Design of Intelligent Environmental Management and Decision-Making Platform for Small- and Medium-Sized Hydropower-Intensive Watersheds

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Abstract. Watershed management includes the management of water resources, water environment, and water ecology. The use of intelligent management methods has become a new development trend. Facing the current situation of river basin management in China and the latest management requirements, the positioning of intellectualization in the top-level design of watershed management is clarified. Based on the vulnerability and complexity of ecosystem in small- and medium-sized hydropower-intensive watersheds, the overall framework of intelligent management and decision-making platform is designed, which covers water resource allocation, pollution source analysis, risk early warning, ecological monitoring, industrial access, ecological compensation, public participation, and other functional modules and forms a government–enterprise–society multi-management system.

1 Introduction

Water resource is the basic condition for human survival and development and is an irreplaceable basic resource. As the birthplace of rivers, small- and medium-sized watersheds are mostly located in mountainous areas with high altitude and complex topography. Basins have generally poor storage capacity, short confluence time, and high ecosystem vulnerability, and they are more vulnerable to natural disasters compared with large rivers. In human development and utilization, due to the small water energy, the installed capacity of hydropower stations in small- and medium-sized watersheds is not large, and most of them exist in cascade hydropower stations, which pose a great threat to the river ecosystem. In China, over 1,500 small- and medium-sized watersheds have a drainage area of over 1,000 km². Cities on the verge of small- and medium-sized watersheds account for 85% of the national cities and contribute 70% to the national industrial gross product^[1,2]. Therefore, strengthening the management of water resources in small- and medium-sized watersheds is the key to realize the sustainable utilization of water resources in small- and medium-sized basins and to ensure the healthy development of the national economy.

Given the complex, multi-scale, and multi-objective river basin ecological environment, decision support system, as a high-performance simulation and visualization tool, plays an irreplaceable role in helping river basin managers determine management objectives, design management plans, and comprehensively evaluate river basin conditions. To cope with the increasingly complex watershed management issues, countries are actively developing nationally appropriate decision

support systems, such as AQUA-Tool^[3], MIKEBASIN^[4], RIBASIM^[5], and WEAP^[6], which are mature applications, bringing huge social economic benefits. China began the research and development of such systems in the late 1990s. Despite achievements, limitations still exist, and the intelligent integrated decision support system based on multi-objective model remains in the trial stage. Therefore, under the strictest water resource and water environment policy requirements in the “Action Plan for Prevention and Control of Water Pollution,” an intelligent management and decision-making platform for river basin must be established with the help of electronic information technology, such as Internet+^[7], Internet of things^[8], big data^[9], cloud computing^[10], and mobile communication.

At present, China face the following problems in watershed management informatization: First, the data source is single. The environmental data in relevant research and application are mainly the environmental quality monitoring data provided by the government, which are insufficient to serve the intelligent management platform. More data sources must be integrated, and the automatic creation of computer data must be explored. Second, platform decision-making functions are insufficient. The research on decision-making models and information system construction are independent of each other and have not been integrated, which leads to the application of watershed management system staying in the information display level, lacking comprehensive decision-making function, and the platform is still in the information stage rather than the intelligent stage. Third, the operability of the system must be improved. The current water management system with decision-making function requires complex algorithm support, so it mostly

exists in the form of stand-alone software, which leads to its disadvantage in information sharing, interaction, and other aspects. The web version of water management decision-making system developed based on the Internet has not been studied.

Therefore, this paper takes small- and medium-sized hydropower-intensive watershed as the research object from the perspective of the whole basin to solve above problems. Guided by improving the participation mechanism of diversified subjects, this paper establishes a government–enterprise–public tripartite cooperative network system. In terms of water resources, water quality, water ecology, and comprehensive management, and with the existing research results, intelligent decision-making models are embedded in different subsystems to provide necessary theoretical support and technical reference for local and international research of related systems.

2 Design of system overall architecture

The basin water environment management system adopts browser and server structure. Facing water resource management and decision-making, it contains the water resource allocation subsystem. Facing water environment management and decision-making, it contains pollution source analysis and disturbance source dynamic supervision subsystem, especially natural disturbance source risk early warning system by considering the high risk and complexity of natural disasters in small- and medium-sized watersheds. Facing water ecological management and decision-making, it contains biodiversity supervision and ecological flow supervision subsystem by fully considering the stress of cascade hydropower station construction on watershed. Facing the comprehensive management decision-making, it contains the subsystem of industry access, ecological compensation, public supervision, and performance appraisal. According to the functional framework of business layer, the appropriate databases are selected. The overall frame design of the system is shown in figure. 1.

Figure. 1. Design of system overall architecture

The service objects of watershed intelligent management and decision-making platform include government, enterprises, and the public, but the tasks and functions of different roles in the system are different. Thus, different users should be classified into different levels and use rights. For example, super administrator users can modify and update all information in the system and take charge of system maintenance. Public users only have the right to query information. Enterprise users can continuously generate new data in accordance with the functions provided by the system. Government users not only can generate data but can also obtain information from enterprises and the public for scientific decision-making.

3 Design of intelligent environmental management and decision-making system for small- and medium-sized hydropower-intensive watersheds

3.1 Establishment of database

According to the overall structure design of the system, the data sources include remote sensing data, ground monitoring data, statistical data, and scientific research data. The data types include text, pictures, video, audio, raster data, and vector data. The data layer covers seven

sub-databases: user information, basin basic information and socio-economic information, water resource information, water environment quality information, disturbance source information, water ecology information, and work information.

3.2 Design of system function module

3.2.1 Module of water resource management and decision-making

Referring to MIKEBASIN of Denmark; WMS, Aquarius, and Riverware of the United States; Waterware of Austria; ICMS and IQQM of Australia; and other water resource management software^[11], water resource allocation model is embedded in the subsystem. The subsystem can calculate and provide the most suitable scheme automatically for water resource supply and demand balance and intelligently solve the contradiction of water resources among regions.

3.2.2 Module of water environment management and decision-making

(1) Subsystem of water quality online monitoring and pollution source analysis

The monitoring section is scientifically arranged in the basin. The routine and special monitoring indicators are selected. The water quality monitoring station is established to transmit water quality data in all-weather, all-year-round, and fully automated conditions. Based on the calculation of the subsystem, the quantitative and qualitative results of water quality comprehensive evaluation are obtained, whether the water quality meets the standard is judged, and the over-standard factors are indicated. Moreover, the principal component analysis module is embedded in the subsystem. Through the calculation of large data, the main pollution sources of different river sections at different times are analyzed to provide decision for the government to scientifically control water pollution.

(2) Subsystem of disturbance source dynamic supervision

① Natural disturbance source

The small- and medium-sized watersheds are located in areas with complex geological structure and are prone to natural disasters, such as landslides and debris flows, which pose a threat to river ecosystems and the human society. Based on remote sensing monitoring data and hydrological, meteorological, and geological survey data, an algorithm is designed to identify risk sources and automatically classify risk levels. Moreover, the natural disaster risk early warning system is developed by using risk assessment model. Through information monitoring and forecasting, the scientificity and timeliness of decision-making can be guaranteed, and the losses caused by geological disasters can be reduced.

② Anthropogenic disturbance source

Industrial, agricultural, and domestic pollution are the three major social factors that pose a threat to water bodies.

For industrial pollution sources, an intelligent sewage control system can be installed at the sewage outlet of the enterprise to monitor the water quality and discharge total in real time for the following reasons: to ensure that the industrial wastewater meets the requirements of accepting water quality and the discharge total amount meets the permit of sewage discharge, to prevent enterprises from overdischarge through video surveillance. A water pollution diffusion simulation system based on pollutant diffusion and hydrodynamic models is designed and developed. Once a sudden pollution accident occurs, the system can lock in the source of pollution for the first time, ensure “who pollutes, who governs,” visualize temporal and spatial dynamics of water quality, and divide priorities according to the level of risk in time.

For agricultural pollution sources, the agricultural non-point source automatic identification and extraction module can be developed based on the principle of spectral reflectance difference of ground objects. By constructing the agricultural sewage discharge accounting model, the system can calculate the production and inflow of agricultural pollutants according to topography, precipitation, farmland area, and other parameters and account for the contribution of agriculture to water pollution. By comparing the contribution value of different pollution sources, the main pollution sources of different river sections are identified to realize gridded and refined management of the river basin.

For domestic pollution sources, the water quality can be judged to determine whether it meets the standards through automatic online monitoring of sewage at outlets of urban sewage treatment plants and township sewage treatment facilities.

3.2.3 Module of water ecological management and decision-making

(1) Subsystem of biodiversity assessment

For different watersheds, different aquatic species databases are established and improved. The subsystem uses four typical aquatic organisms, such as zooplankton, phytoplankton, benthic animals, and fish as indicator species; obtains species richness data through periodic sampling and investigation; and matches data with species databases. Reasonable indicators (such as the Shannon–Wiener index) are selected to evaluate the current status and change trend of the biodiversity of aquatic ecosystems in the basin, and the protection levels of species are constantly updated.

(2) Subsystem of cascade power station supervision

For hydropower-intensive basin ecosystem, flow reduced river reaches and dehydration river reaches caused by the construction of hydropower stations, especially diversion hydropower stations, will have a serious impact on the living environment of aquatic organisms, such as fish. Therefore, the ecological flow of small hydropower must be strictly guaranteed. First, based on the hydrology method, hydraulics method, habitat method, and other models, considering the installed capacity of hydropower stations and the spatial relationship between hydropower stations and important

ecological function areas, the calculation model of small hydropower's ecological flow is designed and developed. The fluctuation threshold of ecological flow is set through expert evaluation according to the actual situation of the basin. Second, through the establishment of cascade power plant monitoring system, the online monitoring of ecological flow is realized by combining flow meter monitoring with video monitoring, which ensures that the monitoring value is higher than the minimum ecological water demand.

3.2.4 Module of comprehensive management and decision-making

(1) Subsystem of comprehensive assessment of water health and decision-making of industrial access

The comprehensive assessment of water health takes the whole basin as the research object; builds a comprehensive index system of water resources, water environment, and water ecology; and forms a comprehensive evaluation model of water health based on multi-objective decision-making. According to the functional zoning of water body, the water environmental capacity is calculated, and the pollution capacity and intensity of different regions are calculated by coupling the health status of water bodies. The subsystem can implement the industry access and elimination on "one map" by closely connecting with the results of the demarcation of the regional "ecological red line."

(2) Subsystem of ecological compensation

As a policy tool to regulate the interests of stakeholders, ecological compensation has become mature in theoretical research. Compared with other compensation methods, capital compensation is the most direct, convenient, and widely used compensation method. With the continuous popularization of electronic money transactions, it has powerful operability to carry out ecological compensation relying on the Internet + information platform.

① Government compensation model

The compensation subject for current and future watershed ecological compensation remains dominated by the government due to the externality of environmental resources. In the subsystem of ecological compensation, government financial fund transfer channels, including vertical transfer between the lower and upper levels of government and horizontal transfer between governments at the same level, can be set up. At present, China has fully implemented the river chief system to determine the main subject of river basin protection responsibility, which solves the problem of horizontal ecological compensation in the river basin and is conducive to the informatization of ecological compensation. Moreover, a fund supervision system must be established to guarantee the exclusive use of compensation funds.

② Market compensation model

A clear property right system is a prerequisite for market transactions. Through much research and practice, the water and emission rights trading in China have reached a mature stage. Based on the principle of beneficiary payment, the natural resource property rights

trading channel is set in the subsystem of ecological compensation. Through scientific pricing, the transaction between upstream and downstream watershed can be freely carried out. Large data analysis of transaction information can be carried out through the backstage of the system to provide an empirical reference for water resource trading.

③ Social compensation model

Taking the river chief as the main leader and the river chief office as the responsible institution, the river basin ecological protection fund should be set up. The Internet public welfare channel should be opened in the ecological compensation subsystem to raise donations from individuals, enterprises, public welfare organizations, and social groups. It can enrich the financing channels of protection funds, enhance the participation of social forces in ecological compensation, and achieve a government-social co-governance system.

(3) Subsystem of public participation

With the deepening of the concept of ecological civilization development, citizens' demand for the right to know environmental information and the right to participate in environmental management is increasing. In addition to publishing basic information and routine water quality monitoring data to citizens, the information platforms should display information, such as ecological monitoring data, pollution source and sewage discharge data, environmental risk data, water health data, environmental protection supervision data, and law enforcement data, and open channels for public supervision and reporting. Leveraging the advantages of mobile supervision and mobile law enforcement, we will provide full play to the power of the "supervisors" of the citizens and achieve social co-governance.

(4) Subsystem of the river chief's work

This subsystem serves the river chief and other government staffs. Through online and offline linkages, it evaluates the river chief's achievements based on river patrol records, water quality information, and public feedback processing. This subsystem aims to implement the responsibility of the river chief.

4 Result and discussion

In this paper, a water management system prototype is constructed for small- and medium-sized hydropower-intensive watersheds to protect watershed ecosystem and provide intelligent service decision. The prototype realizes integrated management system of water resources, water environment, and water ecology. Moreover, it establishes a pluralistic management model among the government, enterprise, and society. The system has certain reference to the construction of other environmental management and decision-making systems.

However, this paper only puts forward some suggestions for the intelligent management scheme of small- and medium-sized hydropower-intensive watersheds from the top-level design. Given the uncertainty of the decision-making model, the limitation of data source, and the constraint of the management system, the materialization of this system needs further

study.

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