

# Study on Water Resources Scheduling

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**Abstract.** The rapid development of China's economy has brought about problems such as water shortage, water pollution and deterioration of water environment. Meanwhile, carrying out water resources scheduling is an important measure to realize the optimal allocation of water resources and support the sustainable development of the economy and society. Based on the understanding of water resources scheduling by many scholars, this paper summarizes the definition of water resources scheduling and puts forward the theoretical basis of water resources scheduling, including the system framework and key technologies. Finally, the development trends and research hotspots of water resources scheduling are forecasted.

## 1. Introduction

China's total water resources are about 2.84 trillion m<sup>3</sup>, ranking sixth in the world. However, per capita water resources are only 2,100 m<sup>3</sup>, which is 28% of the world average [1]. At the same time, China's water resources are unevenly distributed in time and space, and about 60-80% of the runoff is concentrated in the annual flood season. The northern region accounts for 64% of the country's land area, but its total water resources only account for 19% of the country [2]. In recent years, with the rapid development of China's economy and society, problems such as water shortage, water pollution and deterioration of water ecology have become increasingly acute, and the contradiction of water use has become increasingly prominent [3]. Carrying out water resources scheduling is conducive to promoting the implementation of water allocation plan and total water consumption control system, which is conducive to further coordinating water quantity, water quality and water ecological protection, and is conducive to the macro and refined management of water resources in the basin. In addition, water resources scheduling can help to improve water resources management capabilities in an all-round way, so as to achieve sustainable economic and social development through sustainable use of water resources.

## 2. The definition of water resources scheduling

After decades of continuous exploration, Chinese scholars have made many achievements in the field of water resources scheduling. The connotation of water resources scheduling is constantly enriched, the concept is continuously developed, and the service field is continuously broadened. However, there is still no clear and unified statement about the concept of water resources scheduling. The National Science and Technology Terminology Committee defined water resources scheduling as "Water resources scheduling is the process of blending water resources in different regions by engineering and non-engineering measures, so as to improve water use efficiency to meet the water demand of human society and the natural environment" under the water resources entry of the



resource discipline. At the same time, the water resources optimization schedule was defined as “Water resource scheduling is the optimization and application of water resources in existing water projects or existing rivers, reservoirs and underground aquifers in order to achieve maximum economic, social and environmental benefits.” in its water science and technology term published in 1997.

In addition, some scholars believe that the reservoir is a tool, the object of dispatching is water resources, and water resource scheduling is essentially reservoir scheduling [4]. Regarding the relationship between water resources allocation and water resources scheduling, it is generally believed that “Water resource allocation and water resource scheduling are two related but different concepts in the field of water resources allocation. Water resources allocation focuses on future water supply and demand situation forecasting and rational planning, while water resources scheduling focuses on real-time operational control rules and water supply management of water conservancy projects. The former is the basis of scheduling implementation, and the latter promotes the implementation of configuration schemes, which are inseparable.” Some scholars have described that “water resources scheduling is a macro concept, covering a wide range of content, while water volume scheduling, water conservancy scheduling, and reservoir scheduling mainly refer to specific scheduling content, which should be within the scope of water resources scheduling” [6].

Combining the above various statements about water resources scheduling, the author of this paper gives a definition: with water conservancy projects as a means of control, water resources scheduling is a general term for a series of behavioral activities that are reasonably arranged in time and space, which considers economic, political, cultural, social, ecological and other factors.

### 3. The theoretical basis of water resources scheduling

#### 3.1. The system framework of water resources scheduling

Based on the content and basic process of water resources scheduling, the system framework (Figure. 1) is established and divided into five parts: “simulation-prediction-scheduling-control-evaluation”.

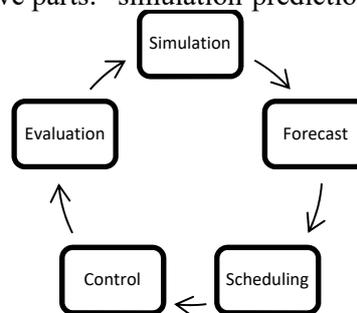


Figure.1 The system framework of water resources scheduling

The simulation is the basis of the water resources scheduling theory, which aims to explore the temporal and spatial changes of water, understand the formation and evolution of water resources, explore the interaction of various elements of the water cycle of the basin and achieve the re-emergence and abstraction of the water cycle process and laws of the basin.

According to the previous or current hydrometeorological data, the forecast is an important part of water resources scheduling, which aims to predict the next stage of water resources and provide usable information for the next stage of scheduling decision.

Scheduling is the core of water resources scheduling theory. It is a theoretical level technology, and it is also a scheduling scheme based on decision objectives. Water resources scheduling can be divided into project scheduling, planning and scheduling and real-time scheduling. Project scheduling is a watershed (regional) water administrative agency that determines watershed water allocation and planning and scheduling schemes based on water rights allocation. On the basis of water rights allocation in the basin (regional) water administrative agency, Project scheduling refers to determining the water allocation and planning and scheduling scheme of the basin. Planned scheduling refers to the

use of water conservancy project scheduling as a means to formulate regional water use plans, water conservancy projects, and key section scheduling plans through methods such as water resource forecasting and water resources scheduling model solving. Through the development of real-time monitoring and control systems, real-time scheduling refers to the generation of real-time scheduling instructions, real-time scheduling of water resources, implementation of scheduling plans, and assessment, evaluation and scheduling and revision of scheduling instructions after completing a scheduling period.

Control is the operational level of water resources scheduling and a tool for achieving optimal water resources scheduling. The function of the scheduling plan needs to be operated in accordance with the scheduling decision-making instructions, comprehensive consideration of working conditions, and determination of operational instructions for water resources projects such as reservoirs, gates, and pumping stations.

The evaluation of water resources scheduling needs to analyze and judge the deviations of social, economic, ecological, realistic and expected effects that may be caused by different scheduling schemes, which aims to prevent the scientific and rationality of the evaluation from being influenced by subjective preferences or incomplete objective information in the process of program formation and decision making.

### 3.2. Key technologies for water resources scheduling

#### 3.2.1. Water cycle simulation technology

##### (1) Distributed hydrological model

Distributed hydrological model refers to a distributed parameter hydrological model with strict physical basis based on watershed scale. For one thing, it can be used for real-time hydrological forecasting; for another thing, it can be used to analyze the response of surface water circulation systems to different water conditions and different water regimes. Distributed hydrological model analyzes the regional surface water and water cycle process from different angles to determine the impact of different water resources scheduling schemes on the surface water and water cycle.

##### (2) River and water reservoir hydrodynamic model.

The hydrodynamic model of the river and lake reservoir realizes the real-time and dynamic simulation of the flow, water level and water quality of the rivers and lakes under certain control conditions, and its purpose is to evaluate the post-evaluation of the scheduling scheme.

##### (3) River water quality simulation model.

The water quality model is a mathematical equation describing the relationship between the migration and transformation of pollutants in water and time and space, and is an important tool for decision analysis of water environmental pollution control planning.

##### (4) Three-dimensional numerical simulation model of groundwater.

In the evaluation of groundwater resources, it is necessary to obtain the change process of groundwater level and hydrogeological parameters by solving the corresponding mathematical model.

#### 3.2.2. Hydrological forecasting technology

##### (1) Medium- long term hydrological forecasting model

Medium-long term hydrological forecasting refers to the method of constructing mathematical models, finding historical hydrometeorological data, and predicting future hydrological factors. At this stage, the main focus is on runoff forecasting. The medium-long term forecasting methods can be divided into traditional forecasting methods and intelligent hydrological forecasting methods. The traditional forecasting methods include physical cause analysis methods and mathematical statistics methods.

##### (2) Water demand prediction model

Water demand is usually divided into: water production outside the river (life, industry, and agriculture), ecological water demand outside the river, production water demand in the river,

ecological water demand in the river. The water demand forecast is generally calculated directly from the water quota. The general industrial water demand forecast is predicted by the water consumption method of 10,000 yuan of output value; the fire (nuclear) power industry is predicted by the unit kilowatt installed water consumption method. Meanwhile, the irrigation water demand forecast for farmland is calculated by the irrigation quota method. The forecasting of ecological environment water demand, such as urban greening water, shelter and forestry water, etc., with vegetation water demand as the main body, can be determined by quota forecasting method. Lakes, wetlands, urban rivers and lakes, etc., to map the difference between the water surface evaporation and precipitation is the ecological environment water demand. Besides, the ecological water demand prediction method in the river channel includes the ecological water demand calculation method based on the basin hydrological model, the habitat simulation method, the wet period method, the Tennant method, the Texas method and the minimum monthly average measured net flow method.

### 3.2.3. Scheduling technology

#### (1) Water quantity and water quality indicator allocation model

According to the water supply situation in the river basin, the groundwater exploitation capacity and the sewage capacity, and the water quality and water quality distribution characteristics, different annual distribution methods can be adopted. It includes the same ratio of water distribution, weighted water distribution, user participation in water distribution, multi-objective optimization of water distribution.

#### (2) Multi-objective joint scheduling model for reservoirs

The joint scheduling of reservoirs is not only the basis for realizing the sustainable utilization of water resources in the basin, but also the necessary condition for realizing the benefits of hydrological compensation, storage capacity compensation, power compensation and comprehensive utilization in the basin. The establishment and solution methods of multi-objective joint scheduling model for reservoir group mainly include simulation technology, optimization technology, simulation and optimization coupling technology and multi-objective analysis technology.

#### (3) Water resources system analysis model

Based on the results of water inflow forecasting and water demand forecasting, taking the river section and section control indicators as constraints, considering the supply and consumption process, the socio-economic and ecological environment, and the reservoir and lake storage capacity, we construct the water resources system analysis model to maximize water use efficiency in the basin or region.

### 3.2.4. Control technology

The control technology mainly refers to the joint regulation model of the dam pumping station group. The key to real-time scheduling is how to realize the scheduling tasks assigned by the annual scheduling plan and the monthly (circle) scheduling scheme through the regulation of the dam group.

The problem to be solved by the joint control model of the gate dam pumping station group is to ensure that the actual dispatching can be carried out according to plan, and the prepared dispatching plan and plan can be implemented. According to the scheduling target and the real-time status of the system, the joint control model of the dam pumping station group automatically generates the dispatching command of the gate dam pumping station group in real time.

### 3.2.5. Evaluation technology

In order to accurately provide scientific basis for decision makers or decision-making institutions, it is necessary to analyse and judge the social, economic, ecological, and subsequent sustainable scheduling levels that can be caused by different scheduling schemes. In addition, due to the scheduling scheme is affected by many uncertain factors, the effect achieved by each scheme is deviated from the effect under certain conditions. Therefore, the cause, extent and possibility of such deviation are analysed and judged, that is, the uncertainty evaluation of the scheduling scheme, also

known as the risk assessment of the scheme. The evaluation methods used in water resources scheduling mainly include principal component analysis, analytic hierarchy process analysis, grey system theory evaluation method, and matter element analysis.

#### **4. The development trend and research hotspot of water resources scheduling**

##### *4.1. Joint scheduling of water resources in the basin*

###### **(1) Joint scheduling of cascade reservoirs**

In terms of safe operation, production management, and comprehensive coordination of cascade hydropower stations, it is necessary to implement joint scheduling of cascaded reservoirs in the basin according to the characteristics and scientific laws of the river basin, which aims to complement each other and give full play to the enormous adjustment capacity of the cascade reservoirs. Joint scheduling of cascade reservoirs not only improves the flood control standards of the river basin, but also improves the comprehensive utilization rate of water resources and maximizes the power generation efficiency of the cascade hydropower stations in the basin.

###### **(2) Joint scheduling of water quantity and water quality**

Water quantity and water quality are the dual attributes of water resources. The two influences are not divided. The requirements of water quantity and water quality are different. It is necessary to schedule water quantity in combination with water quality requirements. In addition, pollution load control of water quality scheduling is of great significance for water pollution control.

###### **(3) Multi-water source, multi-target joint scheduling**

Whether it is cross-basin water resource scheduling or unified scheduling of water resources in large basins, the relationship between local water and transferring water, surface water and groundwater, conventional water and unconventional water, water transfer and water saving is extremely complicated. At the same time, water resources scheduling involves many scheduling objectives, not only to meet the main objectives of water supply security, flood safety, food security, energy security, but also to consider ecological water, environmental water, shipping water and other goals, so the competition for water use is fierce. How to rationally dispatch water resources of various water sources, how to coordinate the interests of all parties concerned, how to comprehensively consider many scheduling objectives, and achieve a harmonious and efficient use of water resources is an important issue to be solved in water resources scheduling.

##### *4.2. Interbasin water diversion project*

###### **(1) Joint scheduling of transferring water and local water**

The joint scheduling of transferring water and local water is one of the main guarantees for the full benefit of the inter-basin water diversion project. Two important issues related to the comprehensive realization of the inter-basin water diversion project scheduling objectives, including how to balance ecological water use, reduce groundwater exploitation, reduce groundwater subsidence, control ground subsidence, and gradually improve the ecological environment of the water receiving area on the basis of urban life and industrial water supply; how to return the amount of water that has been squeezed into agriculture in the original city to agriculture, and use the return water that has been treated with some or all of the water to solve the problem of insufficient water for agriculture.

###### **(2) Evaluation of ecological environmental impacts of inter-basin water diversion**

After the completion of the inter-basin water diversion project, pollution prevention and control plans should be implemented simultaneously to reduce the impact of water diversion. At the same time, the operation of the inter-basin water diversion project may have some adverse effects on the water source area and the water receiving area. Therefore, appropriate measures should be taken as soon as possible to reduce the impact of the inter-basin water diversion project on the ecological environment.

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### **References**

- [1] Ren G Z and Pan Y S 1998 Water Resources Planning and Design 11 10-13
- [2] Zhang G D and Chen Z K 1991 Journal of Hydraulic Engineering 22 22-29
- [3] Chen M 2013 China Water Resources 15 15-16
- [4] Fang Z Y 2005 Advances in Science and Technology of Water Resources 25 1-5
- [5] Lu F, Jiang Y Z, Wang H, Wang H C and Shen Y Y 2010 Water Resources and Hydropower Engineering 41 11-14
- [6] Deng K, Zhang X, Yang Y S and Liu J T 2011 Journal of Economics of Water Resources 29 23-27