中文标题

Summary

- **第一章**总体概述
- **第二章**设计思路
- **第三章**详细设计
- **第四章**设计与调试过程
- **第五章**实验总结与心得
- **第六章**控制器源代码

Keywords: keyword 1, keyword 2, etc.

Contents

1 Introduction

1.1 Problem Background

For centuries, people have constructed dams across rivers and streams to hold back water to create reservoirs to manage water supplies. These reservoirs store water for a variety of uses, like agriculture, industry, residential, fishing, preventing downstream flooding, genetating electricity, etc.

However, with climate changing, the volume of water feeding dams and reservoirs id decreasing in Corolado River.Thus it may not be able to meet the demands for water in Arizona(AZ), California(CA), Wyoming(WY), New Mexico(NM), and Colorado(CO). Moreover, water flow gets lower. This reduces the amount of hydroelectric power generated by the dam. More seriously, if the water level is low enough, hydropower generation will stop.

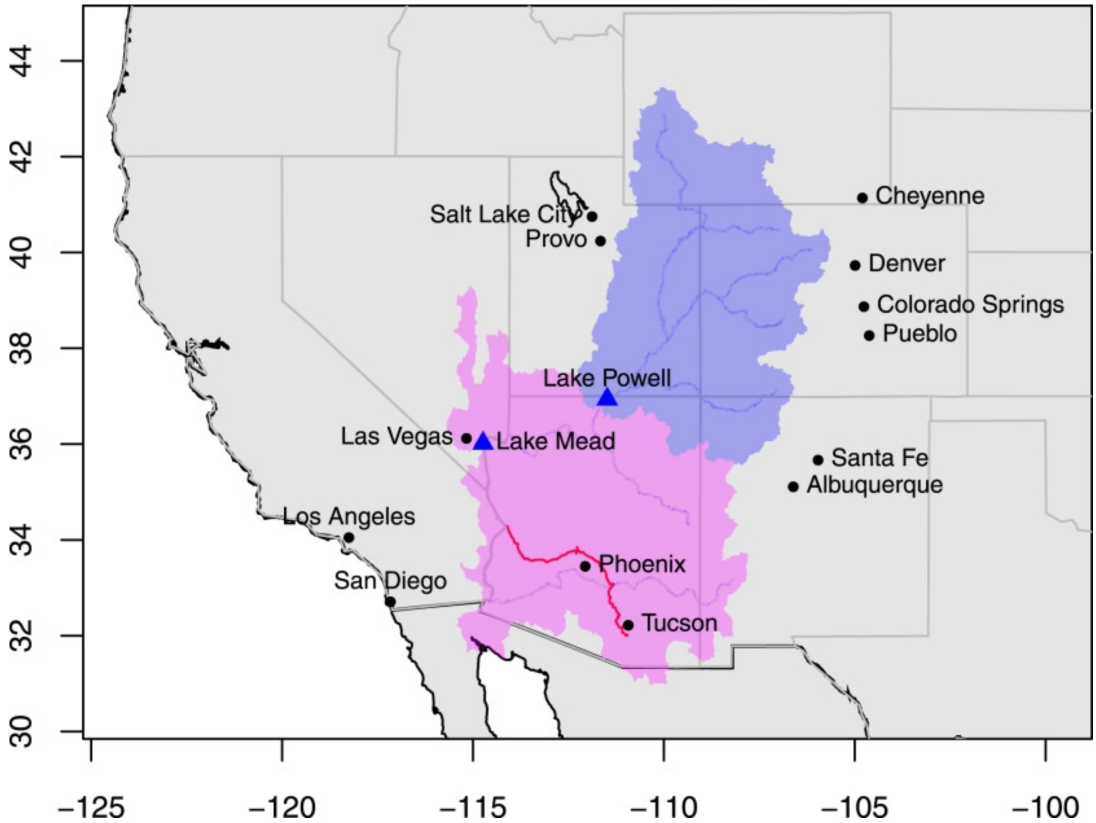

Figure 1: Map of the Colorado River Basin.

The Colorado River Water Allocation Agreement, which was once signed by the states, has allocated more water than the Colorado River currently has. If drought conditions continue in the Colorado River basin, The basic water and power needs of these states will not be met. Consequently,**We need to find a new water allocation plan**.

According to a recent research [1] on Colorado River, the Colorado River has been at or near average for only five of the past 22 years, and below average for the other 17. Hoover Dam's installed capacity is 2,074 megawatts if it is under full storage conditions. Now under drought conditions the capacity is 1,560 megawatts; the storage can provide power to 450,000 households at full capacity, and now it has dropped to about 350,000 households, and its generating capacity has fallen by 25 percent from full capacity.

1.2 Restatement of Problem

With basic knowledge of river water modeling forecasting and planning, we analyzed water changes and water reallocation in the Colorado River under the current drought conditions. Our team was assigned to solve the following problems:

- ◎ **Problem 1:** Describe how much water must be exported from Lake Mead and Lake Powell to meet each state's water demand if **the volume of water** in each lake is M and the volume of water in Lake Powell is P. How long will it take to meet these demands if **no additional water is considered and water demands are considered to be fixed**? How much **additional water** must be supplied over time to ensure that **water demands are met**?
- ◎ **Problem 2:** Build the **system dynamics model** of Colorado River water resources prediction model over time. Considering the impact of the **ongoing drought** on water quantity.
- ◎ **Problem 3:** Use the model to solve **water allocation problem** for agriculture, domestic, industrial and power generation.
- ◎ **Problem 4:** Solving the problem of what to do when there is **not enough water available for agriculture, domestic, industrial and power generation industries**.
- ◎ **Problem 5:** Answer what happens when **the demand for population, industry and power generation in drought-affected areas changes**, what happens when **renewable energy technologies (e.g., hydropower) are more advanced** than the model predicts, and what happens when **external water sources and power conservation measures** are used.

1.3 Analysis of Problem

To work out the four problems, our solutions will be proceeded as follows.

- ◎ **Problem 1:** To solve this problem, the first step is to determine the agricultural needs, industrial needs, residential needs and power generation needs of the five states, noting that Lake Mead also requires water from Lake Powell. So Lake Powell **has one more water demand target** than Lake Mead. After finding the water demands of the five states in recent years, we used **system dynamics modeling** to develop **a time-varying target planning model**, and to allocate water from the two lakes to the five states accordingly.
- ◎ **Problem 2,3: Prioritization of water supply** for general (agricultural, industrial, residential) and power generation uses, taking into account the importance of each use in terms of water demand, to address the issue of supply priorities and how to allocate water **when there is a shortage**.
- ◎ **Problem 4:** The change in water and electricity demand over time is determined by using **system dynamics methods** based on **the increase or decrease** in population, agriculture and industry in the area concerned, adjusting the parameters of hydropower generation efficiency according to **the improvement of renewable energy generation technologies**, and taking into account **the additional water and electricity savings** in a certain way, and then adjusting the model parameters to obtain the results of the model after changing the parameters.

Above is a sketch of the analysis process on the four problems.

2 Assumptions

◇ **Assumption 1: Input your system dynamics model asumption**.

↪ **Justification: Input justification**.

◇ **Assumption 2:** The first step is to extract experience, protocols, requirements and other elements from the actual dispatching experience, protocols, requirements, etc., and form a rule base containing the scheduling characteristics of the actual reservoir group. rule base that contains the characteristics of the actual reservoir group.

↪ **Justification:** On this basis, the existing scheduling modeling methods mentioned above are introduced at different times for limited optimization, so as to achieve the optimal scheduling method.

◇ **Assumption 3:**

↪ **Justification:**

◇ **Assumption 4:**

↪ **Justification:**

3 Notations

Table 1: Important Notations.

Symbol	Description	Unit
$S_{cylinder}$	side surface area of cylinder	m^2
$\boldsymbol{E}$	electric field intensity on the surface of uniformly charged cylinder	N/C
Φ	electric flux	$N \cdot m^2/C$
DR	decomposition rate	Unitless
α	fungi linear density	Unitless
ε_{DR}	environmental decomposition constant	Unitless
ACT	fungal activity factor	Unitless
β	fungi areal density	Unitless
HER	hyphal extension rate	mm/day
RMT	relative moisture tolerance	Unitless
R^2	sample correlation coefficient	Unitless
$N(t)$	current population size	Unitless
RGB	relative growth blocking index	Unitless
X	time series data	Unitless

4 The Models

A system dynamics model and a combined reservoir scheduling model are needed to determine the water volume in the lake over time and to allocate the water to agriculture, industry, housing and power generation.

4.1 System Dynatics Model

4.2 Reservoir transfer-supply model with possible external water transfer

The simulation and optimization method is used to study the operation and scheduling of reservoirs with possible external water transfers, which is divided into two parts: the simulation module and the optimization module. The simulation module is based on water distribution, water transfer and water supply rules to adjust and calculate external water transfer and natural water supply, and set water transfer and water supply rules for the inflow reservoirs to meet the remaining demand as much as possible; the optimization module is based on the analysis of reservoir scheduling performance to optimize the set water transfer and water supply rules.

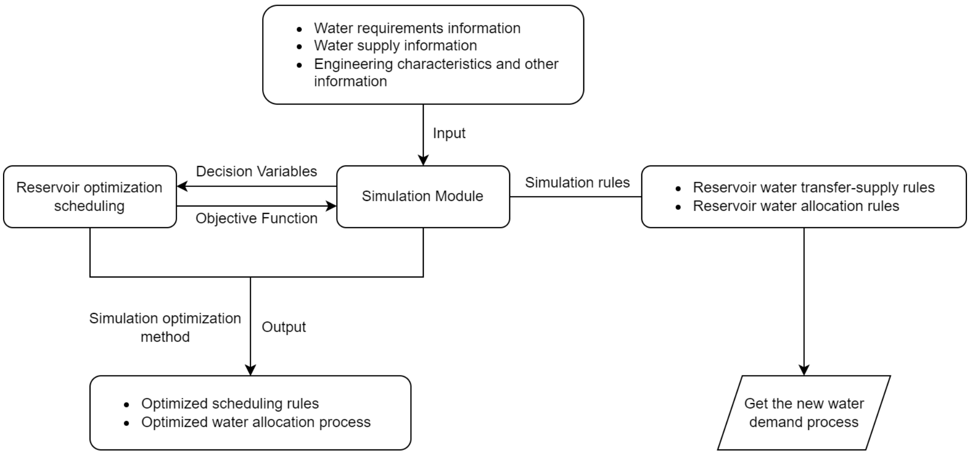

Figure 2: Model Framework Diagram

4.2.1 Analog Module

(1) The existence of external water transfer when the deployment rules.The process of blending natural water and external water transfer is:

- Calculate the new storage volume for user i at time t: $N_t^i = D_t^i$, Where, D_t^i is the water demand of user i at time t. This storage volume is deployed using the following reservoir transfer-supply rules.

(2) Reservoir water transfer - water supply rules. According to the theory of reservoir capacity zoning, four scheduling lines are set up for the receiving side to control the transfer and supply of water from the reservoir. When the initial reservoir storage is above the start line S_Y, the reservoir can supply water without external water transfer. Otherwise, water is transferred according to the reservoir's time transfer capacity Y_t^{max} and the maximum external transfer flow Z_t^{max}. The other three scheduling lines S_1, S_2 and S_3 restrict water supply to agricultural, industrial and residential users at a time, which are called water supply restriction lines. [2]

In time t, the reservoir transfer-supply operation is as follows:

- When the initial storage volume V_t is above the start line S_t^Y, the reservoir transfer volume $Y_t = 0$. Otherwise, the water is transferred according to the transfer capacity Y_t^{max} and the transfer flow Z_t^{max}.

- Determine the relationship between the initial storage volume V_t and the water supply limitation lines S_t^1, S_t^2, S_t^3 for each user at time t:
  (a) If $V_t \geq S_t^1$, each customer is supplied with water on demand:
  $$W_t = N_t^1 + N_t^2 + N_t^3 \tag{1}$$
  (b) If $S_t^2 \leq V_t \leq S_t^1$, water supply for agricultural users is restricted:
  $$W_t = (1-\alpha_1)\cdot N_t^1 + N_t^2 + N_t^3 \tag{2}$$
  (c) If $S_t^3 \leq V_t \leq S_t^2$, water supply for agricultural users and industrial users is restricted:
  $$W_t = (1-\alpha_1)\cdot N_t^1 + (1-\alpha_2)\cdot N_t^2 + N_t^3 \tag{3}$$
  (d) If $V_t \leq S_t^3$, water supply for all users is restricted:
  $$W_t = (1-\alpha_1)\cdot N_t^1 + (1-\alpha_2)\cdot N_t^2 + (1-\alpha_3)\cdot N_t^3 \tag{4}$$
- Calculate the water storage at the end of the period:
  $$V_{t+1} = V_t + I_t + Y_t - W_t - q_t \tag{5}$$
  Where, W_t is the total reservoir water supply at the time, N_t^i is the water demand of agricultural, industrial and residential users at time t respectively; α^i is the water supply limitation coefficient of user i, I_t is the incoming reservoir water at time t; Y_t is the reservoir water transfer at time t, q_t is the reservoir abandonment at time t.

4.2.2 Optimization Module

4.2.2.1 Objective Function When there is an external water source, it is not reasonable to abandon a large amount of water due to the limitation of reservoir capacity. In order to improve the efficiency of external water supply, we need to ensure that the amount of water abandoned by the reservoir is as small as possible, and set the objective function as:

(1) Minimize the sum of squares of water deficiency

$$\min f_1 = \sum_{t=1}^{N} \frac{N_t - W_t}{N_t} \tag{6}$$

N_t is the total water demand.

(2) Minimize annual average reservoir disposal

$$\min f_2 = \frac{1}{T}\sum_{t=1}^{N} q_t \tag{7}$$

Where, T is the number of years, q_t is the total amount of water abandoned by the reservoir, the smaller the amount of water abandoned, the higher the utilization rate of external water sources.

4.2.2.2 Binding Conditions

(1) Balance reservoir initial and final water constraints

$$V_{t+1} = V_t + Y_t + I_t - W_t - q_t \tag{8}$$

Where, V_{t+1} and V_t denote the initial and final water demand of the reservoir at time t respectively.

(2) Reservoir Capacity Constraints

Due to the functional and mechanical characteristics of the reservoir, the water demand at each time must be within a certain range.

$$S_t^{min} \le V_t \le S_t^{max} \tag{9}$$

Where, S_t^{min} is the minimum storage limit,S_t^{max} is the maximum storage limit.

(3) Water Demand Constraint

$$W_t^i \le N_t^i \tag{10}$$

(4) External water constraint

$$Y_t \le Y_t^{max}; \qquad Z_t \le Z_t^{max} \tag{11}$$

(5) Reservoir water supply limit line constraints

According to the priority order of water users (i.e., the three restriction lines), there are the following constraints

$$S_t^{min} \le S_t^3 \le S_t^2 \le S_t^1 \le S_t^{max} \tag{12}$$

Where, S_t^1, S_t^2, S_t^3 are the water supply limit lines for agricultural, industrial and residential water respectively in time period t.

(6) Non-negative constraint

According to the reality, each decision variable is non-negative.

4.2.2.3 Solving Method The optimization model established in this paper is a multi-objective model, and converting the multi-objective into a single-objective solution is the main idea of multi-objective optimization solution. In this paper, the system dynamics method is used to solve the reservoir optimal scheduling model as follows: first, the SD method is applied to each single objective $f_i(x)$ to solve its optimal value f_i; then, the optimal value f_i of each objective is used as the ideal value of each objective function approximation to build a new single objective function

$$g(x) = \sqrt{\sum_{i=1}^{n} (f_i(x) - f_i)^2} \tag{13}$$

Finally, the SD method is applied to find a solution of $g(x)$, according to which the value of each objective function is derived.

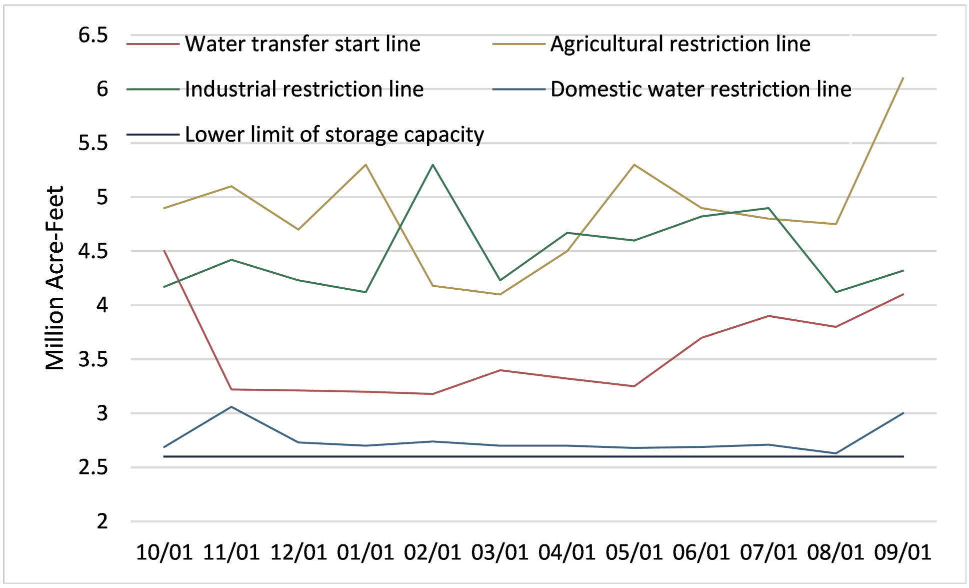

Figure 3: Water transfer and supply rules of Powell Lake

4.3 Analysis of reservoir scheduling results

The water transfer and supply rules for Lake Powell are obtained according to the previous model as shown in Fig.

When the storage volume is above the transfer line, no external water transfer will be introduced; on the contrary, external water transfer will be introduced according to the transfer capacity of the period. The higher the transfer line, the higher the chance of transferring water in that month. The start line in the graph indicates that the overall chance of transferring water during the non-flood season is high because the water is less after the end of the flood season.

The reason for this is that urban users have to meet both the high guarantee rate of water supply and the low depth of damage, which requires high water supply, and the chance of water supply being restricted is small. The higher the dispatch line is, the greater the chance that the agricultural customers' water supply will be restricted. This is due to the unevenness of agricultural water demand. Industrial water use is similar.

When water levels in Lake Powell and Lake Mead are high enough, the needs of all users are met; when levels are not high enough, water is allocated according to a reservoir allocation scheme that limits water use.

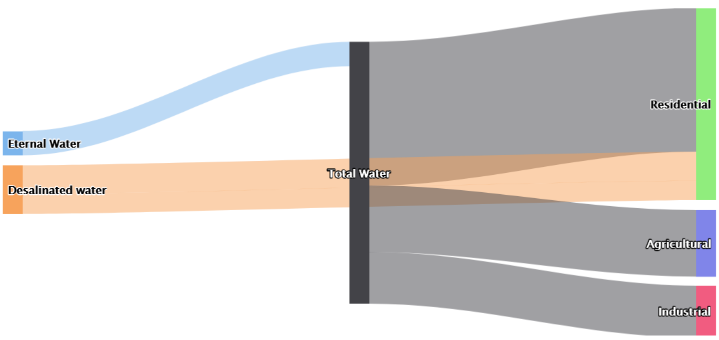

Figure 4: Water distribution chart for customers with external water sources

Figure 4.3 visualizes the relationship between the allocation of water to users in the presence of external water sources using Sankey diagrams, and the thickness of the line between the water users indicates the magnitude of the water. The higher the allocation of external water sources, the lower the total reservoir water supply, where the external water sources are mainly used for residential and industrial users, and the water that would otherwise be used for these users is allocated to agriculture. This restores water to agriculture, which is squeezed by urban water, while protecting urban water.

5 Sensitivity Analysis

5.1 Analysis of Rapid Environmental Fluctuations

5.2 Sensitivity Test

6 Strengths and Weaknesses

6.1 Strengths

- In the absence of sufficient time series data, we used the target point method and a system dynamics model to predict and optimize the water allocation of Lakes Powell and Mead.

6.2 Weaknesses

- In the modeling, we simplified the policy practical considerations, which may lead to a decrease in the guidance of water allocation to reservoirs.
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References

[1] Homa Salehabadi et al. "The future hydrology of the Colorado River Basin". In: *The Future of the Colorado River Project, White Paper No. 4. Logan, UT: Utah State University, Quinney College of Natural Resources Center for Colorado River Studies. 71 p.* (2020).

[2] Xiang Zeng et al. "Water transfer triggering mechanism for multi-reservoir operation in inter-basin water transfer-supply project". In: *Water resources management* 28.5 (2014), pp. 1293–1308.