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Water Resource Allocation and Planning in Water Conservancy and Hydropower Engineering Systems

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Abstract: *In response to the contradiction between water supply and demand brought about by the rapid development of the economy and society, this article deeply explores the optimization strategies for water resource allocation and planning in water conservancy and hydropower engineering systems. By analyzing the water cycle characteristics and water use structure of the watershed, a multi-objective optimization based water resource scheduling model was constructed, aiming to balance ecological environment protection and economic benefits output. The research focuses on the regulatory role of water conservancy hub projects on runoff at the spatiotemporal scale, and proposes a systematic approach that couples macro planning and micro configuration. The results indicate that scientific allocation planning can not only significantly improve the efficiency of water resource utilization, but also enhance the resilience of the system to cope with disaster risks in dry years. This article aims to provide theoretical basis and technical support for the sustainable management of regional water resources and the coordinated layout of hydropower projects.*

Keywords: *water conservancy and hydropower engineering; Water resource allocation; Multi objective optimization; scheduling model*

1. Introduction

With the rapid evolution of global climate change and regional economic structure, the contradiction between the uneven spatial and temporal distribution of water resources and the diversification of social needs has become increasingly prominent, becoming a core bottleneck that restricts the effectiveness of water conservancy and hydropower projects. In the modern watershed management system, a single engineering regulation and storage system is no longer able to meet the multidimensional balance of ecology, agriculture, and industry. Therefore, building a water resource allocation system based on complex simulation theory and intelligent perception to achieve precise mapping from macro level allocation to micro level irrigation has become an inevitable direction for industry research. This article aims to explore the optimization logic of resource allocation in water conservancy and hydropower systems. By analyzing key technologies such as simulation, multi-objective scheduling, and intelligent agricultural water conservancy, a systematic planning scheme is provided to enhance the resilience of regional water security guarantee.

2. Analysis of Water Resource Allocation System and Construction of Theoretical Model

In the modern water conservancy and hydropower engineering planning system, water resource allocation is no longer a single allocation of supply and demand, but a complex adaptive system involving natural runoff evolution and social water demand. By systematically integrating water conservancy hubs, diversion routes, and water receiving areas within the watershed, a resource allocation network that supports regional development can be constructed. At the theoretical level, the configuration model needs to fully consider the uncertainty in the water cycle process, and use complex adaptive system theory to simulate the behavioral responses of different water users under policy and environmental changes. This model can organically combine macro resource planning with micro engineering operation, and achieve a dynamic balance between social and economic benefits and ecological environment protection through multi-objective collaborative optimization[1]. Scientific system analysis is the foundation for determining the scale of water supply engineering construction. It can not only identify bottleneck areas with resource shortages, but also provide accurate decision-making references for subsequent water conservancy project layouts.

3. Layout and spatial configuration planning of water conservancy and hydropower projects

The spatial layout of water conservancy and hydropower projects is the material basis for achieving efficient allocation of resources across regions. In the planning process, it is necessary to rely on the existing river system structure and backbone water conservancy hubs to form an engineering configuration network that combines "points, lines, and surfaces"[2]. For areas with a high degree of urbanization, the focus of configuration planning should shift to the system integration of engineering networks, and improve the water supply guarantee rate of the system to cope with extreme dry years by building a multi-source complementary and interconnected water supply pattern. At the same time, spatial configuration also needs to pay attention to the application of geographic information systems (GIS), optimize the design of water transmission lines through high-precision spatial data processing, and reduce the loss and pollution risks of water during long-distance transportation. In modern planning practice, digital and information-based scheme design has become the key to improving configuration efficiency[3]. By deploying intelligent sensing networks and real-time decision-making platforms, accurate monitoring of the operation status of water conservancy systems can be achieved, ensuring that configuration schemes can be adjusted in real time according to measured flow and demand changes.

4. Complex simulation theory and multidimensional scheduling optimization strategy for water conservancy and hydropower engineering systems

In the deep logic of water conservancy and hydropower engineering planning, the simulation of water resource allocation system is no longer a simple calculation of water balance, but a highly dynamic and nonlinear system simulation process. In order to ensure the scientificity of the configuration plan, it is necessary to construct a full process simulation system for the complex water conservancy hub group in the watershed. The core of this simulation technology lies in the deep coupling of natural runoff processes, artificial regulation and storage processes, and social consumption processes. In practical operation, researchers need to use long-term hydrological data to set scenarios for different frequencies of wet, dry, and normal years. By accurately characterizing parameters such as storage capacity curve, discharge flow rate, and water diversion capacity, they can identify vulnerable nodes in the system's water supply under extreme weather conditions. When constructing a simulation environment, it is necessary to further refine the boundary conditions in the hydraulic model. By introducing 3D visualization technology and numerical fluid dynamics analysis, transient simulations of hydraulic transition processes in key areas such as water conveyance tunnels and pressure regulating wells can be conducted. This refined modeling can accurately predict pressure fluctuations and water hammer effects that may occur during long-distance water transfer processes, thus reserving sufficient defense space for the safe operation of the project [4]. At the same time, the simulation process should also integrate the terrain and vegetation information obtained from remote sensing technology to correct the loss parameters of runoff and convergence models in real time, making the physical model closer to the complex geographical situation. The simulation of water engineering systems can not only provide basic data support for configuration schemes, but also verify the adaptability of different scheduling rules in dealing with complex inflow conditions through multi-dimensional simulation experiments, thereby providing a quantitative decision-making base for determining the scale of subsequent large-scale projects.

Further deepening the optimization research of scheduling strategies is a key link in improving the operational efficiency of water conservancy and hydropower engineering systems. The traditional static water distribution mode is no longer able to meet the ultimate pursuit of resource utilization in modern society, so it is necessary to establish a joint scheduling model based on multi-objective collaboration. This model needs to consider multiple competitive objectives such as maximizing social and economic benefits, minimizing water shortage rates, and ensuring ecological flow of rivers. When constructing this model, it is necessary to deeply analyze the nonlinear mapping relationship between the water conservancy project and the receiving area, and conduct high-dimensional search on the parameter space of the scheduling function by introducing heuristic algorithms [5]. This in-depth analysis can reveal the weight evolution law between different objectives, especially in special periods of extreme water scarcity. The model can assist decision-makers in finding the critical balance point between survival water use and production water use. In addition, in order to enhance the disturbance resistance of the scheduling scheme, a sensitivity analysis module needs to be added to the planning to evaluate the impact of rainfall forecast errors and water quota fluctuations on the stability of the configuration scheme. During the scheduling process, the water conservancy hub serves as the core energy and water control node, and its operating rules need to be dynamically adjusted based on real-time feedback from the receiving area. By introducing the theory of complex adaptive systems, it is possible to simulate the interactive behavior of water users under resource scarcity or policy changes, and use distributed algorithms to solve the optimal allocation sequence[6]. This multidimensional scheduling strategy emphasizes "replenishing drought with abundance" and "complementing time and space", utilizing cross basin and cross regional water network connectivity projects to achieve optimal physical flow of water resources and maximize economic value.

At the same time as building a high-precision simulation system, it is necessary to establish a correction mechanism based on big data feedback to solve the deviation problem between theoretical models and actual engineering operations. By deeply mining the historical data of water conservancy project operation, the system response rules under different scheduling scenarios can be further extracted. This feedback mechanism requires the engineering management system to be able to capture key information such as channel water level, pump station energy consumption, and real-time flow in the receiving area in real time, and input them in reverse into the configuration model for parameter verification. In this process, the system needs to use machine learning algorithms to reduce the dimensionality of massive monitoring data, identify key driving factors that affect water distribution accuracy, and achieve online rolling correction of physical parameters such as gate roughness and river leakage loss in the model algorithm. By introducing edge computing technology, the configuration system can achieve second level data response to ensure that the generation of dispatching instructions is not only based on macro trend judgment, but also based on micro level instantaneous hydraulic condition changes. This deep data self-healing capability greatly enhances the system's efficiency in parsing complex boundary conditions, enabling configuration planning to have the ability of self evolution and collaborative optimization. Through this closed-loop logic of "prediction execution feedback optimization", water resource allocation schemes can smoothly transition from an idealized planning state to a practical scheduling state. This not only greatly improves the reliability of simulation results, but also provides more flexible technical response space for dealing with sudden water surges or interruption risks in the watershed, ensuring the precise implementation of resource allocation under complex working conditions.

At the execution level of simulation and scheduling, modern configuration systems increasingly demand refined management, which is not only reflected in the control of macro water volume, but also in the deep optimization of micro engineering operating parameters. In large-scale water diversion and storage projects, configuration planning needs to establish a real-time scheduling platform that couples energy consumption control based on the performance curves of different water conservancy facilities. For example, in the operation of pump stations and the opening and closing of water gates, by establishing a control algorithm based on dynamic programming, the energy consumption of system operation can be significantly reduced while ensuring water distribution accuracy. At the same time, the scheduling process must embed strict ecological environment constraints to ensure that the discharge flow always meets the minimum requirements for maintaining biodiversity and river health in the pursuit of economic output. This comprehensive configuration mode integrating engineering mechanics, hydrodynamics, and management represents the forefront direction of current water conservancy and hydropower planning technology, which can effectively solve the regional shortage problem caused by uneven distribution of water resources and provide technical certainty for the long-term operation of the water resources guarantee system.

5. Optimization Configuration System of Farmland Water Conservancy Engineering and Design of Intelligent Irrigation System

As the core water terminal of the water resource allocation system, the improvement of water use efficiency in agricultural water conservancy projects directly affects the success or failure of overall allocation planning. In the overall design of water conservancy and hydropower projects, the optimal allocation of agricultural water resources should be based on a profound understanding of crop water demand mechanisms and dynamic changes in soil moisture. By building an intelligent irrigation configuration system, the traditional "scheduled water supply" mode can be completely transformed into the "on-demand allocation" mode. The transformation of this model requires planners to finely reconstruct the spatiotemporal water demand characteristics within the irrigation area, establish a more responsive resource allocation mechanism by introducing a water profit and loss sensitivity index for crop growth[7]. In engineering practice, this means that the existing final canal system needs to be modularized by embedding flow control components with self regulating capabilities to ensure that every allocation of water resources can be accurately mapped to the physiological threshold of crops.

This deep supply-demand adaptation not only improves the granularity of the configuration scheme, but also provides a reliable physical and chemical basis for the subsequent implementation of cross regional dynamic water rights replacement. This requires the establishment of a comprehensive water distribution network within the irrigation area, utilizing backbone channels, regulating gates, and final canal systems to form a hierarchical and responsive hardware system. In terms of configuration rules, it is necessary to develop refined water allocation quotas based on the different growth stages of crops, and dynamically adjust irrigation priorities in combination with the actual water resource carrying capacity of the receiving area. This kind of agricultural water conservancy planning based on the concept of systems engineering can maximize the potential for water conservation, transform the inefficient loss of irrigation water into strategic resources that can be allocated, and alleviate the pressure of water competition in the industrial and ecological fields.

In the process of deepening the logic of resource allocation, it is necessary to pay close attention to the precise control of water fertilizer coupling within the irrigation area. The traditional single water distribution model often ignores the deep impact of nutrient element migration with water on soil environment. Therefore, in modern agricultural water conservancy planning, the water distribution backbone network should be functionally upgraded and integrated with water and fertilizer integrated control units. While implementing precise fertilization, the planning also needs to be coupled with a mathematical model of dynamic migration of soil salinity. By adjusting the combination of irrigation frequency and intensity, abnormal accumulation of salinity in crop roots can be prevented. This type of deep engineering regulation requires the system to have real-time analysis capabilities for multiple parameters, utilizing instantaneous data feedback from conductivity sensors to automatically induce the water distribution system to execute rinsing or water control commands. Through this micro simulation of soil physical and chemical environment, the function of hydraulic engineering has evolved from a single "water transport" to "farmland habitat optimization", fundamentally enhancing the marginal output capacity of cultivated land. This means that the system not only needs to accurately deliver water at the spatiotemporal scale, but also needs to use automated dispensing equipment to dynamically ratio water and fertilizer concentrations based on the nutritional status of crops. This deep coupled configuration system requires the water conservancy system to have extremely high flow stability and pressure regulation accuracy. Through efficient water-saving terminals such as micro drip irrigation or sprinkler irrigation, water and fertilizer resources are directly applied to the root zone of crops. This not only significantly reduces the risk of groundwater pollution caused by nutrient loss, but also enhances the output value of unit water volume through intensive resource utilization, providing a key technical pillar for improving the quality and efficiency of water conservancy engineering systems in the agricultural field.

The engineering design of intelligent irrigation systems must emphasize the deep integration of hardware facilities and digital management platforms. In the irrigation grid of the water receiving area, monitoring points based on the Internet of Things should be densely arranged to form a data perception layer covering the entire irrigation area through real-time collection of soil moisture, groundwater level, and microclimate parameters. In order to improve the data processing efficiency of the perception layer, edge computing gateways need to be introduced in the planning to preliminarily clean and extract features of massive environmental parameters, so as to ease the computing pressure of the cloud platform and improve the system response speed. This distributed computing architecture ensures that irrigation instructions can still be accurately issued to each end effector even under complex operating conditions such as network fluctuations[8]. In addition, the system also needs to integrate a high-precision hydraulic simulation module, which can automatically correct the gate opening and pump frequency by real-time calculation of the water level fluctuation mechanism in the canal system, in order to offset the hydraulic oscillation caused by the sudden increase in water distribution demand. The configuration center analyzes these massive data and uses artificial intelligence algorithms to predict the effective rainfall and evaporation intensity in the future, thereby automatically generating precise irrigation plans for different planting units. The implementation of this scheme relies on automated execution mechanisms such as electric control valves, intelligent water pump stations, etc., achieving full process digital control from water source extraction to field irrigation. Through this approach, water resource allocation not only achieves precise delivery in space, but also achieves precise calculation in scale, significantly improving the comprehensive irrigation guarantee rate and water production rate of agricultural water conservancy and hydropower projects.

In addition to the intelligence of terminal hardware, the resilience of the configuration system is also reflected in its ability to dynamically regulate heterogeneous water sources. In modern agricultural water conservancy planning, an engineering model of "three water" joint regulation of rainwater, surface water, and groundwater should be established. By configuring small distributed water storage projects around the plot, instantaneous capture and on-site storage of surface runoff during heavy rainfall can be achieved. This auxiliary engineering can quickly fill the water shortage through an intelligent switching system when the water receiving area encounters conventional channel water supply maintenance or drought peak, thereby reducing the single dependence on the backbone hub configuration scheme.

In addition, the configuration planning of agricultural water conservancy systems also needs to have a high degree of ecological compatibility and resource cycling. In modern engineering schemes, a secondary allocation mechanism for water resources should be established through the planning and design of field drainage collection systems and recycling projects. The excess water from farmland irrigation can be collected, precipitated, and biofiltered before being reintroduced into the regional configuration system for irrigation of non sensitive crops or replenishment of landscape water bodies. In the construction of this cyclic system, it is necessary to introduce automated interception technology based on water quality feedback, monitor the salt and chemical indicators in the effluent through online sensors, and ensure that the recycled water source meets safety configuration standards. This type of deep resource excavation requires the engineering layout to perfectly match the natural slope, utilizing low-energy gravity flow water diversion technology to accurately direct agricultural wastewater to artificial wetlands or ecological buffer pools for deep purification. This not only improves the microcirculation system of the water receiving area, but also provides important endogenous power to cope with seasonal shortages in long-distance water transfer projects. This closed-loop configuration approach not only reduces the impact of agricultural non-point source pollution on river systems, but also significantly increases the number of times water resources are recycled per unit. At the level of water rights trading and management, intelligent metering systems provide technical tools for refined quota management, enabling traceability of the flow, magnitude, and cost of every drop of water. This agricultural water conservancy configuration system, which integrates engineering physics optimization, intelligent algorithm regulation, and circular utilization mechanisms, is not only an important engineering support for China's food security, but also a concrete manifestation of the modernization, intelligence, and greening of water conservancy and hydropower engineering system planning.

6. Conclusion

In summary, the allocation and planning of water resources in water conservancy and hydropower engineering systems is a complex system engineering that involves natural laws and social needs. This article deeply explores the core aspects of configuration theory, simulation, and intelligent irrigation of farmland, and clarifies that modern water conservancy planning should be guided by systems theory and rely on information technology to improve the accuracy of resource regulation. Research has shown that scientific allocation schemes can not only effectively alleviate regional supply-demand contradictions, but also achieve the optimal balance of social and economic benefits while ensuring ecological flow. In the future, with the deep integration of perception technology and intelligent algorithms, water resource management will evolve towards a more dynamic and refined direction. By building a modern water network system that is complementary and interconnected from multiple sources, water conservancy and hydropower projects will undoubtedly better play their strategic support role as infrastructure, laying a solid foundation for the sustainable development of river basins and the efficient utilization of resources.

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