Water Resources Allocation of the Changjiang To Huai River Water Diversion

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ABSTRACT. The Changjiang river to Huaihe river water diversion project plans to divert water from the lower reaches of the Changjiang river to replenish water in the middle reaches of the Huaihe river, mainly for the purpose of ensuring urban and rural water supply, developing Jianghuai shipping and improving river and lake ecology. In this paper, we predict the four aspects water demand including domestic, industrial, agricultural and ecological water demand in the river channel in 2030. According to the rules of lakes and water supply projects, we can obtain the water supply under different typical years. The balance of water supply and demand is analyzed for different circumstances. It is concluded that the average annual total water demand in the planned area in 2030 is 18.335 billion m³, the total water supply is 15.356 billion m³, and the water shortage is 2.979 billion m³.

1. Introduction

The Changjiang river and Huaihe river project connects the Changjiang River and Huaihe River basins and belongs to one of the 172 major water-saving and water supply projects determined by the State Council and started construction in 2016[1]. The water supply scope of the project covers 12 cities in Anhui province and 2 cities in Henan province, covering a total of 55 districts and counties, covering an area of 70,600 km², benefiting 41.32 million people. The scale of the Changjiang River and Huaihe River project is 300m³/s, the scale of the Huaihe River is 280m³/s, and the total irrigation area of the Huaihe River Basin is 10.85 million mu. In 2030, the average annual water diversion of the Changjiang River Estuary is 3.302 billion m³; the water input into the Wapu Lake is 2.136 billion m³. It is an urgent problem to be solved whether water resources can be developed and utilized according to the principle of sustainable development, and provide services for the life, industry, agriculture and ecological development in the planned areas so as to obtain the maximum socio-economic and environmental benefits. The rational allocation of water resources is the main means to solve the shortage of water resources, maintain the balance between supply and demand, and water ecology and environmental protection[2]. To this end, this paper needs to conduct a rational allocation study of water resources to achieve the purpose of alleviating the contradiction between supply and demand of water resources.
2. Available water supply analysis

Available water supply analysis is to sum up the available water supply of a calculated area in the same planning level year and the same guarantee rate.[3]. The analysis of water supply capacity includes surface water availability analysis, groundwater availability analysis, water reuse for water reuse, and external water transfer analysis for the South-North Water Transfer Project[4].

2.1 Surface water availability analysis

Ground surface water calculation formula:

\[ W_s = \min \left( Q_i, Y_i \right) \]  

Formula: \( W_s \) is the water supply quantity of diversion project; \( Q_i \) is the amount of water that can be transferred to meet the water quality requirements in period \( i \); \( Y_i \) is the project water pumping capacity[5]. In general, the amount of available surface water should be less than or equal to the amount of available surface water[6].

Finally, according to the long series of adjustments, the planned annual average water supply in 2030 is 8.709 billion m³.

2.2 Groundwater availability analysis

Groundwater availability can be divided into shallow and deep groundwater availability[7]. The average annual shallow groundwater supply was 2.329 billion m³ in 2010. By 2030, the average annual water supply of shallow groundwater is 2.381 billion m³. At the same time, the deep groundwater will be used as an emergency water source and will not participate in the water allocation. Therefore, the influence of deep groundwater is not considered in the calculation of available water supply[8].

2.3 Analysis of available supply of reclaimed water

According to the proportion of water and drainage in recent years, the urban sewage discharge rate is determined to be 75%, in which all domestic sewage is collected by the pipe network. According to the requirement of reuse rate of industrial water in the planned year, 80% of the total amount of industrial sewage discharged shall be recycled within the plant, and the remaining 20% shall be discharged into the urban sewage pipe network. In the planning scope of 2030, water consumption is 559 million m³.

2.4 Analysis of available water supply of external mixed water

The water supply scope of the Changjiang river and Huaihe river project and the water supply scope of the East Route of the South-to-North Water Transfer Project are duplicated in HuaiBei and Suzhou city. The water volume of the East Route of the South-North Water Transfer Project will be deducted from the scope of this plan. The East Route of the South-to-North Water Transfer Project plans to supply 254 million m³ of water to HuaiBei and Suzhou in 2030.

3. Water demand forecast

The water demand can be divided into two types of water demand in the river channel and outside the river channel. The water demand in the river channel is the average annual water volume of a specific section. The water demand outside the river channel needs to further distinguish the socio-economic water demand and the artificial ecosystem water demand, and the quota method is used for prediction [9].

Water demand of social economy is divided by life, industry and agriculture. Living water needs include urban life and rural life. Industrial water requirements include the power industry (non-hydropower) and the non-power industry[10]. Agricultural water needs include farmland irrigation and forestry, animal husbandry and fishing.

3.1 Forecast of domestic water demand

Living water demand mainly includes urban and rural residents’ water demand, which is predicted by
quota method. Estimates of their total domestic water needs need to take into account population and quotas. The domestic water demand of residents is predicted by the per capita water quota method, and the total domestic water demand of the year is predicted by the population in 2010 and the water quota. The domestic water needs of urban residents and rural residents are calculated separately, the calculation formula is shown as follows:

\[ W_{ji}^t = P_i^t \times L_i^t \times 365 / 1000 \]  

(2)

\[ W_{mi}^t = P_i^t \times L_i^t \times 365 / 1000 / \eta_i^t \]  

(3)

Formula: \( i \) is the user classification number, \( i=1 \) is the town and \( i=2 \) is the countryside; \( t \) is the planning year serial number; \( W_{ji}^t \) is the net water demand of residents in year \( t \); \( P_i^t \) is the number of water users in year \( t \); \( L_i^t \) is the net living quota (liter/person. day) of residents in the \( t \) year; \( W_{mi}^t \) is gross water demand of residents in year \( t \) (Ten thousand m³); \( \eta_i^t \) is the domestic water utilization coefficient of residents in year \( t \).

Total population in planning year can be predicted by quota method:

\[ p = p_0 (1 + k)^n \]  

(4)

Formula: \( p \) is the total population in the planning year; \( p_0 \) is the total population in 2010; \( k \) is the natural growth rate of population during the forecast period; \( n \) is the predicted years.

3.2 Forecast of industrial water demand

The prediction of industrial water demand can be divided into general industry and thermal power industry, the calculation formula is shown as follows:

\[ Q_i^t = Q_i^{t_1} \times (1 - r_i^{t_2})^{t_2 - t_1} \]  

(5)

Formula: \( t_i^{t_2} \) is the annual decline rate of water intake quota of industry \( i \) in year \( t_2 \) and \( t_1 \) (\%); \( i \) is the general industry or thermal power industry; \( Q_i^{t_1} \) and \( Q_i^{t_2} \) is the water intake quota of industry \( i \) in year \( t_1 \) and \( t_2 \), the calculation formula is shown as follows:

\[ W_j^t = \sum_{i=1}^{n} (X_i^t \times Q_i^t) \]  

(6)

\[ W_m^t = \frac{W_j^t}{\eta_i^t} \]  

(7)

Formula: \( W_j^t \) is the industrial net water demand in year \( t \); \( X_i^t \) is the industrial development index of the \( i \) industry sector in year \( t \); \( W_m^t \) is the industrial gross water demand in year \( i \); \( \eta_i^t \) is the industrial water supply utilization factor of industry sector \( i \) in year \( t \).

3.3 Forecast of agricultural water demand

(1) Forecast of irrigation water demand

According to the surface irrigation area and groundwater irrigation area, the effective irrigation area and water consumption quota are predicted respectively. The comprehensive irrigation quota for farmland is formulated according to the factors such as net irrigation quota for individual crops, current irrigation water level, crop planting structure and utilization coefficient of irrigation water, etc from 1956 to 2010.

Calculate the net quota of comprehensive irrigation:

\[ Q_j = \sum_{i=1}^{n} Q_i \times A_i \]  

(8)
Formula: $Q_j$ is net quota of irrigation (m$^3$/mu); $Q_i$ is the net quota of irrigation for crops (m$^3$/mu); $A_i$ is the percentage of crops planted (%).

According to the comprehensive net irrigation quota, calculate the net water requirement for farmland irrigation:

$$W_n^t = \sum_{j=1}^{3} (S_j^t \times Q_j)$$  \hspace{1cm} (9)

Formula: $W_n^t$ is the net water demand for farmland irrigation in year $t$ (10,000 m$^3$); $j$ is the type of irrigation area; $S_j^t$ is the irrigated area of category $j$ in year $t$ (10,000 mu).

Calculation of irrigation gross water requirement:

$$W_g^t = \sum_{j=1}^{3} (S_j^t \times Q_j) / (\eta_i^t - \eta_q^t) - W_n^t / (\eta_i^t - \eta_q^t)$$  \hspace{1cm} (10)

Formula: $W_g^t$ is the gross irrigation water demand in year $t$ (10,000 m$^3$); $\eta_i^t$ is the utilization coefficient of irrigation water in year $t$.

(2) Water demand forecast for forest, animal husbandry, fish and livestock

The calculation method of water demand of forest, animal husbandry, fish and livestock is the same as above.

3.4 Ecological water demand prediction

Ecological water demand refers to the amount of water needed to maintain ecological environment functions.

(1) eco-environmental water demand inside the river channels

The water demand of ecological environment in river is the amount of water needed to maintain river ecosystem. Ecological water demand in river course is not included in supply and demand analysis.

(2) The ecological environment outside the river needs water

The water demand for the ecological environment outside the river course refers to the water demand for the protection, restoration or construction of the ecological environment in a region and the replenishment of water for the maintenance of lakes, marshes and wetlands with a certain surface. The urban ecological environment water demand is predicted separately according to greening, river and lake water supply and environmental sanitation, and the water demand per unit area is multiplied by the corresponding area forecast. Calculation steps are as follows:

$$W = S_G \times q_G + S_C \times q_C$$  \hspace{1cm} (11)

Formula: $S_G$ is the green area (hm$^2$); $q_G$ is green irrigation quota (m$^3$/hm$^2$); $S_C$ is urban area (m$^2$); $q_C$ is the amount of water needed for sanitation per unit area (m$^3$/m$^2$).

4. Consider the regulation and storage of three lakes

4.1 Basic characteristics of lake

After the implementation of the Changjiang river and Huaihe river project, the project relies on caizi lake, chaohu lake and wabu lake as storage areas. During the flood season, the lake stores a large amount of water, thus reducing the river water level. During the dry season, the water stored in the lake flows into the river, thus supplementing the river water source. Storage plays an important role in the allocation of water resources. In this regard, it is necessary to consider the regulation and storage of the three lakes, where the simple storage rate can be used for simple optimization. The refill index refers to the ratio between the available water supply and the effective storage capacity of a lake. When the storage capacity of a lake is small, the inflow can make the effective storage capacity be
refill for multiple times, and the refill index can be greater than 1. When the reclosing index is 1, the flows of caizi lake, chaohu lake and wabuhu are respectively 31.25 m$^3$/s, 58.64 m$^3$/s and 7.72 m$^3$/s.

4.2 Consider the local water supply for three lakes
According to the above lake regulation and storage rules, water resource regulation allocation was carried out and the lake water storage capacity was $V_{t+1}$ through water balance analysis.

$$V_{t+1} = V_t + I_t + W_t - D_t$$  \hspace{1cm} (12)

Formula: $V_{t+1}$ is the water storage capacity of the lake at the beginning and end of the $t$ period; $I_t$ is the natural amount of water; $W_t$ is the amount of water introduced at time $t$; $D_t$ is the water demand of the region in time period $t$.

Combined with the above equation, the water storage situation at the end of the period was analyzed and decided.

When $V_{t+1} < V_{t, min}$, it is necessary to maintain $V_{t+1}$ not lower than $V_{t, min}$ on the basis of ensuring water supply in the water demand area, and the discharge amount during this period is:

$$Q_t = 0$$ \hspace{1cm} (13)

Formula: $V_{t, min}$ is the lower limit control reservoir capacity of the lake in the $t$ period; $Q_t$ is abandoned water;

When $V_{t, min} < V_{t+1} < V_{t, max}$, it is necessary to ensure that $V_{t+1}$ is not higher than $V_{t, max}$, and the discharge during this period is:

$$Q_t = 0$$ \hspace{1cm} (14)

Formula: $V_{t, max}$ is the upper storage capacity of the lake in the $t$ period.

When $V_{t+1} \geq V_{t, max}$, $V_{t+1}$ is equal to $V_{t, max}$, and the discharge during this period is:

$$Q_t = V_{t+1} - V_{t, max}$$ \hspace{1cm} (15)

5. Water supply and demand balance analysis
The Changjiang river and Huaihe river project covers a wide range which spans the Changjiang river and Huaihe river. The balance of water supply and demand is calculated monthly in a long series, with 1970, 1992 and 1978 as the typical years with 50%, 75% and 95% guarantee rates, respectively. The analysis results of supply and demand balance in 2030 within the planning scope of the project are shown in table 1[11].

This study uses a long series of adjustment calculation methods to calculate the balance of water supply and demand within the scope of the Changjiang river and Huaihe river planning in 2030. It is 18.335 billion m$^3$, the total water supply is 15.356 billion m$^3$ and the water shortage is 2.981 billion m$^3$. According to the spatial distribution situation of water shortage, the water shortage situation is relatively serious in the area west of anhui vortex river, east of anhui vortex river, west of henan vortex river and east of henan vortex river[12]. 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].

Table 1 Table of analysis results of supply and demand balance within the planning scope of jianghuai project in 2030(Unit: billion m$^3$)

| Calculating area | Year  | Water demand | Water supply |
|------------------|-------|--------------|--------------|
|                  |       | Live industrial Agricultural Ecological Total | Local surface water Lakes to regulate Shallow groundwater Water reuse External water lack of water |
| Changjiang       | 50%   | 8.76 14.15 20.35 2.49 45.75 43.91 0 1.84 0 45.75 0 |
6. Conclusions and Suggestions

(1) In 2030, 50%, 75%, 95% and perennial average water shortages are 2.702 billion m$^3$, 3.806 billion m$^3$, 8.392 billion m$^3$ and 2.981 billion m$^3$ respectively. Even after considering the water supply of the eastern route of the south-to-north water transfer project and increasing the utilization of reclaimed water, the increased water supply still cannot meet the demand of the planning scope and the water shortage situation is still severe.[14].

(2) This study is mainly based on the reasonable allocation of water resources from the Changjiang river to the Huaihe river. However, the optimal allocation of water resources on how to increase the guarantee rate of water resources by improving the utilization efficiency of local water and water from the Changjiang river remains to be further studied.

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