

Prediction and Analysis of Water Resource Allocation Schemes in River Basin

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Abstract

Amidst the relentless advancement of societal and economic growth, the demand for water resources in human society is progressively escalating. Within the confines of stringent water resources management policies, it becomes indispensable to facilitate the optimal allocation of river basin water resources and augment their utilization efficiency. Based on the analysis of the social and economic development, water supply and demand contradictions, and water allocation status of the river basin, this paper comprehensively considered the water resources conditions in both the basin and administrative regions, future water supply capacity and demand, and coordinates surface water with groundwater, as well as water within and outside the river course, and proposed a framework for predicting and analyzing water resource allocation schemes for river basins. Taking the Wulang River Basin in China as a case study, we calculated the predicted results of the water allocation scheme for 2030 and analyzed the main control section index of the basin. The results will provide a reference for rational development and utilization of water resources in river basins.

Keywords

River Basin, Water Resources Allocation, Water Allocation Prediction

1. Introduction

In response to the current situation of water allocation in our country, the Ministry of Water Resources has further refined and implemented the work of river basin water allocation and water resource allocation based on the need to solve

the major contradictions in water resources in the major rivers basins, improving the efficiency of water resource use and implementing the strictest water resource management system. It will create favorable conditions for clarifying the total water intake permits of basins and regions, and lay a solid foundation for implementing the strictest water resources management system and determining the red line of total water use control. Wulang River belongs to the first level tributary of Jinsha River and is an important tributary of the upper reaches of Jinsha River, spanning Ninglang County and Yongsheng County of Lijiang City. With the development of economy and society in recent years, the contradiction of water use and the deterioration of water ecological environment in Wulang River Basin have become increasingly prominent. Therefore, the changing rules and influencing factors of supply and demand forecast, water resources allocation and water allocation scheme in Wulang River Basin were analyzed. It can not only better coordinate the water use relationship between the upper and lower reaches of the basin, the left and right banks, the main and tributaries and other areas, but also realize the efficient and reasonable utilization of water resources [1]-[3]. It can also coordinate the surface water and groundwater, water inside and outside the river course, and consider the water for living, production, ecology and environment as a whole. It also has a very important guiding significance for local ecological environment protection and economic development.

2. Study Area

Wulang River Basin (100°26'E - 101°00'E, 26°40' - 27°08'N) is located at the junction of Yunnan-Guizhou Plateau and Hengduan Mountains. It belongs to the first-level tributary of the upper part of Jinsha River system. It originates from Wanhooliangzi, Pangmapping Town, Ninglang County, Lijiang City, Yunnan Province, and joins Jinsha River from Jinanqiao, Da'an Town, Yongsheng County. The basin covers the Ninglang Yi Autonomous County and Yongsheng County of Lijiang City, which involves seven townships: Yongbei, Xichuan, Shunzhou, Guanghua, Yangping, Songping and Da'an, and four townships: Pangmapping, Zhanhe, Xibuhe and Xichuan. The basin is fan-shaped with a total area of 2080 km², including 925 km² in Yongsheng County and 1155 km² in Ninglang County. The annual average runoff of the control section of the total Guantian hydrology station is 861.52 million m³. The runoff in the basin is mainly from precipitation, and the surface water is supplied by atmospheric precipitation and karst water. Wulang River Basin is located in the low-latitude plateau monsoon climate area, with unique characteristics of mountain monsoon climate. The dry and wet seasons are obvious, and the rainfall varies significantly from year to year. The water vapor is abundant from May to October, and the precipitation is concentrated. Runoff is mainly concentrated in the summer and autumn rainy seasons, and the runoff from June to October accounts for 83% of the annual runoff. The great annual variation of runoff is an important feature of annual runoff in Wulang River Basin. The villages and towns in Ninglang County that are involved in the

upper reaches of the Wulang River Basin have a low level of economic development and small economic aggregate, which are dominated by agriculture and animal husbandry and are not highly industrialized. The lower reaches of the basin are mainly located in Yongsheng County, which has relatively better economic development and industrialization. As of 2019, the gross production value of the Wulang River Basin was about 4.595 billion RMB, with a total population of 205,700 people.

3. Methodology

3.1. Total Water Use Control Indexes of the Basin

According to the relevant achievements in the “Comprehensive Water Resources Planning of Lijiang City”, and in combination with other relevant data and the new changes in the future water supply situation, the original forecast results of supply and demand and the results of water resources allocation were reviewed. After review, the variation trend of various economic indicators in recent years is basically consistent with the calculation of water demand forecast in the “Comprehensive Water Resources Plan of Lijiang City”. Therefore, the forecast results of supply and demand in 2030 and the allocation results are predicted by referring to the results in the “Comprehensive Water Resources Plan of Lijiang City”. According to the forecast, the Wulang River Basin will have an average annual water demand of 103.1 million m³, a water supply of 101.47 million m³ and a water shortage of 1.63 million m³ in 2030, with a water shortage rate of 1.6%. The results of supply and demand analysis under different frequencies (**Table 1**) and the results of water resources allocation (**Table 2**).

Table 1. Analysis of the results of the supply and demand balance in Wulang River Basin in 2030.

Frequency	County level administrative region	Water requirement	Water supply	Lack of water	Water shortage rate
Multi-year average	Yongsheng County	9087	8950	137	1.5%
	Ninglang County	1223	1197	26	2%
	Wulang River Basin total	10,310	10,147	163	1.5%
50%	Yongsheng County	8940	8587	353	4%
	Ninglang County	1194	1183	11	0.9%
	Wulang River Basin total	10,134	9770	364	3.6%
75%	Yongsheng County	9679	9232	447	4.6%
	Ninglang County	1285	1212	73	5.7%
	Wulang River Basin total	10,964	10,444	520	4.7%
95%	Yongsheng County	10,455	9730	725	7%
	Ninglang County	1375	1208	167	12%
	Wulang River Basin total	11,830	10,938	892	7.5%

Note: unit: ten thousand cubic meters.

Table 2. Results of water supply allocation in Wulang River Basin in 2030.

Frequency	County level administrative region	Surface water	Groundwater	Other sources of water	subtotal	Call in	Total
Multi-year average	Yongsheng County	8770	95	85	8950	0	8950
	Ninglang County	1049	110	38	1197	0	1197
	Wulang River Basin total	9819	205	123	10,147	0	10,147
50%	Yongsheng County	8407	95	85	8587	0	8587
	Ninglang County	1035	110	38	1183	0	1183
	Wulang River Basin total	9442	205	123	9770	0	9770
75%	Yongsheng County	9052	95	85	9232	0	9232
	Ninglang County	1064	110	38	1212	0	1212
	Wulang River Basin total	10,116	205	123	10,444	0	10,444
95%	Yongsheng County	9550	95	85	9730	0	9730
	Ninglang County	1060	110	38	1208	0	1208
	Wulang River Basin total	10,610	205	123	10,938	0	10,938

Note: unit: ten thousand cubic meters.

According to the “Opinions of the People’s Government of Lijiang on Implementing the Strictest Water Resources Management System” (Li Political Office issued No. 53 [2014]), “The Notice of the People’s Government of Lijiang on Printing and Distributing the Assessment Methods for Implementing the Strictest Water Resources Management System in Lijiang” (Li Political Office issued No. 79 [2014]), and “The Office of the Leading Group of the Assessment for Implementing the Strictest Water Resources Management System in Lijiang Letter on the Issuance of the ‘Three Red Lines’ Control Indicators for Implementing the Strictest Water Resources Management System during the 13th Five-Year Plan Period”. The Lijiang City puts forward the 2020 and 2030 Total Water Consumption Control Index (TWCCI) for each district and county, among which the TWCCI for Yongsheng County and Ninglang County (**Table 3**).

Table 3. TWCCI of Yongsheng and Ninglang counties.

County level administrative region	TWCCI by 2020	TWCCI 2030
Yongsheng County	25600	25900
Ninglang County	10300	10600

Note: unit: ten thousand cubic meters.

Yongsheng County and Ninglang County haven’t yet put forward the decomposition results of the TWCCI decomposition in the Wulang River Basin. Based

on the total water use indexes of Yongsheng County and Ninglang County, combined with the “Comprehensive Water Resources Plan of Lijiang City”, and considering the water demand of each county under the premise of not breaking the regional total water use control, The total water use indexes of Yongsheng County and Ninglang County are decomposed into the Wulang River Basin.

Considering that the allocated water supply of some districts and counties determined in the “Comprehensive Water Resources Plan of Lijiang City” and the “Comprehensive Plan of Wulang River Basin of Lijiang City of Yunnan Province” exceeds the TWCCI divided into each district and county by Lijiang City, the TWCCI of each district and county shall be decomposed according to the proportion of the planned allocated water supply of Wulang River Basin in the comprehensive water resources plan of each district and county. The decomposition results of the TWCCI for Yongsheng County and Ninglang County are obtained. Namely, the TWCCI for Wulang River Basin in Yongsheng County and the TWCCI for Wulang River Basin in Ninglang County (**Table 4**) in 2030 are 78.48 million m³ and 13.78 million m³.

Table 4. Decomposition results of TWCCI in 2030 in each county-level administrative region of Wulang River Basin.

County level administrative region	“Comprehensive water resources planning of Lijiang City” Results of configuration	“Comprehensive plan of Wulang River Basin in Lijiang City, Yunnan Province” Results of configuration	TWCCI by 2030
Yongsheng County	28597	/	25,900
Among them: Wulang River Basin	8950	11,462	7848
Ninglang County	9056	/	10,600
Among them: Wulang River Basin	1197	2764	1378

Note: unit: ten thousand cubic meters.

3.2. Calculation of the Water Allocation Scheme

This water allocation plan takes Wulang River Basin as the object, based on the results of TWCCI of Yongsheng County and Ninglang County, and considers the water demand of each county administrative region to decompose the TWCCI of Wulang River Basin. Combined with the configuration results of the “Comprehensive Water Resources Planning of Lijiang City” and the “Comprehensive Plan of Wulang River Basin of Lijiang City, Yunnan Province”. The results of water supply allocation plan in 2030 within the distribution range will be finalized (**Table 5**).

3.3. Control Section Selection and Ecological Base Flow Calculation

In Wulang River Basin, there are Zong Guan Tian Hydrology Station (National Basic Hydrology Station) and Liangguan, Songping, Machangping, Bai Caofao, Chuma Ping, Muler Ping, Zhanhe and other rain measuring stations (National

basic rainfall measuring stations), among which Zong Guan Tian hydrology Station is located in the mainstream of Wulang River.

Table 5. Results of different schemes in Wulang River Basin in 2030 and the final configuration results adopted this time.

County level administrative region	“Comprehensive water resources planning of Lijiang City” results	“Comprehensive Plan of Wulang River Basin in Lijiang City, Yunnan Province” results	TWCCI results	Results of this adoption
Yongsheng County	8950	11,462	7848	7848
Ninglang County	1197	2764	1378	1378
Wulang River Basin	10,147	14,226	9226	9226

Note: unit: ten thousand cubic meters.

According to the requirements of water resources management in the basin, the control sections were selected according to different types, such as important water system nodes, cross-administrative control sections, important water conservancy projects and important cities. In order to facilitate the supervision and inspection of water consumption in various regions in the basin, the hydrology station in the main field was selected as the main control section of the Wulang River Basin in combination with the layout of hydrology station network. The Shutian Hydrology Station is the only hydrology station in Wulang River Basin. It was established by Yunnan Provincial Bureau of Hydrology and Water Resources on January 1, 1959. The station is located in Shutian Village, Sanchuan Town, Yongsheng County, Lijiang City, Yunnan Province. The basic situation of control section in Zongguantian (**Table 6**).

Table 6. Basic situation of control section of Zongguantian.

Section of control	Longitude	Latitude	Type of section	Level of section	Current construction situation	Administrative Region	Control watershed area (km ²)
Zongguantian	100°34'12"E	26°48'00"N	River system node	Provincial control section	A hydrological station has been built	Yongsheng County, Lijiang City	2083

According to the “Code for Calculation of Water Demand of River and Lake Ecological Environment”(SLT712-2021), for rivers with a long series of hydrological data, the ecological base flow can be calculated by Qp and Tennant, and the ecological base flow in Zongguantian section of control can be calculated by two methods: 90% guarantee rate of the driest monthly average flow and 10% of the average annual flow.

4. Results and Discussion

4.1. Results of Water Distribution Scheme

The 2030 allocated water volume of Wulang River Basin involved in Yongsheng

County and Ninglang County is divided into each water source by referring to the proportion of water supply from each water source in the multi-year average allocation results of the “Comprehensive Water Resources Plan of Lijiang City” and considering the water supply situation and the requirements of water resource conservation and protection. The water allocation plan of each county is reasonably determined to obtain the water share of surface water, groundwater and other water under the multi-year average, 50%, 75% and 95% inflow frequency of each county [4]-[6].

According to the preliminary results of the groundwater control index plan of Lijiang City, the groundwater control index of Yongsheng County in 2030 is 4.6 million m³, which can be converted to 1.4 million m³ for the Wulang River Basin involved. The groundwater allocation amount in the water resources allocation scheme is 830,000 m³, which does not exceed the requirements of the groundwater control index. Therefore, the groundwater supply in Wulang River Basin involved in Yongsheng County in 2030 will be based on the results of the water resources allocation scheme, namely 830,000 m³.

According to the preliminary results of the groundwater management indicator scheme for Lijiang City, the groundwater management indicator for Ninglang County will be 2 million m³ by 2030, which translates to 310,000 m³ for the Wulang River Basin involved. The groundwater allocation amount in the water resources allocation scheme is 1.1 million m³, which exceeds the requirements of the groundwater control index. Therefore, the 2030 groundwater supply of Wulang River Basin involved in Ninglang County is translated by the groundwater control index, which is 310,000 m³.

The water supply from other sources is the result of the water resource allocation scheme. Namely, the Wulang River Basin involved by Yongsheng County and Ninglang County will have 750,000 m³ and 440,000 m³ respectively in 2030.

Finally, the configuration results of surface water, groundwater, and other water sources in the Wulang River Basin that are involved in Yongsheng County and Ninglang County are obtained (Table 7).

Table 7. Results of water supply allocation by source in Wulang River Basin.

County level administrative region	Multi-year average	P = 50%	P = 75%	P = 95%	Amount of water transferred	Groundwater supply	Other water supply
Yongsheng County	7690	7372	7937	8374	0	83	75
Ninglang County	1208	1191	1225	1220	0	31	44
Total	8898	8563	9162	9594	0	114	119

Note: unit: ten thousand cubic meters.

4.2. Calculation Results of the Main Control Section Discharge

4.2.1. Results of the Minimum Discharge Flow

In this paper, the 31-year series average of surface runoff of the control section of

the Zongguantian hydrological station is analyzed. The selection of typical years is based on the empirical frequency of the annual runoff series of the hydrological station, and the years with frequencies around 50%, 75% and 95% are selected as the representative years. According to the hydrology station of Zongguantian, the average annual surface runoff (**Table 8**) is 861.52 million m³.

Table 8. Surface runoff with different frequencies at control sections of the main field hydrology station of Wulang River.

Frequency	Multi-year average	50%	75%	95%
January	2094	2071	1829	1515
February	1468	1590	1383	1120
March	1260	1238	1054	824
April	1016	1027	855	645
May	1163	1085	781	455
June	3617	3148	1814	681
July	15,411	13,548	8501	3797
August	21,825	17,893	12,835	9941
September	20,629	19,569	13,515	7279
October	10,465	9931	7499	4764
November	4332	4294	3345	2246
December	2764	2692	2210	1625
Annual runoff	86,152	82,582	64,325	43,206

Note: unit: ten thousand cubic meters.

Considering that Wulang River Basin has a low degree of exploitation and utilization, little water demand for economic and social development, and a high degree of river ecological flow guarantee, the ecological base flow of the main field hydrology station section of Wulang River Basin is determined by 90% of the dry month (**Table 9**), that is, 3.92 m³/s. If the natural runoff is less than the ecological discharge, the natural runoff shall be discharged.

Table 9. Flow data table of important control sections in Wulang River Basin.

Section of control	Multi-year mean flow	Multi-year average 10%	90% Darkest moon	Results of adoption
Zongguantian	27.3	2.73	3.92	3.92

Note: unit: ten thousand cubic meters.

In consideration of the ecological and downstream water demand for living, production and shipping, the minimum lower discharge index of the control section of the Wulang River Basin is determined by comprehensively considering the existing achievements. The specific achievements (**Table 10**).

Table 10. Results of the control indexes of the minimum lower discharge of the control section in Wulang River Basin.

Section of control	Multi-year mean flow	Ecological base flow	Water flow outside the river for production and domestic use	Minimum discharging volume calculated this time
Zongguantian	27.30	3.92	0	3.92

Note: unit: ten thousand cubic meters.

4.2.2. Results of the Discharge Water Volume

According to the selected control section, the water discharge index of each section is determined by deducting the surface water consumption above the section by the surface runoff at each frequency, and taking into account the water transferred in, transferred out and the storage of the main control project. The calculation formula is shown in Equation (1).

$$W_D = W_M + W_{Pin} - W_I - W_{Pout} - \Delta W \tag{1}$$

where:

W_D : The amount of downward discharge in section;

W_M : Section measured runoff;

W_I : Increased surface water consumption above section;

W_{Pin} : Plan to transfer water volume above section;

W_{Pout} : Plan to transfer water from the above section;

ΔW : Water. Storage variables of important control projects above the section (increase is positive, decrease is negative).

Under the multi-year average of 2030, P = 50%, P = 75% and P = 95%, the discharge water of Wulang River Basin at different frequencies (**Table 11**).

Table 11. Discharge of Wulang River.

Name of river	Name of Section	Multi-year average	50%	75%	95%
Wulang River	Zongguantian	86152	82582	66231	47316

Note: unit: ten thousand cubic meters.

5. Conclusion

Based on the “Comprehensive Water Resources Planning of Lijiang City” and related data results, this paper predicts the water supply and demand in Wulang River Basin in 2030. According to the principles and methods followed by water resources allocation, the TWCCI for 2020 and 2030 in Yongsheng County and Ninglang County of Lijiang City are first determined. Based on the TWCCI results of Yongsheng County and Ninglang County, considering the water demand of each county administrative region, the TWCCI involving Wulang River Basin in two county administrative regions are decomposed and obtained. Combined with the “Comprehensive Water Resources Planning of Lijiang City” and the “Comprehensive Planning of Wulang River Basin of Lijiang City of Yunnan Province”, the final TWCCI is comprehensively predicted and determined. The TWCCI of

Wulang River Basin involves Yongsheng County in 2030, which is 78.48 million m³, and the TWCCI of Wulang River Basin involves Ninglang County in 2030 is 13.78 million m³. By referring to the water supply ratio of each water source in the annual average allocation results of the “Comprehensive Water Resources Plan of Lijiang City”, the predicted annual allocation water quantity of each county-level administrative region in the Wulang River Basin is decomposed into each water source, and the results of water distribution schemes of surface water, groundwater and other water in 2030 under different guarantee rates are predicted finally. Finally, the MCSI of Wulang River Basin is analyzed and determined. The average annual surface runoff of the control section of the Zongguantian hydrology station is 861.52 million m³, the minimum discharge is 3.92 m³/s, and the average annual discharge is 861.52 million m³.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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