The Optimal Allocation of Water Resources in Baojixia Up-tableland Irrigation District Based on the Ecological Basic Flow of Weihe River

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Abstract—**A simplified multi-objective optimization model for optimal allocation of water resources in Baojixia up-tableland irrigation district was established based on the ecological basic flow of Weihe River aiming at the problems that water resource is insufficient and the ecological basic flow is hard to guarantee in Weihe River watershed. Then the model was solved according to the actual situation of river runoff in Linjiacun and water supply and irrigation demand in the irrigation district. The results showed that monthly irrigation water demand and ecological basic flow in the normal year could be guaranteed in the whole year by optimizing the allocation of water resources under the current irrigation technical conditions. The monthly guarantee rate of irrigation water during the non-flood season in the dry year could be up to 80% when the monthly ecological basic flow rate was not less than 50%. The results showed that both the guarantee rates of the ecological basic flow of Weihe River and the irrigation water were different in different hydrologic years in the current condition of water-saving techniques.**

Keywords-the ecological basic flow; Baojixia up-tableland irrigation district; multi-objective

I. INTRODUCTION

The optimal utilization of water resources, is receiving more and more attention due to limitation and competition of water resources. The fundamental purpose is to coordinate varies of competition and promote efficient utilization of water resources, and then ensure coordinated development among social, economy, resources and environment [1]. However, the conflict of water resources was always resolved through ecological water giving way to economic water consumption, which caused many river healthy problems such as insufficient ecological basic flow, ecological degradation,and so on.

Since the 1990s, main stream of Weihe River has sharply dropped, and in the 1990s average measured runoff of Linjiacun was just 606 million m^3, which was less than one third of mean value of that before 1990s. It was mainly attributed to sharp natural runoff decline and water withdrawal from Linjiacun of Weihe River since 1972. The annual water withdrawal accounted for about 28% of Weihe runoff, and even 98% in dry season, which made the river runoff close to zero or drying up[2]. The ecological basic flow of Linjiacun was recommended 10 m^3/s according to "comprehensive management plan of Weihe River in Shaanxi Province", while it was found there were 8 years from 1995 to 2004 that, the ecological basic flow could not be met through the comparative analysis of runoff and ecological basic flow before and after diversion (Figure 1).

Baojixia irrigation district, whose total control area is 2355 km^2, is located in the western of Guanzhong Plain in Shaanxi Province. The total control area of up-tableland irrigation is 1658 km^2, accounting for 70.4% of total area. The water resources are runoff of Weihe River as main source and groundwater as the subsidiary[3]. Agricultural irrigation is the main water user, and the irrigation area is about 186.3 million Mu. Average annual irrigation water accounted for more than 60% of the water diversion (Figure 3). Groundwater is also used for irrigation in addition to a little living and production water. Meanwhile, there are also 5 reservoirs used for irrigation.

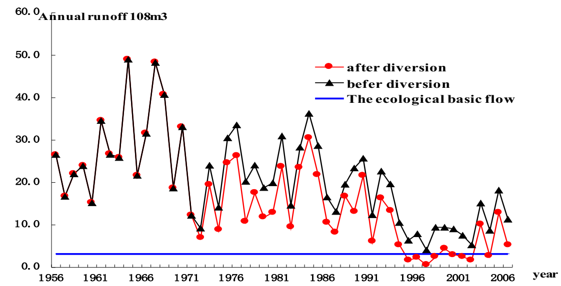

Fig. 1 Annua runoff change in Linjiacun section of Weihe River

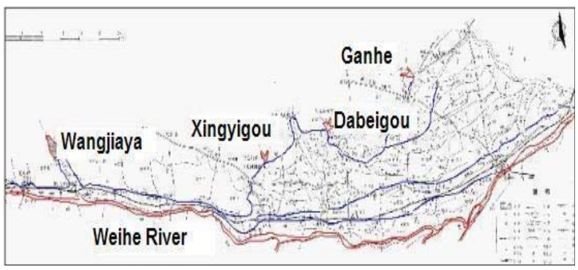

Fig. 2 The Planar graph of Baojixia Irrigation District in Diversion of Weihe River

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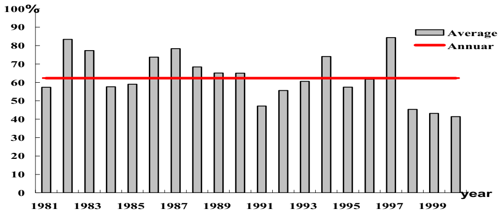


Fig. 3 The percentage of irrigation water accounting for water diversion

Based on the above consideration, a multi-objective optimization model for optimal allocation of water resources in irrigation district was established in this paper, to solve the problems of ecological basic flow of Weihe River and irrigation water demand.

II. MATERIALS AND METHODS

A. *The optimized allocation model of surface water and groundwater based on the ecological basic flow*

Rational allocation of watershed water resources was very complex and uncertain. It often involved varies of competition or conflicts among different levels, goals and users. While water resources allocation model provided a necessary tool to solve these problems for policy makers[4]. Water resource utilization of Baojixia up-tableland irrigation district also involved multiple targets, such as social, economic, ecological etc. Therefore multi-objective programming model was adopted to allocate water resources in this district.

1) The principle for water resources allocation g

The principle was to joint operation of surface water and groundwater based on making full use of groundwater, at aiming at minimizing the shortage of irrigation water demand and ecological basic flow.

2) Objective function establishment

a) Economic goals

Economic goals in irrigation district were generally represented as economic income which convert crop yields to income and subtracted the water supply cost. It often involves many factors changing with time and areas. The economic benefits of irrigation district could be reflected by water deficiencies when the irrigation requirement fixed. So the minimum water deficiencies of irrigation were treated as the economic targets:

$$f(x) = min \sum_{i=1}^{m} \left(\sum_{j=1}^{n} a_{ij} - \sum_{k=1}^{b} x_{ik} \right) \tag{1}$$

$f(x)$—the irrigation water deficiencies; m—calculation interval, the unit was month ($m=1,2,\ldots,12$); n—the crop species; a_{ij}—the irrigation requirement of j crop in the i month; b—the water supply types, including water diversion, reservoir water and groundwater; x_{ik}—the water supply of k type in the i month.

b) Ecological goals

Considering the weak ecological environment in Linjiacun section and the life health of river, the minimum ecological basic flow deficiencies were set up as the ecological goals:

$$f(y) = min \sum_{i=1}^{m} (w_i - y_i) \tag{2}$$

$f(y)$ — the ecological basic flow deficiencies; w_i — the ecological basic flow in the i month; y_i—the supplying water for ecological basic flow in the i month

3) Constraints conditions establishment

a) Constraints of incoming water

$$\sum_{i=1}^{m} (x_{i1} + y_i) \le \sum_{i=1}^{m} z_i \tag{3}$$

z_i—river runoff for irrigation water

b) Constraints of diversion for irrigation water

$$x_{ik} \le min\ (z_i - y_i,\ w_{di}) \tag{4}$$

w_{di}—the actual channel diversion in the i month

c) Constraints of groundwater supply

$$\sum_{i=1}^{m} x_{i2} \le w_g \tag{5}$$

w_g — groundwater for irrigation water

d) Constraints of reservoir for irrigation water

$$\sum_{i=1}^{m} x_{i3} \le w_r \tag{6}$$

w_r—Reservoir water supply for irrigation water

e) Constraints of irrigation water guaranteed rate

$$\sum_{i=1}^{m} (x_{i1} + x_{i2} + x_{i3}) \le \varepsilon \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} \tag{7}$$

ε—Minimum guaranteed rate of irrigation water, taking 80% in the text

f) Constraints of minimum ecological basic flow

$$.\ w_{min} \le y_i \tag{8}$$

w_{min}—Minimum ecological basic flow in the i month

g) Constraints of non-negative variables

$$0 \le y_i \quad 0 \le x_{ik} \tag{9}$$

B. The optimal allocation of water resources for ecology of Weihe River in Baojixia up-tableland irrigation district

The precipitation frequency in the irrigation district was analyzed using daily precipitation records in the recent 30 years. And then the normal year and dry year were selected on basis of it. Then the model was solved according to the supply and demand of water resources.

1) Available water supply of irrigation district

a) River water supply for irrigation

Water diversion was influenced by runoff and sediment condition. The sediment concentration of water diversion at Linjiacun was no more than 3%~8% (weight ratio). So the river water supply for irrigation was related to river ecological-demand water and water diversion. The maximum river water for irrigation was the smaller value between the runoff subtracting the ecological demand water and water diversion. The runoff and water diversion in normal year and dry year were shown in Fig. 4 and Fig. 5 respectively.

b) Groundwater supply for irrigation

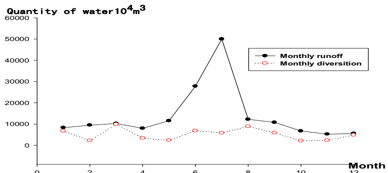
The available groundwater supppy was 183 million m^3 in normal year and 158 million m^3 in dry year accroding to reference [5].

The groundwater resource was also used for living and industrial in this irrigation district. In this study, the amount of groundwater for irrigation was referred to the available groundwater subtracting 40% used for living and industrial.

The amount of water demand for living and industrial was 205 million m^3, so the groundwater amount for irrigation was 76 million m^3 in dry year. They were 181 and 111 million m^3 in normal year respectively. The average annual amount of groundwater for irrigation was 61 million m^3 and 58 million m^3 in normal year and 74 million in dry year.

c) Reservoir water supply for irrigation

There were five reservoirs (Linjiacun head, Wangjiaya, Xinyigou, Dabeigou, Ganhe) and their total effective capacity was 203 million m^3. The available water supply for irrigation was computed though reservoir water supply regulation subtracting water for living and industrial.



Fig．4 Monthly runoff and diversition of Linjiacun in the normal year

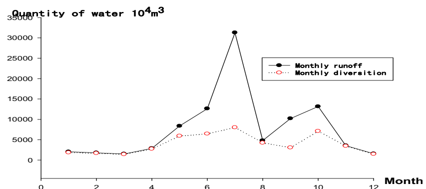


Fig. 5 Monthly runoff and diversition of Linjiacun in the dry year

2) Water Requirement

a) The ecological basic flow demand

It was important for the comprehensive development of watershed to determine the scale of river water resources development reasonably and leave enough ecological water in the river[6]. On the basis of "comprehensive management plan of Weihe River in Shaanxi Province", in the paper 10 m^3/s was chose as the basic flow in Linjiacun section, namely 315 million m^3 every year, which was considered to be reasonable[6]

However in some years, especially in the non-flood season of dry year, the monthly river runoff was difficult to meet the ecological basic flow requirements. Meanwhile it was the peak time of agricultural irrigation. At this critical moment, the ecological water should make some concession. This article used guarantee rate (v_i) of the ecology basic flow to measure the satisfaction degree of ecology basic flow demand:

$$. v_i = w_{i\,v} / w_i \times 100\% \tag{10}$$

v_i—the guarantee rate of ecology basic flow; w_i—the ecology basic flow in the i month, w_{iv}— the available water supply for ecology basic flow actually.

Certainly, when river runoff was small, groundwater and reservoir water were mainly considered, rather than unlimited squeeze of ecological water. In this article the smallest v_i was 50%.

b) The irrigation requirement

The irrigation requirement was calculated directly by the law of irrigation quota. This water-saving irrigation system was established according to actual situation in irrigation district. It had been used by many researchers, such as Li Zhang, Xiao-mei Wei [3], Ya-ping Zhang and Huai-en Li [7] and so on. The annual average irrigation water use efficiency was 0.552. By computing, the total irrigation requirement was 322 and 502 million m^3 respectively in normal year and dry year.

C. Algorithm

Turning the multi-objectives into a single objective is a classical method which was often used in multi-objective programming. The common methods include the main object method, linear weighted sum method, ideal point method and so on[8]. Each method has its characteristics. The ideal point method was selected in this research.

The theory of the ideal point method is to make the objective close to ideal point as much as possible. K single objective equations were solved in multi-objective programming f:

$$\min f_j(x),\ j=1,2,\ldots,k \tag{11}$$

Let f_j^* as the optimal value, then $f_j^* = (f_1^*, f_2^*, \ldots, f_k^*)$ is called a ideal point in range which is often difficult to reach. So f, the closest to f_j^*, is selected as the approximate value[9]. The shortest euclidean distance between f and f_j^* is often regarded as the evaluation function:

$$\min u(f(x))=\min \| f(x) - f^* \| \quad (12)$$

So the optimum solution x_j of minimization problem above was the optimum solution of multi-objective programming in the feasible region.

III. Results and Discussions

A. Results

The results were given by the model based on above analysis. The allocation of the monthly water resource in normal year and dry year were given in Tab 1 and Tab 2.

TABLE I. THE RESULT OF OPTIMAL ALLOCATION OF WATER RESOURCES IN NORMAL YEAR ($10^4 M^3$)

Normal year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*total*
Ecological basic flow water	2678	2419	2678	2592	2678	2592	2678	2678	2592	2678	2592	2678	31536
v_i %	100	100	100	100	100	100	100	100	100	100	100	100	
Irrigation water demand	0	2112	6687	945	0	2368	5434	3034	0	0	4472	7113	32165
Diversion	0	2112	6687	945	0	1810	4295	3034	0	0	2334	2863	24080
Groundwater	0	0	0	0	0	558	1139	0	0	0	2338	4250	8285
Reservoir water	0	0	0	0	0	0	0	0	0	0	0	0	0
The irrigation water deficit	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE II. THE RESULT OF OPTIMAL ALLOCATION OF WATER RESOURCES IN DRY YEAR ($10^4 M^3$)

Dry year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*total*
Ecological basic flow water	2678	2419	2678	2592	2678	2592	2678	2678	2592	2678	2592	2678	31536
Actual ecological water	2055	1209	1339	1296	2678	1296	2678	2678	2592	2678	2592	1339	24430
v_i %	76. 7	50	50	50	100	50	100	100	100	100	100	50	
Irrigation water demand	0	1808	8479	5081	2476	9667	4005	8561	0	0	3904	6219	50200
Diversion	0	584	191	1586	2476	6462	4005	2141	0	0	975	237	18657
Groundwater	0	0	0	1590	0	1272	0	0	0	0	0	4738	7600
Reservoir water	0	862	8249	889	0	0	0	6420	0	0	2929	0	19349
The irrigation water deficit	0	−362	−39	−1016	0	−637	0	0	0	0	0	−1244	−3273

B. Discussions

The ecological water demand and irrigation requirement were 315 million m^3 322 million m^3 in the normal year respectively. The water supply quantity consisted of 240 million m^3 of river water and 83 million m^3 of groundwater. When the ecological basic flow was 10 m^3/s, the surface water irrigation was the main source (315 million m^3) and groundwater irrigation was the subsidiary (17 million m^3) in spring and summer irrigation period, While under the same condition, a great amount of groundwater was in need (about 66 million m^3) in winter irrigation period (table 1).

Water demand of irrigation and ecology could be met by the optimal allocation during the flood season in dry year. Both them were almost insufficient every month during the non-flood season. The total water deficiencies were more than 3000 million m^3 during the non-flood season by full using of surface water and groundwater.

IV. Conclusions

Based on the water supply and demand equilibrium theory, the optimized configuration for water resources in Baojixia up-tableland irrigation district was made in the paper. The main conclusions were shown as follows:

1) The monthly irrigation water demand and ecological basic flow could be guaranteed in normal year by the optimal allocation of surface water irrigation as the main source and groundwater irrigation as the subsidiary;

2) When the monthly ecological basic flow rate was not less than 50%, the monthly guarantee rate of irrigation water could be up to 80% during the non-flood season with the characteristic of huge water deficiencies in the dry year under the same conditions of water deficit irrigation;

3) Both the guarantee rates of the ecological basic flow of Weihe River and the irrigation water were different in different hydrologic years in the current condition of water techniques.

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