Research on optimal operation of Chaohu Lake Based on the Particle Swarm Optimization algorithm

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Abstract. There is a shortage of water resources in the Huaihe River area. With the development of the economy and society, the shortage of water resources is becoming more and more serious. Among them, the Yangtze to Huaihe Water Division is a strategic backbone project to solve the contradiction between water supply and demand in the Huaihe River Basin and the Jianghuai Water Shortage Area, which can improve the water resources allocation capacity in the basin. Chaohu Lake is an important storage place for the Yangtze to Huaihe Water Division. This paper takes the Chaohu optimal operation of the Yangtze to Huaihe Water Division as an example and uses the partial swarm optimization algorithm to solve the problem. When P=95%, through the comparison of conventional operation, after the optimal operation, the water diversion was reduced by 0.071 billion m³. When P=50%, through the comparison of conventional operation, after the optimal operation, the water diversion was reduced by 0.03 billion m³. The results show that the optimal operation can reduce the water diversion of the Yangtze to Huaihe Water Division River project more effectively.

1. Introduction

The water transferring line of Yangtze to Huaihe Water Division have some natural lakes such as Caizi Lake, Chaohu Lake, Wabu Lake. Among them, Chaohu Lake is one of the five major freshwater lakes in China[1]. It is located in the lower Yangtze river and in central Anhui Province. The drainage area is 13486 km² and the normal water surface is about 780 km²[2]. It is an important of regulation and storage of antze to Huaihe Water Division. Natural runoff is injected into Chaohu lake through the Fengle River, Hangyi River, NanfeiRiver, Baishitian River, which to supply the needs of users in Chaohu lake basin.

Chaohu regulsting storage capacity up to 608 million m³, which makes Chaohu Lake particularly important in the Yangtze to Huaihe Water Division. On the one hand, it can coordinate the allocation of water resources in the river and realize the mutual adjustment of water resources within the system. On the other hand, it can form a water regulation system for water transmission lines along the line, which has various practical uses such as realizing pre-adjustment of water resources and rational use of flood water resources. However, how to scientifically and rationally use the water storage in Chaohu Lake to greatly improve the water resources allocation capacity is a difficult problem.

About the optimization of the lake was first started in the South-to-North Water Transfer Project. The optimal operation of the lake was first started in the South-to-North Water Diversion Project. The self-optimization simulation model of joint operation was used by five lakes in the first phase of the South-to-North water diversion project in paper of Leishenglong[3]. Lei has presented
self-optimization simulation model of joint operation which was used in the first phase of the South-to-North water diversion project. In this paper, taking the minimum amount of pumping as the target, considering the constraints such as supply and demand water and reservoir control water level meter scheduling rules, a low-energy water diversion scheme that can basically meet the water demand of the system is obtained. On that base, YuFengchun[4] combining the characteristics of the South-to-North water diversion project, according to the three lakes in the Eastern Jiangsu Province, a multi-objective optimal operation model with the minimum of two targets is constructed, and the NSGA-II algorithm is used to solve the model. Therefore, the optimal water allocation scheme of the lake group system for the East line of the South-to-North Water Diversion Project is obtained. Fuhansheng[5] based on the analysis and generalization of Jiangsu project in the South-to-North water diversion project, the water resources scheduling scheme in Jiangsu water-receiving area is optimized by combining basic dynamic programming with simulated annealing Algorithm. The model results are good and superior to the conventional scheduling method of the system. In the paper of Shizhengtong[6], in order to solve the problem of joint operation of reservoir groups, this paper puts forward the aim of minimizing the lack of water in the whole system during the calculation period, and the decision variable of the water supply of each reservoir during each period. The optimization and dispatch model of water resources in several lakes with water balance and storage capacity of each reservoir as constraints, and the "Hongze Lake-Luoma Lake-Nansi Lake" reservoir group system in the first phase of the South-North Water Diversion Line as an example, using the large system-dynamic planning polymerization algorithm to solve the model. Results Compared with the conventional scheduling, the water supply of the system has been improved accordingly, and the water shortage and total water disposal have been reduced accordingly.

Summarizing the results of the current research, it is found that most of the optimal operation of lake at this stage is involved in the South-to-North Water Diversion. However, the Yangtze to Hauihe Water Division, as another trans-basin water transfer project carried out in recent years, has little research on it[7]. So, as an important storage place for the Yangtze to Hauihe Water Division, Chaohu Lake is particularly important to study its optimal operation.

This paper takes the Chaohu optimal operation of the Yangtze to Hauihe Water Division as an example and uses the partial swarm optimization algorithm to solve the problem. In this way, the plan for the minimum water shortage of water users at various times is obtained and formulate the scheme of how much water to draw from the Yangtze river.

2. **Study area**

2.1. **Case study**

In the preliminary design report of the Yangtze to Hauihe Water Division (*initial design*), the scope of the Yangtze River and Hauihe River project will be divided into six regions, the Yangtze River, Hauihe and Huainan, and four areas north of the Hauihe River. In this paper, only takes the Yangtze River area as the research object (figure 1), and only considered to the regulation and storage capacity of Chaohu Lake in *initial design*.

Located in Hefei, Anhui Province, Chaohu Lake is one of the five largest freshwater lakes in China[1]. It is an important regulation and capacity sites for the Yangtze to Hauihe Water Division and drainage area is 13,486 square kilometers, which accounting for 93% of the total area of Anhui Province. The highest lake water level was 12.93 m (August 31, 1954, before wuwei major dam collapse) in Chaohu Lake. After the completion of the Chaohu Gate in 1962, the highest water level in Chaohu Lake was 12.71m(July 14, 1991) and the lowest water level was 6.47 m.(November 9, 1978), Chaohu has an annual average water level of 8.33 m. In the Yangtze to Hauihe Water Division, the lowest operating water level of Chaohu Lake is 5.8m, the highest operating water level is 6.6m, and the average annual runoff is 3.03 billion m³. As a multi-year regulating reservoir, its annual regulating water volume is 608 million m³.
2.2. Lake Optimization model

2.2.1. Objective function
This paper uses the minimum water shortage model of water users in the Yangtze River area as the research. The objective function

$$W = \min \sum_{t=1}^{N} W_t - X_t$$

In the above formula, $W$ is volume of water shortage, and $W_t$ is water demand of $t$ times, $X_t$ is quantity of water supply of $t$ times.

2.2.2. Constraint condition
A Water budget constraint.

$$V_t = V_{t-1} + I_t - X_t$$

Where,

$V_t$ is the storage capacity of $t$ times.

$V_{t-1}$ is the storage capacity of $t-1$ times.

$I_t$ is the discharge into reservoir of $t$ times.

B restriction of water level constraint

$$Z_t^{\min} \leq Z_t \leq Z_t^{\max}$$

Where,

$Z_t^{\min}$ maximum water level.

$Z_t^{\min}$ minimum water level.
$Z_t$, dynamic water-level.

C Discharge flow constraint
- $Q_t^\text{min} \leq Q_t \leq Q_t^\text{max}$

Where.
$Q_t^\text{min}$ maximum discharge flow.
$Q_t^\text{max}$ minimum discharge flow.
$Q_t$ dynamic discharge flow.

D Water supply and abandoned water constraint
- $V_t > V_t^\text{max}$ \( C = V_t - V_t^\text{max} \)
- $V_t \leq V_t^\text{max}$ \( C = 0 \)

Where.
$V_t$ is storage capacity of t times.
$V_t^\text{max}$ maximum storage capacity.
$C$ is abandoning water.

3. Methodology

3.1 Particle Swarm Optimization

When applying PSO to solve problem of optimization, the solution of the problem corresponds to the "particle" in the search space[8-12]. Each particle has its own position and velocity (determining the direction and distance of flight) and a fitness determined by the optimization problem correspondence function. The process of particle optimization is the process of particle memory, following the current optimal particle, and constantly searching in the solution space. Each iteration of the particle is not completely random. If a better solution is found, save it and use it as a basis to find the next solution. When PSO solves the optimization problem, it first initializes to generate a group of random particles (corresponding to a set of random solutions to the problem). In each iteration, the particles update themselves by tracking two extreme values. One is the optimal solution found by the particle itself so far, namely the pbest, and the other is the optimal solution found by the entire population so far, namely the gbest. After finding this solution, the particles update their speed and position according to equations (1) and (2). Let the particle velocity information, position information, etc. be represented by an N-dimensional vector. Position vector $X^k = (x^k_1, x^k_2, ..., x^k_N)$. Velocity vector $V^k = (v^k_1, v^k_2, ..., v^k_N)$

The current optimal position of the particle (local optimal solution to the problem) $x^k_p = (x^k_{p1}, x^k_{p2}, ..., x^k_{pN})$

current optimal position of the particle (Global optimal solution corresponding to the problem) $x^k_g = (x^k_{g1}, x^k_{g2}, ..., x^k_{gN})$

Then the speed and position update formula is as follows.

- $v_n^{k+1} = w \times v_n^k + c_1 \times \text{R}nd_1 \times (x_{p_n}^k - x_n^k) + c_2 \times \text{R}nd_2 \times (x_{g_n}^k - x_n^k)$ (1)
- $x_n^{k+1} = x_n^k + v_n^{k+1}$ (2)

Where.
$w$ is the inertia weight.
$v_n^{k+1}$ is the speed of the n dimension of the particle in the k+1 iteration,
$x_n^{k+1}$ is the position of the n dimension of the particle in the k+1 iteration.
$c_1$ and $c_2$ are acceleration factors.
rand1 and rand2 are random number between(0,1).

3.2 Solution procedure

Step1: Initialize particle population let $k = 0$, randomly generate $L$ particles according to specific research questions

$P^k = (X^k(t), V^k(t))(t = 1, 2, ..., L)$ among them, is the position and speed.
\( X^k(l) = (x^k_1(l), x^k_2(l), \cdots, x^k_n(l)) \)

\( V^k(l) = (v^k_1(l), v^k_2(l), \cdots, v^k_n(l)) \)

Stept2: Calculate the current fitness of each particle
\( F^k(l), F^k(l) = f(X^k(l)) \)

Stept3: Update local best individuals and global best best individuals. Find the best fit for each individual so far, recorded as \( F^k \) and remember that its corresponding position vector is \( X^k \).

\[
X^k_{p,l} = (x^k_{p,1}(l), x^k_{p,2}(l), \ldots, x^k_{p,n}(l))
\]

Stept4: The individual's position vector and velocity vector are updated to produce the next generation particle swarm. Update each speed element and position element in all individuals using the following formula:

\[
v^{k+1}_{n,l} = v^n_{n,l} + c_1 \times Rnd_1 \times (X^k_{p,n,l} - x^n_{n,l}) + c_2 \times Rnd_2 \times (X^k_{g,n,l} - x^n_{n,l})
\]

\[
x^{k+1}_{n,l} = x^n_{n,l} + v^{k+1}_{n,l}
\]

Stept5: Verify that the algorithm iterative termination condition is satisfied, and if it is satisfied, stop the iteration and output the optimal result; no \( k=k+1 \), turn to be.

\[
\frac{F^{k+1}_g - F^k_g}{F^k_g} \leq \varepsilon \quad (\varepsilon \text{ is the accuracy given in advance})
\]

4. Results and discussion
According to 2030 \( p=50\% \), \( p=95\% \) of incoming water frequency, water demand, local water supply volume to solve the water shortage in the Yangtze River area of the Yangtze to Hauie Water Division. The PSO algorithm is used to establish the optimal operation model calculation, and the calculation results are compared with the rule scheduling results in this paper.

| Months | Water demand \((10^8m^3)\) | Water supply \((10^8m^3)\) | Water diversion \((10^8m^3)\) | Conventional operation | Optimal operation |
|--------|----------------|----------------|----------------|-----------------|----------------|
| 1      | 4.74           | 2.17           | 2.57           | 2.57            |                |
| 2      | 4.74           | 2.17           | 2.57           | 2.57            |                |
| 3      | 4.74           | 2.17           | 2.57           | 2.57            |                |
| 4      | 4.74           | 2.19           | 2.55           | 2.55            |                |
| 5      | 6.28           | 6.15           | 0.13           | 0.13            |                |
| 6      | 8.33           | 8.83           | 0.00           | 0.00            |                |
| 7      | 8.33           | 11.73          | 0.00           | 0.00            |                |
| 8      | 6.28           | 10.54          | 0.00           | 0.00            |                |
| 9      | 4.74           | 6.18           | 0.00           | 0.00            |                |
| 10     | 4.74           | 3.39           | 1.35           | 0.64            |                |
| 11     | 4.74           | 1.90           | 2.84           | 2.84            |                |
| 12     | 4.74           | 1.78           | 2.96           | 2.96            |                |
| Amount | 67.14          | 59.2           | 17.54          | 16.83           |                |

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| 7      | 8.33           | 11.73          | 0.00           | 0.00            |                |
| 8      | 6.28           | 10.54          | 0.00           | 0.00            |                |
| 9      | 4.74           | 6.18           | 0.00           | 0.00            |                |
| 10     | 4.74           | 3.39           | 1.35           | 0.64            |                |
| 11     | 4.74           | 1.90           | 2.84           | 2.84            |                |
| 12     | 4.74           | 1.78           | 2.96           | 2.96            |                |
|   |   |   |   |   |
|---|---|---|---|---|
| 1 | 3.82 | 2.11 | 1.71 | 1.71 |
| 2 | 3.82 | 2.11 | 1.71 | 1.71 |
| 3 | 3.82 | 2.16 | 1.66 | 1.66 |
| 4 | 3.82 | 2.18 | 1.64 | 1.64 |
| 5 | 4.8  | 9.24 | 0.00 | 0.00 |
| 6 | 6.12 | 6.76 | 0.00 | 0.00 |
| 7 | 6.12 | 8.89 | 0.00 | 0.00 |
| 8 | 4.8  | 8.78 | 0.00 | 0.00 |
| 9 | 3.82 | 6.05 | 0.00 | 0.00 |
| 10| 3.82 | 4.98 | 0.00 | 0.00 |
| 11| 3.82 | 3.96 | 0.00 | 0.00 |
| 12| 3.82 | 2.14 | 1.68 | 1.38 |
| Amount | 52.4 | 59.36 | 8.40 | 8.10 |

Figure 2. \( P=95\% \) compare results

![Figure 2](image-url)
The PSO-based Chaohu optimal operation model uses 2010 as the current base year to predict the monthly water demand in the near-term planning year of 2030. According to the runoff data of the Yangtze River region from 1976 to 2010, the P-III curve was established, and the P=50% and P=95% incoming water frequency were taken for modeling analysis. It can be seen from the above table that under the conventional operation, at the water frequency of p=95%, the 2030 Yangtze River Basin needs to transfer water by 1.751 billion m$^3$ through the Yangtze to Hauile Water Division. After the optimal operation, the Yangtze river region needs to transfer water to 1.683 billion m$^3$. Through the comparison of conventional operation, after the optimal operation, the water diversion was reduced by 0.071 billion. In 2030, when P = 50% of the incoming water frequency, 0.84 billion m$^3$ of water needs to be diverted through conventional operation. However, after the optimal operation, the water diversion needs to be 0.81 billion m$^3$, and the optimal operation can effectively reduce the project water transfer by 0.03 billion m$^3$.

5. Conclusions

Affected by climate change and human activities, the runoff in the Huaihe River Basin has been declining in the past 10 years. With the rapid development of economic construction, the increasing population and the rapid development of urbanization, the shortage of water resources is becoming more and more obvious. In the contradiction between economic and social development and ecological environmental protection, it is impossible to fundamentally solve the problem of water shortage in the region by relying on water conservation and tapping the potential of local water resources. To alleviate the increasingly sharp contradiction between supply and demand of water resources, in the long run, cross-basin water transfer projects must be implemented[13]. Among them, the Yangtze to Hauile Water Division is a strategic backbone project to solve the contradiction between water supply and demand in the Huaihe River Basin and the Jianghuai Water Shortage Area, which can improve the water resources allocation capacity in the basin.

As one of the three important storage lakes for the Yangtze to Hauile Water Division, Chaohu Lake has functions such as flood control, water supply, irrigation and shipping. In this paper, Chaohu Lake is taken as the research object, which is an annual regulation lake. The minimum water demand (water diversion) needs to be the objective function. The local water supply of the reservoir in each period is the decision variable, and the reservoir capacity is the state variable in each period. Based on
the reservoir water balance and the reservoir water level, the Chaohu optimal scheduling model was established and solved by particle swarm optimization (PSO). The results were compared with the conventional operation, and the results were compared and analyzed. The results show that the optimal operation can reduce the water diversion of the Yangtze to Huaihe Water Division River project more effectively.

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