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Key Points:

- Maslow's hierarchy of needs theory was introduced to improve the water resource regulation model from the demand side
- Different from fairness, the equilibrium is a stable state under the influence of diversity of interests and other factors
- Based on the satisfaction function and Gini coefficient, an equilibrium function was constructed to guide the regulation of water resources

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A Water Resource Equilibrium Regulation Model Under Water Resource Utilization Conflict: A Case Study in the Yellow River Basin

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Abstract The mismatch between the spatiotemporal distribution patterns of water resources and recent regional socioeconomic development threatens social stability and sustainable development, particularly in river basins affected by water scarcity. Therefore, it is necessary to adapt a water resource regulation model to address these new challenges. Based on the theory of Maslow's hierarchy of needs and the Gini coefficient, in this study, a water resource equilibrium regulation model is constructed from the demand side and applied to the Yellow River Basin (YRB). Different from fairness, equilibrium is a stable state under the influence of diversity of interests and other factors. The results show that the model realizes the spatial and temporal equilibrium regulation of water resources. The water supply assurance rates of ecological and agricultural water users increase significantly to 94.1% and 74.3%, respectively. In particular, in dry years, the rigid demands of water users can be well met, and irreversible losses can be avoided. Compared with Scheme 1987, the proportion of water supply for upstream provinces increases to 42.34%, which will contribute to the balanced development of the basin. This model has the potential to be used in a wide range of applications, providing not only theoretical and technical support for the adjustment of Scheme 1987 in the YRB but also a reference for other governments and water resource management institutions around the world.

1. Introduction

The regulation of water resources between competitive regions and water users is an urgent issue for many countries and their water resource management sectors. The key is how to reconcile the growing demand for water resources with the finite supplies (Jackson et al., 2019). Unfortunately, according to the 2019 World Water Development Report (WWDR), more than two billion people will live in severely water-scarce areas, and approximately four billion people will suffer from terrible water scarcity for at least 1 month each year by 2050. The shortage of water resources will lead to more conflicts and competition in the future. In their research reports, UNESCO, the World Bank, and other institutions have indicated that poor water regulation aggravates the conflict and competition over water resources (Amprako, 2016; Mekonnen & Hoekstra, 2016). It is therefore vital to improve adaptive regulations under limited water resources (Borgomeo et al., 2014; Gohari et al., 2013), and doing so is one of the most significant challenges faced by governments and the water resource management sector.

Most countries in the world have clearly defined the public ownership of water resources, which means that water resources belong to all citizens and the state (Stensrud, 2019; Teerink & Nakashima, 1993; Zheng et al., 2012). There is widespread agreement that fairness must be prioritized in water resource regulation, especially in areas with fierce competition (Whited et al., 2011; Wilder & Ingram, 2018). Fair access to water resources and their benefits will help improve the gap between rich and poor groups within society. Furthermore, the fairness of water resource regulations is directly related to social stability (Cullis & Koppen, 2009; D Exelle et al., 2012). However, most water resource management sectors around the world are continuing to pursue efficiency as their primary goal rather than fairness. Because the pursuit of fairness often results in a loss of benefits, it is likely to be opposed by stakeholders. Despite the efforts of the international community during recent decades, problems related to the fairness of water resources persist and, in some cases, have even worsened. The fair allocation of water resources between competing regions and water users is still a difficult policy decision (Cullet, 2018; Syme et al., 1999; Wilder & Ingram, 2018).

Related to fairness, studies on water resource regulation have reached beyond economic considerations to encompass social morality (Cai, 2008; Schmidt & Peppard, 2014; Syme & Nancarrow, 1996; Wutich et al., 2013). Compared with efficiency, less attention has been paid to fairness. In addition, fairness issues are extremely difficult to solve. The main reason is that the standards for fairness judgments are always affected by subjective factors, similar to other social problems (Dinar & Tsur, 1995; Suzuki & Nakayama, 1976; Syme et al., 1999; Wang et al., 2015). A fixed or proportional reduction in water supply for all water users is considered fair by governments and water management agencies, and it is a common strategy in areas affected by water scarcity (Iftekhar & Fogarty, 2017). Because of the heterogeneity in the utilization efficiency and importance of water resources across different water users, both fixed and proportional reduction strategies are unreasonable (Grafton & Ward, 2008). In academia, various qualitative and indirect methods have been developed to guide the fairness of water resource regulation (Cai, 2008; Hu & Eheart, 2014; Patrick et al., 2014). Hu et al. (2016) constructed an optimal allocation model to evaluate the fairness of water resource allocation based on interregional economic benefits. In a follow-up study, considering the differences in the characteristics of water users, Hu et al. (2016) established fairness evaluation methods for particular types of water users, including domestic and industrial water users. Dai et al. (2018) characterized the fairness of water resource allocation through the matching relationship between population and water resources among administrative districts.

However, how can we evaluate the fairness of water resource regulation among different water users, such as domestic, industrial, and agricultural water users? Few relevant studies on this topic have been conducted. The characteristics and water resource utilization efficiencies of different water users vary greatly. Absolute fairness means treating all people equally, ignoring factors such as the diversity of interests, the needs of socioeconomic development and policy preferences. If the government and water resource management sectors blindly pursue fairness, doing so will inevitably lead to a loss of benefits and affect socioeconomic development (Hu et al., 2016). What we should actually pursue is equilibrium between different water users and regions. Equilibrium is a state of stability (Nash, 1950), which is different from fairness. Equilibrium can reflect the diversity of interests, but in a sense, those interests influence the deviation from initial endowments and deviations from full fairness. Of course, deviation may not arise purely from diversity, and policy preferences and the needs of socioeconomic development also influence deviation. For example, water resources management agencies will set water supply priorities based on regional development needs, which will lead to unfair initial endowments. Hence, equilibrium will be unfair if derived from a particular unfair initial endowment.

The key to this study is how to use uniform parameters or indicators as the basis to guide the equilibrium regulations among different water users and regions. The Gini coefficient is the most widely used socioeconomic indicator for characterizing fairness (Dai et al., 2018; Fann et al., 2018; Hu et al., 2016). However, equilibrium and fairness are different. How can the Gini coefficient be used to characterize the equilibrium of water resource regulations? As the key to this problem, the basic indicators used in calculating the Gini coefficient must be unified and able to characterize the diversity of interests. Water resource regulations are demand oriented. From the perspective of human motivation, survival is the most basic, followed by development and enjoyment. Hence, this problem can be solved on the demand side. The American psychologist Abraham Maslow first proposed a theory of a hierarchy of needs based on human motivation (Maslow, 1943), and this theory provides a new direction and theoretical basis for our present study.

Maslow's hierarchy of needs characterizes the common laws of human behavior and psychological activities. Maslow pointed out that human demands are continuously developing from low-to high-level needs. When low-level demands are satisfied, high-level demands become the main motivation driving human activities (Hou et al., 2014; Taormina & Gao, 2013). As an important theory of human psychology, Maslow's hierarchy of needs has been widely used in research on numerous social problems, such as education, medicine, sociology, and the environment (Goel et al., 2018; Hale et al., 2020; Han et al., 2021; Hutchins et al., 2019). However, its application in the field of water resources is still in the exploratory stage, and there have been few relevant studies (Russo et al., 2014; Sadeghi et al., 2020). Melloul and Collina (2003) proposed a pyramidal hierarchy of water resource management needs based on Maslow's hierarchy of needs to most efficiently fulfill the water requirements of society. Hou et al. (Hou et al., 2018; Pan et al., 2018) established a hierarchical theory of household water demand based on Maslow's hierarchy of needs in which household water is classified into three levels. Based on Maslow's hierarchy of needs and the Gini coefficient, in this study, a water resource equilibrium regulation model is constructed from the demand side. Additionally, the model is applied to the Yellow River Basin (YRB) in China.

The YRB is an important food production area and energy base in China, and it is facing a serious shortage of water resources. The Yellow River provides water for approximately 12% of the population and 17% of irrigated agricultural lands in China, but the basin holds only 3% of the country's water resources (Cai & Rosegrant, 2004; Chen et al., 2020; Li et al., 2021). The per capita water resources in the YRB are only 500 m^3, which is less than 1/4 of China's per capita water resources and 1/15 of the world's per capita water resources. The competition for water resources among water users and regions is fierce. Domestic and industrial water users have long held the water resource share of agricultural and ecological water users (Cai & Rosegrant, 2004; Zhou et al., 2022). The Yellow River Conservation Commission (YRCC) promulgated the Yellow River Water Allocation Scheme 1987 (Scheme 1987) and Comprehensive Planning of Water Resources in the YRB (2013). These policies were aimed at allocating the water share of each province (Zhang & Oki, 2021). However, with socioeconomic development and the increasing demand for water resources, the water resource conflict between regions is becoming more serious. Most regions want to increase their share of water resources. The coordination of the share of water resources between regions and water users is a challenge for the water resource management sectors in the YRB. As a typical basin affected by water scarcity, research on the water resource equilibrium regulation model of the YRB can provide new ideas and references for other basins around the world.

2. Methodology

Based on Maslow's hierarchy of needs, combined with the membership function and Gini coefficient, in this study, a quantitative evaluation method for water resource equilibrium among different water users is proposed. Furthermore, coupling the optimization of the cascade reservoir operation and water resource allocation, a double-layer water resource equilibrium regulation model is established. The research path of this study is shown in Figure 1.

2.1. Theoretical System of Water Resource Equilibrium Regulation

2.1.1. Stratification of Water Resource Demand

According to Maslow's hierarchy of needs, the various demands of people are summarized into five levels, namely, physiological, security, social, respect, and self-actualization demands, and their internal relationships are clarified (Maslow, 1943). Maslow considers the five levels of demand to be a ladder, moving from low to high. After low-level demands are satisfied, they will develop into high-level demands. Before high-level demands appear, low-level demands must be properly satisfied. Maslow's hierarchy of needs first systematically expounds on the relationship between human needs and behavior.

In this study, the water demands of different water users are stratified based on Maslow's hierarchy of needs. Combining the actual development status and characteristics of different regions and water users, their water demands are stratified into three levels: rigid, elastic, and luxury demands (Figure 2). Rigid water demand is defined as the basic water to meet the demands of biological survival, normal industrial production, and the ecological health of rivers and lakes, and it will cause irreparable losses if it cannot be met. Elastic water demand is water to improve people's quality of life, develop industry, and maintain a suitable ecological environment for rivers and lakes, and at this level, losses caused by water scarcity are reparable. Luxury water demand is the amount of water required to sustain luxury consumption, high water-consuming industries, and high water-consuming landscapes in real life (Hou et al., 2014; Hou et al., 2018; Pan et al., 2018). The standard for water resource demand stratification varies from region to region and is not absolute.

2.1.2. Satisfaction Function of Water Users

This study constructs a satisfaction function based on the water resource hierarchy demands and membership function, as shown in Equations 1 and 2. As a type of fuzzy evaluation function, the membership function is the application basis of fuzzy control and is widely used in research on water resource management and evaluations (Hasanzadeh et al., 2020; Li et al., 2021; Li et al., 2019). The satisfaction function is a piecewise function (monotonically decreasing function, as shown in Figure 3) that aims to characterize the diversity of interests. $SAT_{i,t}$ is a normalized variable. Satisfaction depends on the level of water demand that is not met. For example, when $d_i^* < d_{i,t} \leq 1$, that is, the rigid demand of a water user is not met, the third function of Equation 1 is used to calculate satisfaction.

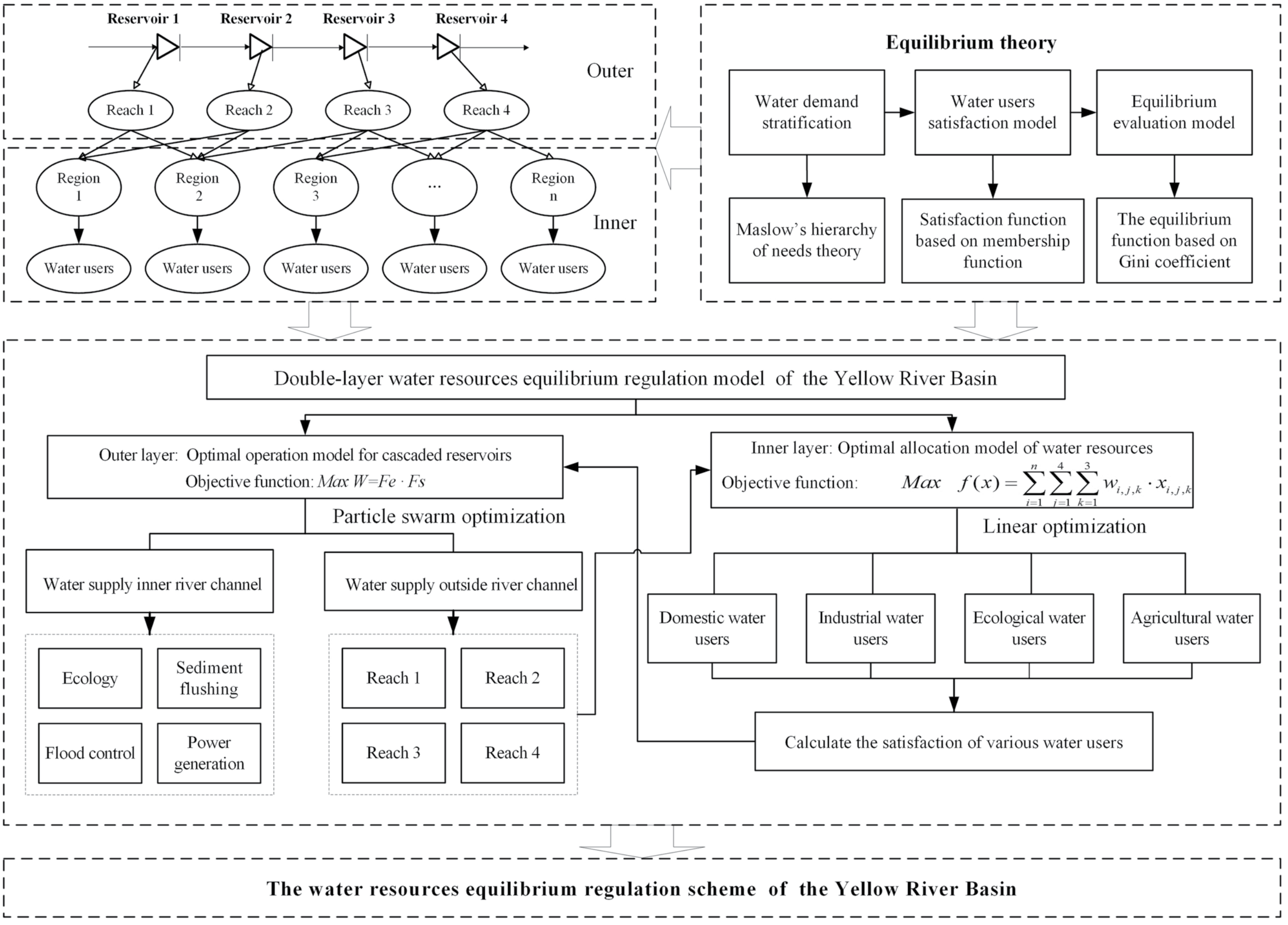

Figure 1. Framework of the water resource equilibrium regulation model.

$$SAT_{i,t}=f(d_{i,t})=\begin{cases}1+\dfrac{(a-1)\times d_{i,t}}{d_i^{**}}, & 0<d_{i,t}\le d_i^{**}\\ \dfrac{d_{i,t}-d_i^{*}}{d_i^{**}-d_i^{*}}\times a+\dfrac{d_{i,t}-d_i^{**}}{d_i^{*}-d_i^{**}}\times b, & d_i^{**}<d_{i,t}\le d_i^{*}\\ \dfrac{d_{i,t}-1}{d_i^{*}-1}\times b, & d_i^{*}<d_{i,t}\le 1\end{cases} \tag{1}$$

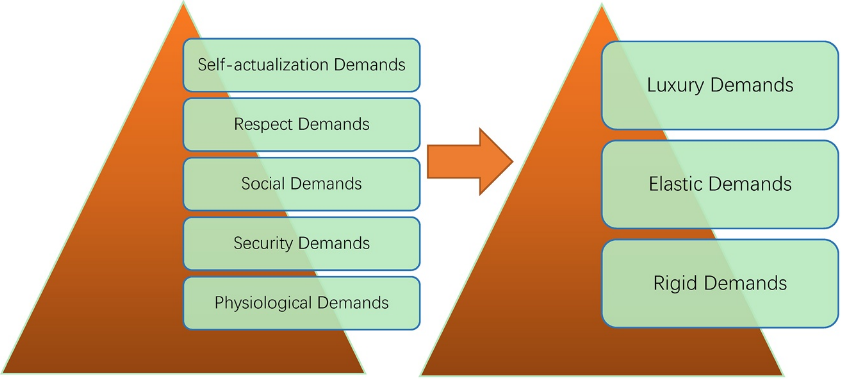

Figure 2. Hierarchy of water demands.

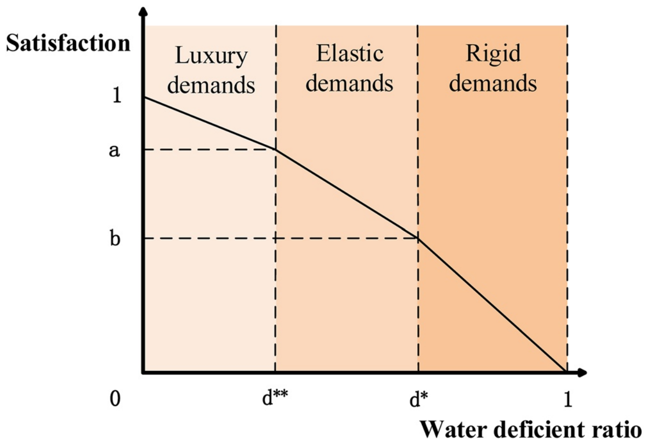

Figure 3. Satisfaction function curve.

$$d_{i,t} = 1 - \frac{x_{i,t}}{wd_{i,t}} \tag{2}$$

Here, $SAT_{i,t}$ is the satisfaction of water user i at time t and is a function of $d_{i,t}$; $d_{i,t}$ is the water deficient ratio of water user i at time t; $x_{i,t}$ and $wd_{i,t}$ are the water supply and water demand of water user i at time t, respectively; and d_i^* and d_i^{**} are the corresponding water-deficient ratios when the rigid demand and elastic demand of water user i are met, respectively (Figure 3).

The values of d_i^* and d_i^{**} differ for different users. For example, if the rigid demand of a water user accounts for 60% of total water demand, $d_i^* = 0.4$. Water demand stratification is used to solve d_i^* and d_i^{**}; in addition, a and b are the corresponding satisfaction of water user i when rigid demand and elastic demand are met, respectively. Unified standards are adopted to normalize the satisfaction of different water users. If a water user has rigid, elastic, and luxury demands, $b = 0.6$ and $a = 0.9$; if a water user has rigid and elastic demands, $b = 0.6$ and $a = 1$; and if a water user has only rigid demand, $a = b = 1$.

2.1.3. Equilibrium Function of Water Resource Regulation

The Gini coefficient is an index that is used internationally to measure the income gap of residents in a country or region (Gini, 1921). The Gini coefficient is the ratio of A (the area between the line of perfect equality and the observed Lorenz curve) to $A + B$ (the area between the line of perfect equality and the line of perfect inequality), as shown in Figure 4 (Masaki et al., 2014). It ranges from 0 to 1, and the larger the value is, the more uneven the resource distribution. Gini (1921) proposed a direct calculation method for the Gini coefficient. In this study, we use the empirical distribution function shown in Equation 4 to calculate the Gini coefficient of $\overline{SAT}_i$ and to characterize the equilibrium between water users, as shown in Equations 3–6. This method has no specific requirements for sample distribution characteristics and is commonly used in various research fields to evaluate fairness, including water resource management (Cheng et al., 2019; Dai et al., 2018; Fann et al., 2018; Hu et al., 2016). Satisfaction sequence $\overline{SAT}_i$ is rearranged from small to large to generate a new sequence, SAT_i':

$$\overline{SAT}_i = \frac{1}{T}\sum_{t=1}^{T} SAT_{i,t} \tag{3}$$

$$P_i = \sum_{i=1}^{i} SAT_i' \Big/ \sum_{i=1}^{n} SAT_i' \tag{4}$$

$$G_{SAT} = 1 - \frac{1}{n}\sum_{i=1}^{n}(P_{i-1} + P_i) \tag{5}$$

$$F_e = 1 - G_{SAT} \tag{6}$$

Here, $\overline{SAT}_i$ is the average satisfaction of water user i during period T; n is the number of water users; P_i is the cumulative frequency of satisfaction for water user i; G_{SAT} is the Gini coefficient of water user satisfaction $\overline{SAT}_i$; and F_e is the equilibrium function of water resource regulation and is used to characterize the equilibrium of water resource regulation among different water users.

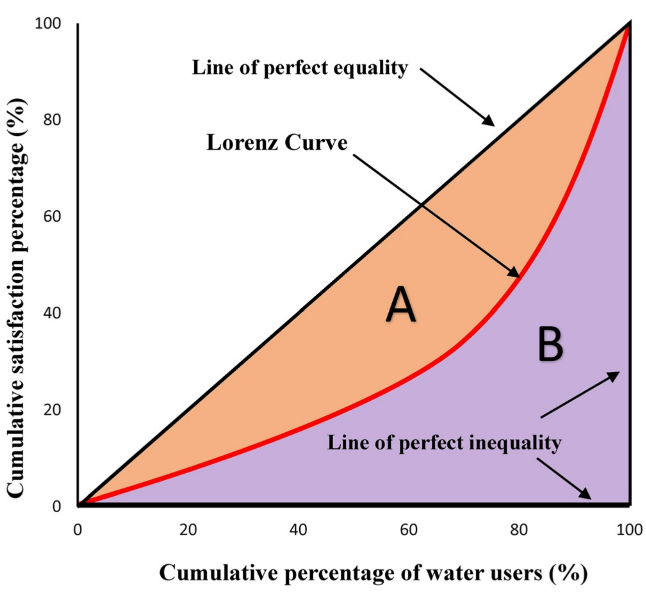

Figure 4. Lorenz curve of water user satisfaction.

2.2. Double-Layer Water Resource Equilibrium Regulation Model

In this study, a double-layer structural optimization model is established based on reservoir operation and water resource allocation. The outer model is the optimal operation model of cascade reservoirs, and it aims to exert

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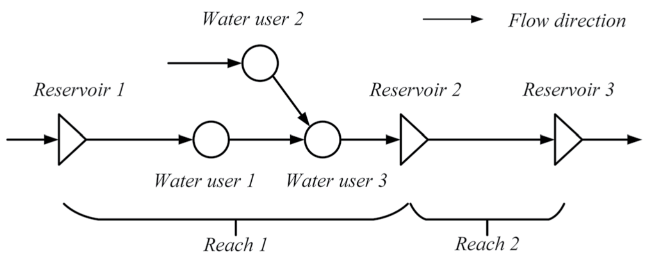

Figure 5. Node schematics for a simple example.

the capacity of cascade reservoirs and realize the redistribution of water resources in space and time. The inner model is the optimal allocation model of regional water resources. Taking the reservoir discharge as the input, water resources are optimized based on the optimization rules. Taking Figure 5 as an example, the double-layer model structure is described as follows (Sections 2.2.1 and 2.2.2).

2.2.1. Outer Layer: Optimal Operation Model of Cascade Reservoirs

Based on the specific conditions of different reaches, the corresponding constraints should be considered in the outer layer optimization model, such as the minimum ecological flow constraints of downstream rivers, flood control constraints, and ice flood control constraints. The outer layer optimization model is guided by water resource equilibrium regulation function F_e. If the outer layer optimization model is guided only by the goal of maximizing F_e, it may lead to equilibrium at a low level of satisfaction. That is, the F_e value will be high, but the satisfaction of all water users will be low. To avoid such problems, function F_s, as shown in Equation 8, is added to the objective function to ensure equilibrium at a high level of satisfaction. In addition, F_s is the average of $\overline{SAT}_{i,t}$. The objective function and main constraints of the outer layer optimization model are shown in Equations 7–15.

For the objective function,

$$W = max\{F_s \cdot F_e\} = \overline{SAT} \cdot (1 - G_{SAT}) \tag{7}$$

$$F_s = \overline{SAT} = \frac{1}{n \times T} \sum_{t=1}^{T} \sum_{i=1}^{n} SAT_{i,t} \tag{8}$$

$$\overline{SAT}_t = \frac{1}{n} \sum_{i=1}^{n} SAT_{i,t} \tag{9}$$

where W is the objective function of the outer layer optimization model; F_s and $\overline{SAT}$ are the average of $\overline{SAT}_{i,t}$; $\overline{SAT}_t$ is the average satisfaction of water users at time t; and G_{SAT} is the Gini coefficient of $\overline{SAT}_i$ during regulation period T.

As the main constraints,

$$Q_{out,t} = Q_{in,t} - Q_{wc,t} + \sum_{t=1}^{T} V_{S,t} - \sum_{t=1}^{T} V_{E,t} \tag{10}$$

where $Q_{out,t}$ and $Q_{in,t}$ are the outflow and inflow of the basin at time t, respectively; $Q_{wc,t}$ is the water consumption of water users in the basin at time t; and $V_{S,t}$ and $V_{E,t}$ are the initial and end capacity of the cascade reservoirs at time t, respectively.

$$Zd_{i,t} \le Z_{i,t} \le Zu_{i,t} \tag{11}$$

Here, $Z_{i,t}$ is the water level of reservoir i at time t, and $Zd_{i,t}$ and $Zu_{i,t}$ are the lower and upper limit water levels of reservoir i at time t, respectively.

$$q_{d\,i,t} \ge \max q_{e\,i,t} \tag{12}$$

$$q_{r\,i,t} \ge q_{sand\,i,t} \tag{13}$$

$$q_{r\,i,t} \le q_{ice\,i,t} \tag{14}$$

$$q_{r\,i,t} \le q_{max\,i,t} \tag{15}$$

10.1029/2021WR030779

Here, $q_{d\,i,t}$ and $q_{e\,i,t}$ are the minimum flow and ecological base flow inside the downstream reach of reservoir i at time t, respectively. $q_{r\,i,t}$ is the discharge of reservoir i at time t; $q_{sand\,i,t}$ is the flow of sand flushing required for reservoir i at time t; $q_{ice\,i,t}$ is the limited flow for ice prevention inside the downstream reach of reservoir i at time t (Jin et al., 2019); and $q_{\max i,t}$ is the maximum discharge capacity of reservoir i at time t.

Particle swarm optimization (PSO) is used to solve the outer layer optimization model. The stability of PSO is strong, and PSO has been applied in many scientific research fields (Li et al., 2021; Mohammadi et al., 2021; Niu et al., 2020; Ye et al., 2019). The maximum number of iterations is 5,000, and in our study, the population size is 100. The other parameters of the model are as follows:

$$phi_1 = 2.05 \tag{16}$$

$$phi_2 = 2.05 \tag{17}$$

$$phi = phi_1 + phi_2 \tag{18}$$

$$w = chi = 2/(phi - 2 + \sqrt{phi^2 - 4 \cdot phi} \tag{19}$$

$$wdamp = 1 \tag{20}$$

$$c_1 = chi \cdot phi_1 \tag{21}$$

$$c_2 = chi \cdot phi_2 \tag{22}$$

Here, w is the inertia weight; $wdamp$ is the inertia weight damping ratio; c_1 is the personal learning coefficient; and c_2 is the global learning coefficient.

2.2.2. Inner Layer: Optimal Allocation Model of Water Resources

The water supply outside the river is optimized using the inner layer optimization model to realize the equilibrium allocation of water resources among different water users. Owing to the different amounts of water resources, different industrial structures, and different social development levels, the priorities of water users will also differ in different regions. For example, in the Qujiang River Basin, which is rich in water resources and dominated by agriculture, the priority of water resource allocation is as follows: domestic, agricultural, industrial, and ecological water (Hu et al., 2016). In the YRB, which is a typical basin with a water shortage, the priority of water resource allocation is as follows: domestic, industrial, ecological, and agricultural water (Cai & Rosegrant, 2004; Wang et al., 2020; Yang et al., 2012).

To avoid wasting water resources and damaging the rights and interests of water users, particularly in extreme drought, we should prioritize meeting the rigid demands of each water user and then meet their elastic and luxury demands in turn. Therefore, based on the current priority of water resource allocation in the YRB and combined with the hierarchical demand of water resources, the coefficients of water users in different provinces are shown in Table 1 and Figure 6. Water users with high coefficients have priority in terms of water supply. For rigid demand, the coefficients of the same type of water users are the same, which is done to safeguard the basic rights and interests of water users in different areas. For elasticity and luxury demand, the coefficients are determined based on the efficiency of water utilization (Wang et al., 2020). For example, the water utilization efficiency of industrial water users is the highest in Henan Province, with a coefficient of 7.9, and the lowest in Sichuan Province, with a coefficient of 7.1.

Here, $\alpha_{D,R}$ is the coefficient of the rigid demand of industrial water users. D, I, E, and A represent domestic, industrial, ecological, and agricultural water users, respectively. R, E, and L represent rigid, elastic, and luxury demands, respectively.

Taking Reach 1 in Figure 5 as an example, a linear optimization model of water resources (inner optimization model) is constructed. The objective function and constraint conditions of the model are as follows:

$$\text{objective function：} \quad Max\, f(x_{i,j,t}) = \sum_{i=1}^{3} \sum_{j=1}^{3} \alpha_{i,j} \cdot x_{i,j,t} \tag{23}$$

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Table 1
Coefficients of Water Users in the YRB

	Domestic water			Industrial water			Ecological water			Agricultural water		
Province	Rigid demand	Elastic demand	Luxury demand	Rigid demand	Elastic demand	Luxury demand	Rigid demand	Elastic demand	Luxury demand	Rigid demand	Elastic demand	Luxury demand
Qinghai	12.0	8.6	4.6	11.0	7.2	3.2	10.0	6.6	2.6	9.0	5.3	1.3
Sichuan	12.0	8.4	4.4	11.0	7.1	3.1	10.0	6.1	2.1	9.0	5.2	1.2
Gansu	12.0	8.8	4.8	11.0	7.5	3.5	10.0	6.2	2.2	9.0	5.4	1.4
Ningxia	12.0	8.9	4.9	11.0	7.3	3.3	10.0	6.3	2.3	9.0	5.1	1.1
Inner Mongolia	12.0	8.3	4.3	11.0	7.6	3.6	10.0	6.4	2.4	9.0	5.5	1.5
Shaanxi	12.0	8.7	4.7	11.0	7.7	3.7	10.0	6.7	2.7	9.0	5.6	1.6
Shanxi	12.0	8.1	4.1	11.0	7.4	3.4	10.0	6.5	2.5	9.0	5.8	1.8
Henan	12.0	8.2	4.2	11.0	7.9	3.9	10.0	6.8	2.8	9.0	5.9	1.9
Shandong	12.0	8.5	4.5	11.0	7.8	3.8	10.0	6.9	2.9	9.0	5.7	1.7

$$x_{i,t} = \sum_{j=1}^{3} x_{i,j,t} \tag{24}$$

$$wd_{i,t} = \sum_{j=1}^{3} wd_{i,j,t} \tag{25}$$

$$\text{constraint conditions}: \begin{cases} 0 \le x_{1,t} \le In_{1,t} + RD_t \\ 0 \le x_{2,t} \le In_{2,t} \\ 0 \le \sum_{i=1}^{3} x_{i,t} \le In_{1,t} + In_{2,t} + In_{3,t} + RD_t \\ 0 \le x_{i,t} \le wd_{i,t} \\ 0 \le x_{i,j,t} \le wd_{i,j,t} \end{cases} \tag{26}$$

Here, $i = 1$, 2, and 3 represent water users U_1, U_2, and U_3, respectively. $j = 1$, 2, and 3 represents rigid, elastic, and luxury demands, respectively. $\alpha_{i,j}$ is the weight coefficient of part j of water user i. $x_{i,j,t}$ is the water supply of part j of water user i at time t. RD_t is the discharge flow of Reservoir 1 at time t. $In_{i,t}$ is the self-produced water in the area where water user i is located at time t. $wd_{i,j,t}$ is the water demand of part j of water user i at time t.

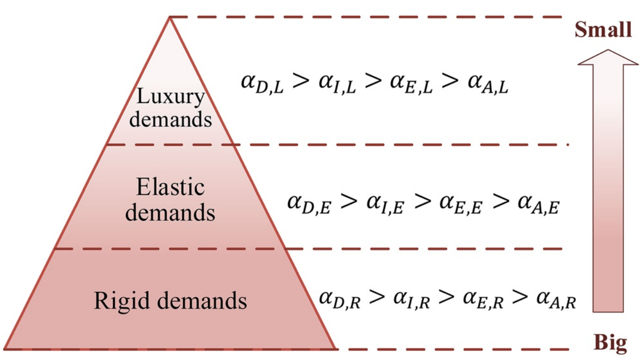

Figure 6. Coefficients of water users.

3. Case Study

3.1. Study Area and Data

Taking the YRB as the study area, this study constructs a water resource equilibrium regulation model on a monthly scale. The Yellow River flows through the nine provinces of Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong (Figure 7), and it involves 68 municipalities and 45 catchment areas. In this model, we divide the YRB into 264 nodes (185 water use nodes and 79 other types of nodes, including reservoirs, hydrological stations, diversion works, and important hydrological sections). There are 524 water users (157 domestic, 146 industrial, 57 ecological, and 164 agricultural water users) in the water use nodes. A node map of the YRB is presented in Appendix A.

The regulation system for water resources in the YRB is composed of many reservoirs. Considering the storage capacity and regulating capacity of

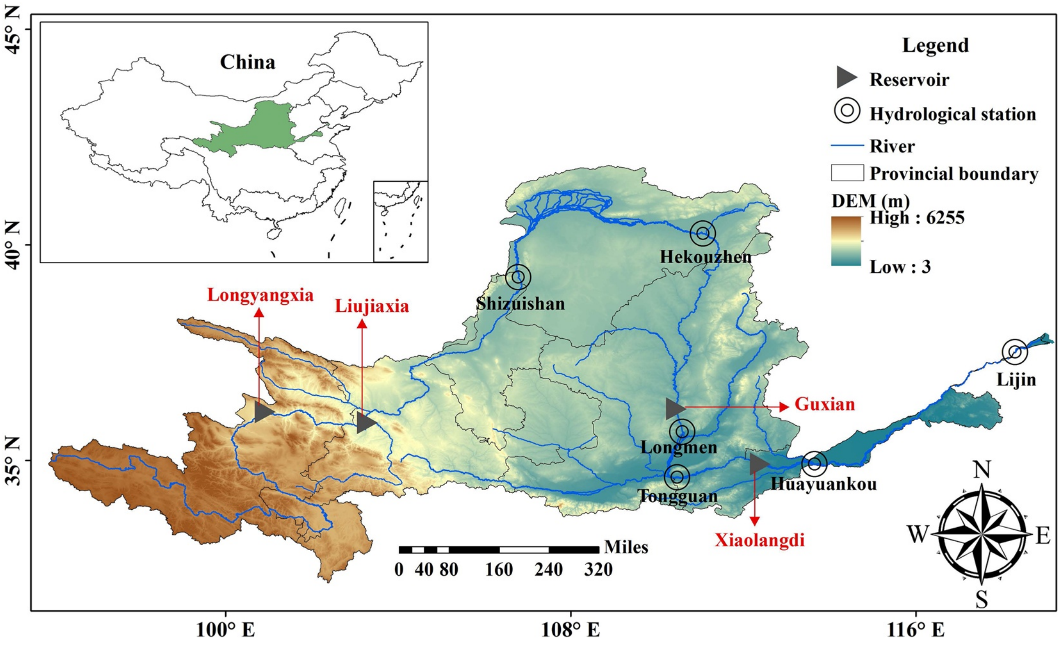

Figure 7. Map of the YRB

reservoirs, Longyangxia (LYX), Liujiaxia (LJX), Guxian (GX), and Xiaolangdi (XLD) on the main stream of the Yellow River are selected to participate in the outer layer optimization model. LYX is a multiyear operation reservoir, and LJX, GX, and XLD are annual operation reservoirs. The main parameters of the four reservoirs are listed in Table 2. GX is under planning and construction (to be completed in 2030), and its parameters are the designed parameters. Owing to the long distance between the LJX and GX reservoirs, a 1-month runoff delay time between the two reservoirs is set.

The datasets used in this study include the natural monthly runoff data (1956–2016) and monthly surface water demand data (2030 level) for each node. The monthly runoff data are the results of the Third National Survey and Evaluation of Water Resources provided by the Yellow River Water Resources Commission (YRWRC). The monthly water demand data are the surface water demand data for 2030. The average annual natural runoff in the YRB from 1956 to 2016 was 49.22 billion cubic meters (including 239 million cubic meters in the inner flow area), and the water diversion from the other basins was 1.76 billion cubic meters per year (YQJS, YHJS, YHJW, and SNWD). The available water resources in cascade reservoirs in the initial state were 12.78 billion cubic meters.

Table 2
Reservoir Characteristics

Reservoir	DSL (m)	NPL (m)	FLWL (m)	IC (MW)	APG (10^6 kWh)	MPF (m^3/s)
Longyangxia	2,530	2,600	2,594	1,280	5,294	1,192
Liujiaxia	1,694	1,735	1,726	1,160	5,760	1,350
Guxian	588	627	617	2,100	5,645	1,717
Xiaolangdi	230	275	254	1,800	5,851	1,776

Note. DSL denotes the dead storage level; NPL means the normal pool level, that is, the maximum level to which water may rise under normal operating conditions; FLWL indicates the flood-limited water level; IC represents the installed capacity; APG denotes the designed annual power generation; and MPF indicates the maximum power flow.

3.2. Water Demand Stratification

At present, there are few studies on the stratification of water resource demand, and the division standards for different regions are also adjusted to local conditions (Hou et al., 2018; Hou et al., 2014; Melloul & Collin, 2003). Based on the characteristics of different water users, the standard for water demand stratification in the YRB is shown in Table 3 (Gleick, 1996; Wang et al., 2020; Wu et al., 2020). The values of water demand stratification in the YRB are listed in Table 4.

As shown in Table 3, domestic water is mainly divided into two parts: rigid demand and elastic demand. Rigid demand is defined as the daily domestic water demand of residents, which is calculated based on the future population and water quota. According to the Comprehensive Planning of Water Resources in the YRB, the individual domestic water quotas of urban and rural residents are 124 L/d and 72 L/d, respectively. Elastic demand is the

Table 3
Standard for Water Demand Stratification in the YRB

Domestic	Rigid demand	Daily life of residents
	Elastic demand	Public living (service industry, catering industry and others)
Industrial	Rigid demand	General industry and construction
	Elastic demand	High water consumption industry
Ecological	Rigid demand	Urban greening, lake wetland ecology, ecological shelter forest and others
Agricultural	Rigid demand	The basic grain ration
	Elastic demand	Grain for consumptive self-sufficiency
	Luxury demand	Grain for export

water demand for public life, mainly including water for the tertiary industry and social public services. Industrial water is also divided into two parts: rigid demand and elastic demand. Considering the shortage of water resources in the YRB, we define the water demand of general industry and construction as rigid demand and that of high water consuming industry as elastic demand. Following the principle of ecological priority in China, the water demands of ecological water users are all defined as rigid demands. Agricultural water demand includes irrigation water demand and forestry, animal husbandry, fishery, and livestock water demand. Since the proportion of irrigation water demand exceeds 90%, we use the stratification of irrigation water demand to represent the stratification of agricultural water demand. Irrigation water demand is calculated by the following equation:

$$IWD = \frac{PCG \times POP}{GYP} \times WQP \tag{27}$$

Here, IWD is the irrigation water demand; PCG is the per capita grain share; Pop is the population; GYP is the grain yield per unit of irrigation area; WQP is the water quota per unit of irrigation area. Rigid demand, elastic demand and luxury demand are defined as the irrigation water demand to ensure a per capita grain share of 180 kg, 180–400 kg and more than 400 kg, respectively.

4. Results and Discussion

The outer-layer optimization model uses a PSO algorithm with constriction coefficients. At approximately 3,000 iterations, the objective function becomes stable. As the final optimization result, the objective function is $W = 0.82$, $F_e = 0.92$, $F_s = 0.89$, and $G_{\overline{SAT}} = 0.08$. When the Gini coefficient is less than 0.2, it proves that the distribution of resources is in equilibrium.

Table 4
Ratio of Water Demand Stratification (%)

	Domestic		Industrial		Ecological	Agricultural		
Provinces	Rigid	Elastic	Rigid	Elastic	Rigid	Rigid	Elastic	Luxury
Qinghai	75.5	24.5	73.4	26.6	100.0	50.8	49.2	0.0
Sichuan	75.0	25.0	75.0	25.0	—	56.5	43.5	0.0
Gansu	74.5	25.5	44.5	55.5	100.0	49.6	50.4	0.0
Ningxia	79.7	20.3	50.7	49.3	100.0	51.0	49.0	0.0
Inner Mongolia	69.7	30.3	51.5	48.5	100.0	36.8	23.8	39.4
Shaanxi	73.2	26.8	69.5	30.5	100.0	58.7	41.3	0.0
Shanxi	80.2	19.8	60.6	39.4	100.0	53.9	46.1	0.0
Henan	71.1	28.9	81.1	18.9	100.0	44.1	44.3	11.6
Shandong	73.5	26.5	67.1	32.9	—	55.1	44.9	0.0
Hebei-Tianjin	—	—	—	—	—	55.1	44.9	0.0
YRB	74.6	25.4	63.0	37.0	100.0	49.3	41.8	8.9

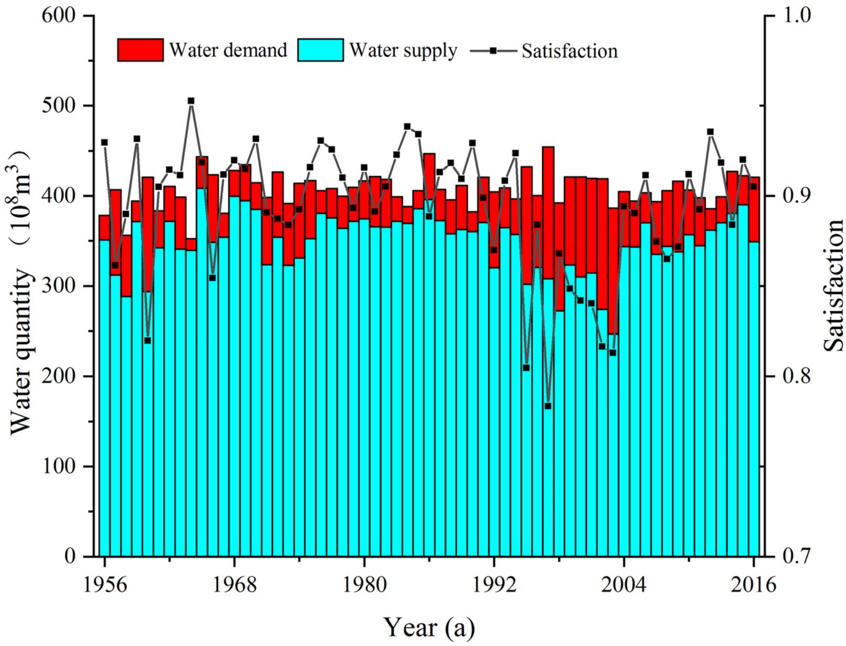

Figure 8. Process of water supply and demand in the YRB (1956–2016).

4.1. Temporal and Spatial Equilibrium of Water Resource Allocation

The average annual demand for surface water in the YRB is 40.73 billion cubic meters, and the average water supply is 34.88 billion cubic meters. Figure 8 shows the water demand, water supply, and $\overline{SAT}_t$ of all water users in each year over the 1956–2016 period. The years with low $\overline{SAT}_t$ were mainly concentrated during the 1995–2003 period. After 1995, $\overline{SAT}_t$ began to gradually decline, reaching a minimum value of 0.78 in 1997. The main reason for this decline is the decrease in precipitation after 1995, which led to a sharp decrease in natural runoff in the YRB. In contrast, owing to the decrease in precipitation, the available precipitation for agriculture was reduced, leading to a surge in demand for agricultural irrigation water. The proportion of agricultural water demand in the YRB is extremely large, which directly affects the total water demand. The maximum $\overline{SAT}_t$ occurred in 1964. The natural flow and water demand in 1964 were at the maximum and minimum. In conclusion, the supply and demand of water resources in the basin are affected by precipitation. The greater the amount of precipitation there is, the greater the amount of precipitation that is available, and the lower the surface water demand. The average $\overline{SAT}_t$ in the 1956–2016 period was 0.89. The Gini coefficient of $\overline{SAT}_t$ for the 1956–2016 period was 0.021, indicating that the allocation of water resources was efficient and in equilibrium.

The $\overline{SAT}$ of domestic, industrial, ecological, and agricultural water users are 0.92, 0.90, 0.94, and 0.84, respectively. The gap between the $\overline{SAT}$ of different water users is small, and all of them are greater than 0.8. The shape of the shadow in Figure 9 characterizes the uniformity of the satisfaction distribution over time, that is, the equilibrium of water resource allocation over time. The rounder the shadow is, the greater the extent to which the allocation of water resources is balanced over time. The results show that the $\overline{SAT}_t$ of ecological water users in the 1956–2016 period was the most evenly distributed over time, followed by the $\overline{SAT}_t$ of domestic water users, the $\overline{SAT}_t$ of industrial water users, and the $\overline{SAT}_t$ of agricultural water users. The Gini coefficients of $\overline{SAT}_t$ in the 1956–2016 period for domestic water users, industrial water users, ecological water users, and agricultural water users were 0.015, 0.017, 0.005, and 0.040, respectively (Table 5). These results show that water resource allocation is balanced over time.

To explore whether water resource allocation is balanced among the same type of water user, we calculate the Gini coefficient of $\overline{SAT}_i$ of domestic, industrial, ecological, and agricultural water users in the 1956–2016 period. The Gini coefficients of $\overline{SAT}_i$ for domestic, industrial, ecological, and agricultural water users are 0.057, 0.072,

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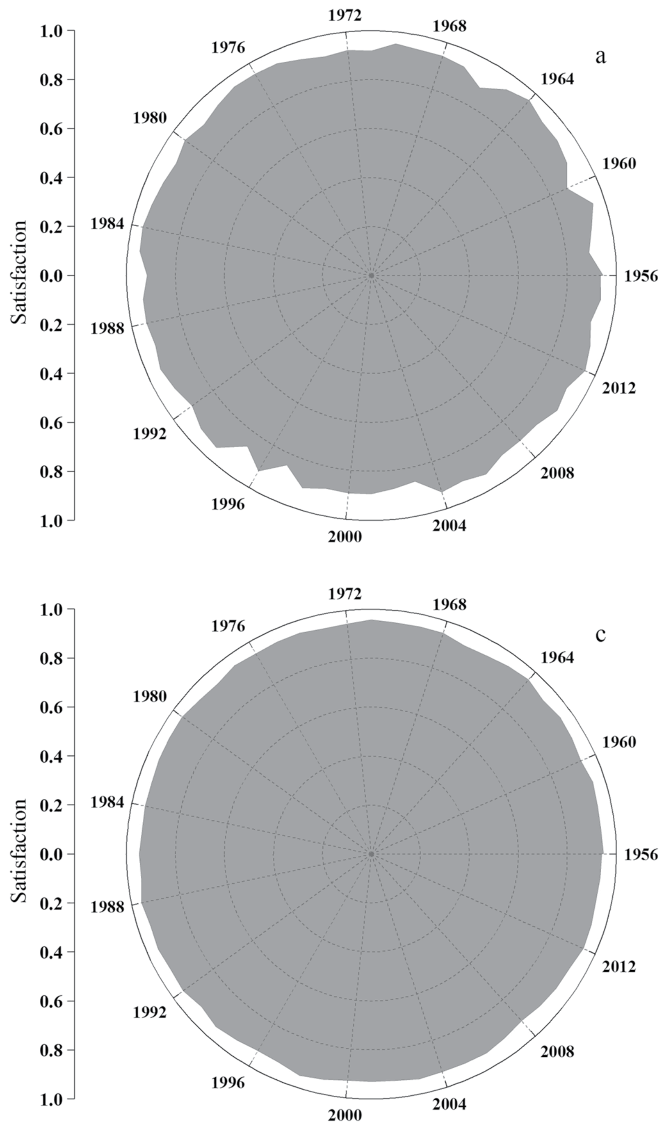

Figure 9. The average satisfaction of different water users in the 1956–2016 period: (a) domestic, (b) industrial, (c) ecological, and (d) agricultural water users.

0.056, and 0.106, respectively (Table 5). These results show that water resource allocation is balanced among the same type of water user. Because each water user is located in a different node (area), the results also prove that the allocation of water resources is balanced in space.

The coefficient (Table 1) directly affects the satisfaction of water users and the equilibrium of water resource allocation in time and space. Different regions have different priorities and preferences for their water management policies. Developed countries pay more attention to the impact of water resources on ecology and the environment, whereas developing countries pay more attention to socioeconomic development (Saleth, 2004). The water demands of human life are generally met first, and the differences mainly focus on the water supply priorities of industrial, ecological, and agricultural water users. The priorities of water resource allocation must be determined based on the industrial structure and socioeconomic development of a region or watershed and cannot be generalized. In addition, the priorities of water resource allocation in the same region are not invariable, and there will be different emphases during different periods. Therefore, the priorities

Table 5
Gini Coefficient of Water User Satisfaction (%)

	Gini coefficient				
	Domestic water	Industrial water	Ecological water	Agricultural water	All
$\overline{SAT}_t$	0.015	0.017	0.005	0.040	0.021
$\overline{SAT}_i$	0.057	0.072	0.056	0.106	0.082

Table 6
Statistics of the Water Supply Guarantee Rate (1956–2016)

	Domestic water	Industrial water	Ecological water	Agricultural water
Rigid demand	96.2%	93.5%	94.1%	86.2%
Elastic demand	85.5%	83.5%		76.0%
Luxury demand				73.9%
Total	85.5%	83.5%	94.1%	74.3%

for water allocation should also adapt to local conditions and keep pace with the times.

4.2. Analysis of Stratified Water Supply

The conflict over water resources among different water users in the YRB is fierce. Part of the water resource share of agricultural and ecological water users has long been held by domestic and industrial water users. As a result, the water supply guarantee rate of agricultural water users has been low, and the ecological environment has deteriorated. The equilibrium regulation model of water resources can be used to address these problems. As shown in Table 6, outside the river, the water supply guarantee rate of ecological water users is 94.1%, which will help maintain the virtuous circle of the ecosystem. The water supply guarantee rate of agricultural water users is 74.3%, and that of rigid demand reaches 86.2%. The water supply guarantee rate of rigid demand for domestic water users reaches 96.2%, which is higher than the standard requirement of 95%. The water supply guarantee rate of industrial water users is 83.5%, and that of rigid demand reaches 93.5%. The water supply guarantee rate is the proportion of months in which the demands of water users are met (monthly water supply guarantee rate). Compared with the traditional water resource regulation model, although the water supply guarantee rate of domestic and industrial water users has decreased slightly, the water supply of ecological and agricultural water users has been well guaranteed. The rigid demands of all water users are well satisfied. The water resource equilibrium regulation model can safeguard the rights and interests of water users, ensure food security, and protect the ecological environment of the basin.

The stratification of demand also clearly affects the water supply of water users and should be based on regional socioeconomic and ecological environment development. Not all water demands of users are divided into three levels. Following the principle of ecological priority in China, the demands of ecological water users in the YRB are all defined as rigid demands. For this reason, the water supply guarantee rate of ecological water users is higher than that of other water users. Without considering other factors, the water supply guarantee rate of rigid demand is higher than that of elastic and luxury demands. This higher rate ensures that the rigid demand of water users can be prioritized during extreme droughts.

In the case of continuous dry years or extreme drought, the model can ensure that the rigid demand of each water user can first be met and that the remaining water can meet elastic and luxury demands in turn. This can protect the basic rights and interests of water users and prevent irreversible heavy losses. The average natural annual runoff of the YRB from 1995 to 2002 was 78% of that from 1956 to 2016. The natural runoff in 2002 was the lowest, only 66% of that from 1956 to 2016. To verify the reliability of the model in dealing with uncertainty and extreme events in water availability, we analyze the water supply from 1995 to 2002 and in 2002. The water supply guarantee rates for these years are shown in Table 7.

During the period of water shortage, the rigid demands of water users have been well met, and the water supply guarantee rate has been maintained at a high level. Water shortages mainly affect the water supply of the elastic demand and luxury demand. Compared with the situation of irreversible losses caused by unmet rigid demand (e.g., food crises and factory closures), the losses caused by unmet elastic and luxury demands are easier to accept and solve. Although water shortages have the greatest impact on the water supply of agricultural water users, such users are more tolerant of water shortages than other water users. Compared with the traditional water

Table 7
Statistics of the Water Supply Guarantee Rate in Dry Years (1995–2002 and 2002)

	Domestic water		Industrial water		Ecological water		Agricultural water	
	1995–2002	2002	1995–2002	2002	1995–2002	2002	1995–2002	2002
Rigid demand	96.2%	96.2%	92.8%	92.7%	93.3%	93.0%	73.5%	68.6%
Elastic demand	76.3%	73.0%	72.9%	69.4%			57.1%	50.7%
Luxury demand							41.0%	14.4%
Total	76.3%	73.0%	72.9%	69.4%	93.3%	93.0%	54.3%	45.5%

Table 8
Equilibrium Allocation of Water Resources in the YRB (10^8 m^3)

	Domestic water		Industrial water		Ecological water		Agricultural water		Total		Water share of scheme 1987
	Supply	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply	Demand	
Qinghai	0.43	0.44	1.51	1.80	0.14	0.14	13.91	16.43	16.00	18.81	14.1
Sichuan	0.01	0.01	0.01	0.01	0.00	0.00	0.28	0.28	0.30	0.30	0.4
Gansu	2.00	2.19	5.27	9.20	0.18	0.53	20.28	27.81	27.73	39.73	30.4
Ningxia	0.58	0.59	2.59	2.69	0.58	0.58	43.65	51.86	47.41	55.73	40.0
Inner Mongolia	0.72	0.80	3.98	4.12	2.11	2.11	49.41	62.38	56.22	69.41	58.6
Shaanxi	3.50	3.54	10.11	10.25	0.68	0.68	36.28	40.14	50.56	54.61	38.0
Shanxi	2.22	2.26	10.54	11.14	0.09	0.09	24.06	26.73	36.91	40.22	43.1
Henan	1.84	1.89	8.14	8.31	0.06	0.06	37.46	42.59	47.50	52.85	55.4
Shandong	0.59	0.81	8.47	9.41	0.00	0.00	51.25	58.99	60.30	69.21	70.0
Hebei-Tianjin	0.00	0.00	0.00	0.00	0.00	0.00	5.84	6.20	5.84	6.20	20.0
YRB	11.89	12.53	50.60	56.91	3.85	4.20	282.42	333.43	348.77	407.07	370.0

Note. The water supply and demand in the table are average values from multiple years.

resource regulation model (giving priority to domestic and industrial water users), the water resource equilibrium regulation model can ensure the basic rights and interests of agricultural water users and avoid irreversible losses. Until the rigid demand of agricultural users is met, water resources will not be used to meet the elastic and luxury demands of other users. The water resource equilibrium regulation model proposed in this study can deal well with the risks caused by extreme events and water resource uncertainty and reduce losses.

4.3. Water Resource Equilibrium Allocation Scheme in the YRB

Table 8 shows the equilibrium scheme for water resource allocation in the YRB. The province with the highest water-deficient ratio is Gansu. The long-term average water-deficient ratio in Gansu Province is 30.2%, which is much higher than that of the other provinces in the basin. The main reason is the water shortage in Gansu Province. For example, the annual water deficit of the Lanzhou node in Gansu Province is between 500 and 700 million cubic meters. As shown in Appendix A, the Lanzhou node cannot divert water from the main stream of the Yellow River, and it can only use its own regional surface water resources. This is an engineering water shortage. After the operation of the West Route Project of the South to North Water Diversion, this problem will be significantly improved. Engineering water shortages also occur in other provinces. The water diversion projects in Shanxi and Shaanxi Provinces are relatively sound, and their average annual water-deficient ratios are 7.4% and 8.2%, respectively.

During the last century, to accelerate economic construction and development, more water resources were allocated to downstream provinces with more developed industries and agriculture, such as Shandong, Henan, and the Hebei-Tianjin region. With social development, the water demands of upstream provinces have increased. The upstream provinces have repeatedly requested the YRWRC to increase their water resource share. Considering the equilibrium development of the basin, Scheme 1987 is no longer applicable to the YRB. Compared with Scheme 1987, the proportion of water supply for midstream and upstream provinces increased in the equilibrium scheme (Figure 10). The proportion of the water supply for upstream provinces (Qinghai, Sichuan, Gansu, Ningxia, and Inner Mongolia) increased from 38.78% to 42.34%, and that of midstream provinces (Shaanxi and Shanxi) increased from 21.92% to 25.08%. In contrast, the water share of downstream provinces (Henan, Shandong, and the Hebei-Tianjin region) decreased from 39.30% to 32.58%.

In the YRB, the adjustment of Scheme 1987 not only is a scientific issue but also involves society, the economy, the ecological environment, and even ethics. The imbalance between upstream development and downstream development under the existing scheme threatens social stability. However, reducing the proportion of the water supply in the developed downstream provinces will affect the economic development of the YRB. Downstream provinces are bound to oppose the implementation of the equilibrium scheme. This is a game of social stability

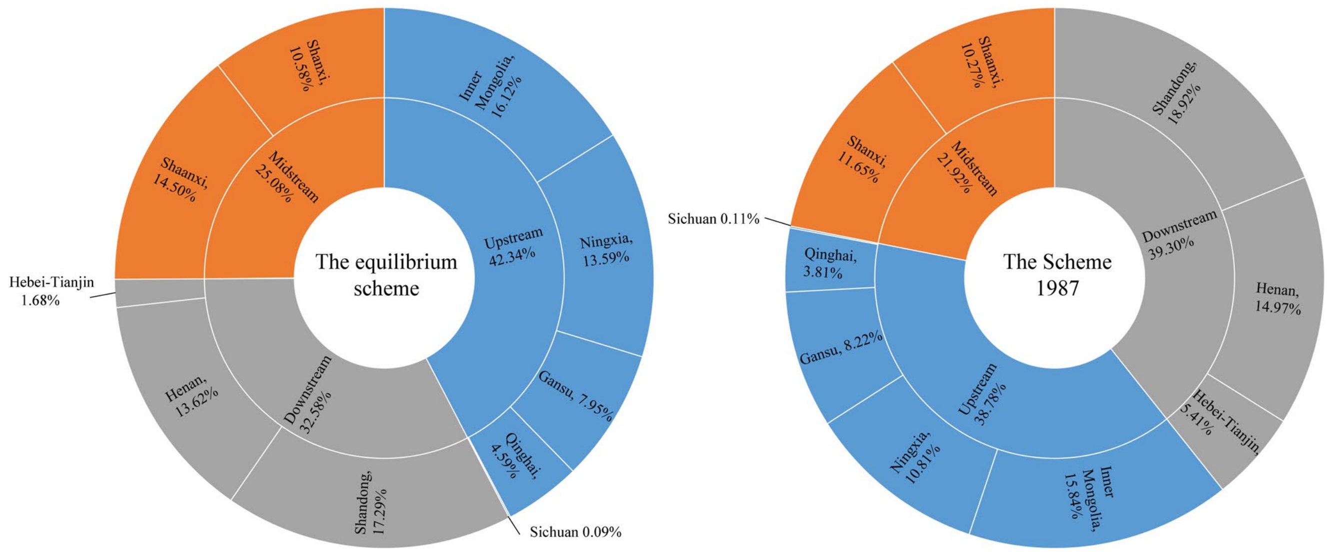

Figure 10. Proportion of water resources allocated to provinces in the YRB.

and development. In 2014, the national government recognized regional equilibrium as a basic principle of water resource management. The strategy of ecological protection and the high-quality development strategy of the YRB in 2019 emphasized the importance of balanced development of river basins. Although the water resource equilibrium regulation scheme will affect economic development and will be opposed by some provinces, it will still be beneficial for the comprehensive development and stability of the basin. This also caters to the current development strategy and developmental ideals of the YRB and China. Of course, there are still many problems to be solved for the adjustment of Scheme 1987. To that end, our study provides theoretical and technical support.

4.4. Water Supply Inside the River

One of the main purposes of the water resource equilibrium regulation model of the YRB is to ensure the basic water demand inside the river. According to the CWRPOYRB, before the west line of the South to North Water Diversion Project is put into operation, the average annual runoff of the Lijin section should be no lower than the water demand for sediment flushing and estuarine ecology, which is 15.4 billion cubic meters in low flow years and 18.7 billion cubic meters in normal flow years. The annual runoff of the Lijin section during the nonflood season should not be lower than 5.0 billion cubic meters. From 1956 to 2016, the YRB was generally dry, with an average annual natural runoff of 49 billion cubic meters, which was only 84.4% of that from 1919% to 1975% and 91.6% of that from 1956 to 2000. The results of the annual runoff of the Lijin section under the equilibrium scheme are shown in Figure 11. The average annual runoff of the Lijin section is 16.2 billion cubic meters. Only the nonflood season runoff in 2003 was less than 5 billion cubic meters. After the operation of LYX, the measured average annual runoff of the Lijin section is 10.2 billion cubic meters (1988–2016), which is less than 13.4 billion cubic meters in the equilibrium scheme. Especially in the nonflood season, the measured runoff over 13 years is less than 5 billion cubic meters, which is much greater than that in 1 year in the equilibrium scheme.

The basic ecological flow inside the river is the minimum flow required to maintain the ecological cycle of water in the river basin. The monthly runoff and ecological base flow of important monitoring sections in the YRB are shown in Figure 12 (Lu et al., 2021). The guarantee rates for the ecological base flow of the Shizuishan, Toudaoguai, Longmen, Tongguan, Huayuankou, and Lijin sections are 97.6%, 100%, 99.8%, 96.1%, 99.3%, and 96.8%, respectively. The guarantee rates for the ecological base flow of each section are higher than the measured data. Among them, the improvement of the Lijin section is the most significant. From 1988 to 2016, the guarantee rates for the ecological base flow of the Lijin section were only 63.5%, far lower than that of the equilibrium scheme, 95.1%. As more water resources were allocated to upstream provinces, the monthly runoff of the Shizuishan section decreased compared with the measured data. In contrast, because the excessive water diversion in Inner Mongolia is stopped in the equilibrium scheme, the monthly runoff of the Toudaoguai section

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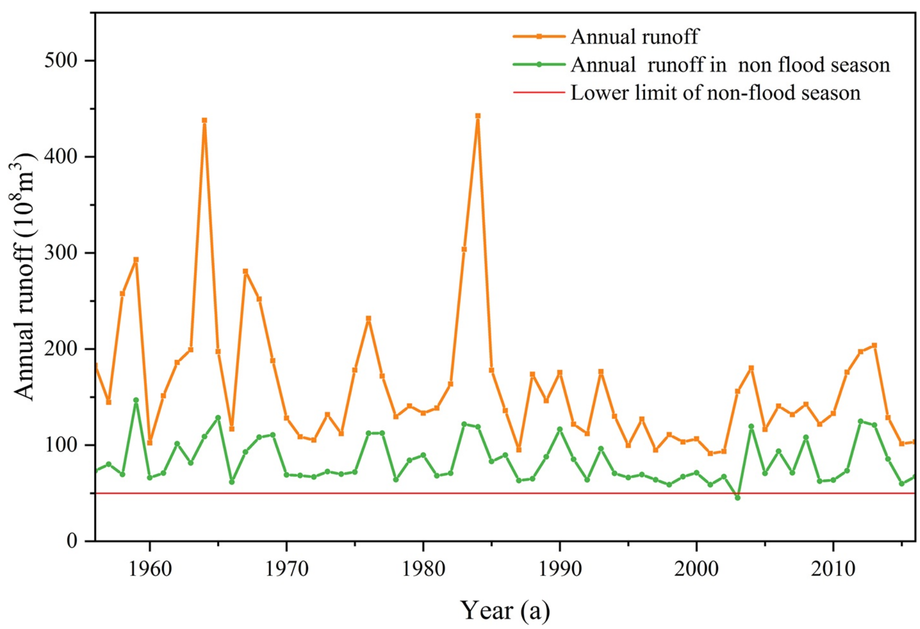


Figure 11. Runoff process of the Lijin section for the 1956–2016 period under the equilibrium scheme.

is higher than the measured data. Affected by the impoundment of GX, the runoff of the downstream Longmen section in the flood season is lower than the measured data. The equilibrium regulation model established in this study can effectively improve the water supply inside the river.

As shown in Table 9, the average annual power generation of LYX, LJX, GX, and XLD is 4.71, 4.73, 5.43, and 5.64 billion kWh, respectively, and these results are all less than the design value. In addition, LYX and LJX used runoff data from 1920 to 1970 in their design. The natural runoff of the Yellow River during this period was relatively large, resulting in excessively designed annual power generation. The same is true for GX and XLD. However, the runoff data of GX and XLD used in their design are close to those used in this study, and thus, their average annual power generation is close to the design value.

5. Conclusion

Water resources are natural resources with both social and natural attributes. With social development, the supply and demand structure of water resources in basins has significantly changed. The contradiction of water resources between different regions and water users is becoming increasingly serious, particularly in river basins affected by water scarcity. Achieving an equilibrium between different regions and water users in water resource regulation impacts economic development, social stability, and the ecosystem. Moreover, achieving such an equilibrium has always been a hot but difficult issue in academic research and actual operations.

In this study, Maslow's hierarchy of needs was introduced to improve water resource regulation from the demand side, and a water resource equilibrium regulation model was proposed. The water resource equilibrium regulation model proposed in this study can meet the demands both inside and outside the river in the YRB. In this way, the $\overline{SAT}$ of all water users in the 1956–2016 period reached 0.89, and the satisfaction Gini coefficient $G_{\overline{SAT}}$ was 0.08, which is considered to be sufficiently balanced and efficient. The ecological water supply inside and outside the river is well guaranteed, catering to China's current ecological priority development concept. The issue of domestic and industrial water holding the share of agricultural water has also improved. The water supply guarantee rate of agricultural water users has increased to 74.3%, ensuring food security. The rigid water demand of all water users has been well guaranteed. The proportion of water supply

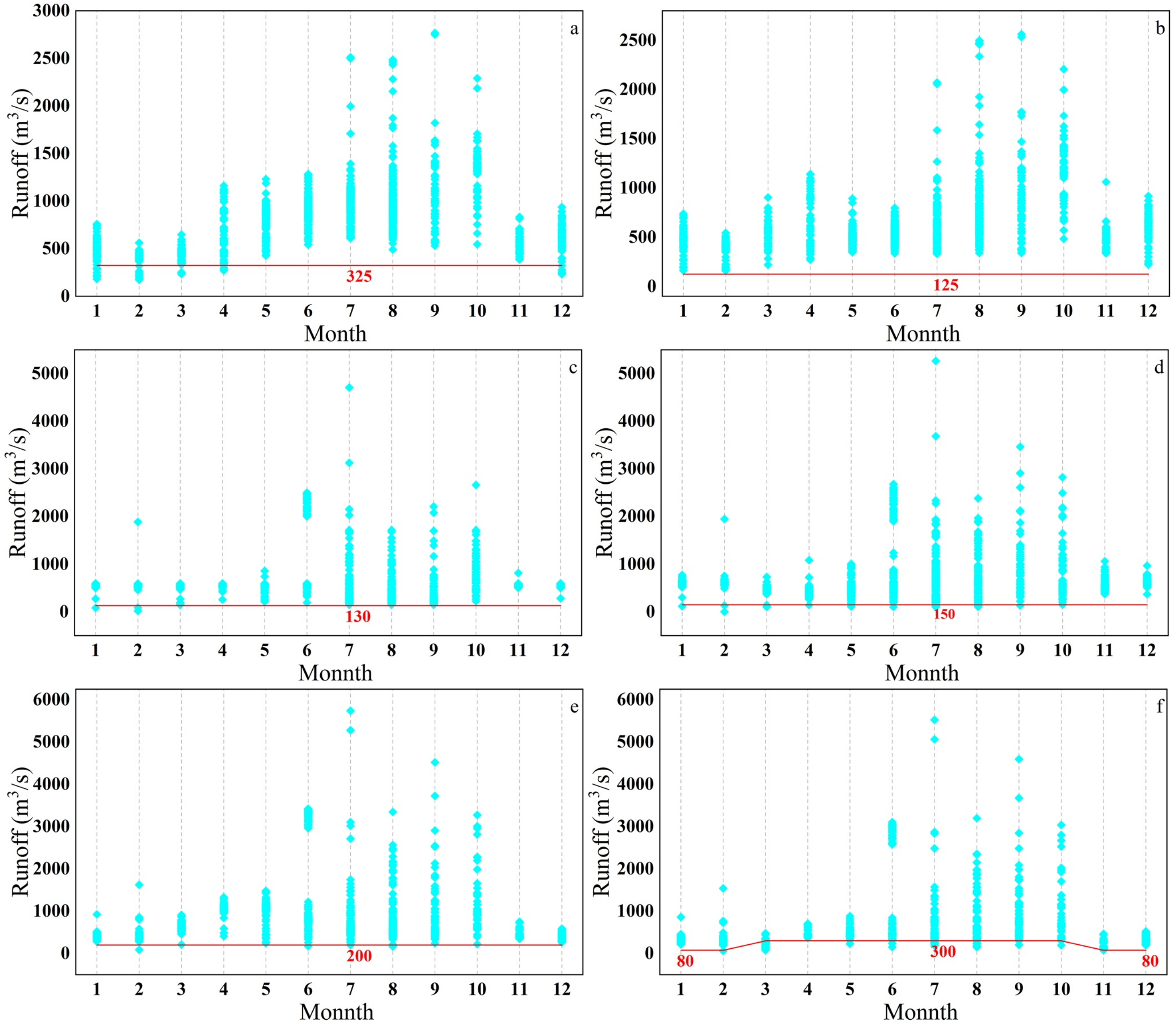


Figure 12. Monthly runoff of important sections of the main section of the Yellow River: (a) Shizuishan, (b) Toudaoguai, (c) Longmen, (d) Tongguan, (e) Huayuankou, and (f) Lijin sections.

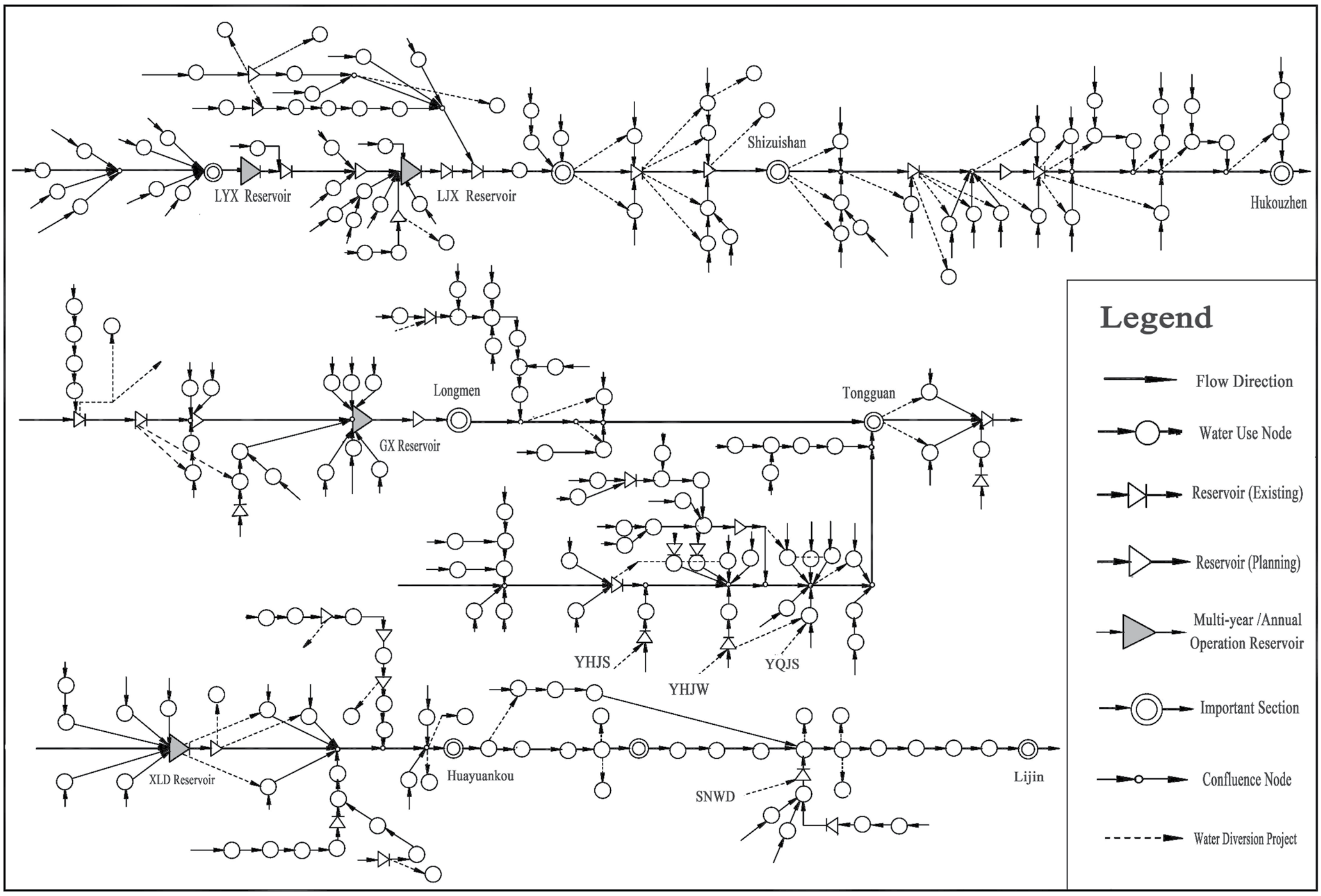
Table 9
Annual Power Generation of Cascade Reservoirs (10^8 kWh)

	Maximum annual power generation	Minimum annual power generation	Average annual power generation	Designed annual power generation
LYX	79.01	18.48	47.10	52.94
LJX	69.04	24.30	47.31	57.60
GX	95.48	363.19	54.29	56.45
XLD	92.65	28.64	56.41	58.51

for midstream and upstream provinces is higher than that of Scheme 1987, which is conducive to improving the unbalanced socioeconomic development in the basin.

However, some limitations of this study need to be addressed. In this study, rather than water users, the demands inside the river are considered to be a constraint. In addition, water resources are allocated to a type of water user in the node rather than to one or two specific water users, and for the same type of water user within a province, the same stratification standard for water resource demand is adopted. Such aspects will be addressed in future research.

Appendix A: Nodes Map of the Yellow River Basin



Source: UNCTAD

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The original data used in the paper is available online (http://www.doi.org/10.11922/sciencedb.00691).

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