Multi-Objective Optimal Scheduling of Wangwu Reservoir Based on NSGA-II

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Abstract: Wangwu Reservoir is a multi-purpose reservoir that integrates urban water supply, irrigation, industrial water and landscape ecological water supply, and a multi-objective optimal scheduling model is established to explore the relationship between water supply loss and landscape loss caused by water shortage in Wangwu Reservoir. Based on the GANetXL program, the NSGA-II algorithm is applied to the optimal scheduling model of Wangwu Reservoir, and the Pareto optimal solution sets are obtained in the three different incoming water conditions of high flow year, normal flow year and low flow year. These optimal solution sets provide decision-making basis and specific program references for the optimal scheduling method of Wangwu Reservoir.

1. Introduction
With the development of social economy, the dispatching methods of reservoirs and the factors that need to be considered are also increasing. Some reservoirs are multi-purpose reservoirs that integrate urban water supply, irrigation, industrial water, and landscape ecological water replenishment. Therefore, multi-objective optimization scheduling is particularly important. At present, domestic scholars have carried out many researches on the multi-objective scheduling problem of reservoirs and achieved rich results. Wang Yu[1] transformed the double objective into a single objective by using the ideal point method to deal with multi-objective problems; Li Yinghai[2] proposed multi-objective scheduling of cascade hydropower stations with consideration of the downstream ecological water replenishment. In solving method, the two-stage constrained method was used to reduce the dimension of multi-objectives, then the dynamic programming was used to solve the problem. Zhang Shibao[3] applied the NSGA-II algorithm in the multi-objective optimization scheduling of The Yangtze River Three Gorges Reservoir and the optimization scheduling was significant. This paper comprehensively considers the water supply objective and the landscape objective, and the optimal reservoir scheduling model with the minimum annual water supply benefit loss and the minimum annual landscape benefit loss is established. The non-dominated sorting genetic algorithm (NSGA-II) with elite retention strategy is selected as the model optimization algorithm to find stable and uniformly distributed objective non-inferior combinations, that is Pareto optimal solution set. Various optimal scheduling schemes provide more flexible reference for decision makers.

2. Survey of the research area
Wangwu Reservoir is located in the middle and upper reaches of Huangshui River in Longkou city, Shandong Province, with a controlled drainage area of 320 km², a total storage capacity of 121 million m³, and a dead storage capacity of 6 million m³[4,5]. Since the operation has been completed, it has
played a huge role in ensuring the economic and social development of Longkou city. Now it becomes an important water source for urban water supply in whole city. At the same time, Wangwu Reservoir is an important water supply source for the Huangshui River Wetland Park, it is hydrated by the discharge of the Huangshui River to the landscape of the wetland park. The optimal scheduling of Wangwu Reservoir involves water supply objective and landscape objective. There are contradictions between these two objectives, and the units are incomparable. The improvement of one goal may cause deterioration of the others, so two objectives do not exist to achieve their respective optimum at the same time.

Figure 1. Location where the basin reservoir of this study

3. Multi-objective optimization scheduling model of Wangwu Reservoir

3.1 Principles and Features of NSGA-II
NSGA-II is developed from the NSGA algorithm. With the demand of solving multi-objective problems, the NSGA algorithm has been continuously improved. Because the Pareto ordering is repeated, the calculation efficiency is lower, the elite retention strategy is not adopted, and the shared parameters need to be determined in advance in the NSGA algorithm, Deb made an objective improvement to NSGA in 2000, and proposed a non-dominated sorting genetic algorithm with elite strategy, namely NSGA-II. The improvement is manifested in the following three aspects: (1) A fast non-dominated sorting method based on grading is proposed, which greatly reduces the complexity of the algorithm; (2) The congestion degree and congestion degree comparison operator is proposed. The fitness sharing strategy does not need to specify the sharing radius, and it as the winning criterion between the sorted peers, the elements in the quasi-domain can be extended to the entire domain and evenly distributed. As a result, the diversity of the population is maintained; (3) The sampling space is increased by introducing the elite strategy, and compete the parent population with the progeny population to obtain the next generation population, which is easy to get a better next generation. The NSGA-II algorithm process is shown in Figure 2.
3.2 Establishment of Model
The water supply of Wangwu Reservoir includes urban domestic water supply, industrial water supply and agricultural water supply. When water supply is insufficient, it is necessary to ensure domestic and industrial water supply and reduce agricultural water consumption. According to local agricultural planting conditions, the economic loss coefficient is generally about 0.43. The upper limit of landscape water storage is the reservoir capacity of Wangwu Reservoir, and the lower limit is 72.5 million m$^3$. When the reservoir water storage is lower than the lower limit of reservoir landscape water storage, it will cause the landscape ecological loss of Huangshui River Wetland Park. The loss of reservoir landscape is a kind of perceptual loss, which can be expressed by landscape profit and loss water scale [10].

Objective function: This paper aims at minimizing the annual economic benefit loss and the minimum annual landscape loss.

(1) Annual water supply economic benefit loss is minimal:
\[
\text{Min} Z = \sum_{t=1}^{N} Z_t, \quad Z_t = 0.43(D_t - R_t)^2 \quad R_t < D_t
\] (1)

(2) The annual landscape loss is minimal:
\[
\text{Min} Y = \sum_{t=1}^{N} Y_t, \quad Y_t = (SR - S_t)^2 \quad S_t < SR
\] (2)

Constraints: it includes water balance constraint, minimum actual water supply constraint, and maximum and minimum water storage constraint.

(1) Water balance constraint:
\[
S_{t+1} = S_t + Q_t - R_t - O_t
\] (3)

(2) Minimum actual water supply constraint:
\[
R_t \geq R_{\text{min}}
\] (4)

(3) Maximum and minimum water storage constraint:
\[
S_{\text{min}} \leq S_t \leq S_{\text{max}}
\] (5)

Where $t$ is the month; $N$ ($t=1, 2, ..., N; \ N=12$) is the total number of months; $Z_t$ and $Z$ represent the monthly water supply loss and the annual cumulative water supply loss caused by the shortage of water supply; $Y_t$ and $Y$ represent monthly landscape loss and annual cumulative landscape loss; $SR$ represents the lower limit of reservoir water storage capacity; $R_t$, $D_t$, $S_t$, $Q_t$, and $O_t$ represent the actual monthly water supply, the monthly water supply, the reservoir capacity at the beginning of the month, the monthly water volume, and the monthly reservoir overflow, respectively; the economic loss factor is 0.43; $R_{\text{min}}$ represents minimum actual water supply; $S_{\text{min}}$ represents reservoir dead storage capacity; $S_{\text{max}}$ represents reservoir storage capacity.
According to the measured runoff data of the Wangwu Reservoir Hydrological Station from 1970 to 2000, the 1974-1975, 1977-1978 and 1986-1987 years were selected as the typical years of high flow year, normal flow year and low flow year to optimize calculation.

Table 1. The monthly incoming water volume and monthly water supply in different typical years of the reservoir

| Month   | High Flow Year | Normal Flow Year | Low Flow Year | Water demand volume(10^7m³) |
|---------|----------------|------------------|---------------|-----------------------------|
| January | 0.092          | 0.115            | 0.083         | 0.190                       |
| February| 0.079          | 0.094            | 0.041         | 0.213                       |
| March   | 0.146          | 0.058            | 0.028         | 0.203                       |
| April   | 0.152          | 0.132            | 0.015         | 0.238                       |
| May     | 0.371          | 0.102            | 0.151         | 0.263                       |
| June    | 0.369          | 0.191            | 0.059         | 0.470                       |
| July    | 0.698          | 0.742            | 0.237         | 0.255                       |
| August  | 6.086          | 2.058            | 0.675         | 0.235                       |
| September| 0.316         | 0.060            | 0.045         | 0.238                       |
| October | 0.159          | 0.089            | 0.026         | 0.205                       |
| November| 0.245          | 0.130            | 0.011         | 0.195                       |
| December| 0.119          | 0.106            | 0.030         | 0.180                       |

3.3 Setting parameters
The NSGA-II is used to solve the double-objective scheduling model of Wangwu Reservoir, and the actual water supply sequence is used as the chromosome. The optimal reservoir scheduling is the process of searching for the optimal chromosome scheme in the genetic algorithm. The Population Size was selected as $M=50$ and $M=100$, Number of Generations=1000, Crossover Rate=0.95, and Mutation Rate=0.05.

4. Scheduling results and analysis
In Figure 3, (a) (b) (c) are the Pareto frontiers of NSGA-II in the high flow year, normal flow year and low flow year. The abscissa is the annual water supply loss caused by the shortage of water supply. The vertical coordinate is the annual loss of landscape water caused by the storage capacity at the beginning of the month being less than the lower limit of the landscape water demand.
According to Figure 3, whether in high flow year, normal flow year or low flow year, the Pareto front is distributed on a smooth curve. The result shows that the Pareto frontier obtained when population size $M=100$ is more stable and uniform than that obtained when population size $M=50$, and the analysis is more representative. There is no difference between the disassemblies on Pareto frontier, and different schemes are chosen according to different preferences for different target benefits. When the main target of Wangwu Reservoir is to replenish water in Huangshui River Wetland Park, the lower half of the curve can be selected; when the main target of reservoir is to supply water, the upper half of the curve can be selected. In order to analyze the relationship between the two objective functions in detail, according to the principle of extensiveness of the selection, three groups of optimal solutions (scheme 1-scheme 3) were randomly selected from the upper, middle and lower branches of Pareto frontier curve as representative schemes. The location of the selected scheme on the Pareto front is shown in Figure 3. The optimal scheduling results for the proposed scheme are shown in Table 2.

| Schemes | High Flow Year | Normal Flow Year | Low Flow Year |
|---------|----------------|------------------|--------------|
|        | Loss of Water  | Loss of Landscape| Loss of Water| Loss of Landscape| Loss of Water| Loss of Landscape|
|        | ($\times 10^{11}$¥) | ($\times 10^{14}$m$^3$) | ($\times 10^{11}$¥) | ($\times 10^{14}$m$^3$) | ($\times 10^{11}$¥) | ($\times 10^{14}$m$^3$) |
|        | (b) The Normal Flow Year | (c) The Low Flow Year |              |              |              |              |

Table 2. Scheduling results in three different water inflow situations
According to Table 2, with the decrease of water supply benefit loss, the loss of landscape benefit shows an increasing trend. That is, with the increase of water supply of Wangwu Reservoir, the landscape water supply of Huangshui River Wetland Park will decrease. This paper establishes a linear regression equation by analyzing the relationship between water supply benefit loss objective and landscape benefit loss objective. The results show: in the high flow year, the loss of water supply benefit increases by 1.0×10^9, and the loss of landscape water will be reduced by 0.45×10^14 m^3; in the normal flow year, the loss of water supply benefit increases by 1.0×10^9, and the loss of landscape water will be reduced by 0.37×10^14 m^3; in the low flow year, the loss of water supply benefit increases by 1.0×10^9, and the loss of landscape water will be reduced by 0.74×10^14 m^3. It can be seen that the competition between the two objectives in the high flow year is stronger than that in the normal flow year. Although the total amount of water has been very large over the year, the monthly incoming water is very uneven in some special high flow years. This situation will cause the loss of landscape water in high flow year to be greater than that in normal flow year.

5. Conclusion
In view of the contradiction between Wangwu Reservoir water supply and landscape ecological water supply, this paper constructs a multi-objective scheduling model with annual water supply benefit economic loss and annual landscape water loss. Using the GANetXL program, the NSGA-II algorithm is applied to the Wangwu Reservoir optimal scheduling model. The results show that with the increase of population size, the Pareto frontier curve distribution is more uniform and the convergence is better. Different scheduling schemes can be selected according to decision preferences, and the water resources allocation ability of the region can be further enhanced.

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| Scheme 1  | 0.2029 | 1.2585 | 0.2270 | 1.7547 | 0.2402 | 3.9403 |
|----------|--------|--------|--------|--------|--------|--------|
| Scheme 2  | 0.1864 | 1.5980 | 0.1915 | 2.3470 | 0.2068 | 5.7247 |
| Scheme 3  | 0.1754 | 2.7204 | 0.1788 | 3.7180 | 0.1852 | 9.4034 |
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