Irrigation Area of Surface and Ground Water To Conjunctive Use --A Case Study for Ailiao Irrigation Area , Pingtung--

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ABSTRACT

The purpose of this study is to investigate how to effectively utilize the available water resources. The service area of Ailiao irrigation canal of the Farm Irrigation Association of Pingtung was chosen as the study area of this research. Linear programming is applied for the optimization on conjunctive use of surface and ground water. Besides, this research also analyzes the amount of water to be pumped and excess surface water under the condition of optimized, planned, and existing water allocation rate during the period of dry and wet season. Furthermore, the amount of transferable water and its value are also discussed in the study.

Last ten years' average intake water records from Ailiao irrigation canal were used as input data for simulation. The results show that the optimized water allocation rate is significantly different from the existing one in dry season. The minimized volume of ground water required in the study area is 19.558 million tons yearly and under the condition of optimized water allocation rate, the excess surface water is 35.747 million tons per year.

According to the results of this study, approximately about 60% of electricity cost for water pumping will be saved and there are 26.081 million tons of water could be transferred to domestic or industrial water use when surface intake water is close to the volume of water right during dry season.

Keywords : Surface/ground water conjunctive use 、Irrigation 、Linear programming 、Optimization

1. INTRODUCTION

The intake water construction of Ailiao irrigation canal was built in 1938. The original inlet site was in the upstream about 350 m of the present weir. Water was inlet from intake gate, then flow through tunnel about 1.5 Km to connect with Ailiao main irrigation ditch at Shui-Men bridge. Because the flow center line of Ailiao ditch moved to north, the inlet water of intake gate was out of normal function. Another tunnel for conveyance water was built to connect with intake gate in 1941. The entrance of tunnel was often obstructed for topography reason and water wasn't taken normally. The Ailiao weir was build by 11th Water Construction Bureau of Taiwan province in 1958 and handed over to operate by Pingtung Irrigation Association. The plan inlet water was 24 cms and irrigated area were 5,372 ha. This weir was elaborated the raise water level functions and solved the irrigation problem in this irrigation area during the 30 years.

The service area of Ailiao irrigation canal included Chang-Zhi, Nei-Pu, and Yan-Pu Villages of Pingtung County. Due to the society transition and cultivation patterns change, the irrigated areas were reduced to 3,464 ha in which paddy fields were about 23 ha and upper lands were about 3441 ha, where the greater part were fruit trees. The irrigation water resources in Ailiao irrigated area included surface water and groundwater. The surface water is taken from Ailiao irrigation cannel and groundwater is pumped for replenishment with surface water not enough that was induced for rainfall non-uniform distribution in spatial and temporal. The allocation rates of Ailiao irrigation canal were never adjusted since the system was operated. The allocation rate among the irrigated ditch was showed in Table 1-1.

Table 1-1. The allocation rate of Ailiao irrigation canal (Unit:%)

Ditch name	Inter-crop period	Second period	First period
	Nov. 15 ~ Dec. 24	June 1 ~ Nov. 14	Dec. 25 ~ May 31
Xin-Dong-Shi ditch	30	30	35.8
De-Xie ditch	40	40	56.7
Yan-Pu ditch	30	30	7.5

Due to the economic structure changed, industry and commerce speedy growth, the resources were required increasingly during recently years. A great number of farm lands were transferred as other functions. In addition, the cultivation patterns were changed. The allocation rates have to investigate more detail.

1.1 Study motivation

Agriculture is the mail estate in Pingtung County and water is the base of agriculture. While the new water resources are developed difficult and rainfall distribution is non-uniform, therefore, the surface water is gradually shortage in Pingtung County. However, Pingtung Plain possesses abundant groundwater resources which can be used as auxiliary water. Most farm lands are pumped groundwater for irrigation. Since Ailiao irrigation cannel is the only surface water resource in this area. Therefore, how to balanceable utilize groundwater and surface water for irrigated demand has to study more detail.

1.2 Study purpose

Figure 1-1 shows the study area located in Chang-Zhi, Nei-Pu, and Yan-Pu Villages where are belong to Ailiao irrigation area of Pingtung Irrigation Association. In this study, farm lands area, soil type, consumptive use, and quantity of surface water were used as constrain and a linear programming model (LINDO) was used to build mathematical model. The purposes of this study include:

1. To generate the mathematical model for analyzed surface water and groundwater combined used in the study area.
2. To discuss the optimal allocation rate in this study area.
3. To investigate the least pumped of groundwater in the area.
4. To review the possible conditions of release water from this study area.

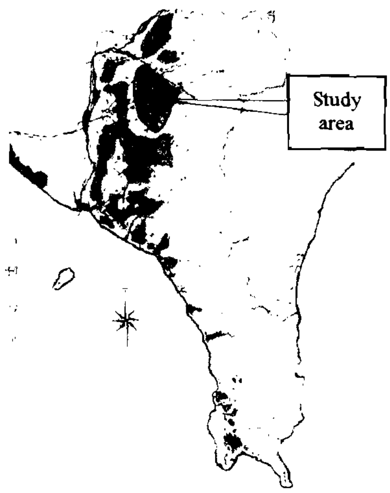

Figure 1-1. The geography site of study area.

1.3 Methods

Ailiao irrigation areas were the study area in this study. The main water demand and the difference of quantity of surface water and groundwater distribution in spatial and temporal were used to analyze the optimal distribution in this area. Then, according to the results discuss the feasibility of diversifying operation in this area. The study methods were described base on the characteristics of consumptive use, leakage of farms, effective rainfall, lands grading water, cultivation pattern, water conveyance loss, optimum model, and diversifying operation.

2. LITERATURE REVIEW

Su et al. (1999) indicated the methods of raised the efficiency of water utilization was to change the crop pattern and adjust the water requirement in agriculture.

Kan et al. (1998) indicated that irrigation water allocation is further destabilized under conditions where water resource is inadequate and external competition is rising. This correspondingly raises the utilization opportunity of other auxiliary water resource; such as, recycled water and groundwater. In the future, irrigation water requirements shall make it imperative to establish a thorough allocation strategy. Auxiliary water resource shall be allocated based on the maneuverability of incoming water volume to achieve the effective utilization of water resources.

Ko and Yu (1997) proposed a methodology emphasizing on how to analyze the record of irrigation water properly dealing with the variation of time and space. From 50 to 60 percent of the total water resources is being consumed by the areas of 17 Irrigation Association in Taiwan; correspondingly the value of rice produced from these areas is less than 2 percent of the total national GDP. In this connection, the prevailing policy regarded the industry as the main stream of the national economic development and the water resources have become one of the major constraints of its development, the pressure on requesting the Associations to release part of their irrigation water to the industry section is increasingly high.

Zhang (1995) proposed three fuzzy linear programming methods and used simple linear membership function to describe the colloquially objection function and fuzzy constrains and the results were better than traditional linear programming method.

Ho (1980) simulated the best benefit for a farm irrigated from dam and optimum cultivation pattern. The model was generated by a linear programming method and constrains included farm area, soil type, the profit of crop, hydrology conditions, and water requirement for industry and public.

The report by Agricultural Engineering Research Center (1999) indicated the irrigation associations have to save water and transfer the remnant water to other objectives for solving the water shortage pressures in other industries.

3. INVESTIGATION OF STUDY AREA

3.1 Outline of irrigated area of Ailiao irrigation canal

The water of Ailiao ditch was inlet from Ailiao irrigation canal, then flow through Ailiao tunnel and divided into nine branch ditches. Figure 3-1 showed the each branch ditch location. The nine branch ditches are Lao-Pi branch, No. 1 to No. 9 branches and Xi-Gua-Yuan branch ditches, in which No. 5 to No. 8 branches are shared the same division gate of Ailiao irrigation canal. Therefore, the four branch ditches was regarded as four sub-branch ditches in this study.

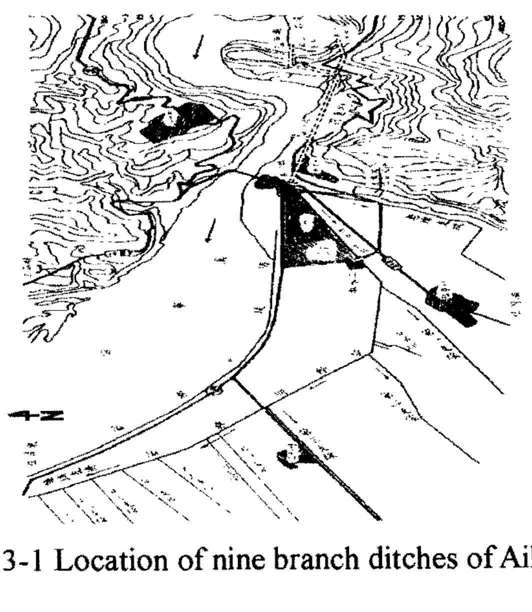

Figure 3-1 Location of nine branch ditches of Ailiao ditch

The main water resources of Ailiao irrigated area is surface water which is taken from Ailiao irrigation canal. The Pingtung Irrigation Association had also dug many wells to pump groundwater for supplement the shortage of surface water in this irrigated area.

3.2 Discharge of Ailiao irrigation canal

3.2.1 Discharge of Ailiao irrigation canal

For assessing of new water resources development and rive management, it is necessary to investigate clearly of the discharge of Ailiao irrigation canal. The Hydraulic Bureau of Ministry of Economic had set a water level gage in San-Di-Men where is the conjoint site of North Ailiao canal and South Ailiao canal. Table 3-1 shows the average discharge at this station during recently decade. The Ailiao irrigation canal has water flow in whole year. Except the discharge of period of ten days is among 20 to 30 cms in December and January, the other months are more higher discharge of period of ten days.

Table 3-1 Average discharge of a period of ten days of Ailiao irrigation canal

Season	Month	Period of ten days	Discharge (cms)
Dry season	January	1st	22.300
		2nd	22.260
		3rd	23.700
	February	4th	28.900
		5th	59.500
		6th	36.300
	March	7th	39.890
		8th	43.460
		9th	44.440
	April	10th	39.440
		11st	83.210
		12nd	93.000
Wet season	May	13rd	170.880
		14th	130.400
		15th	273.570
	June	16th	861.360
		17th	676.930
		18th	650.310
	July	19th	428.450
		20th	440.870
		21st	695.450
	August	22nd	1522.320
		23rd	737.490
		24th	734.560
	September	25th	648.440
		26th	314.430
		27th	355.830
	October	28th	266.140
		29th	330.480
		30th	267.040
Dry season	November	31st	213.050
		32nd	99.860
		33rd	50.770
	December	34th	34.500
		35th	27.680
		36th	30.640

3.2.2 Average discharge of period of ten days at Operation Sites of Ailiao irrigation canal

Table 3-2 shows the percentage of allocation rate of period of ten days in each operation site according to the intake water records of Chang-Zhi, Nei-Pu, and Yan-Pu operation stations. Comparing between Table 1-1 and Table 3-2 that showed the real allocation rate and plan allocation rate has not obviously difference.

Table 3-2 Allocation rate in each operation site of Ailiao irrigation canal

Season	Month	Period of ten days	Nei-Pu	Chang-Zhi	Yan-Pu	Loss
Dry season	January	1st	0.38	0.48	0.11	0.03
		2nd	0.33	0.49	0.15	0.03
		3rd	0.39	0.45	0.12	0.03
	February	4th	0.29	0.54	0.13	0.04
		5th	0.37	0.42	0.12	0.09
		6th	0.33	0.52	0.11	0.04
	March	7th	0.38	0.45	0.12	0.05
		8th	0.31	0.44	0.09	0.16
		9th	0.35	0.46	0.13	0.07
	April	10th	0.35	0.40	0.18	0.07
		11st	0.30	0.49	0.15	0.06
		12nd	0.33	0.46	0.17	0.03
Wet season	May	13rd	0.34	0.40	0.22	0.03
		14th	0.30	0.38	0.28	0.03
		15th	0.31	0.34	0.30	0.06
	June	16th	0.33	0.36	0.29	0.02
		17th	0.33	0.36	0.29	0.03
		18th	0.34	0.37	0.27	0.03
	July	19th	0.29	0.36	0.27	0.07
		20th	0.31	0.38	0.28	0.03
		21st	0.31	0.39	0.28	0.02
	August	22nd	0.31	0.34	0.28	0.07
		23rd	0.29	0.44	0.26	0.01
		24th	0.31	0.35	0.27	0.07
	September	25th	0.31	0.37	0.29	0.03
		26th	0.30	0.37	0.29	0.04
		27th	0.36	0.36	0.28	0.01
	October	28th	0.30	0.38	0.29	0.03
		29th	0.32	0.39	0.29	0.01
		30th	0.31	0.37	0.28	0.03
Dry season	November	31st	0.30	0.36	0.29	0.05
		32nd	0.34	0.38	0.23	0.05
		33rd	0.32	0.39	0.25	0.04
	December	34th	0.32	0.37	0.29	0.02
		35th	0.31	0.40	0.27	0.02
		36th	0.33	0.32	0.31	0.04

4. OPTIMUM MODEL

4.1 Brief introduction to mathematical model

The main irrigated water resource in Ailiao irrigated area is surface water that is taken from Ailiao irrigation canal. While the surface water is shortage the groundwater is pumped to supplement the surface water. The allocation rate of Ailiao irrigation canal is according to the rule that was made in the past. In this study, a linear programming model was used to obtained the optimum parameters under the natural and artificial constrains and minimized the groundwater withdraw for reaching the best efficiency of surface water utilization. In this model, the constrain included water demand in each trench, maximum pumping rate of each pump, maximum conveyance water, equilibrium equation, water loss, and allocation water type. The objective function was a linear equation. According to the characteristics of irrigation ditch and optimum theory, the flow chart of model generation was showed in Figure 4-1. The objective functions and constrains were listed as following:

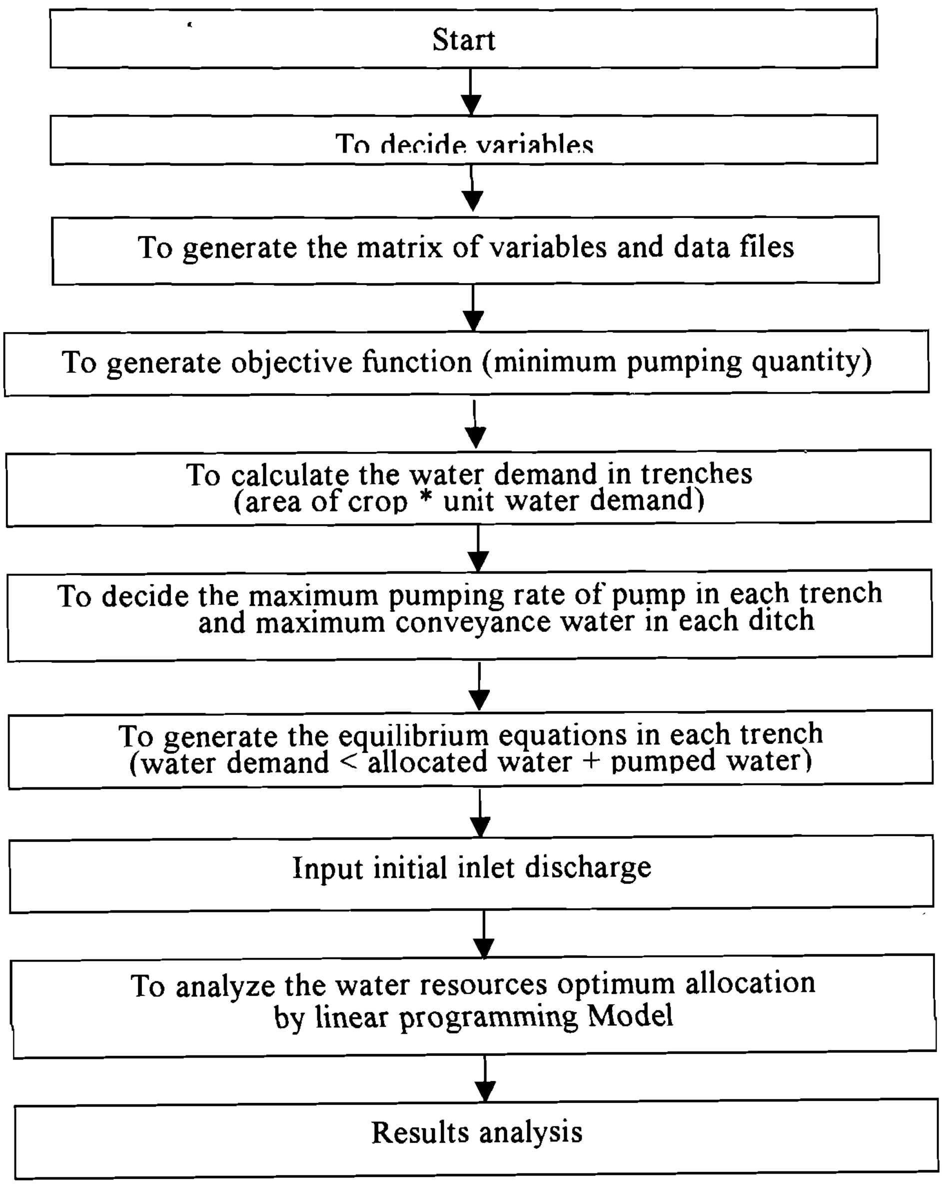

Figure 4-1 The flow chart of mathematical model

4.1.1 Objective function: minimum pumping rate

$$\text{Min}\sum_{i=1}^{9}\sum_{j=1}^{4}\sum_{k=1}^{17} PUMP_{i,j,k} \qquad \text{FOR ALL i,j,k}$$

$PUMP$: Pumping discharge in each trench;

i : Number of system branch;

j : Number of sub-branch of each branch;

k : Trench number of each sub-branch.

4.2.2 Constrain:

1.water demand in each trench

$$DEMAND_{i,j,k} = \sum_{m=1}^{2} AREA_{i,j,k,m} \times U_m \qquad \text{FOR ALL i,j,k}$$

$DEMAND$: Water demand in each trench;

$AREA$: Irrigated area in each trench;

U : Unit consumptive use;

m : Crop type.

1. Maximum pumping rate

$$PUMP_{i,j,k} \leq 0.075 \times T \times PH_{I,J,K} \qquad \text{FOR ALL i,j,k}$$

$PUMP$: Discharge of each pump in each trench zone;

T : Time (period of ten days);

PH : Ratio of horse power and lift of pump.

2. Maximum conveyance water of channel

$$QQ_i \leq D \times T \qquad \text{FOR ALL i}$$

QQ : The total discharge from branch to sub-branch ditches;

D : The maximum conveyance water per unit time;

T : Time (period of ten days).

3. equilibrium equations

$$DEMAND_{i,j,k} = Q3_{i,j,k} + PUMP_{i,j,k} \qquad \text{FOR ALL i,j,k}$$

$DEMAND$: Water demand in each trench;

$Q3$: Allocated volume to each trench;

$PUMP$: Withdrawn volume in each trench.

5.Water conveyance loss and water allocation

(1)main ditch

$$QQ_i = QF \times \left(1 - S \times \frac{L_i}{1000}\right) \qquad \text{FOR} \quad i=1$$

QQ : The total discharge from branch to sub-branch ditches;

QF : Initial discharge;

S : Loss rate;

L : Distance between sub-branch ditches.

$$QQ_i = (QQ_{i-1} - Q_{i-1}) \times \left(1 - S \times \frac{L_i}{1000}\right)$$

FOR ALL $i \geq 2$

QQ : The total discharge from branch to sub-branch ditches;

Q : Allocated volume to each sub-branch ditch;

S : Loss rate ;

L : Distance between sub-branch ditch.

(2)Branch ditch

$$\sum_{j=1}^{4} Q1_{i,j} = Q_i \times \left(1 - S \times \frac{L1_i}{1000}\right) \quad \text{FOR ALL i}$$

$Q1$: Allocated volume to each trench;

Q : Allocated volume to each sub-branch ditch;

S : Loss rate ;

$L1$: Distance from branch ditch to dividing points on sub-branch ditch.

(3)Sub-branch ditch

$$Q2_{i,j,k} = Q1_{i,j} \times \left(1 - S \times \frac{L2_{i,j,k}}{1000}\right) \qquad \text{FOR ALL i,j and k=1}$$

$Q2$: Allocated volume from sub-branch to trench;

$Q1$: Allocated volume in each sub-branch ditch;

S : Loss rate ;

$L2$: Distance between trenches.

$$Q2_{i,j,k} = (Q2_{i,j,k-1} - Q3_{i,j,k-1}) \times \left(1 - S \times \frac{L2_{i,j,k}}{1000}\right)$$

FOR ALL i,j and $k \geq 2$

$Q2$: Allocated discharge from sub-branch ditch to each trench;

$Q3$: Allocated water quantity to each trench;

S : Loss rate ;

$L2$: Distance between trenches

4.2 Assumptive scenarios

According to the discharge records of Ailiao irrigation canal and Ailiao ditch showed that the water quantity was extreme difference between dry season and wet season but the water quality was excellent. The approbation water discharge to Pingtung Irrigation Association is 18 cms, but the real inlet discharge is less than the quantity. Therefore, on the basis of water resources development and effective water utilization, the water allocation rate need to detail discuss.

For investigating the efficiency of agricultural water use in Ailiao irrigation canal and promoting the diversifying operation of the association, the target of water utilization in this area has to modulate base on the water right and water supply for irrigation. Four scenarios were proposed in this study which content and purposes were listed in Table 4-1.

Table 4-1 The content and purposes of four scenarios

Scenario	Content	Purpose
Nil	According to the average discharge of period of ten days during recently decade and present allocation rate, to find the groundwater discharge.	This scenario is the present case and will compare with other scenarios.
A	According to the average discharge of period of ten days during recently decade, to simulate the groundwater and surface water conjunction use for obtaining the optimum allocation rate and the minimum of ground water pumping.	This scenario can provide the new allocation rate for the association to adjust water utilization and to save electric powers.
B	To increase surface inlet 10%, 20%, 30%... up to the approbation water discharge, then to simulate the groundwater and surface water conjunction use for obtaining the optimum allocation rate.	This scenario will be compared with scenario nil and to evaluate the efficiency of save electric powers.
C	According to the average discharge of period of ten days during recently decade, to simulate the groundwater and surface water conjunction use when the surface water shortage 10%, 20%, ...for obtaining the possibility increased of ground water pumping.	This scenario results will be referred to release the water from Ailiao irrigation canal for other purpose.

5. DATA ANALYSIS

According to the optimal model and assumptive scenarios, the simulated results are discussed as following:

5.1 The scenario nil

The statistical results of Table 3-2 showed the real allocation rates of Ailiao irrigation canal were listed in Table 5-1. The allocation rates were divided as first period, second period, and Inter-crop period. Comparing Tables 5-1 and 1-1 indicated that the association flexible adjusted the allocation rate for Yan-Pu ditch and to fit in with the purpose of optimal water utilization.

Table 5-1 The real allocation rate of Ailiao irrigation canal in 2000

Ditch name	Inter-crop period	Second period	First period
	Nov. 15 ~ Dec. 24	June 1 ~ Nov. 14	Dec. 25 ~ May 31
Xin-Dong-Shi ditch	33	28	37
De-Xie ditch	38	42	46
Yan-Pu ditch	29	30	17

In this paper, the allocation rate listed in Table 5-1 and the average inlet of period of ten days in recently decade are used to calculate the groundwater withdraw volume and remnant surface water. The results showed that the total withdraw of groundwater was $31562\times10^3m^3$ which $27985\times10^3m^3$ in dry season and $3577\times10^3m^3$ in wet season. The withdraw volume in dry season occupied 89% of total withdraw. In contrariety, the simulation results indicated the remnant surface water was $14770\times10^3m^3$ which 96% occurred in wet season. Base on previous analysis revealed that the efficiency of pump use was lower in wet season in this study area. The irrigation management had to improve in dry season for saving electric powers. This task is very important for the association to save money.

5.2 Simulation results and analysis of scenario A

The scenario nil indicated the present allocation rate of Ailiao irrigation canal was unwell that caused the groundwater over pumping and the association spent much money. In this paper, the criterion was set by average discharge period of ten days in recently decade and assumed the water loss was 5% per kilometer. The simulation results indicated the groundwater resource did not withdraw in wet season while used optimal allocation rates to allocate water and groundwater had to pump 19558×10^3 m^3 in dry season. The quantity was compared with scenario nil was decreased 8427×10^3 m^3, about 30% of water withdraw in scenario nil. In addition, the peak period of groundwater utilization is in January to March, the association has to emphasis the management work during this time and the maintenance of pumps has to complete before January that can increase the efficiency of pumps.

According to the simulation of scenario A, the water was surplus 35747×10^3 m3, where $737\times10^3m^3$ is occurred in November, the others 35010×10^3 m^3 is taken place in May to October. The efficiency of water resource utilization in scenario A is raised about 1.4 times than scenario nil. The results prove that the decided of allocation rate by scientific method can increase the water use efficiency.

One of the research purposes is to find the allocation rate of Ailiao irrigation canal. The simulated and planned allocation rates were listed in Table 5-2. The numbers in the table found obviously difference that showed the past allocation rate need to renew for effective water utilization.

Table 5-2 Optimum and planned allocation rate in Ailiao irrigation canal %

Ditch name	Inter-crop period	Second period	First period
	Nov. 15 ~ Dec. 24	June 1 ~ Nov. 14	Dec. 25 ~ May 31
Xin-Dong-Shi ditch	59(30)	34(30)	62(35.8)
De-Xie ditch	10(40)	6(40)	15(56.7)
Yan-Pu ditch	31(30)	60(30)	23(7.5)

Note: Number in brackets indicates the planned allocation rate

5.3 Simulation results and analysis of scenario B

The purpose of scenario B is to increase the surface inlet by 20%, 40%..., up to the approbation discharge and to evaluate the possibility of reduce groundwater pumping and to release water for other purposes. Table 5-3 listed the simulation results for scenario B which showed the groundwater reduced when inlet water increased. Even so, the groundwater was pumped 12559×10^3 m3 while inlet water increased to 1.6 times and the occasion almost occurred in dry season. According to the approbation water right, the approbation volume in April is lower than other months and close to the average intake water volume period of ten days. Therefore, the groundwater need to withdraw in dry season can be perceived.

The scenario nil pumping volume 31562 $\times 10^3$ m^3 was compared with 1.6 times of average intake water volume exhibited the difference about 19003×10^3 m^3. Obviously, if the association inlet water close to approbation water right in dry season, the association can save 60% electric power money. Due to the discharge between dry season and wet season has a wide gap. The water was transferred to other purpose is no problem in wet season. How much water can be transferred in dry season is concerned problem in this study.

Table 5-3 Statistical results of minimum pumping and remnant volume in scenario B

Discharge	Minimum pumping (10^3m^3)			Remnant volume (10^3m^3)		
	Total	Dry season	Wet season	Total	Dry season	Wet season
1.2 times of average inlet water	14571	14571	0	48592	2649	45943
1.4 times of average inlet water	12749	12749	0	61324	5703	55621
1.6 times of average inlet water	12559	12559	0	73008	7712	65296
Scenario A	19558	19558	0	35747	737	35010
Scenario nil	31562	27985	3577	14770	634	14136

5.4 Simulation results and analysis of scenario C

The scenario C is considered the weather extraordinary that leads to the inlet water is only 90%, 80%, and 70% of the average discharge of ten years. Table 5-4 indicated the simulation results that revealed the intake water was dropped to 70% of the average discharge of ten years, the groundwater pumped lower than the scenario nil. Therefore, if the association operates appropriate, the electric power loading for pumping groundwater irrigation is not increase while the weather extraordinary or policy required transferring water to other objectives. In a word, the water volume of 30% of average discharge can be transferred to other objectives in dry season base on the present electric power fee in the study area. In addition, although the inlet water decreased to 70%, the remnant water in this case is great than scenario nil in wet season.

Table 5-4 Statistical results of minimum pumping and remnant volume in scenario C

Discharge	Minimum pumping (10^3m^3)			Remnant volume (10^3m^3)		
	Total	Dry season	Wet season	Total	Dry season	Wet season
1.2 times of average inlet water	30715	30715	0	20895	292	20603
1.4 times of average inlet water	26999	26999	0	26674	39	26635
1.6 times of average inlet water	22961	22961	0	31945	364	31581
Scenario A	19558	19558	0	35747	737	35010
Scenario nil	31562	27985	3577	14770	634	14136

6. CONCLUSIONS AND SUGGESTIONS

According the previous analysis showed that the groundwater withdraw can be reduced 12004×10^3 m^3 under optimum allocation rate, that pumping discharge was almost 38% of scenario nil. Referring to Jia-Nan Irrigation Association released water price is about 4.0 NT dollars/m^3; the quantity of water has price almost 4800 NT dollars. This price occupies 12% of the total budget per year of Pingtung Irrigation Association. However, this price was only supplied 6.7 ten thousand tons water per day in dry season. On the other hand, the surplus surface water is 35747×10^3 m^3 in wet season that can be released 19.9 ten thousand tons water per day and was worth almost 3 times in dry season. If the Pingtung Irrigation Association can dredge Ailiao irrigation canal in dry season that can be taken water close to the approbatory water quantity. Therefore, the water can be supplied 14 ten thousand tons per day that total quantity is 22081×10^3 m^3 and worth one hundred million NT dollars.

The research also showed that the allocation rate in Ailiao irrigated area had to renew and the optimum allocation rates were listed in Table 6-1.

Table 6-1 The suggestion allocation rate in Ailiao irrigated area

Ditch name	Inter-crop period	Second period	First period
	Nov. 15 ~ Dec. 24	June 1 ~ Nov. 14	Dec. 25 ~ May 31
Xin-Dong-Shi ditch	59	34	62
De-Xie ditch	10	6	15
Yan-Pu ditch	31	60	23

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