The linear programming model of water resource utilization in the irrigated area of Huaibei

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ABSTRACT: This paper applies the theory of system engineering to Weidian irrigated area in Huaibei in order to get the maximum net profit. Restricted by the available water both of surface and of groundwater, the water quantity which is needed by crops, the ability that well yields, the pumping ability of pump, and the requirement of waterlogging prevention, the better planting pattern which is based on annual water supply and distribution of surface water and ground water are put forward, and thd optimal from of irrigation is provided as well. All these make scientific plan and management of the irrigated area possible.

1 INTRODUCTION

The total infield of Huaibei area in Anhui province is 2.067* 10^6hm^2, and the cultivatable area, which is the important base of grain and cotton, is 50.6% of the infield of Anhui province. In recent years, the increasing population, the increasing industrial and agricultural water demand, and the bad-distributed water resource lead to the conflict between the agricultural supply and demand. Especially in dry year, the groundwater level decreases, and the cost of irrigation increases. Severely, the pumps are left unused, and the benefit of irrigating engineer cannot be achieved. In order to get the maximum profit of irrigation, the problems of Huaibei Area that need to be solved exigently are how to distribute the resource of surface water and ground water, how to arrange the layout of crops and how to choose the best system of water-saving irrigating engineer.

2 THE LINEAR PRIGRAMMING MODEL

2.1 *The general situation of drainage and irrigation in irrigated area*

The irrigated area of Weidian is 55km^2,equal to 4064.5hm^2, and the main crops are winter wheat, cole, summer corn, bean, cotton, peanut, poi, and a little bit of paddy. The re-growing index is 1.85. In order to make a full use of the irrigation resource, integrated drainage systems are built in irrigated areas according to the techniques of water-logging prevention and soil prohibition. The water-transporting system (including the trenches and PVC pipelines), pumping-well (including the shallow well, small well, small available well), reserve clough and other water resource reserving projects are also built, In recent years, as the mobile spray and semi-fixed spray are developed, the integrated system of draining, irrigating, managing and using the irrigation resource comes into being. The shallow groundwater and channel-regulating water are used as the main resources for irrigation.

2.2 *The comprehensive consideration of building mathematical model*

(1) The tow water sources i.e. the ground water and channel-regulating water, can work at the same time. In this paper, four kinds of typical years (75%,80%,90%,95%) are adopted. The regulating cycle is year and the calculating period is month.

(2) The change of the water in the aquifer equals to the gaining minus the losing. It is prescribed that the losing amount should be less than the exploiting should be less than the max permitted depth and meanwhile more than the depth of water-logging prevention and soil prohibition.

(3) The increment of the production due to the irrigation is calculated by the model of Jensen Multiplying.

(4) Many factors, which are dynamic and nonlinear, such as the hydrology, hydrogenlogy, agriculture, economy and produce function, are involved in this model. Fox example, the moisture produce function, the

running cost function, the function of consuming energy by pumping, the coefficient of precipitation recharge and so on. The author linearizes the model and achieves the result by the way of linear programming.

2.3 *The mathematical model*

2.3.1 *The object function*

(1) The annual gross profit of irrigation B'yields:

$$B' = \sum_{J=1}^{J} \varepsilon r_j (g_j - g_{oj}) A_{oj} \qquad (1)$$

Where ε is apportionment of irrigation profit, whose value is between 0.25～0.45 according to the local situation; A_{oj} is the irrigated area of crop j; r_j is the price of crop j; g_i is yield of j after irrigating; g_{oj} is yield of j without irrigating.

(2) The annual cost of irrigation includes the management cost (Z_1) and cost of pumping energy (Z_2). Z_1 consists of the depreciated cost of infield engineer, pumping-well engineer and electro mechanic pump, the repair fee and the salary of manipulators. In this article the combination of different irrigation engineer systems are taken into account. The cost of pumping energy (Z_2) increases due to the increase of pumping and the decrease of ground-water level, so the author's opinion is that Z_2 is the function of pumping quantity and pumping intake level, i.e. Z_2= f(m,H). As for different types of pump (centrifugal pump and pump of unconfined groundwater), the unit energy of consuming is different. The net profit of irrigation is:

$$\max B = \sum_{j=1}^{J} \varepsilon A_{oj} r_j (g_j - g_{oj}) - Z_1 - f(m, H) \qquad (2)$$

2.3.2 *The limitary conditions*

(1)The ratio of a certain kind crop to other kinds in the irrigated area should be less than the corresponding max ratio. It is:

$$X_j \leq X_{mj} \qquad (3)$$

(2) The water that the crops need in the infield at every period comes from pumped groundwater, the regulating water in the trench, the recharge of groundwater and the effective precipitation. The formula is:

$$\eta_{1i} w_i + \eta_{2i} w_i + \sum_{i=1}^{I} G_y + \sum_{i=1}^{I} A_{oj} \alpha_{si} P_{ij} \geq \sum_{i=1}^{I} A_{ij} E_{ij} \qquad (4)$$

where η_1 is coefficient of utilized water in the trench; w is max of pumped water of the trench; η_2 is the coefficient of utilized well water; m is extraction of groundwater; α_s is the coefficient of effective precipitation; P_{ij} is the precipitation during the period of the crops growing; E_{ij} is demand of water of the crop j; G is recharge to the groundwater; i is period i.

(3) The annual extraction of groundwater should be no more than allowed:

$$\sum_{i=1}^{I} m_i + \sum_{i=1}^{I} A_0 E_i - \sum_{i=1}^{I} \alpha_g P_i A_0 - \sum_{i=1}^{I} \beta_1 m_i - \sum_{i=1}^{I} \beta_2 w_i - \Delta u \leq 0 \qquad (5)$$

Where E is evaporation of unconfined groundwater; α_g is the coefficient of precipitation recharge; β_1,β_2 are tropical coefficients of groundwater and trench water respectively.

(4) The regulating water (W) should be no more than the max of possible supply (wm). It is:

$$w_i \leq w_{mi} \qquad (6)$$

(5) The pumped water (m) should be less than the yield of the well (Mm). It is:

$m_i \leq M_{mi}$ (7)

(6) The restriction of the change of the groundwater level

$$H_i=K_i-\frac{\alpha_g P_i}{\mu}+\frac{m_i}{\mu A_0}+\frac{E_i}{\mu}-\frac{\beta_1 m_i}{\mu A_0}-\frac{\beta_2 w_1}{\mu A_0} \quad (8)$$

Where H_i and H_{i-1} are the depths of groundwater at the beginning and the end of period respetively; μ is specific yield of the aquifer. Others are meanings just like what have been mentioned.

(7) The restriction of groundwater level for waterlogging prevention and soil prohibition.

$H_i \geq H_{min}$ (9)

Where H_{min} is the minimum depth of groundwater table to prevent undesired water-logging and soil prohibition. It equals to 0.5m.

(8) The depth of groundwater should be less than the max permitted decline. It is:

$H_i \leq H_{max}$ (10)

Where H_{max} is maximum permitted groundwater table decline. For centrifugal pump, H_{max} equals to 7～8 m.

(9) The positive restrict:

$X_j \geq 0$ $(j=1, 2 \cdots J)$ $m_i, w_i \geq 0$ $(i=1, 2 \cdots I)$ (11)

3 RESULTAND ANALYSIS

3.1 *Result*

The author input the basic data, 75%,80%,90%,95%, of the typical years, including the data of agriculture, economy, hydrology, hydrogeology, the river flow and water consuming, then which were calculated by the method of Excel linear programming. The progress is just to fill the blank cell with the corresponding coefficient of the decisive variant in the restriction equation, and the optimized results can be achieved easily. The optimized results of growing ratio are shown in the Table 1, and the results of max net profit of the engineer system and the optimized water-supplies in every period are computed also. The restriction equations of 75% year are shown in formula (12).

$$\left.\begin{array}{l}
56.9X_1+54.9X_2+45.7X_5-1.0m_{10}-1.0w_{10}\leq 44.6 \\
50.3X_1+38.1X_2-1.0m_{11}-1.0w_{11}\leq 32.2 \\
38.1X_2+28.2X_2-1.0m_{12}-1.0w_{12}\leq 23.1 \\
33.2X_1+27.4X_2-1.0m_1-1.0w_1\leq 9.9 \\
46.2X_1+89.2X_2-1.0m_2-1.0w_2\leq 6.3 \\
131.5X_1+113.0X_2-1.0m_3-1.0w_3\leq 71.0 \\
190.5X_1+153.5X_2+47.2X_8-1.0m_4-1.0w_4\leq 143.8 \\
143.6X_1+73.2X_2+88.7X_8-1.0m_5-1.0w_5\leq 91.8 \\
123.3X_3+79.7X_4+128.2X_5+83.8X_6+213.7X_7+132.9X_8+91.4X_9-1.0m_6-1.0w_6\leq 13.7 \\
239.4X_3+209.7X_4+170.1X_5+150.1X_6+222.4X_7+152.7X_8+137.2X_9-1.0m_7-1.0w_7\leq 193.8 \\
263.9X_3+259.4X_4+259.1X_5+204.5X_6+271.1X_7+183.0X_8+152.2X_9-1.0m_8-1.0w_8\leq 166.0 \\
69.5X_3+104.4X_4+183.8X_5+152.4X_6+229.7X_7+33.5X_8+76.2X_9-1.0m_9-1.0w_9\leq 92.0
\end{array}\right\} \quad (12)$$

Table 1. The result of optimizing the ratio of different crops in different typical years

Tylical Year(%)	Item	Winter wheat	Cole	Summer corn	Bean	Summer cotton	Poi	Paddy	Peanut	Other	Total
75	ratio(%)	80.0	5.0	50.0	20.0	5.0	5.0	5.0	10.0	5.0	185
	area(hm^2)	3217.5	202.0	2030.8	813.4	200.0	202.0	202.0	406.7	202.0	7476.4
80	ratio(%)	71.7	5.0	50.0	20.0	5.0	3.0	5.0	10.0	5.0	175
	area(hm^2)	2913.5	202.0	2030.8	813.4	202.0	122.7	202.0	406.7	202.0	7095.1
90	ratio(%)	79.6	5.0	50.0	0.0	5.0	0.0	5.0	10.0	5.0	160
	area(hm^2)	3236.2	202.0	2030.8	0.0	202.0	0.0	202.0	406.7	202.0	6481.7
95	ratio(%)	80.0	5.0	49.7	0.0	5.0	0.0	0.0	10.0	5.0	155
	area(hm^2)	3250.8	202.0	2021.4	0.0	202.0	0.0	0.0	406.7	202.0	6284.9

3.2 *Analysis of the result*

We can know from the Table 1, the optimized index of re-grow in 75% year, 80% year, 90% year, 95% year are correspondingly 1.85, 1.75, 1.60, 1.55, i.e. the max ratio of growing in 75% year. In 80～90% years, the growing ratios of bean, poi and paddy are limited to some degree. For example, the ratio is zero in 95% year. So we can infer that local area is good for the winter wheat, cole, summer corn, summer cotton and peanut's growing, but the growing of poi, bean and paddy is limited.

We can know from Table 2, the system with the max net profit is the system of small shallow well-mechanical pump－semi-fixed sprayed irrigation, and the second is small shallow well － mechanical pump-PVC pipe. Under the precondition of assurance of water source, the system of small original well － electric pump-original trench can be used as supplement. So, what we should develop is the system of small shallow well － mechanical pump-semi-fixed sprayed irrigation or PVC pipe, not the system of shallow well － electric pump-original trench.

We can know from the Table 3, the peak of water-supply is between Apr. when the spring crops need water most and the summer-autumn crops also need water to grow. And this is consistent with the practical situation. According to the result of optimization, in 75% typical year, the supply of groundwater is enough. But in the 80～95% dry year, the supply of water is not sufficient, so the crops only depend on the groundwater, then the surface water should be reserved as supplement and used with groundwater together to achieve the most economic profit.

4 CONCLUSIONS

The agricultural produce and engineer systems are involved in the model. The author put forward the best distribution of irrigation water and the best layout of agriculture in irrigating areas. It is significant to regulate the structure of growing reasonably, to improve the manage level, to achieve the economic profit of water resource and to accelerate the develop-ment of water-saving agriculture. The results show that the groundwater cannot fully satisfy the demand of irrigation, and the surface water should be reserved for supplement; i.e. under the precondition that the drainage of the infield not be affected, the measures, such as building the dam and gate in the big trench and channel, can be taken. By controlling the groundwater, increasing the reserved of surface water and the recharge to the groundwater, we can make the irrigating water cycle well.