ANALYSIS OF POND IRRIGATION SYSTEM EFFICIENCY FOR TAOYUAN IRRIGATED AREA IN TAIWAN

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ABSTRACT

A pond irrigation system model is developed which is capable of satisfying water demand in an area with canal, river weir and water pond. The purpose of this study is to investigate the possibility to reaccess the original function of the pond irrigation system in Taoyuan Area. The pond irrigation system is expected to make use of the effective rainfall that could cut down agricultural water demand from Shihmen Reservoir, and to promote the water usage efficiency in farmland. In study area, the irrigation water of the 2nd feeder of Taoyuan main canal is supplied from reservoir, river weir and water pond. Moreover, it can completely express the exploitation of pond irrigation system that could regulate irrigation water to provide more than 95% cultivated farms in 2nd feeder area.

INTRODUCTION AND BACKGROUND

Taoyuan pond irrigation system in the northern Taiwan was developed to be a major agricultural water resource system in the early twenty century. The pond irrigation system is the ancestor’s intention to increase the effective rainfall to overcome the particular climate pattern with the use of geographic advantage in this part of Taiwan. However, after the built of Shihmen Reservoir in 1967, the functional use of this special pond irrigation system was gradually ignored. In recent years, industrial development in Taoyuan area is prosperous and encourages mass population migrates into this region. Therefore, the increasing water demand, including agricultural, industrial and municipal demand, can not be supplied by Shihmen Reservoir. For instance, owing to the water deficit dilemma that emerges frequently in Taoyuan area, the agricultural water usage has been transferred to sustain domestic and industrial consumption during years 2002 and 2003.

The ordinary practice of irrigation water distribution has been constructed based on single crops over large areas. The common examples are paddy rice agriculture in Japan and Taiwan (Masakazu, 1999; Chang et al., 2001). The irrigation water of Taoyuan area has been supplied approximately 48% from Shihmen reservoir and 52% from water pond and river weir (Hsieh, 2004). These water ponds could storage the capacity of surface water from river weir and return flow as well for its irrigation area. Chen et al. (2004) analyzed the function of water pond capacity, and suggested that further investigation on expanding effective water storage for ponds is to be performed. Such expanding is expected to reduce the ratios for pond storage and supply and to avoid situations that irrigation cultivation cannot be performed due to shortage of irrigation water.

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CONCEPTS OF EFFECTIVE RAINFALL & WATER POND

The water requirement of a crop is signified the amount of water needed to growth and this includes water to meet both consumptive and special needs, such as land preparation, land submergence, leaching and so on. In view of this current concept, it follows that from the production point of view, the annual or seasonal effective rainfall as far as the water requirement of crops is concerned, should be interpreted as that portion of total annual or seasonal rainfall which is useful directly and/or indirectly for crop production at the site where it falls but without pumping.

Effective rainfall sometimes called excess rainfall, is the component of the storm hyetograph which is neither retained on the land surface nor which infiltrates into the soil. The effective rainfall produces overland flow that results in the direct runoff hydrograph from a sub-area of a catchment.

As showed in Fig. 1, when rain water (1) falls on the soil surface, some of it infiltrates into the soil (2), some stagnates on the surface (3), while some flows over the surface as runoff (4). When the rainfall stops, some of the water stagnating on the surface (3) evaporates to the atmosphere (5), while the rest slowly infiltrates into the soil (6). From all the water that infiltrates into the soil ((2) and (6)), some percolates below the root zone (7), while the rest remains stored in the root zone (8).

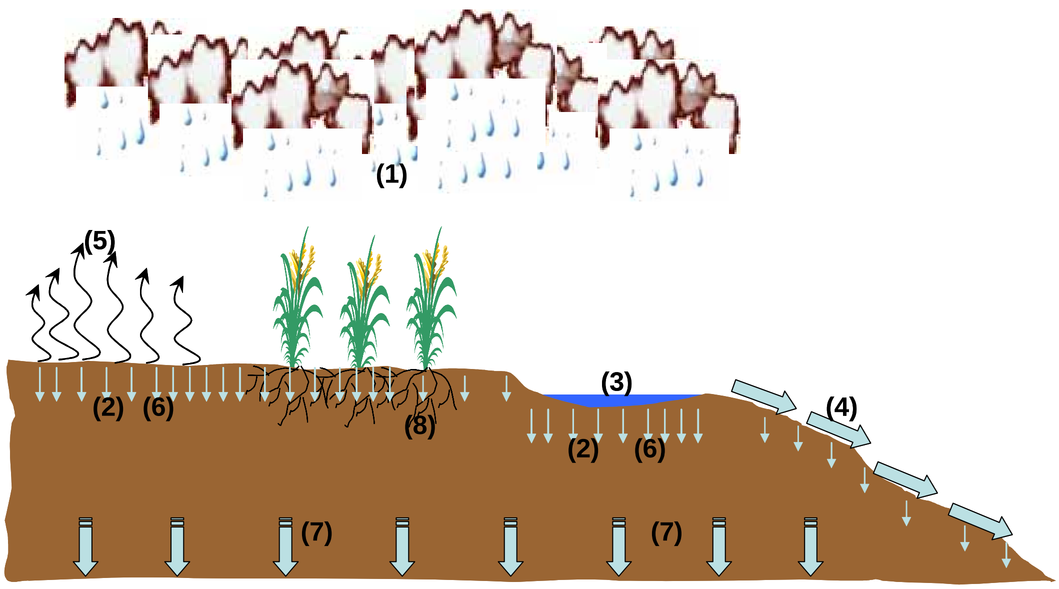

Figure1. Image diagram of the effective rainfall for plants

The effective rainfall (8) is the total rainfall (1) minus runoff (4) minus evaporation (5) and minus deep percolation (7); only the water retained in the root zone (8) can be used by the plants, and represents what is called the effective part of the rainwater.

$$\text{Effective rainfall (8)} = (1) - (4) - (5) - (7) \quad (1)$$

The term effective rainfall is used to define this fraction of the total amount of rainwater useful for meeting the water need of the crops.

The idea of pond irrigation system was to storage excess runoff in ponds and then to supply water to farm land in the drought, just like small reservoirs. It is intentioned to increase the effective rainfall by ancestor to overcome the particular climate pattern with the use of geographic advantage in Taoyuan.

The conception of water pond was developed according to the flat terrain except a few undulate and strong, rapid storm. Due to this particular terrain, geology (Clay loam layer) and climate pattern would bring a lot of runoff into the Taiwan Strait without storing and utilizing. It would easily result in the deficit in irrigation water. As showed in Fig. 2, the trailblazer applied the principle, building water pond on place higher than field to store rainfall, uncontrollable runoff and return flow from upstream, to extend exploitable water in irrigation.

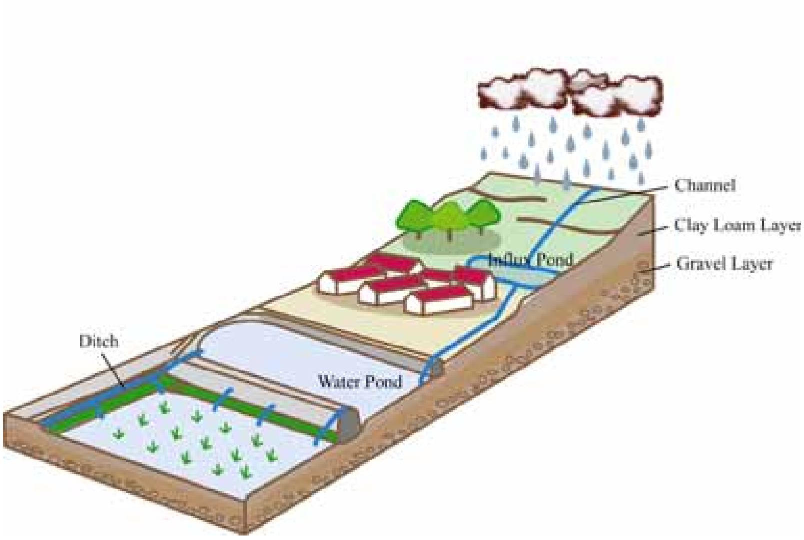

Figure2. Illustration of design theorem of water pond

IRRIGATION POND SYSTEM MODEL

Affecting Factors in Water Distribution

The irrigation water how to convey an adequate amount of water to specific blocks at the right time. It needs overall considerations of crop types, growing stages, crop water requirement, percolation, conveyance loss and so on (Chen et al., 2004). These factors vary with time and locations, which are discussed as follows.

Crop Water Requirement The crop water requirement could be decided by direct measurement or through indirect calculation. Although direct measurement could obtain an actual water requirement, it should cost more money and labor due to morphological constraints. Instead, the indirect calculation is usually used. The calculation equation is expressed as

$$ET_{crop} = K_c * ET_0 \quad (2)$$

where ET_{crop} is the crop water requirement, K_c, varies with season and wind speed is the dimensionless crop coefficient, approximately 0.95~1.35 for paddy rice, and ET_0 refer is the reference evapotranspiration of standard crop canopy, which is often estimated using the Penmen-Monteith method (Monteith, 1994; Kan *et al.*, 1996). According to the growing seasons of all crops (paddy rice), one can determine the total crop water requirement for any period.

Percolation in Paddy Field The percolation process in paddy fields is very complex and varies with soil texture, ponding depth, water temperature, groundwater level, extension of root system, etc. In Taiwan the percolation in paddy fields is estimated using an empirical formula from the Taiwan Water Conservancy Bureau (Kan, 1978). The equation is expressed as

$$P = \frac{240}{S \cdot I} \tag{3}$$

where P is the percolation for paddy field per day, S is the gravity percentage of grain size less 0.005mm, I is the infiltration coefficient.

Paddy Rice Growing Stage In general, the paddy rice in Taiwan needs about 120~130 days for a complete growing process, which was divided into 4 stages, including nutrition growing period, procreation growing period, mature period and harvest. As showed in Fig 3, each stage all required a suitable water requirement to grow. The water depth varied with each stage, but not immersed in water long time.

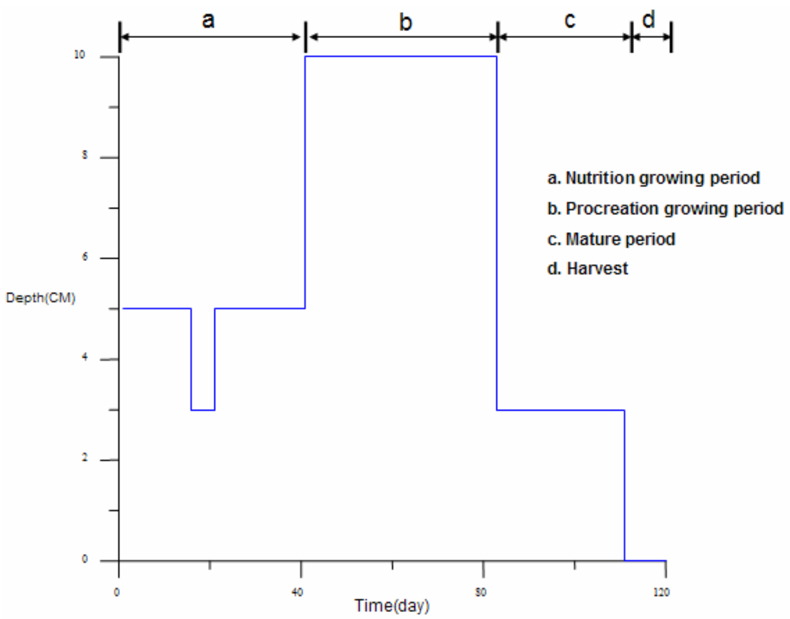

Figure 3. Water requirement for paddy rice in entire growing stage

Conveyance Loss in Canals and Ditch Conveyance loss, including evaporation, seepage, operation loss, is the water lost during the transportation process from source to fields. The transportation path consists of a main canal (from the main intake to a lateral intake), a lateral canal (from the lateral intake to a farm intake), and ditches (from the farm intake to fields). In the past practice of irrigation, the conveyance losses in canals and ditches were generally considered as constant, which range varies with soil texture and type. According to the irrigation plan 2005 of Taoyuan irrigation association, the conveyance loss is determined at 13% in this paper.

Supply Style Classification

In this study area, the irrigation system is divided into 4 supply styles, which are associated with mail canal, water pond and river weir. As showed in Fig.4, style A is the most complete supply style, consisting of mail canal, water pond and river weir, 3components of water resource simultaneously. The supply style of style B includes mainly main canal and water pond, the irrigation water is diverted from main canal into water pond, then through regulating by water pond to provide to crop field. Style C immediately supports irrigation water to farmland with main canal and river weir, and Style D just only has mail canal

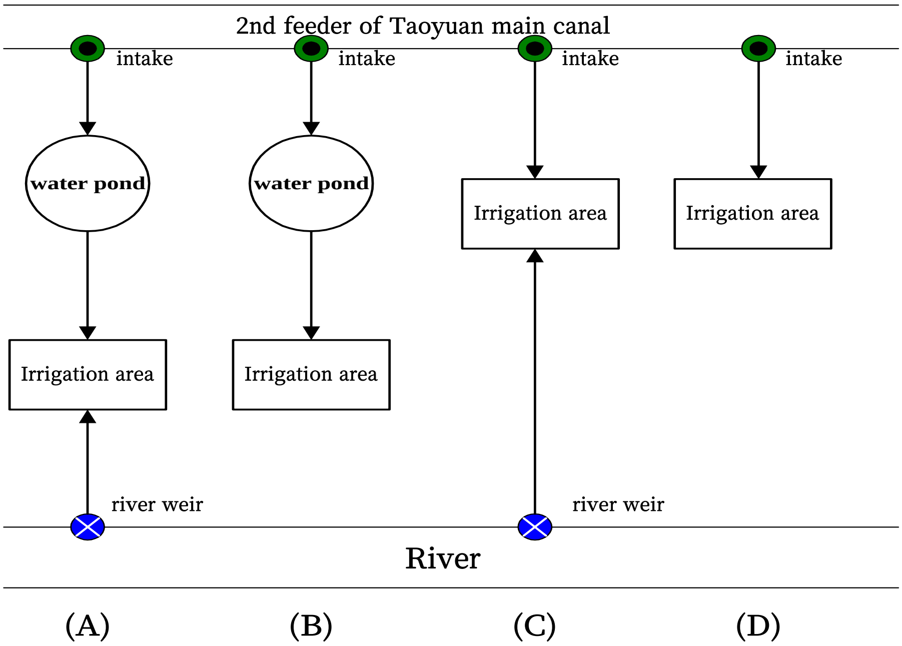

Figure 4. The diagram of supple style to irrigation area

Operation Strategy

The irrigation water is supplied from five sources, including precipitation, return flow from upstream paddy field, river weir, water pond and main canal. In this study, the water usage order is described as follows. Firstly, to calculate the effective rain and storage in paddy field and return flow from upstream field. If not meet the crop water requirement, river weir and water pond were been considered in the irrigation-pond system. Finally, main canal would provide overall deficit. The flowchart of operation strategy is showed in Fig. 5. Besides, it should be noted that the capacity of all water ponds was maintained 80% as well as possible, was regulated by Taoyuan Irrigation Association as backup storage to provide crop water requirement in drought period. Then this issue is controversial problem that would be discussed following statement.

Water Requirement for Land Preparation

During land preparation, the farmland is plowed and a considerable amount of water is applied so that soil is saturated and get ready to transplant paddy seedlings. Theoretically, the water requirement for land preparation is constructed of irrigation for paddy rice and the water needed to saturate the soil. According to the irrigation plan 2005 of Taoyuan irrigation association, the amount of water requirement for land preparation is approximately set at 200mm.

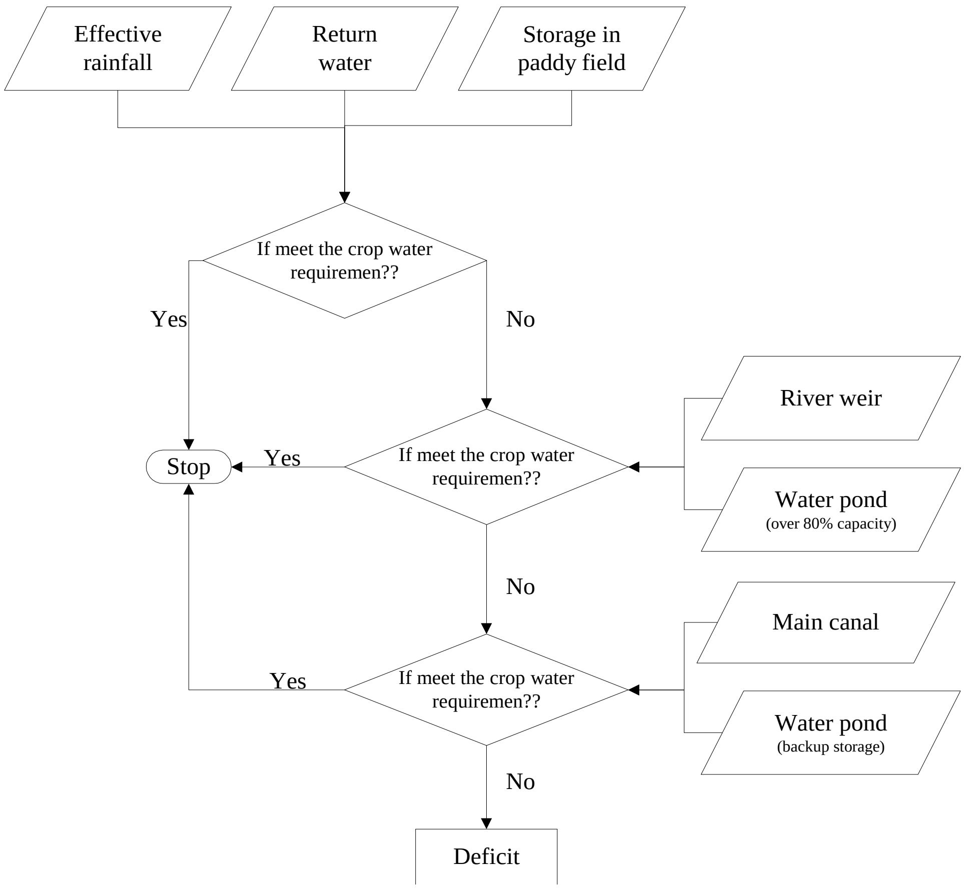

Figure 5. The flowchart of operator strategy

APPLICATION AND DISCUSSION

Study Area Description

The study area is the 2nd of 15 feeders in Taoyuan main canal, with a size of 2,765 ha, belongs to the Taoyuan Irrigation Association. There are 38 irrigation areas, the water requirement were supplied from main canal except 29 areas with water pond had part of water requirement from ponds. The effective capacity of all 29 water ponds is totally 4,707,912 m^3, which geographic positions are showed in Fig 6. A schematic diagram of pond irrigation system for the study area is shown in Fig. 7. There are 16 river weirs in this irrigation pond system, and the water right for each weir is collected and collated in Table 1.

Table 1 The water right of river weir

River weir	Water right(CMD)	River weir	Water right(CMD)
#6	1555.2	#12	8553.6
#7	4060.8	#13	864.0
#7-1	2160.0	#24	691.2
#9	15120.0	#24-8	777.6
#10	1987.2	#24-9	1555.2
#10-2	1209.6	#25-7	21513.6
#10-3	864.0	#28-3	5702.4
#11	3456.0	#28-4	3024.0

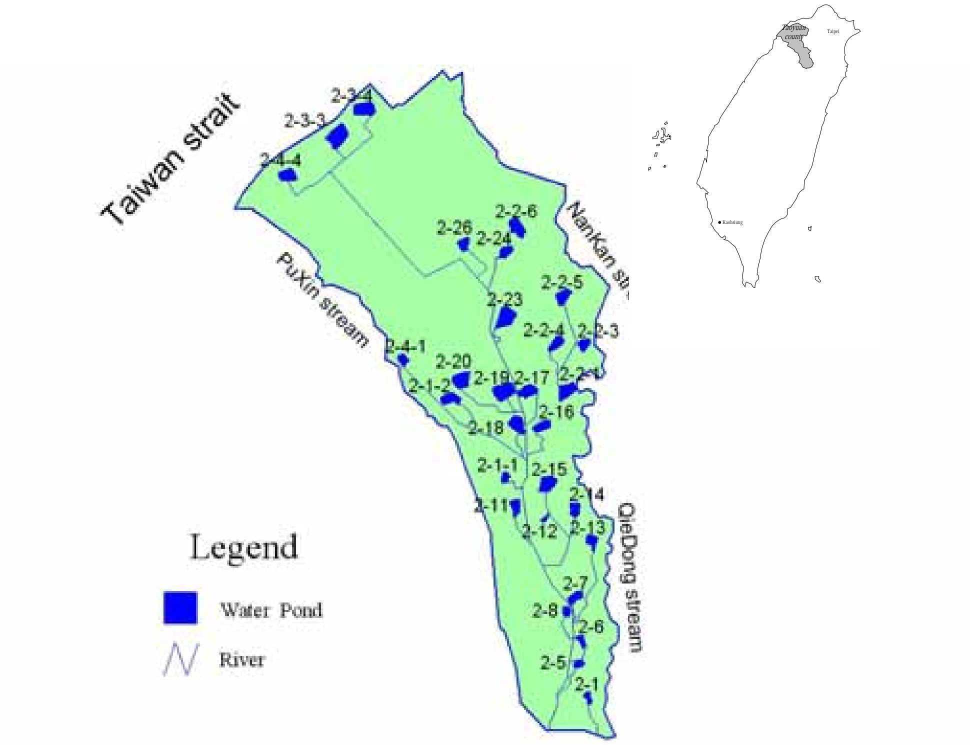

Figure 6. Distribution of water ponds of 2nd feeder in Arcview layer

The study area lies in a subtropical climate. The wet season is from May to September, and the dry season is from October to April. Although the mean annual rainfall is 2658 mm in taoyuan area, about 61.9% is concentrated in the wet season, it's showed the distribution of rainfall is very unevenness. The first-season paddy rice begins in late February and ends in mid-July, while the second-season paddy rice begins in early June and ends in early November. This paper applies pond irrigation system model, and inputs data contained crop water requirement, Taoyuan main canal supply, evaporation, precipitation, water right of river weir, river flow in the first-season period. The analytic time is from March 3rd 2005 to June 30th 2005, total 120 days. The simulation procedure calculates water balance day by day in each irrigation area from upstream to down stream

Relation between water pond capacity & water requirement

The characteristic of pond irrigation system model is that the upstream areas (near Taoyuan main canal) have priority be provided. The areas are occurred likely deficit in the middle and downstream canal when Taoyuan main canal can not supply enough irrigation water. Therefore, the water ponds play an important role to support crop water requirement in this time. The capacity of pond and the demand of responsible irrigation are essential to determine if deficit or not. Table 2 gives the maximum capacity of water pond, the demand of responsible irrigation, and the estimate of pond utility rate of each water pond. The utility rate is large that show the water pond needed to supply the demand of irrigation is huge and this area would easily have deficit while main canal and/or river weir cannot provide adequate irrigation water. In the table2, despite high utility rate in No. 2-1, 2-5, 2-6, 2-8 and 2-1-1 area, because they all locate in upstream of canal so that can obtain sufficient irrigation water from canal and numerous river weirs. Although, No. 2-17, 2-2-6 and 2-3-4 area, locate in middle and /or downstream of mail canal, just can get remaining water and are easier to happen deficit plight.

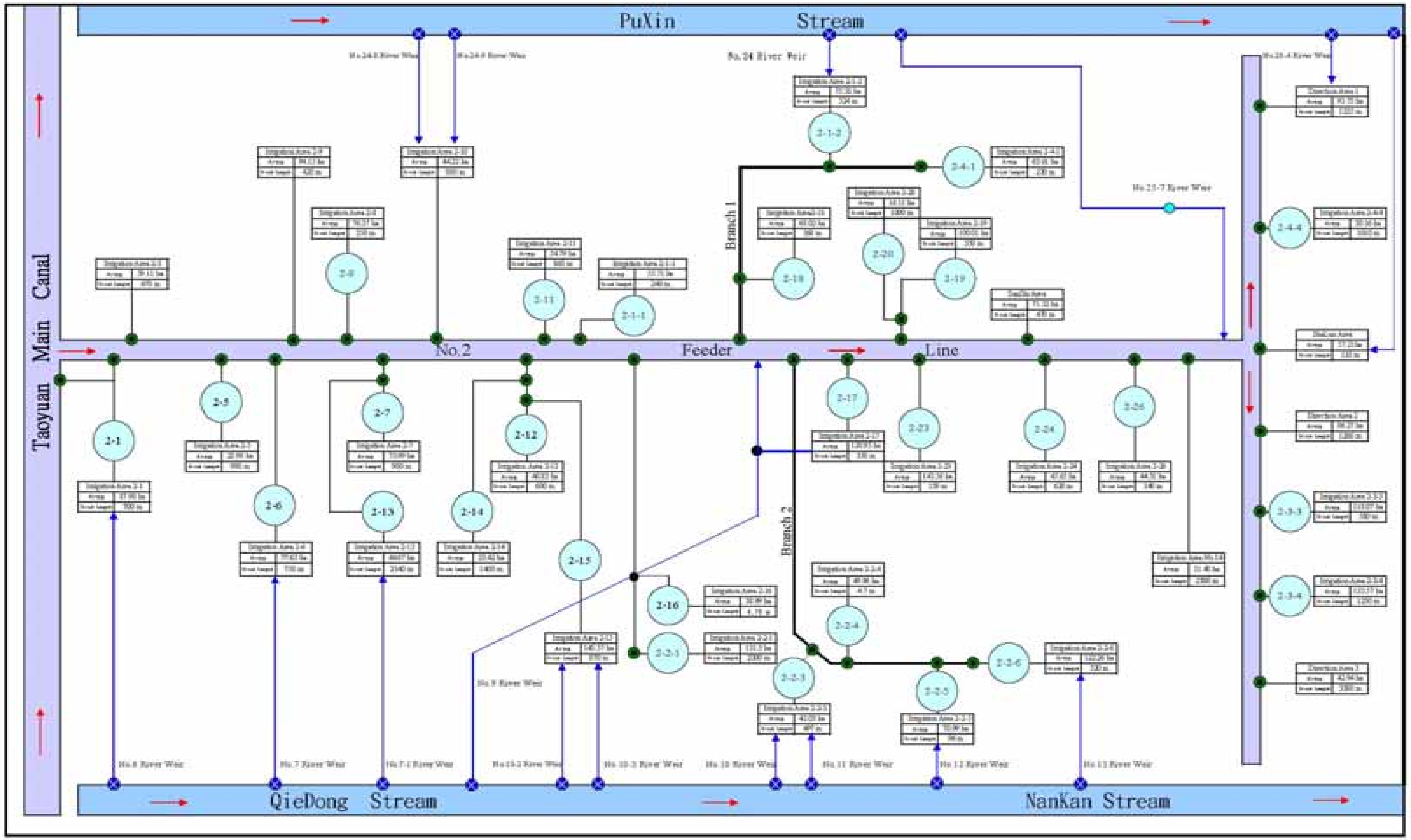

Figure 7. Irrigation System Diagram of The Study Area

Table 2.The attribute of water pond

Pond No.	(1) Max. Capacity (m^3)	(2) Total Water Requirement (m^3)	(3) Utility Rate (2)÷(1)	Pond No.	(1) Max. Capacity (m^3)	(2) Total Water Requirement (m^3)	(3) Utility Rate (2)÷(1)
2-1	41944	805172	19.2	2-4-1	111649	582143	5.2
2-5	24812	210307	8.5	2-2-3	108973	390797	3.6
2-6	60485	710634	11.7	2-2-4	139067	457222	3.3
2-8	47549	698920	14.7	2-2-5	248330	649683	2.6
2-13	147971	408809	2.8	2-2-6	185296	1154654	6.2
2-7	163634	677139	4.1	2-17	161780	1106905	6.8
2-14	137825	214334	1.6	2-20	235031	147435	0.6
2-15	268065	1332222	5.0	2-19	222057	915268	4.1
2-12	67512	373666	5.5	2-23	340683	1249696	3.7
2-11	115476	501425	4.3	2-24	114088	397385	3.5
2-1-1	53079	509845	9.6	2-26	132124	387461	2.9
2-16	119372	356827	3.0	2-3-3	295163	1385606	4.7
2-2-1	231014	1201626	5.2	2-3-4	298228	1567505	5.3
2-18	278682	622503	2.2	2-4-4	202035	353941	1.8
2-1-2	155988	689219	4.4	Total	4707912	20058349	4.3

Analysis in Effective Rainfall

In this study, the pond irrigation system bases on rainfall data from March 3rd 2005 to June 30th 2005 and analyzes the amount of effective rainfall. Effective rainfall is very important for irrigation area, and then levee gap height is crucial factor to determine how much amount of effective rain can be stored in field. Fig 8 shows the relation of rainfall and levee gap height. If rainfall is not over the levee gap height, rainfall can be stored and as the effective rainfall to provide crop water requirement. If it over, however, excess rainfall water has no contribution and is drained off. There is 988 mm cumulative rainfall in this analytic period. As showed in Fig. 9, the cumulative rainfall is very close to the cumulative effective rainfall in earlier period. But accompanying levee gap height change, more excess rainfall water is not utilized in later period.

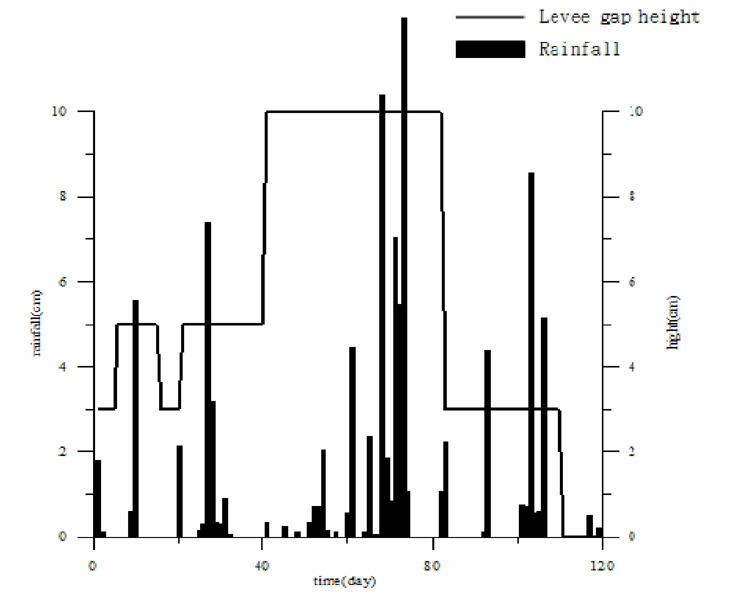

Figure 8. Hyetograph in 2005 and the levee gap height of traditional irrigation

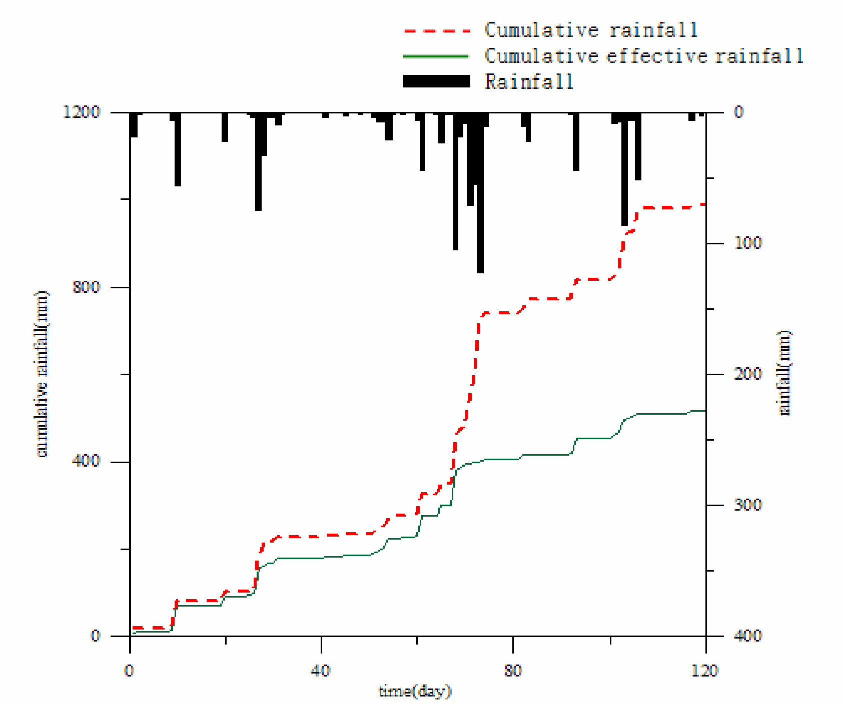

Figure 9. Cumulative rainfall and cumulative effective rainfall

The conception of deep-ponding irrigation is addressed by Kan (1993). He compared the different of irrigation water requirement in Taiwan and Japan, and proposed an adjusted ponding depth from 10 cm to 25 cm. The rice, with deep ponding irrigation, would get better quality than in traditional irrigation (shallow-ponding). However, it was not to raise ponding depth instantly, and then changed with growth stage of paddy rice. The process of ponding depth change is showed in Fig.6 This method not only promotes the production and quality of paddy rice, but also can improve the using efficiency of rainfall and this so-called" Paddy Field is Reservoir "has carried out extensively in Taiwan.

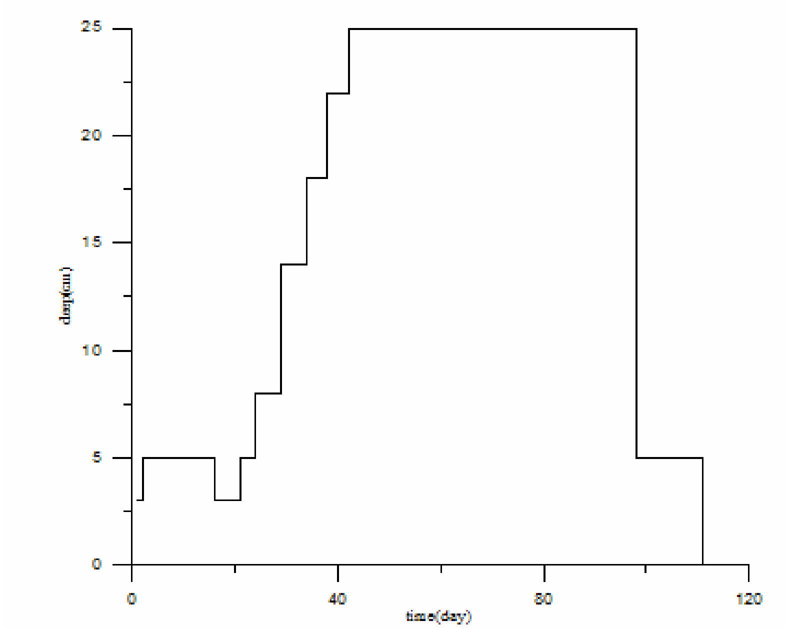

Figure 10. The process of ponding depth change in deep-ponding irrigation

Because of the storage space is increased with heightening levee gap height, deep-ponding irrigation can store availably rainfall water in storm and change into effective rainfall. It is showed in Fig. 11 that the effective rainfall is acquired 210 mm in deep-ponding irrigation more than in traditional irrigation. There are 6 places, which are 2-17, SanShi, No. 14, Direct Area 3, Direct Area 1, ShaLun, would happen deficit in all study area. 2-17 pond area, locates in middle of 2nd feeder canal, is only one deficit place with supplying from water pond. It has two deficit days that resulted from the irrigation water of main canal is used up in upstream area, and out of itself backup storage. According to the comparison in Table 3, the deep-ponding irrigation can shorten deficit day and is able to improve about 24% total shortage amount to 196819m^3.

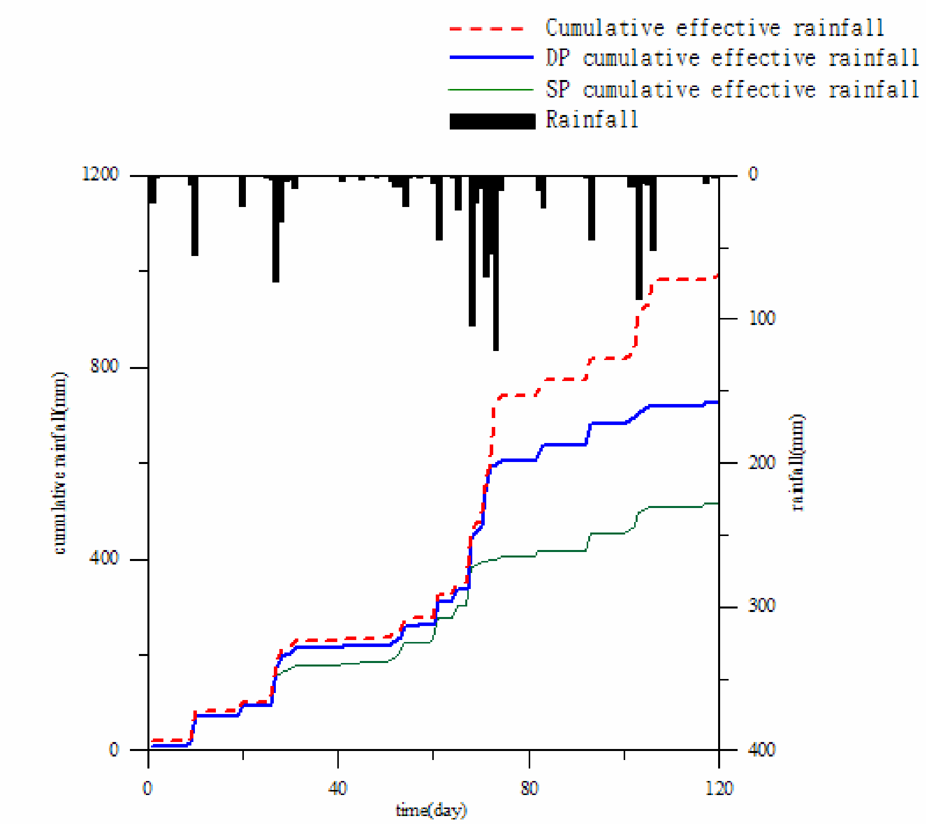

Figure 11. Cumulative effective rainfall of deep ponding irrigation

Table 3. The comparison in traditional and deep ponding irrigation

Irrigation Area	Deficit day (in 120days)		Shortage(m^3)	
	Traditional	Deep ponding	Traditional	Deep ponding
2-17	2	0	8638.6	0
SanShi	36	27	229027.9	176791.8
No.14	36	27	131318.4	102890.4
Direct Area 3	38	26	143247.1	106796.4
ShaLun	39	28	135992.2	106944.7
Direct Area 1	40	27	185062.5	143044.7
Total	-	-	833286.7	636468.0

Evaluation in Efficiency of Water Pond

Following the result of last section, it is showed that the irrigation areas locate in downstream of 2nd feeder canal and without water pond, are easy to occur frequently in deficit plight. In order to evaluate the efficiency of water pond irrigation system in drought period, 9 areas without water pond are set for fallow in this section. Therefore, there are 16 river weirs, 29 water ponds and 29 irrigation areas in this system. Furthermore, branch 1locates in middle of pond irrigation system, and is set as the dividing line to divide 29water ponds into 2 groups. One consists of 2-1, 2-5, 2-6, 2-7, 2-8, 2-11, 2-12, 2-13, 2-14, 2-15, 2-16, 2-1-1and 2-2-1, total 13 water ponds in upstream. Another consists of 2-18, 2-1-2, 2-4-1, 2-2-3, 2-2-4, 2-2-5, 2-2-6, 2-17, 2-19, 2-20, 2-23, 2-24, 2-26, 2-3-3, 2-3-4 and 2-4-4, total 16 water ponds in downstream.

At the Taoyuan irrigation association census, the whole irrigation area of 2nd feeder canal is not different obviously between in 2002 and 2005. As showed in Fig. 12, the rainfall in 2002 was much less from March 3rd to June 30th than in the same in the past decade. 2002 is a drought year and only has 350 mm rainfall, and then setting to simulate the first-season paddy rice period.

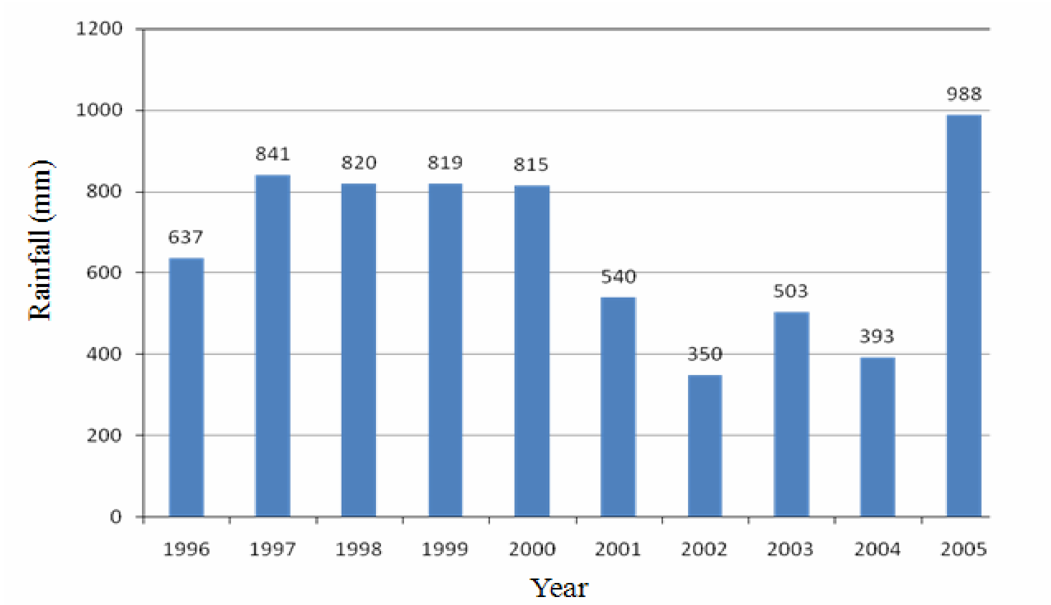

Figure 12. The rainfall statistics from March 3rd to June 30th in the decade

Fig. 13 expresses the relation between the distribution of rainfall and levee gap height from March 3rd 2002 to June 30th 2002, and most of all rainfall water doesn't over the levee gap height in this period. It indicates that rainfall water almost was stored in paddy field and be used to crop requirement. So how to use the backup storage of water pond will become very important components when rainfall water is insufficient and the others water supply is limited. In the past experience, pond irrigation system work with the priority being provided in upstream which stored most of irrigation water in water pond in upstream and was not used more efficiently. Then resulting in irrigation water of main canal had been used up before arriving in middle and/or downstream and had to utilize backup storage in drought period.

There are 5 scenarios will be analyzed for changing backup ratio in this section. Scenario Ⅰ: the capacity of all 29 water ponds was maintained 80% as backup storage. Scenario Ⅱ: the

13 water ponds in upstream are set 80% and the others in downstream are set 90%. Scenario Ⅲ: the water ponds in upstream are set 70% and the others in downstream are set 90%. Scenario Ⅳ: the water ponds in upstream are set 70% and the others in downstream are set 100%.

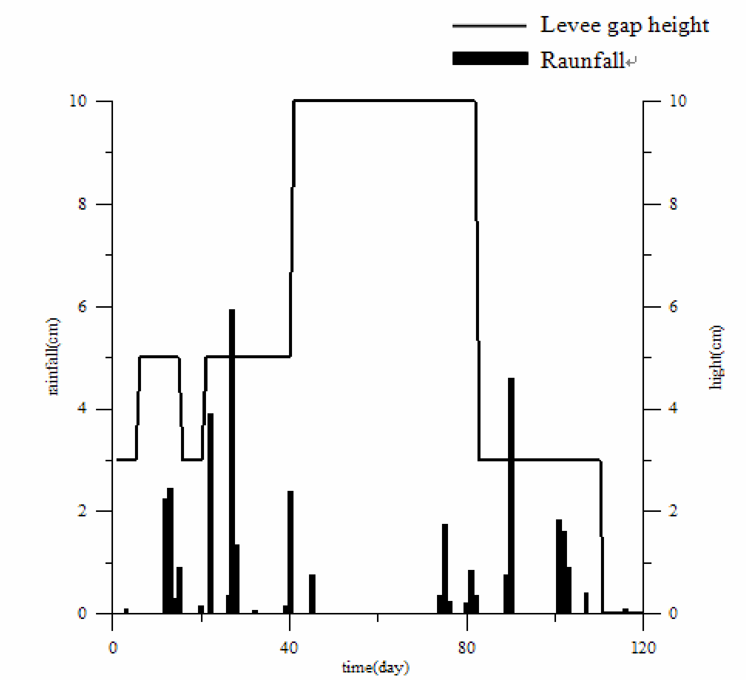

Figure 13. Hyetograph in 2002 and the levee gap height of traditional irrigation

Four water deficits, namely 144,285, 99,409, 86,472, 38,694m^3(referred to as scenario Ⅰ, Ⅱ, Ⅲ and Ⅳ in Table3), are considered. Table 3 presents the amounts of water shortage in deficit area with changing the backup storage ratio of water pond in up and down stream. According to the ratios are presented in fore paragraph, the result expresses that water shortage is reduced as increasing the backup ratio in downstream area. ScenarioⅣ has the brilliant performance and get least water deficit in all 4 scenarios. It can cut off the water shortage to 38,694m^3 less than 144,285 m^3 for Scenario Ⅰ (the ratio keeps on going now).
Due to the water ponds of upstream area close to the source of 2nd feeder canal and can earlier obtain irrigation water from canal. So the backup ratio of water ponds of upstream area can be decreased and release backup water to provide for downstream area. Furthermore, the water ponds of downstream can store more the surplus water to extend supplying day with increasing the backup storage.

Table 4. The comparison in 4 scenarios of capacity of water pond

Irrigation Area	Water Shortage (m^3)			
	Scenario Ⅰ (80%-80%)	Scenario Ⅱ (80%-90%)	Scenario Ⅲ (70%-90%)	Scenario Ⅳ (70%-100%)
2-19	39,550	23,308	23,308	11,314
2-23	31,072	22,872	4,813	-
2-24	37,271	26,680	26,681	16,120
2-26	20,635	8,361	8,362	11,260
2-3-4	15,757	18,188	23,308	-

Total	144,285	99,409	86,472	38,694

CONCLUSIONS

As municipality attempt to meet their continuing water supply demands, how to find more water resource will become a very important issue. Owing to the climate change and the unevenness of rainfall distribution that brings frequently the water deficit dilemma in Taoyuan area. In this paper, a water pond irrigation system model is proposed which is capable of assessing the potential of water pond and the profit adopting deep ponding irrigation. Actual applications of the model are performed. It was found that the water pond irrigation system model can simulate water distribution and finds the crucial area to estimate water pond system. However, to adopt deep ponding irrigation method that it can more efficiency to use rainfall and runoff. It makes paddy fields as reservoirs to store more rainfall and provides crop water requirement. Further, it can promote the potential of supply of system with changing the backup ratio of water pond in up and down stream area. For scenario Ⅵ, the backup ratio at 70% in upstream and 100% in downstream that appears a brilliant performance and reduces the water deficit.

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