

ORIGINAL RESEARCH ARTICLE

Present situation analysis and key technology research prospect of water resources protection in Yangtze River Basin

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ABSTRACT

On the basis of analyzing the present situation and main problems of water resources protection and management in river basins, according to the main responsibilities of river basin organizations in water resources protection and management, and based on the principle of unified protection of water quantity, water quality and water ecology, the content framework of water resources protection in river basins is proposed. According to the demand of water resources protection for science and technology, ten key technologies and main research contents of water resources protection in the Yangtze River Basin are put forward to provide support for the implementation of the idea of “maintaining healthy Yangtze River and building harmony between people and water”.

Keywords: Yangtze River Basin; Water Resources Protection; Framework System; Key Technology

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1. Introduction

Water is the source of life, the key of production and the foundation of ecology. The Yangtze River Basin is ranked first among the seven major river basins in China for its relatively abundant water resources. There are 5,276 tributaries with a catchment area greater than 100 km² and 142 lakes with a water surface area greater than 10 km²^[1]. The annual average surface water resources in the Yangtze River Basin are 9.855×10^{11} m³, and the total water resources are 9.955×10^{11} m³. In 2016, the total amount of surface water resources was 1.1796×10^{12} m³, equivalent to annual runoff depth of 661.7 mm, and the natural endowment of water resources was good. In 2016, the total water supply of the whole basin was 2.039×10^{11} m³, of which the surface water supply was 1.958×10^{11} m³, accounting for 96.0% of the total water supply. More than 44,000 reservoirs have been built in the whole basin, and the utilization rate of water resources is 18.7%, and it shoulders the heavy responsibility of water source diversion in China's South-to-North Water Diversion Project. With the social and economic development inside and outside the Yangtze River Basin, the importance of water resources security is self-evident. At the same time, due to the overexploitation of water resources, the water quality has deteriorated year by year, and the water ecosystem has been destroyed, which has seriously threatened the water resources security in the basin. In January 2016, General Secretary Xi demanded that “at present and for a long time to come, the restoration of the ecological environment of the Yangtze River should be placed in an overwhelming position, and great protection should be paid attention to, and no great development

should be carried out". Therefore, the protection of water resources in the Yangtze River Basin has become a top priority. Throughout the experience of water resources protection in developed countries, water resources protection should be a multi-objective comprehensive protection of water quantity, water quality and water ecology. Water quantity is the foundation, water quality is the key, and water ecology is the focus, so we can't neglect one of them. In the process of water resources protection and management, relying on scientific and technological progress, using advanced and mature key technologies and implementing scientific management of water resources protection are the only way to realize "maintaining healthy Yangtze River and building harmony between people and water".

2. Overview of water resources protection in river basin

Water resources protection in the Yangtze River Basin started in the late 1970s and has been implemented for more than 40 years. At present, the protection of water resources in the Yangtze River Basin presents the basic pattern of "one center, two emphases, three links, four constructions", that is, "taking the management of water functional areas as the center, sewage outlets into rivers and drinking water sources as the key objects, planning, examination and approval and supervision as the key links, and focusing on the construction of talent team, monitoring station network, information platform and law enforcement capacity". Specifically, the general situation of water resources protection in the Yangtze River Basin is as follows.

2.1 The legal system of river basin water resources protection is gradually constructed

According to the *Water Law of the People's Republic of China*, *Law of the People's Republic of China on Water Pollution Prevention and Control*, *Administrative License Law of the People's Republic of China*, *Regulations of the People's Republic of China on River Management*, *Measures for the Supervision and Administration of Water Function Zones*, *Measures for the Supervision and*

Administration of Sewage Outlets Entering Rivers and other superior laws, the Yangtze River Basin has successively completed the drafting of normative documents such as the *Detailed Rules for the Implementation of the Supervision and Management of the Sewage Outlet into the River by the Yangtze River Water Resources Commission*, *Measures for the Setting and Acceptance of the Sewage Outlet into the River by the Yangtze River Water Resources Commission*, and the *Plan for the Functional Classification Management of the Yangtze River Basin and the Southwest Rivers*, among which the first two items have been approved and implemented by the Yangtze River Water Resources Commission, and the other one is under review. And the legislative demonstration of the *Yangtze River Protection Law* is also actively promoted.

2.2 The planning system of water resources protection in the basin has basically taken shape

Since 1986, the Yangtze River Basin has completed the *Water Protection Plan for the Main stream of the Yangtze River*, which was included in the *Brief Report on the Comprehensive Utilization Plan of the Yangtze River Basin (1990)* approved by the State Council. In recent years, nearly 20 water resources protection planning tasks represented by the revision of comprehensive planning of the Yangtze River Basin and comprehensive planning of water resources of the Yangtze River (slice) have been implemented in the basin^[3]. Especially, through the compilation of the *Three Gorges Water Resources Protection Plan*, the technical system of water resources protection engineering was explored and formed, which directly promoted the promulgation of *China's Regulations for the Compilation of Water Resources Protection Plan*. Basically, a planning engineering measure system of water resources protection, which focuses on the layout and regulation of sewage outlets into rivers, water source protection, water ecological protection and restoration, non-point source control and endogenous pollution control; and a non-engineering technical system which concentrates on laws and regulations, institutional

mechanism construction, monitoring capacity construction and scientific research capacity construction are formed^[4]. In 2016, the Ministry of Water Resources issued the *Layout Plan of Sewage Outlets and Emergency Water Sources at the Water Intake along the Yangtze River Economic Belt*, which defined the prohibited areas, general restricted areas and strictly restricted areas for sewage outlets entering the river.

2.3 Information investigation of sewage outfall and water source into the river is carried out in an orderly manner

According to the requirements of the Ministry of Water Resources *Measures for the Supervision and Administration of Sewage Outlets into Rivers* for the investigation and registration of sewage outlets into rivers, in 2006, the Yangtze River Basin completed the first investigation and registration of sewage outlets into rivers, with a total of more than 9,000 sewage outlets into rivers^[5]. According to the national list of important drinking water sources issued by the Ministry of Water Resources, since 2011, the basic information of 56 important drinking water sources in the Yangtze River Basin has been investigated, and the scope of water sources, water intake settings, water supply conditions, water quality conditions, water ecological conditions and water source pipes have been mastered. In 2017, relying on the key work of the Yangtze River Economic Belt, the special verification work of sewage outlets into the river was carried out, and a total of 8,051 sewage outlets above designated size were verified.

2.4 The approval and management of sewage outfall into the river are carried out step by step

On the basis of the investigation and registration of the information of the sewage outfall into the river, we further organized and implemented the demarcation and monument work of the water function area, verified the water pollution-bearing capacity of the water function area, and put forward the control scheme of limiting the total amount of sewage discharge. According to the *Measures for Supervision and Management of Sewage Outfall into the River* of the Ministry of

Water Resources, combined with the most stringent water resources management system currently implemented in China, further standardize the approval procedures for setting sewage outlets into rivers. At the same time, the statistical system of the annual report of sewage outlets directly under the control of river basin institutions has been established^[6], and the local water administrative departments have been jointly engaged to carry out law enforcement supervision and inspection of important sewage outlets into the river, thus steadily promoting the normalization of supervision and management of sewage outlets into the river.

2.5 The network of water environment monitoring stations is becoming more and more perfect

The Yangtze River Basin Water Environment Monitoring Station Network was established in 1977. By 1992, the number of monitoring stations in the whole basin had increased from 156 at the initial stage to 551^[7], with nearly 700 monitoring sections. At present, there are about 2,500 monitoring sections in the main and tributaries of the Yangtze River. Since 1998, the river basin has carried out 35 provincial boundary buffer section water quality monitoring work, reaching 60 in 2006, 111 in 2010, and 164 in 2016, basically achieving full coverage of provincial boundary water body monitoring in the river basin, with about 30 routine monitoring indicators^[8]. More than 400 issues of the *Bulletin of Water Resources Quality of the Yangtze River* and the *Water Quality Bulletin of the Yangtze River Basin and Southwest Rivers* were released on time.

2.6 The informatization level of water resources protection management has been significantly improved

The informatization construction of water resources protection in the Yangtze River Basin has implemented the informatization platform construction step by step according to the principle of “planning first, perfecting the network, highlighting key points and ensuring favorable conditions”. The information management system of drainage outlets in river basins based on GIS is established, and the water resources protection

management information system of water quality, drainage outlets and water sources based on Web GIS is constructed, which realizes the automatic collection of monitoring data and the intelligence of data statistics and analysis. In recent two years, Google Earth and SQL database have been jointly developed in the Yangtze River Basin, and a monitoring system for water resources protection in the Yangtze River Basin has been built, which can quickly query and search related information such as water function areas, sewage outlets into rivers and water sources^[9].

3. Problems faced by water resources protection in river basins

The practical problems of water resources protection in the Yangtze River Basin are more prominent, including water shortage, serious water pollution and ecosystem fragmentation, which are

mainly reflected in the following six aspects.

3.1 The low overall water quality compliance rate of the river basin

In 2011, the State Council issued the *National Water Function Zoning of Important Rivers and Lakes (2011–2030)*, and the Yangtze River Basin comprised a total of 1,181 first-level water function zones (including 416 development and utilization areas) included in the water function zoning of important rivers and lakes in the country, and 978 second-level water function zones were demarcated in the development and utilization areas. A total of 1,506 water functional zones in the first or second zone were identified as class III or better than the water quality targets, accounting for 86.4% of the total. According to the *Bulletin on Water Resources of the Yangtze River Basin and Southwest Rivers*, from 2010 to 2016, although the water quality

Table 1. Standard-reaching rates of water quality in important water functional zones of Yangtze River

Year	Number of functional zones evaluated	Full index method		Double index method	
		Number	Percentage/%	Number	Percentage/%
2010	192	124	64.6	0	0
2011	255	146	57.3	0	0
2012	925	593	64.1	730	78.9
2013	934	621	66.5	779	83.4
2014	1,150	788	68.5	1,008	87.7
2015	971	688	70.9	868	89.4
2016	1,195	882	73.8	1,090	91.2

compliance rate of the water function area (**Table 1**) has improved significantly, the compliance rate of the full index evaluation method (referring to 24 conventional monitoring projects) has increased from 64.6% to 73.8%, but the compliance rate is still low. The compliance rate of the two-index evaluation method (COD and ammonia nitrogen monitoring projects) increased from 78.9% to 91.2%.

3.2 The prominent contradiction between sewage discharge and water environment capacity

According to the *Yangtze River Water Quality Bulletin* and historical statistics, the sewage discharge in the Yangtze River Basin increased to 15 billion tons in the early 1990s, exceeded 20 billion tons by the end of the 1990s, and exceeded 30 billion tons for the first time in 2007, reaching 33.3 billion tons in 2010 and has now

exceeded 35 billion tons, as shown in **Figure 1**. The amount of sewage discharged into the river basin has reached more than 40% of the national total amount, equivalent to the total water volume of a Yellow River. The trend of sewage discharge in the Yangtze River Basin is shown in **Figure 2**. At the same time, the sewage discharge space is concentrated in the urban river section, and the sewage discharge of some sections of the river exceeds the capacity of the water area to absorb pollution, and a continuous pollution belt exceeding the standard has been formed.

3.3 The prominent contradiction between the operation of water conservancy projects and ecological water demand

According to statistics, there are currently more than 2,400 hydropower projects constructed or under construction in the Yangtze River Basin, with an installed capacity of 12×10^8 kW,

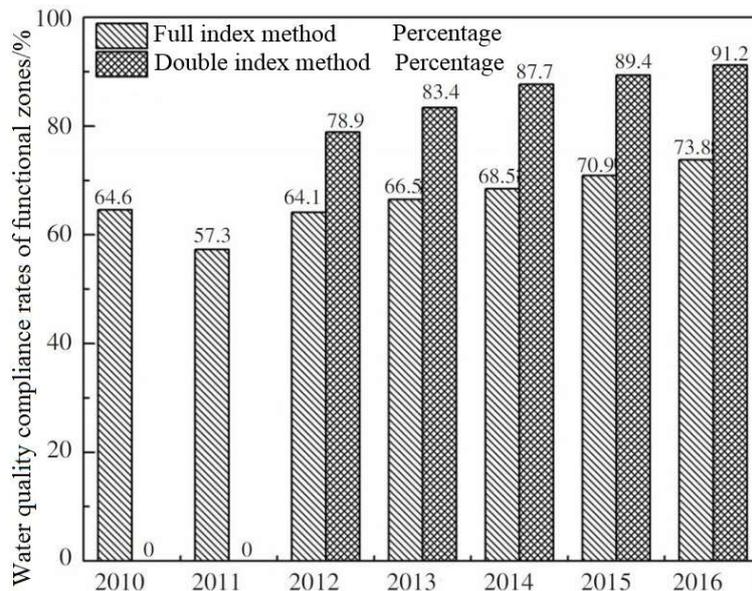


Figure 1. Annual change trend of water quality standard-reaching rates in important water functional zones of Yangtze River.

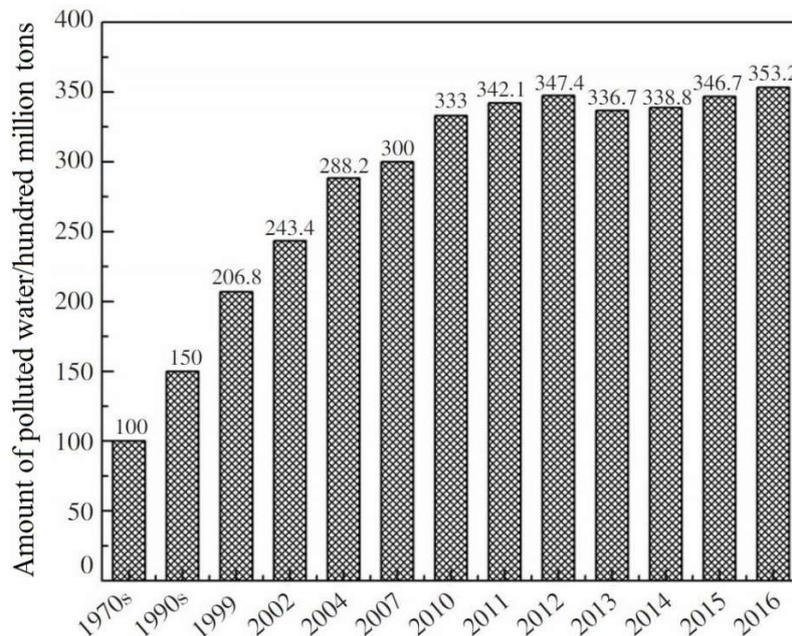


Figure 2. Annual change trend of sewage discharge in the Yangtze River basin.

accounting for 42% of the developable hydropower technology in the whole basin. The total water consumption of the whole basin is $1.984 \times 10^{11} \text{ m}^3$, the total water resources are $1.115 \times 10^{12} \text{ m}^3$, and the development and utilization rate of water resources is 18.7%, which has entered the list of rivers with medium development degree. The upper reaches of the Minjiang River and some tributaries of the Han River are cut off many times, and the ecological water demand process of the upper reaches of the Min Jiang, Dadu River, Jialing River, Wu River and Han River where hydropower development is concentrated is not met.

3.4 The obvious trend of ecological fragility in some waters

Under the dual interference of human activities and climatic variation, the water ecology problems in the Yangtze River Basin are very prominent, mainly manifested in the reduction of habitat area, the singleness of aquatic biomes, and the frequent occurrence of algal blooms. Taking the scale of spawning farm of “the four major Chinese carps” (black carp, grass carp, silver carp, bighead carp) as an example, the survey results in the 1960s showed that there were 36 spawning farms in the main stream of the Yangtze River from Ba County in

Sichuan (now Banan District, Chongqing) to Pengze in Jiangxi, which was reduced to 30 in 1986, of which 11 were located in the upper section of the Yichang River, and after the Three Gorges Reservoir was stored, the hydrological conditions changed, and 11 spawning grounds in the upper reaches faced the disappearance^[10]. In addition, Dianchi Lake, Chao Lake, Hongze Lake, Taihu Lake, Dongting Lake, Three Gorges Reservoir, Land Water Reservoir, and the middle and lower reaches of the Han River have all experienced algal blooms many times, including Taihu Lake, Chao Lake and Dianchi Lake has been identified as a key target for prevention and control since the beginning of the Ninth Five-Year Plan due to the serious problem of algal blooms.

3.5 The low degree of safety and security of drinking water sources

From 2010 to 2016, the water quality of some of the centralized drinking water sources in the Yangtze River Basin participated in the annual standard is shown in **Table 2**, and the water quality

Table 2. Water quality standard-reaching rates in drinking water sources of Yangtze River

Year	Number of functional zones evaluated	Full index method	
		Number	Percentage/%
2010	346	222	64.2
2011	309	210	68.0
2012	356	202	56.7
2013	340	196	57.6
2014	329	193	58.7
2015	335	220	65.7
2016	481	338	70.3

qualification rate of the water source is not optimistic. In addition, according to the survey on the safety and security of 56 national important drinking water sources in the Yangtze River Basin conducted since 2012, the water supply guarantee rate of some water sources is less than the target of 95%, and 22 drinking water sources have not built backup water sources; 23 water sources have failed to implement closed management in the first-level protection areas, 8 drinking water sources still have sewage outlets, some water sources have potential pollution sources such as docks, oil depots, and farms; vegetation coverage is less than 80% in 10 primary water sources protection areas; and 17 water sources without automatic monitoring

system^[11], etc. Other centralized drinking water sources at or above the county level have a lower degree of safety and security.

3.6 The imperfect technical methods of river and lake health assessment

In 2006, the Changjiang Water Resources Commission put forward a new idea of “maintaining a healthy Yangtze River and building harmony between people and water”. What is a healthy river and what is a healthy Yangtze River? Current research and understanding are still incomplete. In 2007, the Changjiang Water Resources Commission organized the “index research of healthy Yangtze River”, the index system of healthy Yangtze River was established from seven aspects: the research on the development and utilization rate of water resources, the water quality standard-reaching rate of the water function area, the degree of ecological water demand satisfaction, fish biodiversity, the excellent river conservation rate of the river, the wetland retention rate, and the soil erosion rate, and the evaluation criteria and evaluation methods of the index were preliminarily discussed^[12]. However, there are still problems such as incomplete indicators, weak operability, and difficulty in quantification.

4. Multi-objective integrated protection framework system for water resources

According to the overall requirements of water resources protection of unified protection in accordance with the “water quantity, water quality and water ecology” in the new era, combined with the responsibilities entrusted by China to river basin institutions in “ecological water demand protection, water quality management in water functional areas, protection of drinking water sources, water ecological protection and restoration, supervision and management of sewage outlets into rivers, and protection of groundwater resources”, water resources protection should start from engineering measures and non-engineering measures to establish multi-objective integrated protection framework system in Yangtze River Basin, as is

shown in **Figure 3**.

The water resources protection system consists of an engineering system and a non-engineering system. In the engineering system, water quantity protection is reflected in the construction project of water conservation forest and the ecological dispatch project of water conservancy project; water quality protection is reflected in the two aspects of point source pollution control and non-point source pollution control in which point source pollution control mainly implements the standardized rectification of sewage outlets, the transformation of sewage outlets and the in-depth treatment of sewage outlets, and the non-point source pollution control is mainly aimed at agricultural non-point source pollution classification and control of pollution, rural domestic pollution and solid waste;

water ecological protection is mainly reflected in shore slope restoration, algal bloom control, water quality purification and comprehensive management of small watersheds^[13]. Non-engineering systems mainly include water resources protection monitoring and water resources protection management. Among them, water resources protection monitoring mainly implements water function area monitoring, sewage outlet monitoring, drinking water source monitoring, water ecology monitoring and emergency monitoring; and water resources protection management is reflected in the construction of laws and regulations, the construction of management mechanisms, scientific research and technology promotion, management capacity building, etc.^[14].

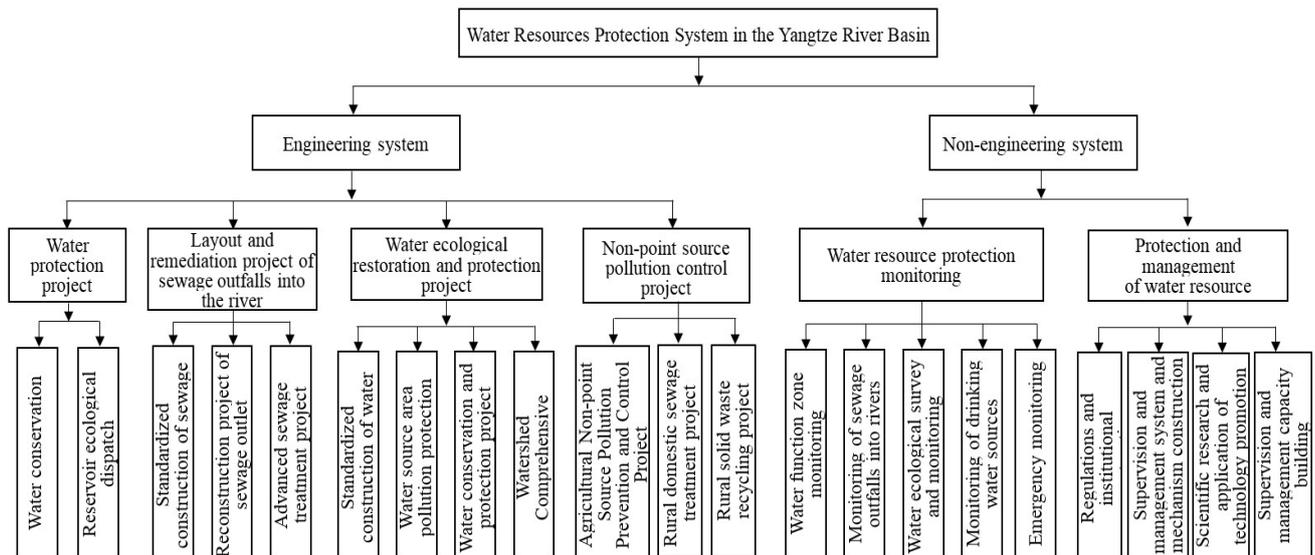


Figure 3. Frame system of water resources protection system in the Yangtze River basin.

5. Technical system of multi-objective comprehensive protection for water resources

According to the framework system of multi-objective comprehensive protection of water resources, scientific research should be aimed at “ensuring the appropriate ecological flow process, the water quality of the water function area and the total amount of sewage discharge, the water quality of drinking water sources, the integrity and function of the water ecosystem, the management and reasonable layout of the sewage outlet, and the standard-reaching quality of the groundwater”,

focus on ten aspects of technical research and development in view of the current problems in water resources protection, and initially form a multi-objective comprehensive protection technology system for water resources in the Yangtze River Basin.

5.1 Suitable ecological water demand process and key technologies guarantee in the Yangtze River Basin

Focusing on the cumulative impact of storage, introduction, lifting and adjustment projects on the runoff process of rivers, establishing a calculation method for the ecological needs of different

characteristic sections of the Yangtze River Basin, constructing a target scheme for the control of ecological water demand in key sections of the Yangtze River Basin, and proposing a guarantee scheme for the suitable ecological water demand process of rivers under strong human interference.

5.2 Key technologies for river and lake health assessment and protection

Focusing on establishing an indicator system for the health of rivers and lakes, establishing quantitative calculation methods for various indicators in terms of water quantity, water quality, water ecology, physical structure, social environment, etc., establishing the standard threshold of indicators for the health of key rivers and lakes in the Yangtze River Basin, and carrying out health diagnosis and restoration of typical rivers and lakes^[15].

5.3 Key technologies for the verification and distribution of pollution absorption capacity in dynamic waters

Focusing on the law of pollutant diffusion and self-purification under different water flow conditions, establishing a calculation method for the pollution capacity of dynamic waters in urban river sections, establishing a distribution plan for the capacity of pollutants in dynamic waters, and establishing a control scheme for the total amount of pollutants entering the river under extremely dry water conditions.

5.4 Key technologies for the setting and management of sewage outlets into the river

Constructing a supervision and management model, law and system for the discharge of sewage into the river basin; exploring the application of the pollution trading mechanism in the management of the sewage outlet of the river; improving the demonstration of the setting of sewage outlets into rivers and the establishment of demonstration guidelines for planning inlets; building information systems for sewage outlets into rivers and optimizing layout methods; implementing the investigation of accident risk sources and the preparation of emergency plans for sudden water pollution accidents.

5.5 Key technologies for water ecological protection and restoration in disturbed waters

To explore the vulnerability indicators of river and lake water ecosystems and their causes, guided by river and lake health standards; researching and developing key technologies for the restoration of water ecological structure and function in important sensitive water areas to explore environmental effect assessment and water quality regulation schemes for the connection of rivers and lakes.

5.6 Control technology on the impact of reservoir groups operation of main stream and tributary on lakes and wetlands

Implementing the ecological survey and evaluation of the “Two Lakes” wetland, and carrying out the analysis of the historical evolution trend of the “Two Lakes” wetland, to study the cumulative effect of the operation of the main stream and tributary reservoir group on the hydrological process of the “Two Lakes” and the response relationship of the “Two Lakes” wetland to the variation of the hydrological process. The optimal scheduling scheme of the main stream and tributary reservoir group for the protection of the “Two Lakes” wetland is discussed, and the habitat and biodiversity conservation scheme of the “Two Lakes” wetland are proposed.

5.7 Causes of algal blooms in large reservoirs in the Yangtze River Basin and their prevention and control technologies

Investigate and evaluate the current status of eutrophication in large reservoirs in the Yangtze River Basin, study the production and perishing process and influencing factors of water algae blooms in reservoirs in different spatial and temporal patterns, identify the driving factors of typical algae blooms and their limiting thresholds, develop ecological risk assessment and early warning technology of algae blooms in typical reservoirs, and propose prevention and control technologies and regulation countermeasures for algae blooms of large reservoirs in the Yangtze River Basin.

5.8 Research on key technologies for water quality protection in water sources in the Yangtze River Basin

Carry out investigation and analysis of the current situation of water quality in large drinking water sources, design ecological compensation mechanisms for typical drinking water sources, and develop key technologies for ecological block control of large drinking water sources and water quality early warning technologies for large water sources based on multi-source indication organisms.

5.9 Key technologies for automatic monitoring of water environment in the Yangtze River Basin

Explore the optimization layout scheme of water quality monitoring sections in key water areas, study multi-source water quality testing and adaptive networking technology in large water

source areas, improve the monitoring and evaluation standards of toxic organic compounds, and develop multi-index online monitoring technology research and equipment.

5.10 Key technologies for the protection of groundwater resources in the Yangtze River Basin

Carry out functional zoning of groundwater and establish water quality management goals, study the simulation technology of pollutant transport in the groundwater system, develop microbial technology for groundwater pollution control, and establish a groundwater quality monitoring and information release system.

The ideas of the key technical framework system for water resources protection in the Yangtze River Basin are shown in **Figure 4**.

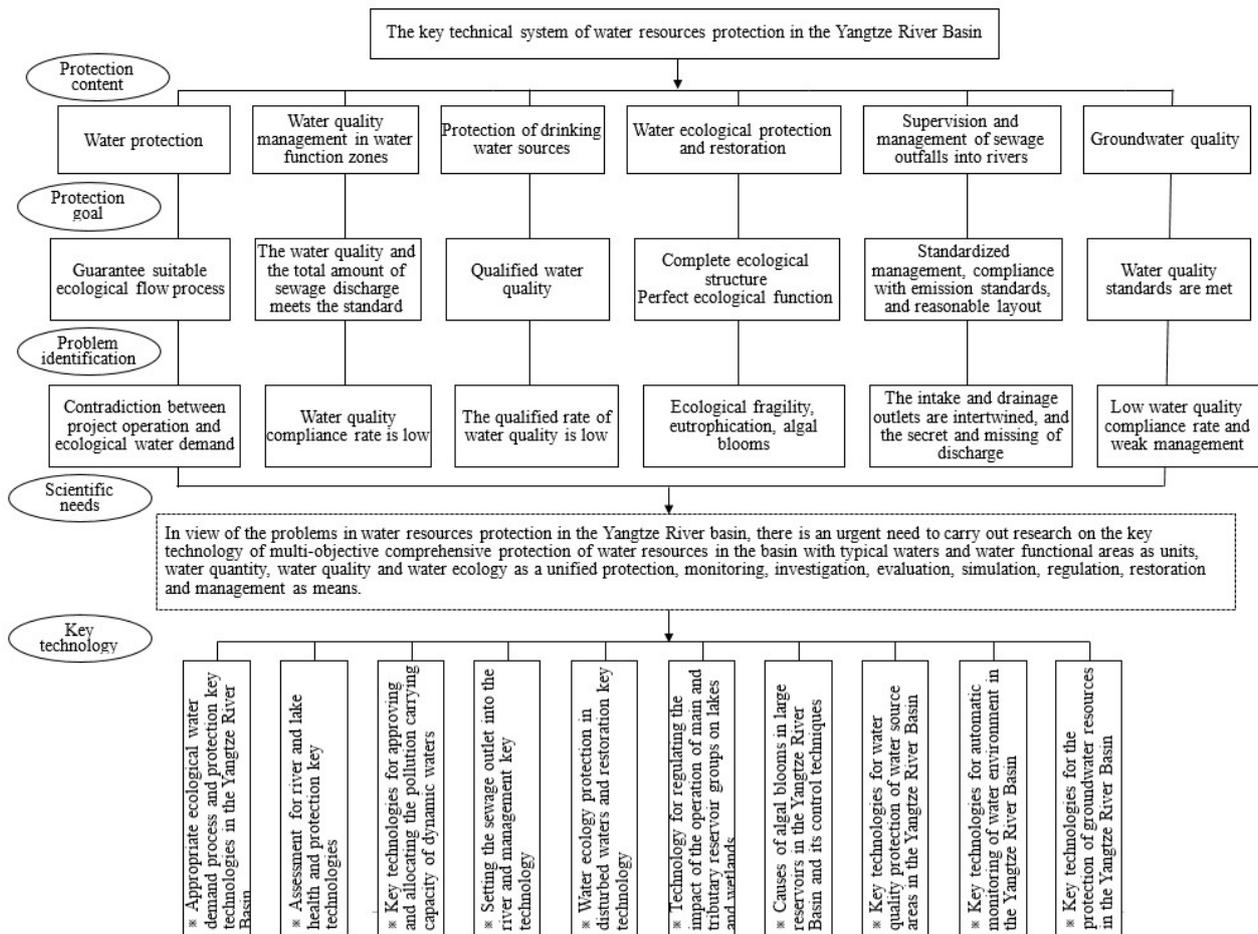


Figure 4. System of water resources protection key technologies in the Yangtze River Basin.

6. Conclusion

The Yangtze River is the third largest river in

the world and the largest in China. Its watershed area accounts for 1/5 of the country's land area, supports 1/3 of China's population, contributes 1/3

of China's GDP, and its important position is self-evident. Under the background of the dual interference of climate change and human activities, the protection of water resources in river basins is facing unprecedented pressure. Although after more than 40 years of unremitting efforts, the Yangtze River Basin has initially established a legal system for water resources protection, the status of water resources protection planning has been continuously improved, the thinking of water resources protection planning has been continuously improved, and the management, scientific research and monitoring capabilities of water resources protection have been continuously enhanced. However, it is still faced with problems such as excessive squeezing of ecological water demand, low water quality compliance rate, fragility of local water ecology, difficulty in ensuring drinking water safety, and more sewage in some water functional areas than the capacity to absorb pollution. In the face of river basin management responsibilities and objective problems, the current water resources protection of the Yangtze River Basin must unswervingly practice the idea of unified protection of "water quantity, water quality and water ecology", taking into account the ecological water needs of rivers, water quality standards, and river entry limits Multi-objective comprehensive protection such as total discharge control, water ecosystem integrity, drinking water source safety, and groundwater quality safety. However, in order to truly achieve the ultimate goal of "healthy Yangtze River", we must also fully rely on the progress of science and technology and establish a technical framework system for the whole process of monitoring, investigation, evaluation, simulation, regulation, restoration and management, so as to promote the protection of water resources in the basin in the direction of rapid, accurate and efficient development.

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Conflict of interest

The authors declared no conflict of interest.

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