Modeling Water Allocation under Extreme Drought of South-to-North Water Diversion Project in Jiangsu Province, Eastern China

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Along with China's economic development and social progress, water scarcity has become increasingly challenging. Optimized allocation of water resources, especially through water transfer project, is one of the important approaches to mitigate water shortages. In this study, authors built a model of water resources allocation simulation and the microcosmic configuration based on a complex water network in the east route of the South-to-North Water Transfer Project in Jiangsu Province, east China. Selecting data from the typical years with assurance rates of P = 95%, 75%, and 50%, the simulation of supply and demand of water resources under the present situation and the tapping scenario of planning project was carried out. The results showed that water supply capacity increased while water deficits decreased remarkably for the diversion projects. Under the assurance rates of P = 95%, 75%, and 50%, the rate of water shortage decreased by 10.3%, 8.0%, and 5.2%, respectively. Under the planning work situation, the amount of water increased by 2,800 million m^3 even during the period of extreme drought. Based on the results, it also provided an effective plan for the hydraulic engineering to optimize the allocation and management of water resources. It is helpful for policy makers to mitigate water shortage in Jiangsu Province and other areas with water transfer projects in China and other countries.

Keywords: water transfer system simulation, water resources allocation modeling, water supply and demand, South-to-North Water Transfer Project, extreme drought

INTRODUCTION

Water is one of the most important resources for human survival and development. As the second largest economic body with dramatically increasing water demand, China has been suffering water scarcity, uneven spatiotemporal distribution, and low utilization. Water allocation has great significance on easing the contradiction between the supply and demand of water resources and promoting regional socioeconomic development (Wada, et al., 2014; Nazemi and Wheater, 2015). Water resources allocation involves several aspects such as engineering, finance, technology, and management (Xu, et al., 2013; Li M, et al., 2015; Zhong et al., 2015). In this modeling, through engineering and nonengineering measures, advices are given for allocation of the limited water

resources of different forms in a certain area to meet the water demand of various levels, objectives, and water use.

Studies on optimized allocation of water resources started in the early 1960s. A large number of studies on the theory and application of water resources emerged with mathematics (Li M, et al., 2015), computer technology (Xu et al., 2001; Yao et al., 2018), large-scale reservoirs (Li C, et al., 2015), multiobjective optimization (Li et al., 2017), and the increasing prominent contradiction of supply and demand for water (Wang, 2006; Abed Elmdoust and Kerachian.2013).Among them, many scholars actively studied optimized allocation of water resources with the South-to-North Water Transfer Project (Yang et al., 2007; Sang et al., 2018; Liu et al., 2020). The South-to-North Water Diversion Project is a major strategic project to alleviate the serious shortage of water resources in North China. It is divided into three lines: east, central, and west. Among them, the eastern route of the South-to-North Water Diversion Project is a state-level transprovincial regional project that transports water from Jiangdu Water Conservancy Project in Yangzhou, Jiangsu, through Jiangsu, Shandong, and Hebei provinces to North China. Of the related study, self-optimization simulation model technical program is widely used in the water transfer project under a macroscopic scale because of its succinct and compact hierarchical structure, fast convergence rate, and so on. Wang et al. (2001) set up the three-level hierarchical model. The principle and methods of hierarchical analysis for this large-scale system are applied to solve the problems of optional water operation for the middle route of the South-to-North Water Diversion Project. On the fulfillment of the total system water supply objects, the optimal regulation diagram of the reservoir is determined via simulation technique combined with the optimization methods. In addition, considering the problems that occurred in the process of large-scale water transfer, some scholars constructed the South-to-North Water Transfer Project water allocation simulation system and water-scheduling model with modern computer simulation technology (Zhao et al., 2002; Liu et al., 2003; Zeng et al., 2018).Previous studies on the South-North Water Transfer Project water allocation model focused more on macro-scale water allocation (Wang et al., 2001; Sang et al., 2018). There was a certain disconnection between water users' actual microscopic demand and its universality; the practicality and operability were weak. At the same time, the study area has a complicated river system and dense river networks (Xu et al., 2020).

As a very important section of the east route of the South-to-North Water Diversion Project, water allocation in Jiangsu Province is vital for the water transfer to North China, but water allocation in Jiangsu Province lacks operational basis with scientific simulation background. As the construction and operation of the east route of the South-to-North Water Diversion Project, it is very urgent to study water allocation (Zhao et al., 2012). The purpose of this study was to improve the allocation and utilization efficiency of water resources based on the micro-level simulation of water supply and demand. Taking the South-to-North Water Transfer Project

intake in Jiangsu Province as the research area, researchers estimated water supply and demand in the intake district and proposed two water allocation schemes under different engineering conditions (benchmark and planning) that were compared accordingly. In the simulation calculation of water resource supply and demand, the data used are accurate to the water intake lock of the water use. Therefore, the model can simulate and output the multi-scale calculation results of different administrative units, such as villages, counties, and cities, as well as segments, trunk lines, and water resources zoning. It is helpful to solve the disconnection between simulation calculation and water resource management. Based on the results, it also provided an effective plan for the hydraulic engineering sector to optimize the allocation and management of water resources. The study is helpful for policy makers to mitigate the water shortage in Jiangsu Province and other areas with water transfer projects in China and other countries.

METHODOLOGY

Study Area
The study area is between 32°27′N–34°50′N latitude and 117°57′E–119°34′E longitude covering all of Huaian, Suqian, Xuzhou, and Lianyungang in Jiangsu Province and Jiangdu, Gaoyou, and Baoying in Yangzhou as well as Funing in Yancheng. It covers 43143.7 km^2, and the total population is about 24 million. It is a subtropical and warm temperate transition zone with an annual average temperature of 14–17°C, annual average rainfall of 700–1,300 mm, and evaporation of 900–1,100 mm. There is flat open terrain, many lakes, and a densely covered drainage network. From south to north, the main five storage lakes are Gaoyou Lake, Baima Lake, Hongze Lake, Luoma Lake, and Nansi Lake. The main river channels include Liyun River, the main irrigation artery in north Jiangsu as well as Zhongyun River, Xuhong River, Hanzhuang River, and Bulao River. The scope of the study area is shown in **Figure 1**.

Water Allocation Model
The water resource allocation model constructed by the research team mainly includes submodules such as confluence, water resource supply and demand, and water engineering scheduling. The main steps include river network generalization, data collection, water resource demand calculation, water supply priority determination, water resources scheduling, water resources allocation scheme, and so on.

Model Building
Framework
The framework is shown in **Figure 2**. The steps of model are as follows:

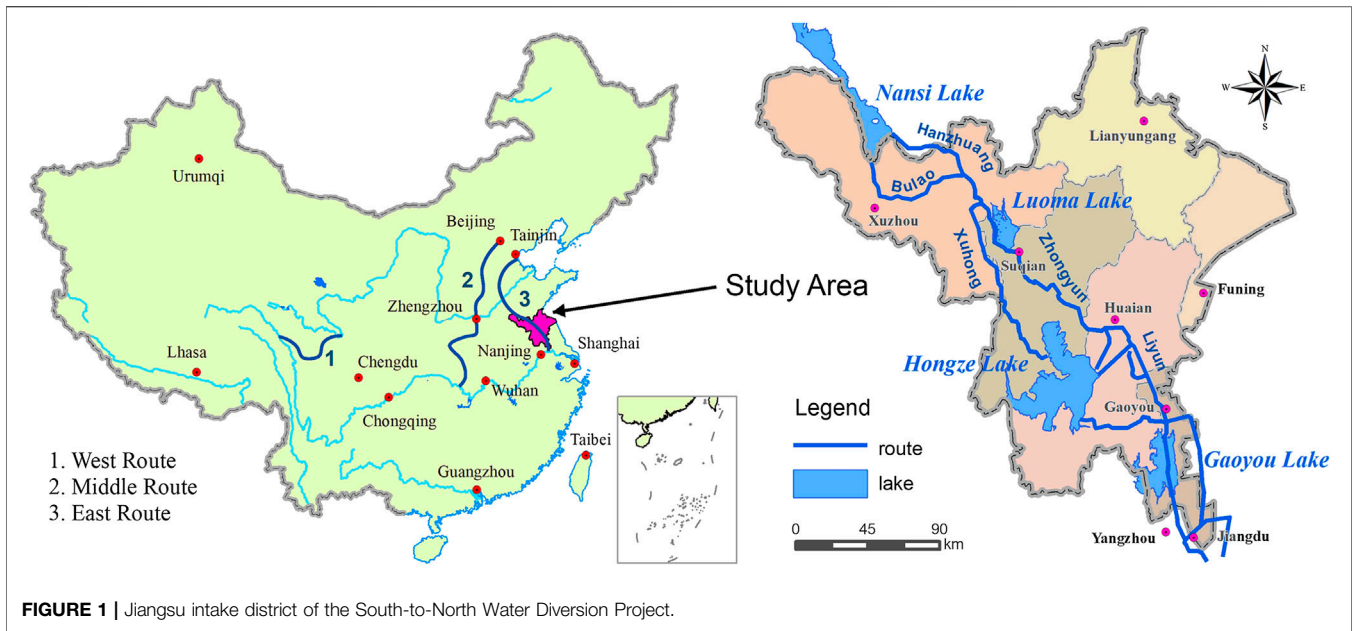1) Survey and basin information collection such as rainfall, evaporation, land use and land cover, drainage features,

FIGURE 1 | Jiangsu intake district of the South-to-North Water Diversion Project.

lock station properties, lock scheduling, and categories and distribution of different types of water use.

2) Water supply network generalization including water channel, nodes, and lakes. Of these, the water channel is divided into main waterline, branch waterline, and other watercourse; nodes are generalized into pump and lock station, water use, management, boundary, ordinary water channel, and so on. The result is shown in **Table 1** and **Figure 3**.

3) Runoff and confluence modeling, water supply and demand calculation, water allocation, and other submodels. The calculation of runoff is divided into four types with different LUCC such as water, paddy field, dry land, and town. The confluence calculation is classified into plain area, hilly, and lakes water confluence. The curve confluence method was used for plain area confluence (Zeng et al., 2014). The unit confluence method was used for the hilly area (Zeng et al., 2014) and direct confluence for lakes. The calculation formula of runoff is as follows, and the parameter meanings are shown in **Table 2**.

Water Runoff: The runoff of water is formed by the difference between the rainfall and evaporation, and if precipitation is less than evaporation, the value of surface runoff generation is negative. The calculation formula is as follows:

$$R_1 = P - \beta E$$

Paddy Field Runoff: The formula for calculating the runoff in paddy field is as follows:

$$H_2 = H_1 + P - \alpha \cdot \beta \cdot E - f$$

If $H_2 \geq H_p$, $R_2 = H_2 - H_p$,
if $H_u < H_2 \leq H_p$, $R_2 = 0$,

if $H_d < H_2 \leq H_u$, $R_2 = 0$,
if $H_2 \leq H_d$, $R_2 = H_2 - H_u$

Dry Land Runoff: The formulas for calculating the runoff in dry land are as follows:

$$W_b = W_m*1.2$$
$$W_{MM} = W_M*(1 + B)$$
$$W_{bM} = W_b*(1 + B)$$
$$W_{mM} = W_m*(1 + B)$$
$$A = W_{MM}*\left[1 - \left(1 - \frac{W}{W_M}\right)^{\frac{1}{1+B}}\right]$$

If $W > W_M$

$$EE = K*E$$

If $W \leq W_M$ $EE = K*E*\dfrac{W}{W_M}$

If $P - EE \leq 0$ $R_s = 0$, $R_u = 0$

If $P + W > W_{bM}$

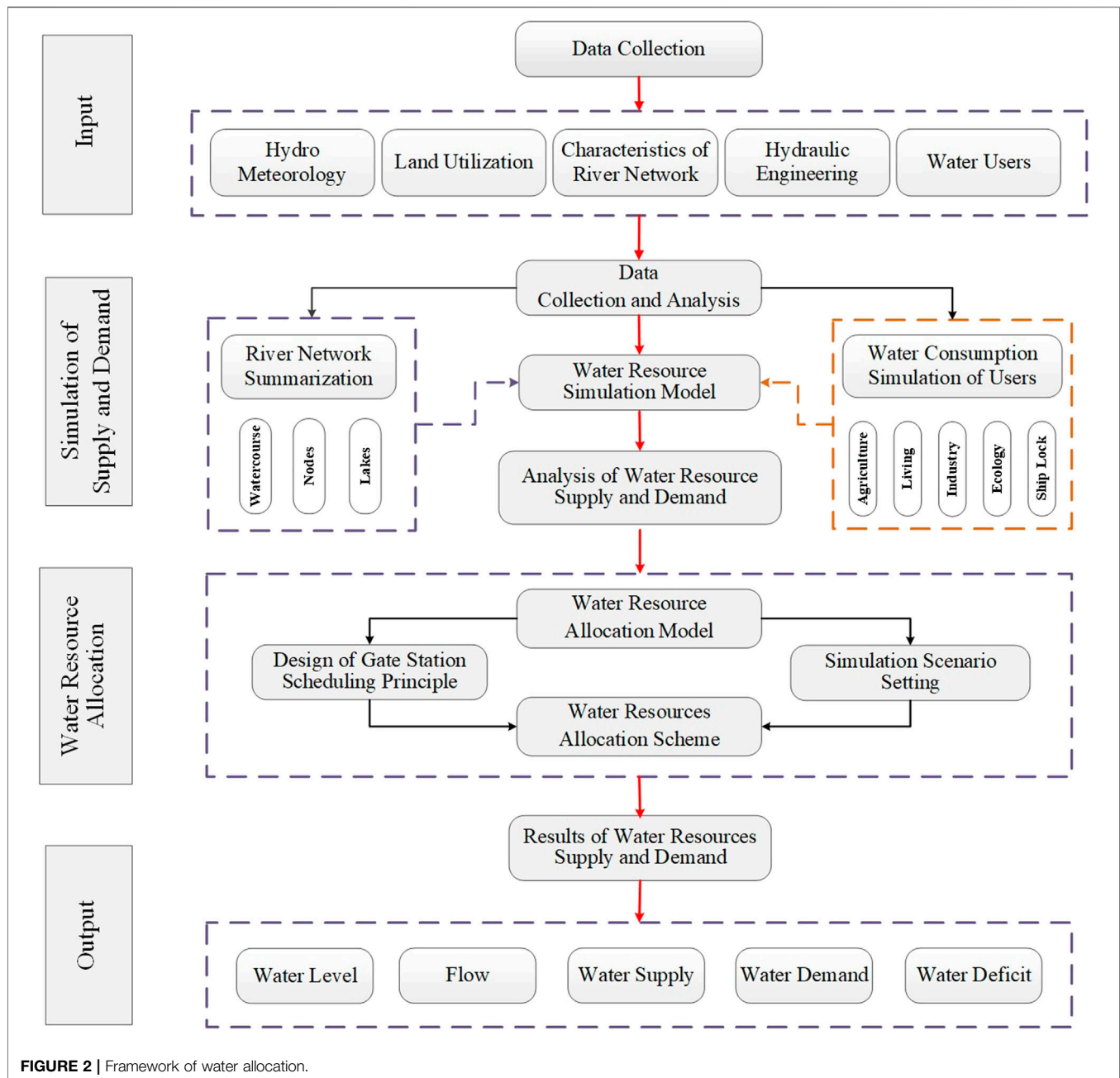$$R_s = P - EE - (W_b - W), \ R_u = W_b - W_m$$

If $W_{mM} < P + W \leq W_{bM}$

$$R_s = P - EE - (W_b - W) + W_m*\left(1 - \frac{P - EE + A}{W_{MM}}\right)^{(1+B)},$$

$$R_u = P - EE - R_s$$

If $P + W \leq W_{mM}$

$$R_s = 0,$$

$$R_u = P - EE - (W_m - W) + W_m*\left(1 - \frac{P - EE - R_s + A}{W_{MM}}\right)^{(1+B)}$$

$$R_3 = R_s + R_u$$

FIGURE 2 | Framework of water allocation.

Town Runoff: On comprehensive consideration of the urban road runoff coefficient, the model can be simply expressed as:

$$R_4 = \varphi P$$

Data

The data and the main parameters that the model required are listed as follows (Zeng et al., 2018). IData: Based on annual precipitation data from 1956 to 2000, typical years are selected according to row frequency—Pearson three curve. Three typical years are 50% assurance representative year (normal flow year), 75% assurance typical years (general drought years), and 95% assurance representative years (special drought years). The benchmark and planning year are selected for the

simulation and calculation of the model, which are determined according to the matching of the new construction of the South-to-North Water Diversion Project, so that the model can provide the optimal water resource allocation scheme under different water conservancy project operation and management. Moreover, for the benchmark year and the typical representative years, hydrology, meteorology, surface covering, five categories of water users, river characteristics, brake properties and scheduling, policies in the utilization of water resources, and other related data were collected and calculated, which were provided by the Jiangsu Provincial Water Resources Department. Hydrology, meteorology, land use (**Figure 3**), water conservancy, river

Table 1 | Generalization of water supply network nodes.

| Project generalization		Generalized result	
Water channel generalization	The number of water channel		171
Node generalization	Lock node	Pumps lock	177
		Ship lock	77
	Ordinary water channel node	Ordinary water channel node	264
	Control and management node	County-level administrative node	66
		Water management node	12
		Hydrological monitoring points	34
		Administrative section	63
		Water partition	10
	Boundary node	Boundary node	31
	Water user node	Water use	173
		Water intake entrance	213
Lakes generalization	Storage node		4
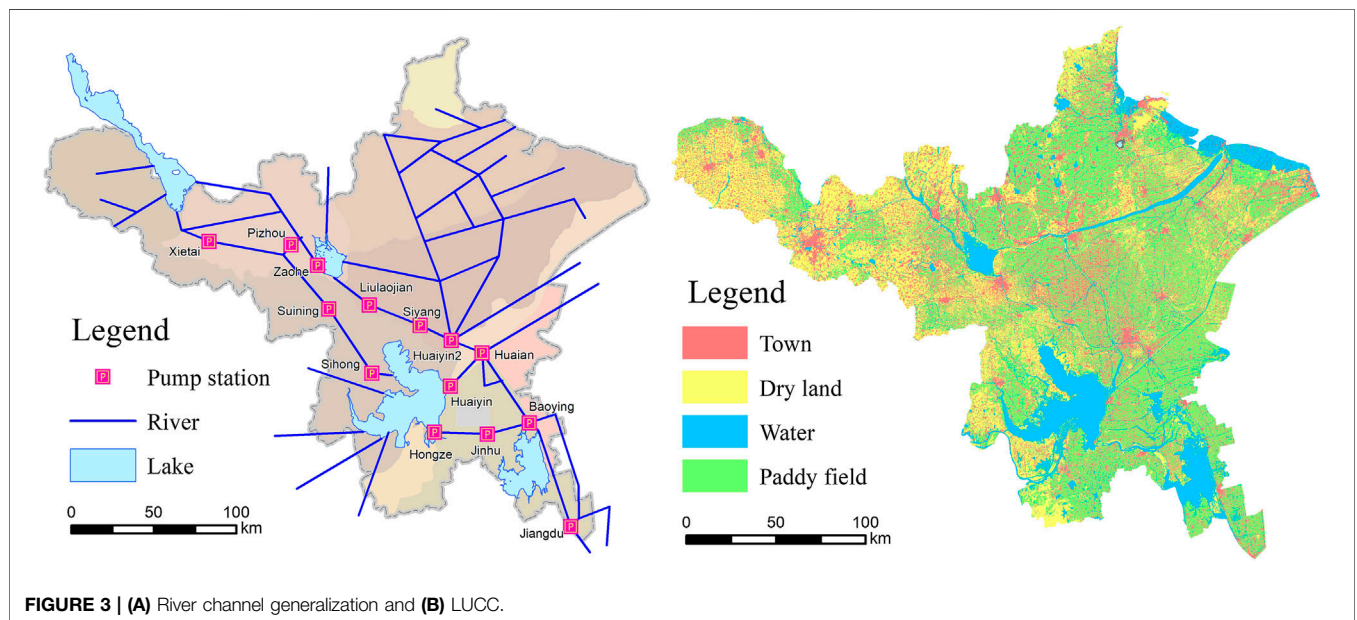
FIGURE 3 | (A) River channel generalization and **(B)** LUCC.

network, water users, and other data are monitored and predicted by water conservancy departments. Among them, the calculation description of the five water users is shown in the part 2.2.2.

Water Demand and Supply Calculation

(1) Water Demand Calculation: Water use in the study area is mainly classified into river channel water use and surface water use. The river channel water use means to take water from the trunk channel. The surface use means the water is used before drain into rivers. The river channel water use include agriculture, industry, domestic, ecology, and ship lock use, which need to take water from the generalized water channel. The agricultural water use demand is calculated by the irrigation system. The other four classes of nonagricultural use and surface water users' demand are calculated by the quota method.

    I. Agricultural water user (irrigation and water area) demand scale is calculated according to the system of irrigation and irrigation area. The irrigation water use coefficient of field is between 0.91 and 0.94, and the irrigation water use coefficient of the river channel is between 0.609 and 0.738 (Xiong et al., 2008; Peng and Ai, 2012). The calculation formula is given as follows:

$$W_a = A_a {}^* K_a / J_f / J_c$$

where W_d (m³) is the agricultural water use, A_a (m²) is the area of farmland, K_u (m³/m²) is the water consumption per square meter of farmland, J_f is the field use coefficient of irrigation water, and J_c is the water consumption per rural resident.

    II. Domestic water use demand scale intake from the river channel (urban and rural water use). The calculation formula is as follows:

$$W_d = N_u {}^* K_u + N_r {}^* K_r$$

where W_d (m³) denotes domestic water use, N_u (person) the urban population, K_u (m³/person) water consumption per urban resident, N_r (person) the rural population, person, and K_r (m³/person) water consumption per rural resident.

TABLE 2 | Parameters of runoff module.

Runoff submodules	Parameters	Meaning of the parameters
Water	P (mm)	Daily average rainfall
	E (mm)	Daily evaporation (E601 evaporating dish)
	B	Evaporation reduction coefficient
	R_1 (mm)	Daily runoff depth of water
Paddy field	A	Water requirement coefficient during rice growing stages
	H_1 (mm)	Water depth at early stage of paddy field
	H_2 (mm)	Water depth at later stage of paddy field
	H_p (mm)	Rice submergence tolerance water depth during growth stages
	H_u (mm)	Rice suitable water depth during growth stages
	H_d (mm)	Rice suitable water depth lower limit during growth stages
	f (mm)	Daily permeate (leakage) quantity of paddy field
	R_2 (mm)	Daily runoff depth of paddy field
Dry land	B	Evaporation reduction coefficient of dry land
	E (mm)	Water storage capacity curve index
	EE (mm)	Evaporation of rainfall period
	A (mm)	Evaporation of dry land
	W (mm)	Soil water content at early stage
	W_{MM} (mm)	Soil moisture content at the initial moment
	W_M (mm)	Maximum value of water storage capacity curve
	W_b (mm)	Basin average water storage capacity
	W_m (mm)	Saturated water content
	W_{bM} (mm)	Maximum saturated water content
	R_3 (mm)	Runoff depth of dry land
	R_s (mm)	Surface runoff depth of dry land
	R_u (mm)	Underground runoff depth of dry land
Town	R_4 (mm)	Runoff depth of town
	Φ	Runoff coefficient of urban road

IVModel parameters calibration and model validation based on the current confluence, water use, water deficit, water level, and the main process for station over the water.

III. Industrial water use: Its demand-scale use (self-built water engineering, specializing in industrial plant) is determined according to the design of the survey data. The calculation formula is as follows:

$$W_i = N_i * K_i$$

where W_i (m³) denotes the industrial water use, N_i (million RMB) industrial production, and K_i (m³/million RMB) water consumption per million RMB industrial product.

IV. Ecological water use (river ecological water users who take water from the main rivers): the minimum value of the demand scale is determined according to the lowest navigable water level of lock design and the lowest water level of water inlet design in the water plant as well as the results of integrated water resources planning research project of ecological water demand in Jiangsu Province. The ecological water requirement out of the river channel without intake from the main rivers as surface water demand is figured out by survey and calculation. The calculation formula is as follows:

$$W_e = A_e * K_e$$

where W_e (m³) denotes ecological water use, A_e (m²) the area of green plants, and K_e (m³/m²) water consumption per square meter of green plants.

V. Ship lock use is determined according to water consumption every time the lock is opened and the times of daily use of the lock. The calculation formula is as follows:

$$W_{sl} = N_{sl} * K_{sl}$$

where W_{sl} (m³) denotes ship locks water use, N_{sl} (time) the times of daily use of the lock, and K_{sl} (m³/time) water consumption per use of the lock.

(2) Water Supply: Water supply is determined by considering the minimum value of the three, such as water use demand, water channel supply, and supply ability of water intake locks. According to the actual needs of the development of national economy, agricultural, industrial, domestic, ecological, and ship lock water have different reliabilities. Thus, water use order is given according to the priority of water use, which is originally proposed by the research team. And it is applied to this study for the first time. Domestic water demand takes first priority. Industrial demand is in second place followed by ship lock water, ecological water, and agricultural water. Specific priorities are listed as follows:

I. Domestic water use and industrial water users should keep the river flowing normally and healthy ecology when water is retrieved from the water channel.

II. Agriculture, ship locks, and green plant ecological water use should keep the water channel level higher than the ecological water level when water is drained for use from the water channel. Defining the priority of water supply can prevent the water channel from drying up to meet the

water use demand, especially when water use demand is particularly large.

III. The ecological water level is set in the model, which is the bottom line that the river can provide agricultural water, ship locks water, and ecological water demand. It is designed to avoid excessive intake of water from the river channel, which would affect the ecological health of the river channel and lead to drying. The determination of the ecological water level has not yet set a clear standard. In this research, mainly the Beijing-Hangzhou Canal canalized water level from the first phase of the Eastern Route Project feasibility study report (I), river ecological water table in Jiangsu Province, and the lowest navigable water level of the lock are used to estimate the ecological water level of the generalized rivers in the South-to-North Water Diversion Project.

IV. If at least one of the above three levels is in the same water channel or node location, then it adopts the lowest water level. If not, then formulate via interpolation methods.

(3) Supply and Demand Balance: Different statistical calibration methods were used as the calculating unit. These include the prefectural-level administrative region, water resource division, trunk channel, and others. Researchers balanced the supply and demand of the water source, entrance, and water channel according to the supply ability of the water resources, water conservancy project, and water demand in the study area. If the locks supply size is smaller than the water demand scale, then the insufficient part is the lack of water locks supply ability. Otherwise, it does not result in water shortage. Thus, the water supply is the minimum value of water demand at the water locks and resource. If water supply is less than the water demand, then record the accumulated water shortage. This is supplied through the optimized water allocation in the South-to-North Water Transfer Project. Researchers also analyze the balance of different calibers and formulate an optimized water allocation scheme for the demand, supply, and shortage of entire study area and mains. The main means of the optimization method, on the one hand, adopt the dual objective constraint of minimum water shortage and minimum water diversion of the Yangtze River. On the other hand, the regional lake regulation and storage capacity can be used to balance the abundance and depletion, via storing water in advance to reduce the water shortage caused by the limitation of water supply capacity.

(4) 4 Water Resource Dispatch: The scheduling scheme was developed for the operation of the North-to-South Water Transfer Project in Jiangsu Province based on different time periods, control nodes, and water resources conditions. Time periods include flood period, nonflood period, drainage period, nondrainage period, and irrigation period. Control nodes include ship locks nodes and lake nodes. Water resources conditions mainly include water, flow, and rain.

RESULTS

Simulation Results and Analysis

The research is based on the status and planning of two different processes of engineering and water resource allocation simulation. The process of benchmark engineering is based on the projects which are used to divert water from the Yangtze River to the north of Jiangsu Province. The process of planning engineering, based on the benchmark engineering, adds new construction engineering of the South-to-North Water Transfer Project, which expands the pumping capacity of the river to 500 m^3/s. There is 8,900 million m^3 of pumped river water and 1,900 million m^3 supply in Jiangsu Province. According to actual irrigation assurance rate level in Jiangsu, water demand and water deficit under water frequency are 95%, P = 75%, and P = 50%.

Results of Water Resources Supply and Demand

As shown in **Table 3**, according to the simulation results, contrast variation of water demand for the planning year and benchmark year, the water demand of P = 95, 75, and 50% increases by 0.8, 4.5, and 5%. It is concluded that when the assurance rate of water demand becomes low, the amount of water demand change increases. In the drought situation, the ship locks, industrial, domestic, and ecological water demand remain constant, but agricultural water demand increases. Agriculture water demand increases by 3 million m^3 in the special drought year vs. average year. Under the same assurance rate, but a different pumped ability of the engineering, the transport remains constant and agriculture and ecological water demand change slightly; industry and living water demand change markedly (41% and 65%, respectively, vs. benchmark). For planning vs. benchmark

TABLE 3 | Water demand based on different pump engineering situation (unit: 100 million m³).

Water use	P = 95%		P = 75%		P = 50%	
	Benchmark	Planning	Benchmark	Planning	Benchmark	Planning
Ship locks	7.9	7.9	7.9	7.9	7.9	7.9
Industry	23.5	33.2	23.6	33.3	23.5	33.2
Agriculture	138.1	121.4	107.4	95.7	102.6	91.5
Domestic	11.3	18.7	11.3	18.7	11.3	18.7
Ecology	5.1	6.2	5.2	6.6	5.1	6.6
Total	185.9	187.3	155.2	162.2	150.3	157.8

TABLE 4 | Water supply based on different engineering progresses (unit: 100 million m³).

User name	P = 95%		P = 75%		P = 50%	
	Benchmark	Planning	Benchmark	Planning	Benchmark	Planning
Ship locks	7.8	7.8	7.9	7.8	7.8	7.8
Industry	22.7	33.0	22.7	33.0	23.3	33.0
Agriculture	113.7	113.6	93.7	92.7	93.2	89.0
Domestic	10.7	18.4	10.8	18.6	11.1	18.6
Ecology	3.4	6.1	4.0	6.2	4.1	6.2
Total	158.3	178.8	139.1	158.3	139.5	154.6

years, the water demand when P = 95% increases by 13.0%. When water demand is P = 75%, it increases by 13.8%, and at P = 50%, it increases by 10.8%. It is concluded that the water supply increases. Based on analysis, under different processes of engineering or under the assurance rate, water supply and demand trends are held consistent (**Table 4**).

Table 5 shows that under the same pump engineering situation, the amount of the water deficit increases when the assurance rate becomes higher, especially the amount of the water deficit is 276 million m³ under the typically drought and benchmark engineering situations. The water deficit of agriculture use is rather prominent, which receives 88.4% of the water deficit. In contrast to the same assurance rate but planning pump engineering situation, it is easy to recognize that water deficit greatly reduces for planning pump's operation. The water deficit decreases to 69.2% at P = 95%, decreases to 75.8% at P = 75%, and decreases to 70.4% at P = 50%. Of these, water deficit for ship locks remains, water deficit for industry remains unchanged, but it decreases to 75% in the special drought year and general drought year. Under the three typical years, the agriculture water deficit was between 26.6 and 78%, and the domestic water deficit was between 50 and 80%. The most apparent is the ecological water deficit, which is decrease by 94% in a special drought year.

Temporal Variations

The month was chosen as the unit of time to analyze the distribution characteristics of water demand, water supply, and water deficit. The water demand, supply, and deficit results of planning engineering contrasted with the benchmark engineering situation under different assurance rates (**Figure 4**). The values in **Figure 4** are the result of the

planning situation minus the benchmark situation. According to the results, water supply all increased under planning engineering vs. benchmark engineering. Water demand reduced in June to August, while it increased in the other months. The variations of water demand, water supply, and water deficit seem alike in January to May, while in June to December, changes are obvious. Changes are greatest during the rainy season. Under assurance rate P = 95%, water demand increases the most in December. The maximum change amount is 400 million m³; water supply changes a large amount in December and August. In the other months, the water supply is between 80 and 200 million m³. The water deficit decreases the most during June to September in the amount of 1,450 million m³, which is 75% of the rest of the year.

At an assurance rate of P = 75%, in contrast to the benchmark engineering situation, the water demand decreased in June to August in planning situation. Most of the decrease was in June. The maximum change value is 260 million m³. The added value of water demand in drought typical year is stable and is between 110 and 14,000 million m³. The added value of water supply in each month changes is about 150 million m³. The water deficit decreases every month. The water deficit decreases most during June to September with an amount of 1,020 million m³ and 83% of the total deficit amount of the whole year. Under an assurance rate P = 50%, the change in water demand is the same for every month similar to a general drought year. In June, water demand decreases the most at a maximum value of 210 million m³. The water supply increases the least of a minimum value of 30 million m³. Water deficit decreases every month, but it is not clear in drought season. In June to September, it decreases the most for a total of 690 million m³ or 91% of the year.

TABLE 5 | Water deficit based on different engineering progresses (unit: 100 million m³).

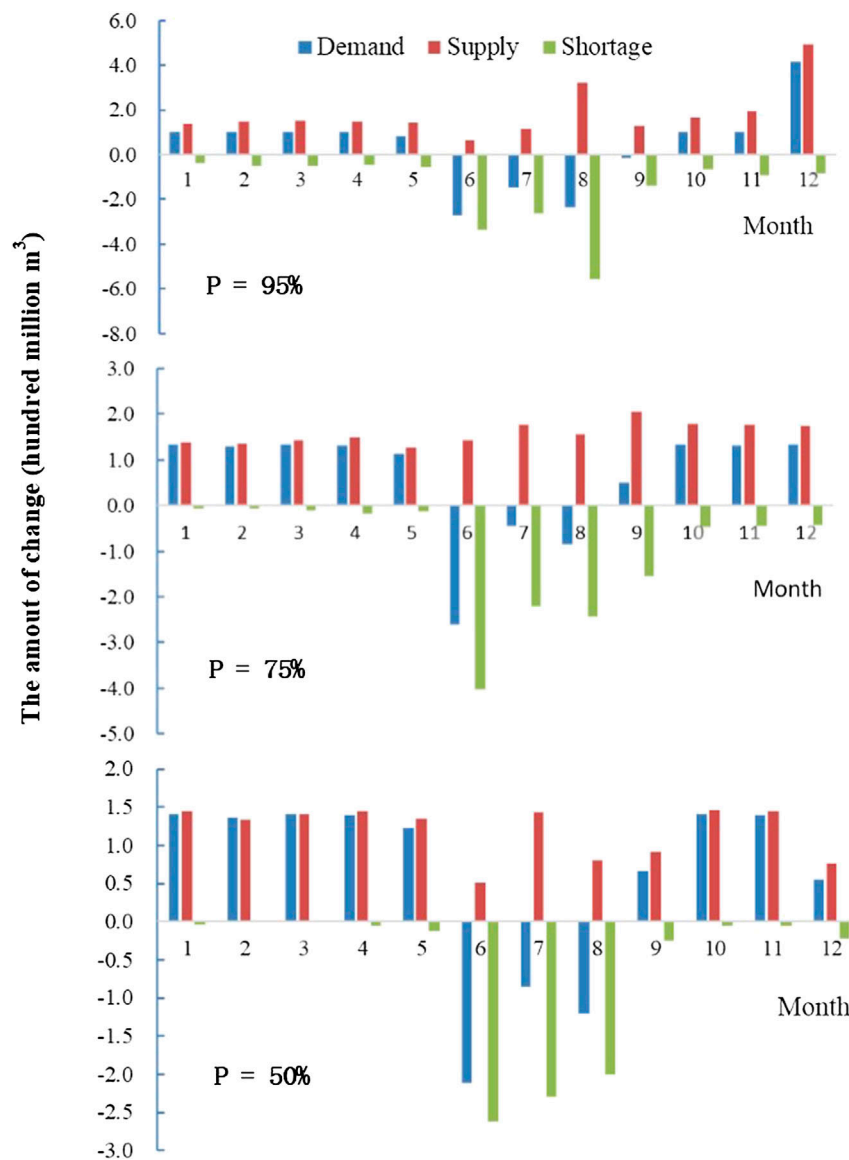| User name	P = 95%		P = 75%		P = 50%	
	Benchmark	Planning	Benchmark	Planning	Benchmark	Planning
Ship locks	0.1	0.1	0.1	0.1	0.1	0.1
Industry	0.8	0.2	0.9	0.3	0.2	0.2
Agriculture	24.4	7.8	13.7	3	9.4	2.5
Domestic	0.6	0.3	0.5	0.1	0.2	0.1
Ecology	1.7	0.1	1.2	0.4	1.0	0.4
Total	27.6	8.5	16.4	3.9	10.7	3.3

FIGURE 4 | Contrast variation of water supply, water demand, and water deficit for planning and benchmark engineering situation under the 95%, 75%, and 50% assurance.

According to model simulation results, the water supply would definitely improve by 2020 and the total water deficit will decrease by a large margin in Jiangsu Province. In the years when P = 95%, the water deficit value is 850 million m^3, and the water deficit rate is 4.5% which is decrease 10.3%. When P = 75%, the water deficit value is 390 million m^3, and the water deficit rate is 2.4% which is decrease 8.0%. When P = 50%, the water deficit value is 330 million m^3, and the water deficit rate is 2.0% which is decrease 5.2%. The water security of the region is obviously improved via the South-to-North Water Diversion Project.

DISCUSSION AND CONCLUSIONS

Researchers studied the intake area of the South-to-North Water Transfer in Jiangsu Province and realized a combination of macro-allocation of water resources and microdemand of water use. The water resource allocation model of this study is built based on agricultural irrigation water demand and optimal water resource allocation, so the proposed water resource allocation scheme is conducive to efficient utilization and protection of water resources. It is used to describe the water security both local and overall including temporal components and overall demand for water resources. Researchers also used benchmark and planning engineering situation to analyze and compare water supply, water demand, and water shortages under different conditions. The planning pump engineering is effective. And the results provide a scientific basis to water resources allocation in the eastern route of the South-to-North Water Transfer Project.

On the basis of water resources quantity estimation, water supply and demand forecast, and analysis and the research of water resource regulation, a reasonable allocation of water resources had been studied. Furthermore, water resources allocation schemes of benchmark and planning engineering situation were put forward. The model can provide different configurations of water supply based on benchmark and planning pump engineering under a different assurance rate of P = 50%, 75%, and 95%. Results showed that the water demand of planning engineering situation increased slightly compared with that in benchmark, and water supply increased obviously. Water deficit is greatly reduced, especially in the common drought typical situation; water deficit of planning engineering situation decreased 76.1% compared with that of benchmark. According to the simulated results of water pumped ability in different typical years based on the benchmark and planning engineering, it was proved that water pumped ability significantly increased in the planning engineering situation, which helps to improve regional water shortage.

It is concluded that when the assurance rate of water demand becomes low, the amount of water demand change will increase. During drought event, the ship locks, industrial, domestic, and ecological water demand remain constant, but agriculture water demand increases. The water deficit of agriculture use is rather prominent, and it is the main part of water shortage. Under the three typical precipitation situation, the agriculture water deficit was between 26.6 and 78%. According to model simulation results, the water supply will definitely improve by 2020 and the total water deficit will decrease by a large margin in Jiangsu Province. Water supply in each period all increased with planning approach *vs.* benchmark engineering. Water deficit is significantly reduced in June to August, which is helpful to solve the agricultural water shortage.

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DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the manuscript/supplementary material.

AUTHOR CONTRIBUTIONS

CZ is the first author and led this research as well as the preparation of the manuscript. Corresponding author is Professor LW offered technical guidance. The second author is Professor JM, and he is the main programmer of the model used in this article. MC helped with hydrological data processing and also evaluated the results. WQ is responsible for preparing figures and CX has assisted with revising the English manuscript.

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