 26-31.
10. Yang K, Xu H Q, Fan H B et al. EFDC model-based water quality simulation and deduction system of