Study on Optimal Operation of Inter-Basin Water Transfer Project Considering Uncertainty of Hydrological Forecast based on Multi-Objective Optimization Method

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Abstract. The shortage of water resources has become an important factor restricting economic and social development, and optimizing the inter-basin water transfer project is the key to solve the shortage of water resources. The purpose of this paper is to study the optimal operation of inter-basin water transfer project based on multi-objective optimization method considering the uncertainty of hydrological forecast. In this paper, a multiple linear regression algorithm is proposed. Based on this study, the experimental results of optimal operation of interbasin water transfer projects based on the uncertainty of hydrological forecast are analyzed. The experimental results in this paper show that the overall change of the forecast optimal dispatch chart considering the uncertainty of hydrological forecast is similar to the traditional optimal dispatch chart, the difference is that it incorporates hydrological data into the forecast, so that the current available water can be more accurately grasped. Therefore, in the flood season, the division of the guaranteed output area and the increased output area is clearer and more reasonable. Moreover, the forecast optimization dispatching chart considering the uncertainty of hydrological forecast can effectively improve the calculation of guarantee rate, which is of great significance to solve the urban water supply problem.

Keywords: Inter-Basin Water Transfer; Multi-Objective Optimization; Hydrological Forecasting; Optimal Operation; Comprehensive Benefits.

1. Introduction

Water resources planning is a level of water resources management, and its purpose is based on the current (annual, monthly, ten-day or less) water resources allocation and project implementation. In the past, research on flood control, power generation, farmland irrigation, urban domestic water supply, industrial water supply, shipping and other aspects of the river basin mainly focused on the scheduling of a single reservoir or reservoir. Due to the continuous growth of regional water consumption, with the expansion of water supply scale, the water supply of a single reservoir has been unable to meet the needs, and the inter-basin water transfer project needs to be optimized. In the inter-basin water transfer project, considering the uncertainty of hydrological forecast is of great significance to improve the water resources utilization and water transfer benefits of the inter-basin water transfer project.

Zhang C. has established a theoretical analysis framework considering the trade-off between water supply benefits and water transfer costs in order to solve the real-time operation problem of inter-basin water transfer projects. First, the optimal decision of the reservoir is discussed. Then, the influence of the uncertainty of the prediction information on the reservoir operation is studied, and based on the acceptable risk of water shortage and overflow, the prediction information utilization criteria are established [1]. Wan Wenhua built a joint optimization operation model, taking into account water supply and transportation, and put forward the concept of "shape constraint" [2]. Guo Y. In order to overcome the shortcomings of the original multi-objective unordered leapfrog algorithm (MOSFLA), which has poor diversity and is easy to fall into local optimal solution, proposed a multi-objective quantum unordered leapfrog algorithm based on real quantum coding, improved quantum gate update strategy and dynamic external archive set. The model is solved by MQSFLA to formulate the best operation plan of the project. Compared with the original MOSFLA, MQSFLA has better diversity and convergence ability, and is more effective in the synergy of water supply and water pump under different conditions [3].

Through the research and analysis of the experimental results of the optimal operation of the inter-basin water transfer project based on the uncertainty of hydrological forecast, this paper draws the following conclusions: compared with the traditional optimal operation diagram, the forecast optimal operation diagram takes into account the uncertainty of hydrological forecast, and has higher economic efficiency, more universality and universality in the formulation and expression of rules.

2. Based on Multi-Objective Optimization Method

2.1 Inter-basin Water Transfer Project

The spatial distribution of global water resources is unbalanced, especially the distribution of land, population and mineral resources. To solve this problem, it is necessary to establish a cross-basin water transfer project [4-5]. Reservoir regulation, also known as reservoir regulation, refers to the use of the regulation and storage capacity of the reservoir to realize the regulation and storage capacity of the reservoir, change the time distribution of natural runoff, and store water in a planned way, so as to maximize the water demand of various departments and achieve the maximum comprehensive benefits [5-6].

Inter-basin water transfer is a kind of water transfer from different watersheds to different watersheds to meet the water demand of water shortage areas [7-8]. Due to the uneven distribution of natural rainfall in time and space, there is a huge difference in water surplus and shortage between different watersheds, which limits their economic, social development and people's life in arid areas. In order to meet the needs of water resources in arid areas, more than two water diversion projects can be adopted to divert water from the Fengshui River basin to promote the economic and social development in arid areas [9-10]. In addition, projects such as diverting water from Luan to Tianjin, diverting water from the Yellow River to Qingdao, and Dongshen water supply are also under construction.

2.2 Management Status of Interbasin Water Transfer Project

With the development of China's inter-basin water transfer project, a series of problems and contradictions have emerged in the construction and management of China's water conservancy and hydropower projects, which has a great impact on the benefits of the entire project [11-12]. Therefore, effective measures should be taken and corresponding governance mechanisms and methods should be formulated to solve the management and development of inter-basin water transfer projects.

(1) The relationship of water resources allocation is relatively complex

In the process of dispatching, executing and controlling inter-basin water transfer projects, with the reallocation of natural resources, it will have a corresponding effect on the process of transfer-in and transfer-out and the economic and social development of the regions along the line [13]. In each link of upstream, transfer, dispatching and left and right bank projects, the enterprise benefits must be considered. However, according to different actual conditions such as project size, resource allocation and water transmission, different decision-making difficulties and obstacles may occur in the specific implementation and adjustment process, which makes the adjustment difficult and long-term.

(2) Difficulty in dispatching operation management

The project involves not only the dispatching and use of drinking water, but also flood control and drainage, environmental protection, shipping and other fields. Especially in water diversion projects in plain areas, drinking water needs to be taken through natural runoff, which has certain randomness. The rivers along the project are vertical and horizontal, and the drainage and irrigation methods are different. The functions of water conservancy, flood control, drainage, shipping and environmental protection are intertwined, and problems will inevitably occur in the process, which makes the scheduling, operation, supervision and operation of the project more complicated.

(3) Water resource management and complex relationship between supply and demand

The investment scale of inter-basin water transfer project is large. According to relevant policies, the cost of water transfer is higher than that of the transfer area. For most of the transferred areas, the inter-basin water transfer project is a public welfare project with the goal of improving the water supply guarantee rate. Due to water price and other reasons, some of the transferred regions have chosen environment and agriculture instead of external transfer. For example, the projects of diverting water from the Yellow River to Qinghai and the Yellow River to Shanxi are all due to the high water price, resulting in the reduction of the actual water supply and the increase of the idle rate of the project capacity. Some problems will also be encountered in the operation and management.

2.3 Multiple Linear Regression Algorithm

Regression analysis is a mathematical model based on random variables, which makes statistical inference on the mathematical relationship between random variables. The multiple linear regression method is used to predict the runoff, focusing on the determination of prediction factors. Generally, the factors that have significant impact on runoff are: precipitation in this period, precipitation in the previous period, runoff in the previous period, and runoff in the previous period. In addition, the winter snowfall in Hengren also played a significant role in the spring flood production in March and April.

The formula of multiple linear regression model is as follows:

$$h = t_1 x_1 + t_2 x_2 + \cdots + u \tag{1}$$

Where, $t_1, t_2, \cdots, u$ is the regression coefficient, $x_1, x_2, \cdots$ is the prediction factor, and h is the prediction object.

In statistics, the least square method is the main parameter estimation of the linear model. This method is also used to estimate the regression coefficient method. The least squares method aims at minimizing the square deviation between the measured runoff value h_i and the estimated value obtained from the regression line.

$$min \sum_{i=1}^{n} (h_i - \bar{h_i})^2 \tag{2}$$

3. Experimental Results of Optimal Operation of Inter-Basin Water Transfer Project based on Uncertainty of Hydrological Forecast

3.1 Overview of Basin Water Transfer

The research object of this paper is Reservoir A, which is located in the middle of the basin and belongs to the head of the cascade reservoir group. The control basin area above the dam site is 104003 km^2. It is a comprehensive utilization hub integrating power generation, flood control and irrigation. The basin is located at 124° 43 '- 126° 50' east longitude and 40° 40 '- 42° 15' north latitude in the northern margin of northeast China. It has good vegetation and annual precipitation of 860 mm, while the precipitation from June to September accounts for more than 70%. The average annual runoff of reservoir A is 0.52, the major flood is mainly from the end of July to the middle of August, and the secondary flood peak is mainly within 3 days, up to 80%. The flood process is steep rise and fall. From November to the end of March or early April of the next year, winter is dominated by snowfall. In addition, in late March or early April, the temperature becomes warmer and the snow melts, forming a spring flood.

Reservoir A is a year-round regulated reservoir with a total storage capacity of 3.46 billion cubic meters, a total installed capacity of 225 million kilowatts, and a power generation capacity of 33000 kw. The maximum water level is 290 m, the normal water level is 300 m, and the flood control limit water level is 300 m. Located in the northern margin of northeast China, it is an area with excellent vegetation. At the end of March or the first ten days of April, the snow melted, forming a spring flood.

After May, the soil moisture content is high, and the runoff generation mode is mainly accumulation and runoff generation; In the non-flood season (November to April of the next year), the runoff change is relatively stable, mainly with ebb tide. The runoff caused by snowfall from November to February is relatively small, while the impact of snow melting and rain is greater from March to April.

This paper compares the operation chart considering the uncertainty of hydrological forecast with the conventional operation chart, and studies and analyzes the advantages of the optimal operation of the interbasin water transfer project considering the uncertainty of hydrological forecast. Based on the current conventional dispatching diagram, the conventional optimal dispatching diagram of reservoir A explores the advantages of dispatching considering the uncertainty of hydrological forecast under 1.5 times of the output line and guaranteed output line.

3.2 Rationality Analysis of Dispatching Diagram Considering the Uncertainty of Hydrological Forecast

In the scheduling chart, the ten-day period is taken as the calculation period (that is, the whole year is divided into 36 periods). The progressive optimization algorithm (POA) algorithm is used to optimize the conventional optimal scheduling chart and the forecast optimal scheduling chart based on the measured runoff data from 1970 to 2000. Finally, the existing optimal scheduling chart is obtained by manual correction on the optimization results.

Whether the dispatching degree diagram is reasonable depends on whether the dispatching rules it represents are consistent with the runoff characteristics of the study area. In the dispatching diagram, the guaranteed output line has a great impact on the guarantee rate of the hydropower station, reflecting the storage and discharge conditions of the reservoir, and increasing the output line to control the annual power generation of the hydropower station system.

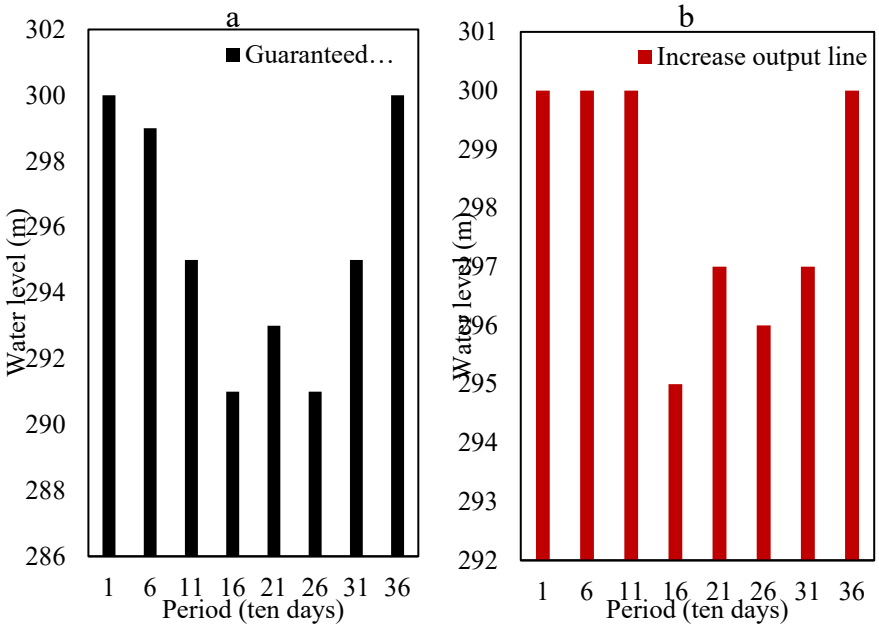


Figure 1. Water level change of guaranteed output line and increased output line under conventional optimal dispatching diagram

As shown in Figure 1 is the conventional optimal dispatching diagram, where Figure 1 (a) is the water level change of the guaranteed output line under the conventional optimal dispatching diagram, and Figure 1 (b) is the water level change of the increased output line under the conventional optimal dispatching diagram. Figure 2 is the forecast optimization dispatching diagram, in which Figure 2 (a) is the change of organic content standard (OCS) of guaranteed output line under the forecast optimization dispatching diagram, and Figure 2 (b) is the change of OCS of increased output line under the forecast optimization dispatching diagram.

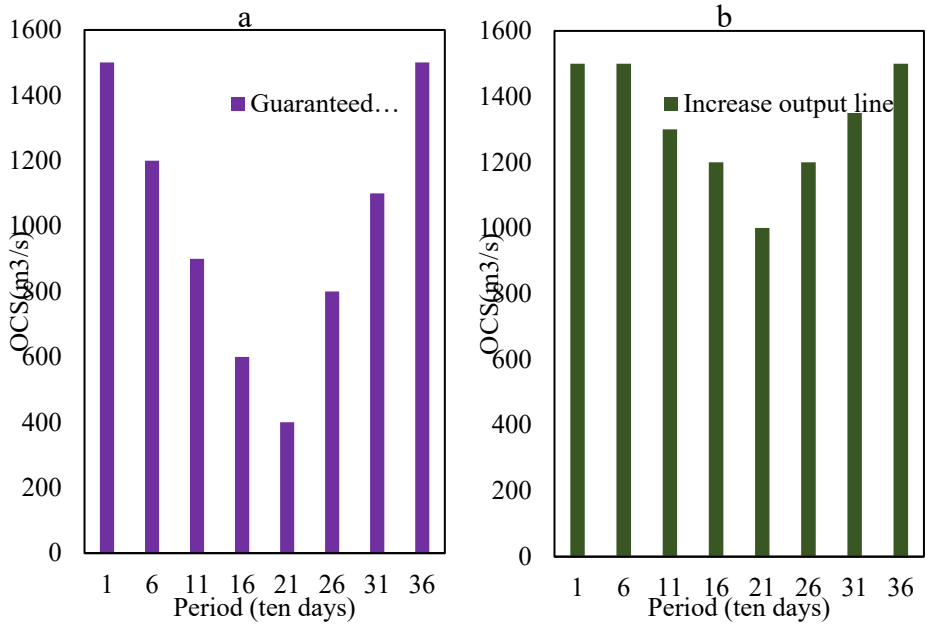


Figure 2. OCS changes of guaranteed output line and increased output line under the forecast optimization dispatching diagram

Compared with Figure 1 and Figure 2, the forecast optimization dispatching diagram considering the uncertainty of hydrological forecast is similar to the conventional optimization dispatching diagram in the overall change. The difference is that the forecast dispatching diagram takes into account the hydrological forecast information and has a more accurate grasp of the current available water, so the division of the guaranteed output area and the increased output area in the flood season is more clear and reasonable.

Table 1. Calculation results of guarantee rate of three dispatching charts

scheduling model	Runoff information	Average annual power generation(10^6KWH)	Guarantee rate(%)
General dispatching diagram	nothing	386.52	61.39
Forecast optimization dispatching chart	prediction	418.74	88.33
Measured drawing	Measured	442.33	90.14

As shown in the calculation results in Table 1, the guarantee rate of the forecast optimized dispatching chart is higher than that of the conventional optimized dispatching chart, and is closer to the guarantee rate under the actual calculation. Through the comparison between the actual rainfall data prediction and the actual observation data, it is found that the prediction effect of the actual rainfall flow is better than the prediction of the predicted rainfall, which is due to the uncertain factors in the rainfall process.

3.3 Optimal Scheduling Analysis

The forecast optimized dispatching diagram considering the uncertainty of hydrological forecast is more reasonable than the conventional optimized dispatching diagram in the formulation and expression of rules, and has higher power generation efficiency, and is more applicable and widely popularized. Considering the uncertain factors of hydrological prediction, an optimal operation of inter-basin water transfer project is proposed, which can effectively improve the calculation efficiency of water and soil conservation rate and provide a strong basis for solving the urban water supply problem.

4. Conclusion

With the rapid development of water conservancy, a series of major engineering measures have been introduced, and China's hydropower projects have changed from "construction" to "management". The research results of reservoir operation theory can significantly improve the flood control and profit benefits under the condition that the scale of the reservoir project remains unchanged, so it is highly concerned by researchers. The decision of reservoir operation depends on the existing water resources and the future available water, so the prediction of rainfall must be considered in the reservoir operation. This paper studies and analyzes the optimal operation of inter-basin water transfer project based on multi-objective optimization method and considering the uncertainty of hydrological forecast. The test results show that the optimal operation chart considering the uncertainty of hydrological forecast is of great significance for inter-basin water transfer.

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