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# Research on the Allocation of Water Resources under Unfavorable Climatic Conditions

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***Abstract:*** *In this paper, we develop three models to simulate the water resources allocation of Lake Powell and Lake Powell. Specifically, based on the objective function and constraints, a multi-objective programming model for hydropower balance is established. The distribution of 4 water quantities is obtained by genetic algorithm. In addition, we established a model for the optimal allocation of regional water resources, and we used the analytic hierarchy process (AHP) to obtain geographic location weights of 0.6 and 0.4 for Lake Mead and Lake Powell, respectively. Further, we establish the target model of the comprehensive benefit of water shortage, and obtain the optimal water resource allocation ratio under the condition of water shortage. Finally, a sensitivity analysis of the model was performed.*

***Keywords:*** *Hydropower balance, planning model, analytic hierarchy process (AHP), sensitive analysis*

## 1. Introduction

Water is one of the essential resources for human survival and development. Hydroelectric power generation converts water energy into electricity. It has become the mainstay of electrical supply. In recent years, some areas in the United States have been experiencing a shortage of water supply from dam and river reservoirs due to climate change, which has caused a power supply crisis. It is worth our attention that Glen Canyon Dam and Hoover Dam provide five continents with hydroelectricity. But in the early 21st century, this modern marvel of engineering faced an ancient enemy: prolonged drought in the American Southwest [1].

Water resource management refers to the optimal design and rational utilization of water resources system. The authors argue that a system with several reservoirs and supporting works on the same river, including its tributaries, is called a water resource system or reservoir complex [2]. River planning and water resource management are basically all about optimally designed systems for the rational use of water resources.

Reservoirs usually have multiple objectives, such as water supply, power generation, shipping, ecology, etc. different goals are contradict each other, so it is necessary to consider all goals and make trade-offs and trade-offs [3]. The potential energy of the water is converted into electrical energy and a motor-generator by a water turbine. Global-scale hydropower offers important advantages over most other power generation technologies [4]. Hydro is Renewable, reliable, clean, and essentially carbon-free, it represents a flexible peak-load technology [5]. Several emerging trends, including growing electricity demand, applied storage technologies for carbon capture, and the pursuit of energy-intensive water supply options, suggest that the conflict between energy and water may intensify in the years ahead, and the availability and quality of energy resources pose a serious threat [6].

In this paper, we build a programming model that satisfies the objective function and constraints. Then use the genetic algorithm to solve it. However, we use AHP to formulate criteria and assign weights. We plan for different levels of water scarcity and propose the best water allocation. Finally, we perform a sensitivity analysis on the established model.

## 2. Multi-objective Planning Model

Based on the look-up data [7], we obtained the water withdrawal and visualized the data, which is shown in Fig.1.

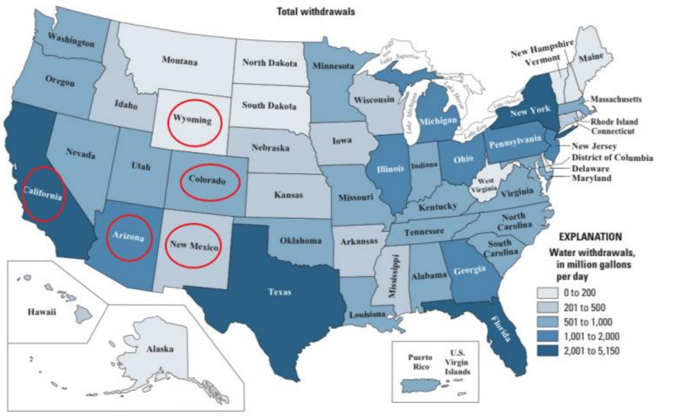

*Figure 1: Total withdrawals*

From the graph we know that California uses the most water, in the interval 2,001 to 5150. However, Wyoming uses the least, in the interval 0 to 200. New Mexico in the interval 201 to 500. Colorado in the interval 501 to 1,000. Arizona in the interval 1,001 to 2,000. We will use this information in the following. The various energy consumption of the United States in 2020 is shown in the Fig. 2. We learn the main distribution of water use in the five states based on [7], which is shown in Fig. 3.

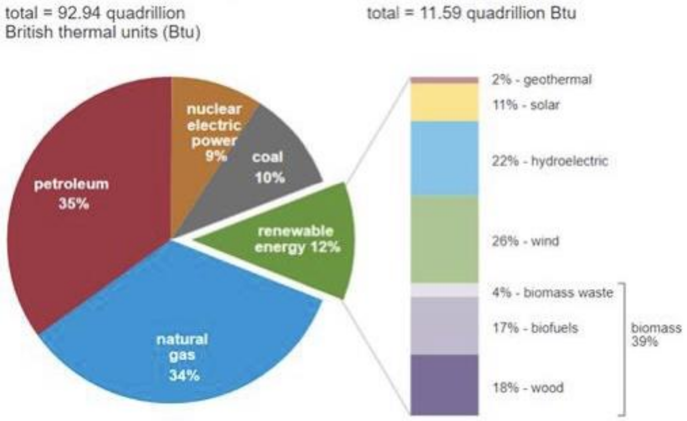

*Figure 2: U.S. energy consumption, 2020*

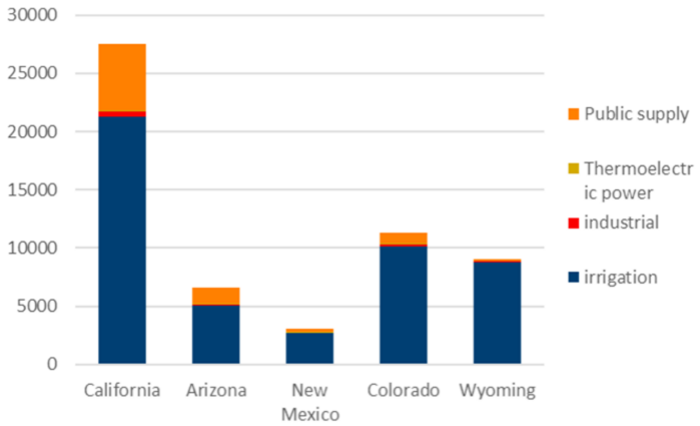

*Figure 3: Water withdrawal by five continents*

To simplify the model, we will consider only the primary allocation of water resources. We divide Glen Canyon Dam water resources into four categories: The fixed supply of water from five states, applied to hydroelectric power generation, flow to hoover Dam and Partial storage in the reservoir. In order, it is noted as a1, a2, a3, a3. And Hoover Dam water resources we divide into these four main categories: The fixed supply of water from five states, applied to hydroelectric power generation, Usage in Mexico and Partial storage in the reservoir. In order, it is noted as b1, b2, b3, b4. It is shown in Fig. 4.

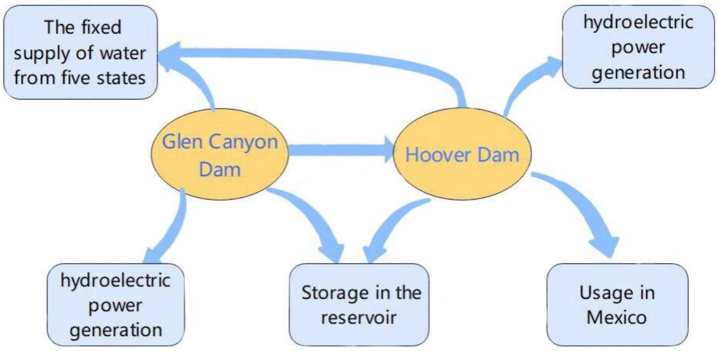

*Figure 4: Allocation of water resources between the two dams*

We can calculate the amount of electricity produced by hydroelectric power generation at Glen Canyon Dam is:

$$\mathrm{W}(powell) = a_2\rho(P + h_1)g\eta \tag{1}$$

The hydroelectric power generated by Hoover Dam is:

$$\mathrm{W}(mead) = b\rho(M + h_2)g\eta \tag{2}$$

Where $\rho$ is Water Density, $h_1$ and $h_2$ are the height of the dam, g takes 9.8, P is the water level of Lake Powell, and M is the water level of Lake Mead. $\eta$ is efficiency about 80%-90%.

Minimal water usage while meeting water demand can be expressed by the maximum value of electricity and water energy remaining after consumption. Thus the objective function is:

$$\text{Min z} = \frac{a_2\rho(P+h_1)g\eta + b\rho(M+h_2)g\eta - \sum y_i}{\sum y_i} + \frac{a_1 + b_1 - \sum x_i}{\sum x_i} \tag{3}$$

The objective function is:

$$\mathrm{z} = \frac{a_2\rho(P+h_1)g\eta + b\rho(M+h_2)g\eta - \sum y_i}{\sum y_i} + \frac{a_1 + b_1 - \sum x_i}{\sum x_i} \tag{4}$$

First, the values of general water consumption and power generation water consumption provided by the two lakes are randomly selected as the initial populations. After the initial populations are generated, they are screened based on their fitness, and the batch with the best fitness is selected to evolve generation by generation to produce increasingly better approximate solutions. In each generation, individuals are selected based on the size of their fitness in the problem domain, and a combination of crossover and variation is performed with the help of the genetic operator of natural genetics to produce populations that represent the new set of solutions, so that the results until the results meet expectations and the final water allocation results are obtained. Our algorithm will be shown in the Fig.5.

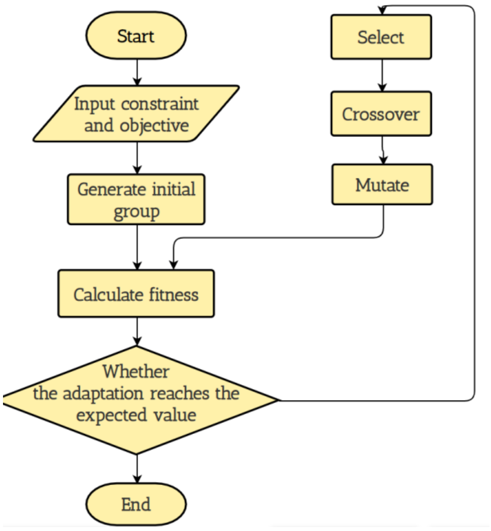

*Figure 5: Genetic algorithm flowchart*

We solve our model using the genetic algorithm to obtain four sets of solutions for a1, a2, b1, and b2. It is shown in the table 1.

*Table 1: Calculation results*

| | $a_1$ | $a_2$ | $b_1$ | $b_2$ | Total |
|---|---|---|---|---|---|
| M=360 m, P=1110m | 113 | 284 | 99 | 247 | 743 |
| M=312 m, P=1110m | 70 | 426 | 188 | 237 | 921 |
| M=360 m, P=1065m | 69 | 500 | 143 | 650 | 1362 |
| M=312 m, P=1065m | 69 | 260 | 143 | 510 | 982 |

From the table 1, we know that when M=360m and P=1110m, the required pumping capacity is 743. When M=312m and P=1110m, the required pumping capacity is 851. When M=360m and P=1065m, the required pumping capacity is 1362. When M=312m and P=1065m, the required pumping capacity is 982.

## 3. Regional Water Resources Optimization Allocation Model

Considering the long-term cycle of agriculture, this paper chooses a solar year as the unit length, considering the whole process of agriculture from sowing to harvesting to benefit from the water supply. The optimal allocation of water resources aims at achieving integrated and coordinated economic, social and agricultural development, and the goals are conflicting and competing with each other. After the analysis, we use The AHP to give geographic location weights of 0.6 and 0.4 to Middlesex Lake and Lake Powell, respectively. We give the schematic diagram of the hierarchy. It is shown in Fig.6.

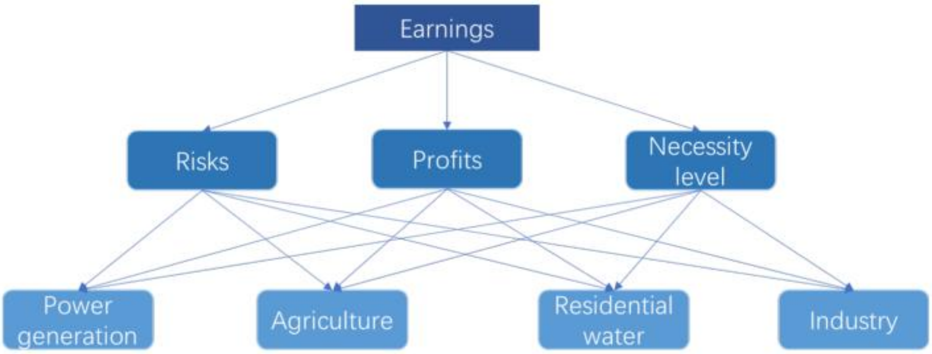

*Figure 6: Hierarchy schematic*

Using the square root method to solve for the weights of each indicator. The expression as follow:

$$W_i = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \tag{5}$$

Calculating hierarchical total ranking weights and consistency tests, where the total ranking consistency ratio formula is as follow:

$$\mathrm{CR} = \frac{a_1 CI_1 + a_2 CI_2 + \cdots + a_m CI_m}{a_1 RI_1 + a_2 RI_2 + \cdots + a_m RI_m} \quad CR < 0.1 \tag{6}$$

We choose the objective functions as agricultural demand, industrial demand, esidential demand and electricity demand maximum. The expressions are as follow:

$$\mathrm{MAX} : \mathrm{F} = f_1 + f_2 + f_3 + f_4 \tag{7}$$

$$f_1 = \frac{(0.4A_1 + 0.6B_1)}{\sum_{i=1}^{5} A_i} \tag{8}$$

$$f_2 = \frac{(0.4A_3 + 0.6B_3)}{\sum_{i=1}^{5} D_i} \tag{9}$$

$$f_3 = \frac{(0.4A_2 + 0.6B_2)}{\sum_{i=1}^{5} I_i} \tag{10}$$

$$f_4 = \frac{\rho g(P+h_1)\eta * 0.4A_4 + \rho g(P+h_1)\eta * 0.6B_4}{\sum_{i=1}^{5} E_i} \tag{11}$$

We obtain MA1, A2, A3, A4 and B1, B2, B3, B4 by MATLAB. The result is shown in Fig.7

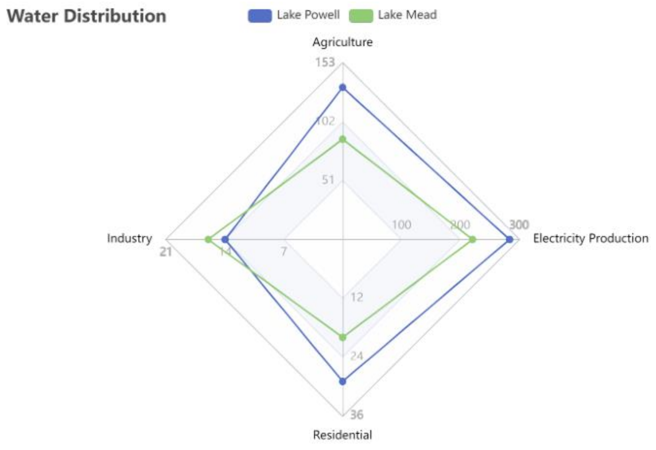

*Figure 7: Water distribution*

As we can see from Fig.7, for Lake Powell, we get that the amount of water allocated to agriculture is 132, industry 14, residents 29, and power generation 284. And for Lake Mead, the amount of water allocated to agriculture is 87, industry 16, residents 20, and power generation 221.The results show that Lake Powell has water to electricity allocation ratio of 1.6:1, while Lake Mead has a ratio of 1.8:1.

## 4. Integrated Water Scarcity Benefit Target Model

We propose the satisfaction function. Considering the water shortage, we need to prioritize the residential water supply. For residential water, we choose $e^x$ as the satisfaction function. Finally, we establish the objective function as follow:

$$\max Y = 0.41 f_1\,(A_1) + 0.35 f_2(A_2) + 0.25 f_3(A_4) + e^{A_3} \quad 0 < A_i < 1 \tag{12}$$

We use agenetic algorithm to calculate the optimal solution of the planning model. The results show that the maximum water supply can reach 2.9427×$10^6$ $m^3$ and 2.9128×$10^6$ $m^3$ in the case of 30% and 10% water shortages. Also, we derive the distribution coefficients A1, A2, A3, and A4. The obtained allocation ratio is shown in Fig. 8 and Fig. 9.

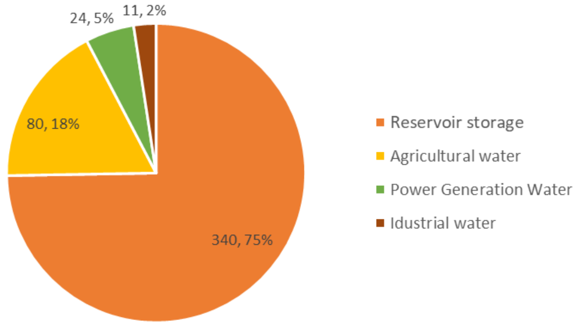

*Figure 8: In case of 30% water shortage*

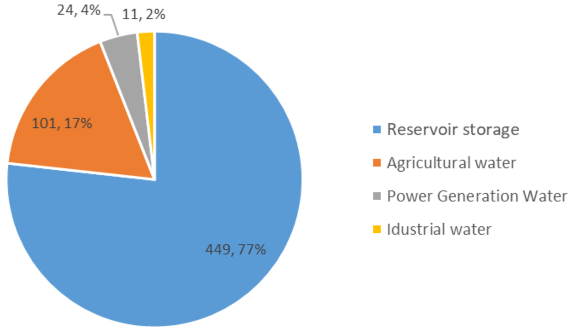

*Figure 9: In case of 10% water shortage*

From the above figure Fig.8 and Fig.9, we can see that at a water shortage of 30%, the proportion of water allocated to reservoir storage, agriculture, power generation, and industry is 75%, 18%, 5%, and 2% in that order. In the case of a 10% water shortage, this ratio is 77%, 17%, 4%, and 2%. We find that these two allocation ratios are extremely close. Therefore, in any water shortage scenario, we can allocate water according to this ratio.

Changing the water levels P and M of the two lakes, re-run the calculations, observe the changes in water allocation results, and conduct a sensitivity analysis of the model, which is shown in Fig.10 and Fig.11.

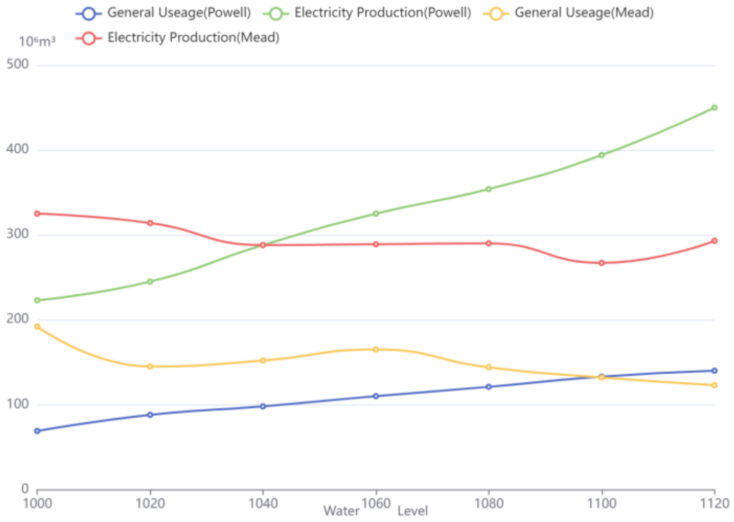

*Figure 10: Change the parameter P*

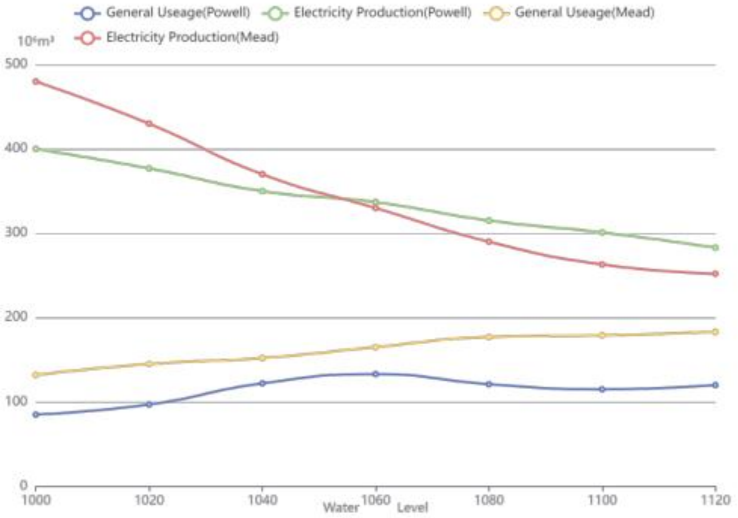

*Figure 11: Change the parameter M*

When the water level of Lake Powell decreases, the water used for power generation in Lake Powell decreases, but has less effect on the water used in Lake Mead, while when the water level of Lake Mead slightly decreases, the water used for power generation in both Lake Powell and Lake Mead increases significantly, which shows that the results of water distribution are more sensitive to the water level of Lake Mead, so the water in Lake Mead should be ensured not to change too much when the two lakes are operated.

## 5. Conclusion

In this paper, based on the objective function and constraints, a multi-objective programming model is established. Four water allocations were obtained by genetic algorithm. On this basis, the optimal pumping volume, running time and water addition volume were calculated. We are dominated by agriculture, industry, households and power generation. And using AHP, the geographic location was determined. By analyzing the comprehensive benefit target model of water shortage, it can be concluded that the optimal water resources allocation ratio under the condition of water shortage is 75:18:5:2.

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