Fight for Our Reservoir

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Abstract: With climate change, water supply from dams and reservoirs in many regions continues to decline. In order to avoid the problem of continued drought in the Colorado Basin that may occur in the future, we are currently implementing reasonable and sustainable water resources based on Lake Mead and Lake Bowmill in Arizona, California, Wyoming, New Mexico and Colorado distribution plan. Model 1: We established a linear programming model according to the water consumption in industry, agriculture, domestic water and power generation of the five continents in question. But in the subsequent problem solving, we found that the water content of Lake Powell and Lake Mead were different in different periods. In response to this problem, we adopted the method of hierarchical discussion, and successively carried out modeling solutions for three different periods.
Keywords: Linear Programming Model; Time Series Analysis; Multi-Objective Linear Regression; Sensitivity Analysis

1. Introduction

1.1 Problem Background

Water is the source of life, the essential of production, and the foundation of ecology. Promoting water conservancy and eliminating water hazards are related to human survival, economic development and social progress. It is necessary to effectively enhance the support and guarantee capacity of water conservancy, and realize the sustainable use of water resources to a large extent. [1]

River runoff is the earliest water resource utilized by human beings, and human civilization also depends on water. The Colorado River is an important source of water resources in the southwestern United States, but the climate difference within the Colorado River Basin is obvious, and the downstream area is in a semi-arid to arid climate zone. At the same time, there are many cities in the downstream area. With the rapid increase in the population in the downstream area, the demand for urban water is also increasing. More than 30 million people rely on the Colorado River for their daily water sources. There are more than 20 water conservancy dams in the Colorado River Basin, mainly used to generate electricity and control the flow of water. [2]

As the drought continues, the amount of water from dams and reservoirs is dwindling, and storage may not be able to meet the water needs of these areas. In addition, low water flow reduces the amount of electricity generated by electricity generation, leading to power outages in some areas. If the water level in the reservoir behind the dam falls below the minimum safe water level, hydroelectric power generation stops. If drought conditions in the Colorado River Basin continue, at some point in the future there will be insufficient water to meet basic demand-side water and power generation needs. Therefore, it is urgent to develop a rational water allocation plan for current and future water supply.

1.2 Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, we need to solve the following problems:

Task 1: Created a model to determine optimal tandem pumping for Lake Mead and Lake Powell, subject to 5-state water demand constraints.

① The demand is fixed, and a model is used to realize the pumping problem for the dam to operate when the water level of Lake Mead is M and the water level of Lake Powell is P.

② Under the condition of no additional water source, explore the time it takes to meet the demand.

③ Predict the amount of additional water that will be withdrawn in the future to meet demand.

1.3 Our Work

We need to develop a reasonable water allocation plan for current and future water supply conditions to meet the basic water and electricity needs of local residents.

For Task 1 , we established a state satisfaction model of water resource allocation for different periods, namely, Lake Powell with water level P and Lake Mead with water level M, by analyzing the recent water use in each state. Determine the pumping volumes of the two reservoirs at different times. And optimize our model to accommodate reservoir pumping and reservoir operating time when demand does not change but no additional water replenishment and when determining increased reservoir pumping and dam work over time through time series analysis, Winter addition models, etc. time

For Task 1, we use the linear programming problem, which is a model that uses mathematical programming methods to determine the optimal solution. In the case of a certain demand, through their respective competing interests, to determine the water consumption of industry, agriculture, domestic water and hydropower generation The problem of quantity allocation, rational allocation of water resources can be transformed into the problem of maximization.

For Task 1, we consider the water supply into two cases, which cannot be met by pumping water from the res-ervoir, and when the reservoir is completely unable to provide resources to industry, agriculture and residents on time and on demand due to severe drought. For the first case, we propose strategy 1: improve resource utilization as much as possible. For the second case, we propose a second strategy: build a loss function and minimize the loss function to reduce the loss caused by drought.

For Task 1, we explored the supply of water in the reservoir under conditions of changing water demand, changing electricity demand and thus changing water demand, and in the presence of other water conservation measures.

2. Assumptions and Justifications

In order to simplify the model, we make the following assumptions:

Evaporation from rivers and reservoirs is not considered.

In the weather forecast of daily life, little attention is paid to the actual evaporation because it is difficult to actually measure it. In scientific research, the change in the latent heat of phase transition required for water evaporation is used to estimate the actual evaporation. Up to now, it is impossible to give a large and accurate value of the actual evaporation, so we ignore the effect of evaporation.

The demand for water other than residential water, agricultural irrigation, and industrial water is not considered. It is assumed that electricity consumption by states is not affected by factors of the spatial distribution of water resources. Assuming that the water drawn from Lake Mead supplies only New Mexico, Arizona, and California, and that Lake Powell's water draws only supplies Wyoming and Colorado.

3. Task one

3.1 Analysis of model I

In order to achieve the best series configuration of Glen Canyon Dam and Hoover Dam and realize close coordination of operation, so as to ensure the normal production and living activities in the five continents of Arizona (AZ), California (CA), Wyoming (WY), New Mexico (nm) and Colorado (CO). Now we need to plan the water supply demand of Glen Canyon Dam and Hoover Dam. [3]

By consulting the hydrological characteristics of the lower Colorado River, it is found that the river water level changes greatly seasonally. Each year is divided into high water period, low water period and other periods are normal water period. Therefore, for the first part of task 1, we calculate the supply and demand situation, and the modeler is divided into three situations. [4]

Wet season: it is a period when river water flow mainly depends on rainfall or snowmelt. Generally, it is in the rainy season or the period when the temperature continues to rise in spring. At this time, the river is rich in water and lasts for a long time.

Dry season: refers to the period when the surface water flow in the basin is exhausted, which is a period when the water source is mainly replenished by groundwater. In addition, the duration of dry season in a year varies with the natural geography and meteorological conditions of the basin.

Normal water period: refers to the period when the river is at normal water level

For water resources, we consider that water resources will be used for agricultural irrigation, domestic water and industrial water. By querying the monthly water volume of five continents based on the above indicators, we can get the average water consumption of each state in each period. By querying the annual power consumption of five continents, we can obtain the total power consumption of each state every month, query the proportion of hydropower demand in each state, and then obtain the total power demand of hydropower in each state in three periods. On this basis, considering that the actual extraction amount of each reservoir is the water demand of each state minus the precipitation in three periods, in order to solve the problem of the best pumping amount of the two lakes, At this time, we establish a satisfaction model based on the use demand of hydropower in various states and the water supply of reservoirs.

3.2 Establish and solve the water and electricity demand modal of each state

3.2.1 Establish and solve the water and electricity demand model of each state

An important issue in the development and utilization of water resources is the relationship between water supply and demand, that is, the contradiction between the actual supply capacity and demand of water resources. Under the premise of ensuring the ownership of water resources, how to achieve the balance between supply and demand is one of the important objectives of water resources planning and management. The availability of water resources is restricted by the quantity, temporal and spatial distribution of water resources and the capacity of water supply projects in a specific range. The actual water demand is related to production development, people's living standards, industrial structure and water utilization efficiency. The available water supply and actual demand in different periods are variable. Therefore, we establish a model according to the demand of water resources in each period, so as to find the best allocation of water resources.

First, by consulting the average monthly water resource demand value of each state in the United States, as shown in Figure 1 [5]. Referring to the rainfall data of various states in the United States, as shown in Figure 2, We consider that the precipitation will not affect the power consumption of each region. Then the total demand of each of the five states can be calculated through equation. Then, Where w represents the total water demand of the above five states in this period, R represents the total rainfall of the above five states in this period, and e represents the total power consumption of the above five states in this period[6].

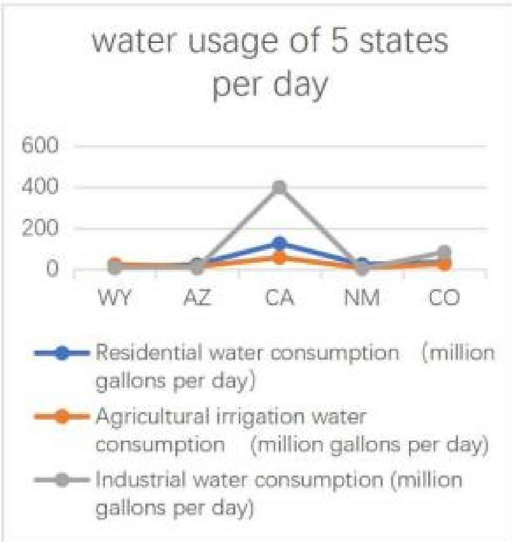

Figure 1 water usage of 5 states per day [6]

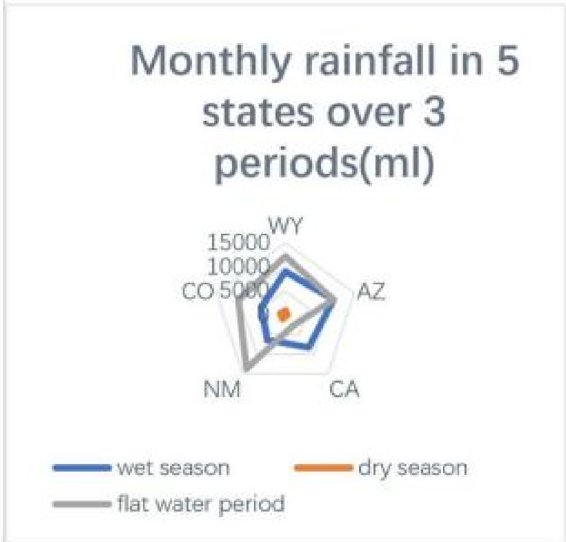

Figure 2 Monthly rainfall in 5 states over 3 period [7]

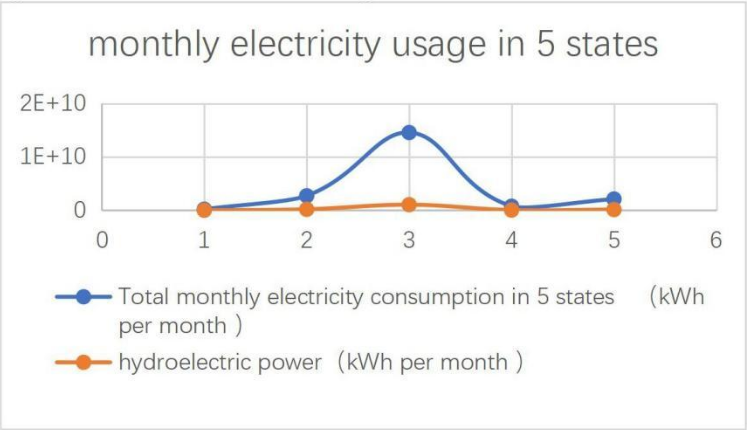

Figure 3 monthly electricity usage in 5 states

Referring to the map of the Colorado River Basin, it is found that Glen Canyon Dam is located upstream of Hoover Dam, so the water from Glen Canyon Dam provides part of the water input to hoover dam. Therefore, if the pumping capacity of Hoover Dam (Lake Mead) cannot meet the needs of the three states passing through it, the insufficient water will be pumped by Glen Canyon Dam (Lake Powell), As a supplementary part, it enters Lake Mead to ensure that the demand is met and the remaining water storage in the reservoir is within the safe storage range. At this time, the two dams must cooperate closely and be used in series to obtain the maximum benefit[7].

According to the analysis of Glen Canyon Dam (Powell Lake), part of the water resources in Powell lake are used for the water resource demand of 5 states, part for the power generation of the dam, part for the Hoover Dam, and part for the remaining storage capacity of the reservoir. some are used for power generation, and some are the remaining storage capacity of the reservoir, respectively.We believe that the water resources used for power generation cannot be quickly put into other uses, so we don't consider its use for the time being.In the hydropower project, the power generation is related to the water volume and water level of the water resources used. At this time, the water level of Mead is m and the water level of Powell lake is p. then the water volume of Mead lake can be obtained from equation[8].

According to Newton's law, the electric energy of hydropower generation is transformed from the potential energy of water. By querying the data, we assume that the hydropower conversion efficiency is 76%.

3.2.2 Establish the judgment model of matching degree between pumping capacity and demand

The remaining storage capacity of Lake Powell and Lake Mead must be within the safe storage depth of the reservoir. Then, by comparing the remaining and safe water storage of Lake Mead, we can judge whether it is necessary to draw water from Lake Powell into Lake Mead to ensure that the demand is met[9].

The safe water storage capacity in three periods can be obtained by querying the data as follows:

Table 1: Reservoir water volume in three periods

water level	Lake Mead	Lake Powell
Maximum safe water	53200000000	33000000000
Minimum safe water volume	204867080	246853760
Safe water volume range	105.139≤퓶4≤152	141≤퓡3≤183,921

We obtained the reservoir storage capacity in the rainy season, dry season, and season by querying the data. The specific data are as follows. The optimal water resources allocation scheme can be obtained one by one according to the water storage

Table 4: Total reservoir water storage in each period

Lake	Wet season	Dry season	the period when a river is at its normal level
Lake Powell	1102700000	922177200	1016223600
Lake Mead	972800000	672889600	822848000

3.3 Salving the Model 1

In terms of the demand of each state, considering that the higher the hydropower conversion efficiency, the higher the utilization rate of water resources. Taking the minimum of hydropower conversion as the standard, we establish a satisfaction model for the allocated hydropower resources according to the needs of each state[10].

By consulting the topographic maps of the two lakes and five states and the southwest of the Colorado River, we now assume that the supply model is that the extracted water of Lake Powell gives priority to the water and power needs of Wyoming and Colorado, and the extracted water of Lake Mead gives priority to the water and power needs of New Mexico, Arizona and California According to the calculation results, compare and analyze whether the remaining water volume of the reservoir in the three periods is in the safe water level.

The available data are shown in the figure 4:

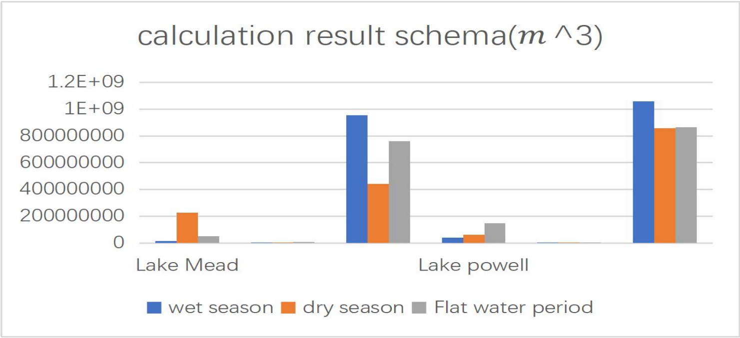

Figure 4 Calculation result schema

In conclusion, by comparing the remaining water volume with the minimum safe water volume, it is concluded that the water volume of the two reservoirs in three periods can meet the demand, so it is not necessary to calculate the water supply from Glen Canyon Dam to hoover dam.

A total of 17370413 lake water needs to be extracted from Mead Lake in wet season. Similarly, it can be calculated that 231082927.7 lake water needs to be extracted from Mead Lake in dry season and 62263938.344 lake water needs to be extracted from Mead Lake in normal season. A total of 43175029.33 lake water needs to be extracted from Powell Lake in wet season, 64333032 lake water needs to be extracted from Powell Lake in dry season and 150362838 lake water needs to be extracted from Powell Lake in normal season.

3.4 Analysis of model result

According to the historical rainfall records and the water level records of Colorado basin, the climate difference within the basin is obvious, and the reservoir water level is low in the dry season. Combined with the aggravation of drought in this region in recent years, we suggest that model I can operate and adjust for many times during the dry season to detect the water volume, so as to ensure that the water storage capacity of the reservoir can be within the safe range. For the flood season, the current water level of the reservoir is low, and there is still a large flood storage space from the maximum flood storage capacity of the reservoir. The number of re operation of the model can be appropriately reduced. In this regard, the reservoir can store flood and replenish dry water, and achieve the maximum water storage on the basis of meeting the demand, so as to alleviate the problem of water level reduction caused by drought[11].

3.4.1 Calculation of dam working time

Under the fixed demand, when there is no additional water supply, we should determine the working time of the dam to meet the allocation of water resources.

Based on Model 1, considering that there is no additional water supplement (rainfall, etc.), we use the monthly average data as the basis, so the water demand of the five states is the data queried in model 1.

According to the query data, the flow velocity at the outlet of Hoover Dam (Lake Mead) is 11000, and the flow velocity at the outlet of Glen Canyon Dam (Lake Powell) is 5900. The required operation time of the dam can be obtained through formula.

Finally, we can conclude that Glen Canyon Dam (Lake Powell) needs to operate 32756s (9.099h) and Hoover Dam (Lake Mead) needs to operate 127498s (35.41h) every month.

3.4.2 Dam working strategy

Now we provide two dam operation strategies for dam staff to choose.

Strategy 1: considering the daily water demand of the water supply City, we evenly allocate the total water supply time of the reservoir every month to each day, and combined with the water and electricity living habits of most residents, through equation (17), we suggest that the Glen Canyon Dam (Powell Lake) discharge 1091s (0.3H) and Hoover Dam (Mead Lake) discharge 4250s (1.18h) every day.

Strategy 2: because the two dams are not only a means to manage water supply, but also a place to improve people's play, leisure and entertainment. Combined with the working hours of the staff in the dam, we suggest that the weekly dam drainage strategy can be adopted to meet the water demand of the five states. Through the calculation of equation (17), it is suggested that the Glen Canyon Dam (Lake Powell) discharges 8189s (2.27h) per week and the Hoover Dam (Lake Mead) discharges 31874.5s (8.85h) per state.

3.5 Establishment and solution of model 3

By building a dam in the lower reaches of the Colorado River, cities in the southwest of the United States can obtain a certain supply of water resources. However, over time, the climate problems caused by human activities may make the water resources provided by the Colorado River to cities in the basin unable to meet people's needs. Here, we predict the precipitation from 2021 to 2026 through time series analysis, Finally, based on Model 1, the additional water volume required by the reservoir is calculated.

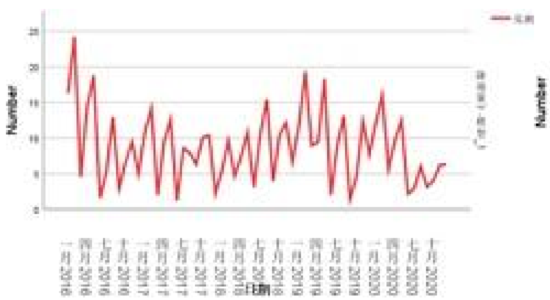

Figure 5 Time series analysis 1

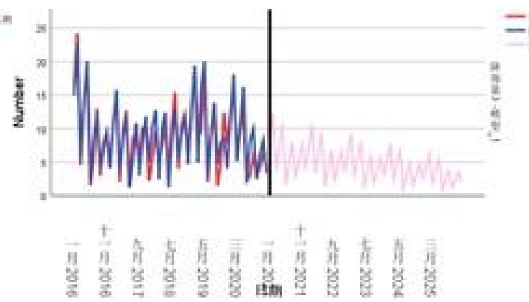

Figure 6 Time series analysis 2

Referring to the data, we can get the precipitation in the five years from 2016 to 2010. For the characteristics of non-stationary series with linear trend and periodic fluctuation, let the parameters constantly adapt to the changes of non-stationary series, and make a short-term prediction of the future trend, that is, using winter addition model. It can be predicted that with the increase of time, the precipitation data in the next five years are as follows

Assuming that the demand for water in production and living events does not change with time and is a fixed value, we can draw a conclusion only considering the change of water supply demand caused by the change of precipitation in the basins of the five states in the future.

The reduced precipitation is the additional water provided by the two reservoirs at this time.

However, in the future, with climate change, the situation may only worsen, making it difficult to accurately predict the rainfall in the Colorado River Basin in three periods. We plan to improve the Rainfall Calculation Model in model 1. Taking the precipitation forecast data in October 2021 as an example, calculate the additional water volume to be extracted in this period, set the additional water volume to be x, and the additional water volume can be obtained through equation.The prediction of water extraction in the next five years is the same, which will not be repeated in this paper. Finally, the required additional extraction water is obtained as shown in the table below:

Table 5: Lake Mead and Lake Powell draw additional water each month

year	2021-11	2022-9	2023-7	2024-5	2025-3

Pumping capacity	225.175	233.055	252.53	243.366	240.345

4. Result

As we all know, water is the source of life, the essential of production, and the foundation of ecology. But as the news goes, water levels in the two reservoirs we depend on are at record lows during the last major drought. The water in the reservoir has been decreasing year by year over the past decade, as shown in the figure below. When the drought will last for a period of time, the optimization of water resources allocation and the sustainable use of water resources are particularly important. In order to alleviate the problem of water resources, our team established a relevant mathematical model to solve it.

From the map, we can know that the production and domestic water in the five continents of Arizona (AZ), California (CA), Wyoming (WY), New Mexico (NM) and Colorado (CO) mainly comes from Lake Powell and Lake Mead. In our model, in order to better allocate water resources and reduce the loss of water during transportation. We assume that Lake Mead mainly supplies the surrounding states of New Mexico, Arizona, and California with total water (water and hydro); Lake Powell mainly supplies the total water of Wyoming and Colorado. On this basis, we use linear programming to build a water resource allocation model, and when a reservoir resource cannot meet the needs of the surrounding states, we will allocate water resources in two reservoirs in series. In our model, we divide a year into high-water, low-water and flat-water periods according to the amount of precipitation in order to solve the problem of different water demand in different periods. After calculating the total demand for water and rainfall, we applied the model to determine the amount of water that needs to be drawn from the reservoir. Use this result to guide the working hours of the dam to make efficient use of water and human resources without wasting.

The model of the first question, we also consider the effect of time. And using the Winter's additive model to optimize and forecast future rainfall, it figured out how much additional water would be needed to meet the states' needs. In addition, we also calculated the interest competition between general water use and electricity use water in order to maximize the benefits under the condition of a certain total amount.

Perhaps, you will also have such doubts as "what should we do if the water in the reservoir is not enough? There is no need to be overwhelmed by insufficient water. After the calculation of our model, we have provided some suggestions for the government to deal with. In addition, we calculated the water savings when using renewable energy technologies to generate electricity.

In summary, although we try to optimize the distribution or sustainable use of water. But water is the root of everything. None of us can forget that every drop of water at our fingertips is so precious. But water is the root of everything. None of us can forget that every drop of water at our fingertips is so precious.

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