THE ESTIMATION OF WATER SUPPLY OF REGIONAL PADDY IRRIGATION SYSTEM BY VENSIM MODEL

Hao-Lieh Huang[1] Ray-Shyan Wu[2]

ABSTRACT

This research investigated into the influence of irrigation water requirement with the irrigation operation including channel supply, wire supply and pond supply. Taoyuan Channel #2 Feeder in North Taiwan was selected as the study area. The agriculture irrigation system model was established by adapting Vensim model and the irrigation water supply data in 2008 was applied.

The simulation result showed that outflow occurred with two main parameters: rainfall, when rainfall is big enough, outflow can be happen; otherwise is paddy ridge changed. The rate of outflow in second crop is higher than that in first crop. The rainfall is hard to store in fields due to typhoon or torrential rainfall and usually happened in second crop. Adding the pond irrigation system into the agricultural irrigation system can afford more water for paddy field and be an importance role at water shortage stage which has no rainfall. The pond irrigation system improved stable irrigation and saving the water from rainfall for irrigation.

INTRODUCTION AND BACKGROUND

The water balance equation is used to simulate water demand during crop growing period. According to crop characteristic, environment of study area and local weather data, and matching different irrigation management, irrigation system was established. Tsai (2009) selected Taoyuan Channel #2 Feeder as the study area, and established agriculture irrigation system model by Vensim model with irrigation water supply data in 2008 applied. The results revealed outflow occurred due to two main factors, one is the excess rainfall that paddy field can't store, the other is paddy ridge, decreasing height of paddy ridge made water outflow. Lin (2010) selected Taoyuan Channel #2 Feeder as the study area, and established pond irrigation system into the model by Vensim model. The result shows that closing pond irrigation system adversely affected on growing of the crops. And the water shortage occurred with the centralization rainfall pattern in second crop under the condition of closing ponds.

CONCEPTS OF AGEICULTURE IRRIGATION SYSTM

The water requirement of a crop is signified by the amount of water needed to growth and it includes water to meet both consumptive and special needs, such as land preparation, land submergence, leaching and so on. The irrigation associations

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always estimated the water demand that assumed all fields belonged to paddy field in its land.

As shown in Fig. 1, when rain water falls on fields, the irrigation water flows into fields from irrigation channel. The rainfall plus irrigation water needs to satisfy water demand. The water demand included crop evapotranspiration, outflow and leakage. The leakage is recharged groundwater. Sometimes outflow can be reused by downstream fields and others are drained to sea.

PADDY RICE IRRIGATION SYSTEM MODEL

Water equilibration principle

According to the water equilibration principle of the hydrologic cycle, calculated water output subtracted from water input, which is equivalent to the changing volume of water storage. This common water equilibration formula for ground water and the underground water system is described in further detail below:

$$I - O = \frac{dS_f}{dt} \qquad (1)$$

Where I is the inflow, O is the outflow, S_f is the field storage, and t is time.

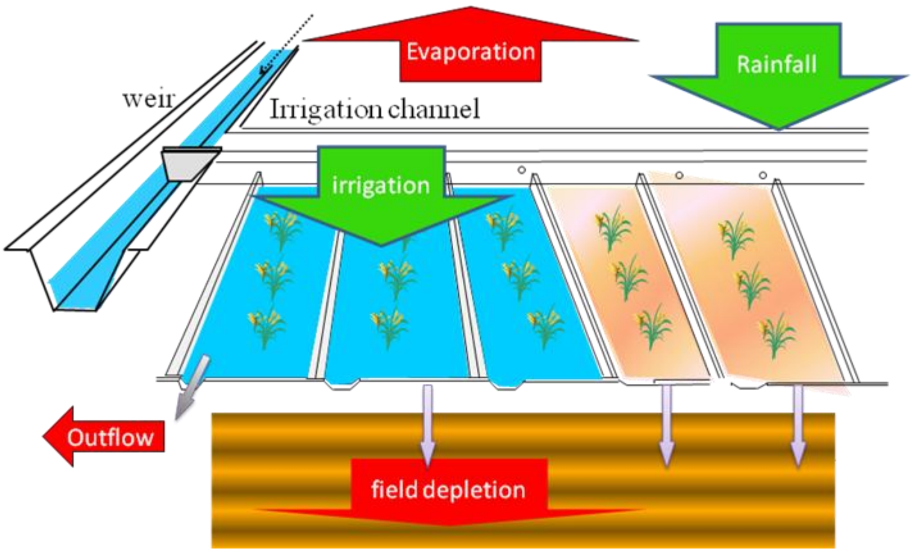

Figure 1. The hydrologic components for crop fields

Analysis of the mechanisms of the paddy field water equilibration in this study, e.g., rainfall, evapotranspiration, irrigation routing water, etc., excluding the study of soil water content, used the paddy field as control volume (Fig. 2). The formula for water equilibration for a specified period is shown below:

$$S_i = S_{i-1} + IR_i + IO_i + W_i + P_i - ET_i + F_i - DR_i \qquad (2)$$

Where S is field storage, IR is irrigation inflow, IO is return flow from upstream, P is rainfall water, ET is evapotranspiration, W is weir irrigation water, F is field depletion, DR is field outflow, and i is a specified period of time. The irrigation water resource included weir and Taoyuan Channel #2 Feeder.

$$\text{if } S_i \geq H_i \text{ , then } DR_i = S_i - H_i \qquad (3)$$
$$\text{if } S_i < H_i \text{ , then } DR_i = 0$$

When the field storage (S) water reserves exceeds the water exiting field ridges (H) , a field return flow volume ($DR > 0$) is observed; no outflow ($DR = 0$) is observed when vice versa. The paddy field ridges refers to Kan (1996) presented the optimal water depth in grow stages for Taiwan paddy rice. The vegetable has bad water resistance therefore it is assumed that the height of paddy ridge is 0 in vegetable field in model.

In this study, the field storage is the sum of the height of pond water (h') plus the height of field capacity (h'') , and soil depth is assumed to be 30 cm. The soil has its field capacity as shown in Tab. 1 (Wang & Yi, 1979).

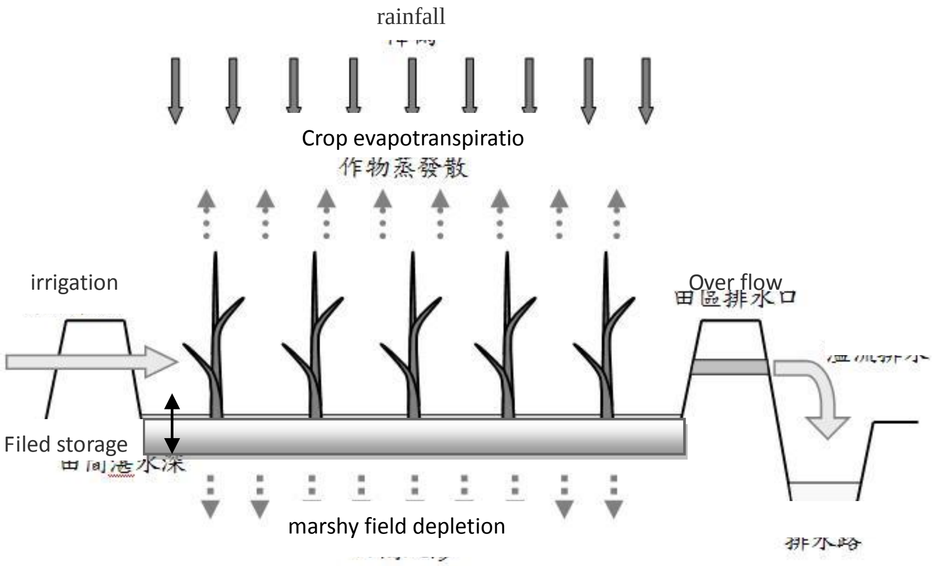

Figure 2. Paddy field water balance model

Table 1. The estimation of soil moisture capacity in different soil

Soil type	Percentage of dried soil	
	Field capacity	Wilting point
clay	36	20
Clay loam	24	15
sandy clay loam	19	10
sandy loam	12	5

Estimation of Evapotranspiration

The crop water requirement can be decided by direct measurement or through indirect calculation. Although direct measurement can obtain an actual water requirement, it costs more money and labor due to morphological constraints. Instead, the indirect calculation is usually used by researches. The calculation equation is expressed as below:

$$\mathrm{ET_{CORP}} = \mathrm{K_c} \times \mathrm{ET_0} \quad (4)$$

$$\mathrm{ET_0} = \mathrm{K_p} \times \mathrm{ET} \quad (5)$$

Where *ETcrop* is the crop water requirement, *Kc* is the dimensionless crop coefficient which varies with season, approximately 0.6~1.5 (first crop) and 0.5~1.7 (second crop) for paddy rice. The *ET0* refers to the reference evapotranspiration of standard crop canopy, which is pan coefficient（*Kp*）multiplied by evaporation（*ET*）. The evaporation used history evaporation data which is measured by pan evaporation. According to the growing seasons of all crops (paddy rice) (Masakazu, 1999; Chang et al., 2001), one can determine the total crop water requirement for any period.

Estimation of field depletion

The estimation of field depletion used experience equation in designing specification which is built by Water Resources Agency, Ministry of Economic Affairs. The experience equation is shown below:

$$\mathrm{P} = \frac{240}{s \cdot I} \quad (6)$$

Where *P* is the field depletion, *s* is the percentage of clay weight, which is under 0.005mm and *I* is leakage coefficient of soil. Consequently, estimation of field depletion on different soils can be calculated, according to soil type data in irrigation associations and result of field experiment which is proceed by Water Resources Agency, Ministry of Economic Affairs as Tab. 2(Kan,1979). In this study, the field depletion in model is ascertained that it is decided by field capacity as shown below:

$$\text{If } S > FC \quad \text{then} \quad \mathrm{DF} = \min(\mathrm{P}, \mathrm{S} - \mathrm{FC}) \quad (7)$$

$$\text{If } S < FC \quad \text{then} \quad \mathrm{DF} = 0$$

$$FC = \text{Soil depth} \times \text{Percentage of Field Capacity}$$

Where *P* is the field depletion (mm/day) and *FC* is field capacity. The soil types are clay, Clay loam, sandy clay loam and sandy loam with the study area of Taoyuan

Channel #2 Feeder.

Table 2. The estimation of field depletion on different soil

Soil type	Clay content（*S*）	coefficient（*I*）	field depletion（mm/day）
sandy loam	14.9	1.4	11.5
Clay loam	21.9	1.6	6.85
clay	33	1.8	4.04

STUDY AREA SYSTEM

In this study, the model estimated by System Dynamics that Prof. Jay W. Forrester and developed in 1960. The System Dynamics included information theory, systematic theory, control theory, decision theory and computer simulation, etc. It had a main purpose to show behavior of system dynamics changed by time. Although it not only had forecast function, but also can reveal relationship of dynamic between system and time. This study established water balance equation by Vinsim model to calculated outflow, crop evapotranspiration and simulated water supply procedure of weir. The model was built up as Fig 3.

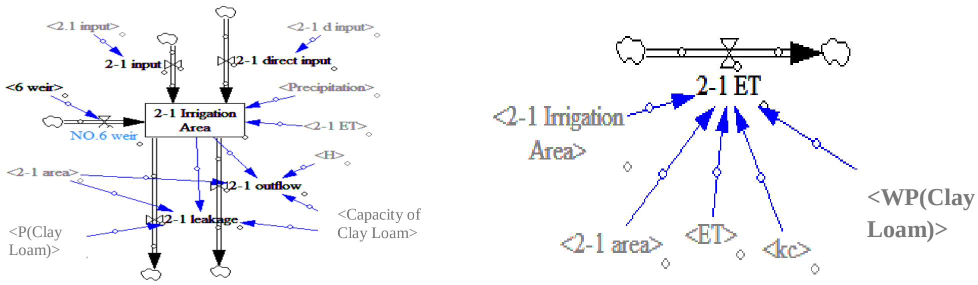

Figure 3. The estimation system of outflow and crop evapotranspiration

Study Area Description

The study area is the second 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 and geographic positions shown in Fig 4. The study area lies in subtropical climate. The wet season is from May to September, with dry season 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 showed that the distribution of rainfall is very uneven. 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.

The soil types included clay , clay loam, sandy loam and sandy clay loam in irrigation site of Taoyuan Irrigation Association. The percentage of soil component in the study area are as following： rate of clay loam is 33.99%, rate of sandy loam is 28.55%, rate of clay is 19.72% and sandy clay loam is 17.75%. The soil types and area in irrigation sites are shown in Tab. 3.

Irrigation resource

The surface irrigation water in Taoyuan Channel #2 Feeder came from reservoirs and rivers. In this study, the reservoir irrigation water data with ten days as the cultivation period is provided by Taoyuan Irrigation Association. The supply water input is from feeder (i.e. the real consumed water in field) and model is assumed to have no water conveyance loss. For the river irrigation water, there are 16 river weirs in this irrigation model, and the water right for each weir is collected and collated by Taoyuan Irrigation Association.

Tao-Yuan pond irrigation system is the ancestor's intention to increase the effective rainfall to overcome the particular climate pattern with the use of geographicadvantage. Ponds are not all used to be agricultural irrigation now, some ponds are used to fish culture, disuse or etc... In this study, all ponds assumed to useable and providing irrigation water to paddy field. The pond data shows by Tab. 4.

Flow direction of outflow

The flow direction of outflow in Irrigation site of the second feeder is according to flow direction in irrigation system of Da Ju work station, which is provided by Taoyuan Irrigation Association to decided irrigation section and flow direction in irrigation site.

In general, rainfall can be stored in paddy field when it the quantity is small and paddy ridge had good height, the outflow does not occur. If the quantity of rainfall is too big to produce pond water depth which is higher than height of paddy ridge, the water will overflow into the neighboring fields. The flow direction of outflow was decided by elevation of irrigation site as Fig. 5.

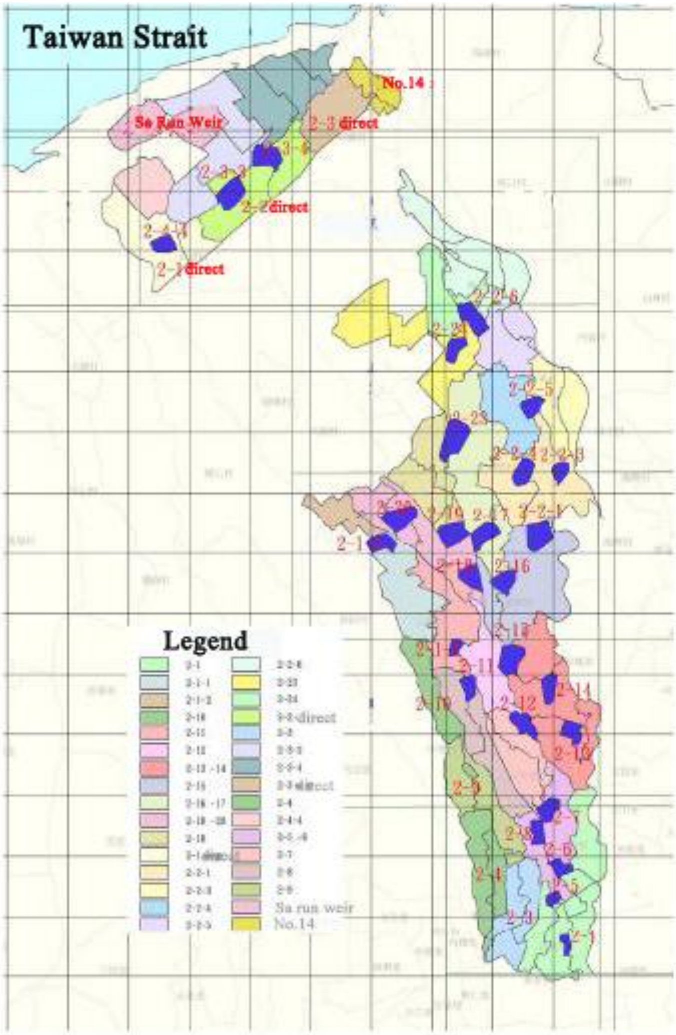

Figure 4. Distribution of Irrigation site of the second feeder

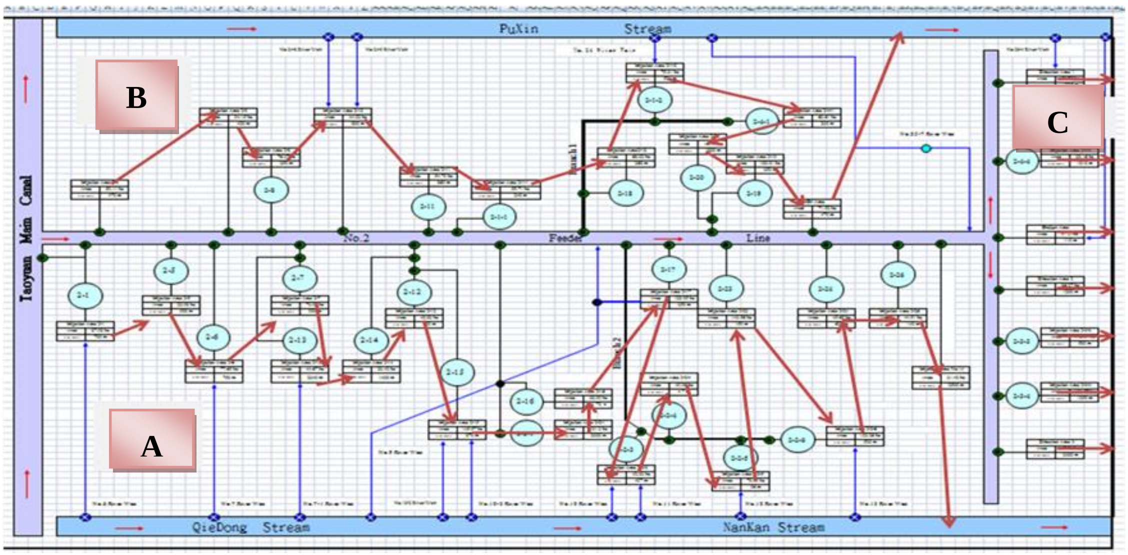

Figure 5. The flow direction of outflow (as arrow)

Table 3. The soil types and area in Irrigation site of the second feeder

Irrigation site	Soil type	Area（ha）	Irrigation site	Soil type	Area（ha）
2-1	Clay loam	87.98	2-1-1	Clay loam	55.71
2-3	Clay loam	59.11	2-1-2	Clay loam	75.31
2-5	Clay loam	22.98	2-2-1	Clay loam	131.3
2-6	Clay loam	77.65	2-2-3	Clay loam	27.47
2-7	Clay loam	73.99		sandy clay loam	14.56
2-8	Clay loam	76.37	2-2-4	Clay loam	49.96
2-9	Clay loam	94.15	2-2-5	Clay loam	70.99
2-10	Clay loam	44.22	2-2-6	sandy clay loam	104.00
2-11	Clay loam	54.79		clay	18.26
2-12	Clay loam	40.83	2-3-3	loamy sand	118.07
2-13	Clay loam	44.67	2-3-4	loamy sand	133.57
2-14	Clay loam	23.42	2-4-1	Clay loam	63.61
2-15	Clay loam	145.57	2-4-4	loamy sand	30.16
2-16	Clay loam	38.99	San Shi direct	Clay loam	71.53
2-17	Clay loam	120.95	No.14 weir	loamy sand	31.40
2-18	Clay loam	16.11	Sa run weir	loamy sand	57.21
2-19	Clay loam	100.01	2-1 direct	Clay loam	18.19
2-20	Clay loam	68.02		loamy sand	75.56
2-23	clay	143.56	2-2 direct	Clay loam	86.27
2-24	clay	45.65	2-3 direct	Clay loam	42.94
2-26	clay	44.51			

Table 4. Ponds in the study area

No.	Maximum Area(m^2)	Maximum water level(m)	Maximum Storage(m^3)
2-1	30,267	2.9	26,294
2-5	32,899	1.8	24,812
2-6	49,340	2.4	60,485
2-7	66,585	3.3	163,634
2-8	34,155	3.0	47,549
2-11	64,940	3.3	115,476
2-12	13,320	1.8	67,512
2-13	58,510	3.2	147,971
2-14	62,171	3.8	131,605
2-15	108,610	3.8	268,065

2-1-1	30,950	2.1	53,079
2-16	68,838	3.6	119,372
2-17	83,267	3.6	161,780
2-2-1	99,600	3.8	211,095
2-2-3	55,436	3.0	108,973
2-2-4	69,134	3.6	139,067
2-2-5	78,770	3.8	232,578
2-18	93,395	4.0	278,682
2-19	140,515	3.1	222,057
2-20	112,496	3.3	235,031
2-1-2	85,389	3.6	155,988
2-4-1	63,956	3.0	111,649
2-23	138,053	4.2	340,683
2-24	59,360	3.3	114,088
2-26	59,336	4.8	102,427
2-2-6	98,560	2.9	137,405
2-3-3	152,927	2.8	233,364
2-3-4	123,440	3.3	285,886
2-4-4	83,920	3.3	202,035

The Fig. 5 showed that Taoyuan Channel #2 Feeder divided irrigation section into 3 parts: A section, B section and C section. In A section, the flow direction of outflow is : 2-1→2-5→2-6 →2-7→2-13→2-14→2-12→2-15→2-2-1→2-16 →2-17 →2-2-3 →2-2-4 →2-2-5 →2-23 →2-24 →2-2-6 →2-26 →No.14 weir. In B section, the flow direction of outflow is :2-3 →2-9 →2-8 →2-10 →2-11 →2-1-1 →2-18 →2-1-2 →2-4-1 →2-20 →2-19 →San Shi direct ; In C section, the outflow flows to river directly.

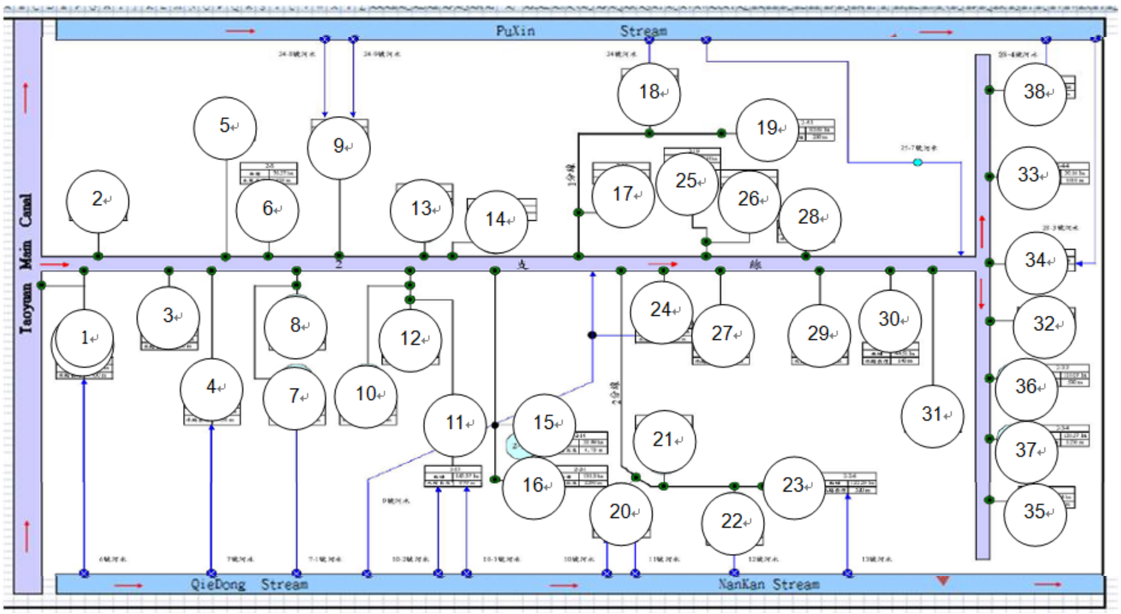

Figure 6. The priority order of irrigation

The pond irrigation system works by different elevation and transporting the water from high elevation to low elevation. Considering the elevation, upstream paddy field has higher priority to take irrigation water than downstream paddy field. It is assumed that when pond irrigation system is established into agricultural irrigation system, the flow direction of outflow is same as priority order of irrigation in 38 irrigation sections as Fig. 6.

Crop and grow period

The simulation procedure calculates water balance daily in each irrigation area from upstream to downstream. In the simulation, initial depth of pond water is 3 cm. The irrigation water is independent supply except No. 9 weir which shared with many fields and needed to consider the order of taken water.

The analytic time is from March 14th 2008 to July 11th 2008, totally 120 days for first crop of paddy field, and August 1st 2008 to November 28th 2008, totally 110 days for second crop of paddy field.

APPLICATION AND DISCUSSION

The irrigation water in model used real irrigation data and matched up irrigation style of Taoyuan Irrigation Association. When irrigation source comes from weir and reservoir, the simulation result is shown in Tab. 5. Most of soil type in section C is loamy sand which has more field depletion than section A and section B. And section C has the lowest average pond water depth.

The variation of pond water depth is shown in Fig. 7, and Fig. 8. The pond water depth has never reached the wilting point. In second crop, rainfall is centralized in several times and there is no rainfall at start. Therefore, the pond water depth in Fig. 8 is low and almost reached the wilting point line at start.

The relationship between rainfall and outflow is shown in Fig. 9, and Fig. 10. It showed that outflow occurred very often along with rainfall. As a result of reservoir irrigation and weir irrigation that barely supplies for water demand, irrigation water is not enough to produce outflow. Therefore, when rainfall is too big to produced pond water depth which is higher than the height of paddy ridge, the outflow occurred. The outflow occurred with two main parameters: rainfall, when rainfall is big enough, outflow can be happen; otherwise is paddy ridge changed. The simulation result showed that the rate of outflow in second crop is higher than first crop. The rainfall is hard to store in fields due to typhoon or torrential rainfall and usually happened in second crop.

Table 5. The simulation result without pond irrigation system

Section	A		B		C	
Crop	first	second	first	second	first	second
Irrigation(reservoir)	322.5	386.6	276	335.3	0	0
Rainfall	808.5	919	808.5	919	808.5	919
Irrigation(weir)	221.9	202.6	47.9	42.7	1131.5	1041.6

Field depletion	822.3	721.9	812.3	660.7	1593.5	1263.1
Outflow	389.1	637.1	204.4	493.2	328.6	704.9
Crop evapotranspiration	169.3	185.4	169.3	185.4	169.3	185.4
Outflow /Rainfall	0.481	0.693	0.253	0.537	0.406	0.767

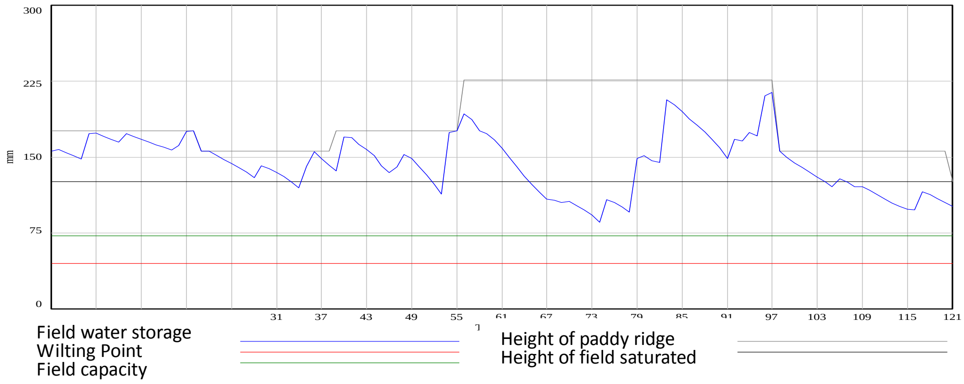

Figure 7. The field water depth in section B (first crop)

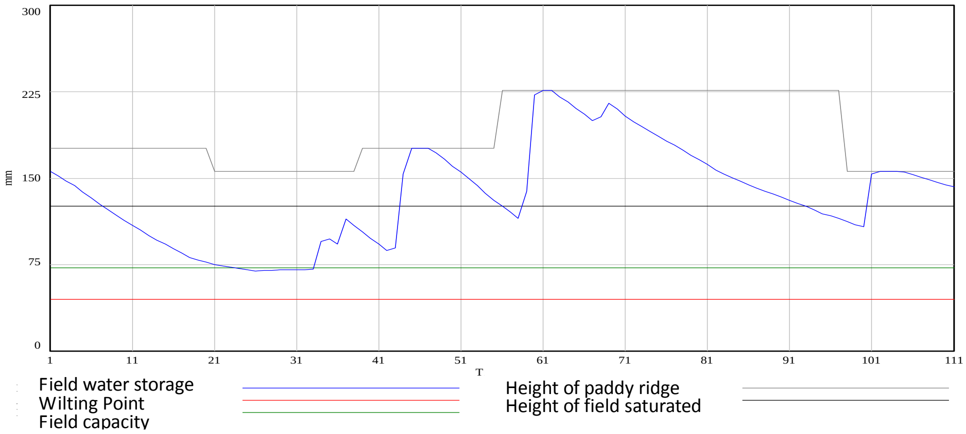

Figure 8. The field water depth in section B (second crop)

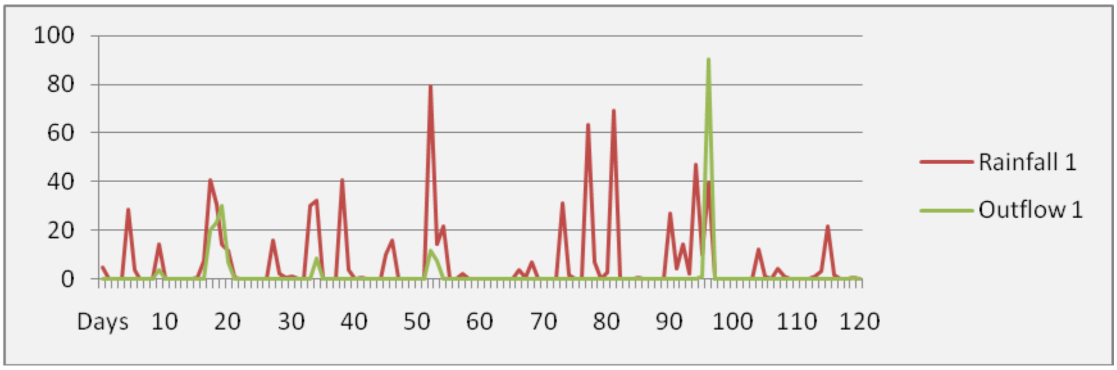

Figure 9. The relationship between rainfall and outflow in section B (first crop)

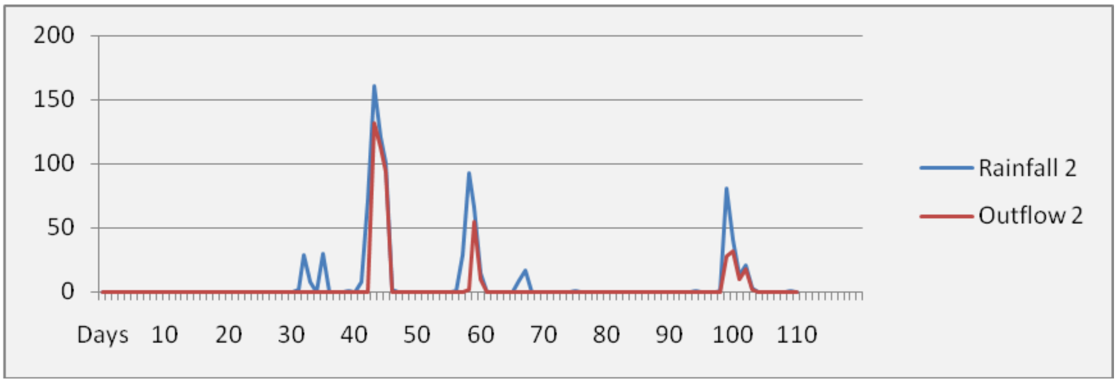

Figure 10. The relationship between rainfall and outflow in section B (second crop)

Adding the pond irrigation system into the agricultural irrigation system and the average field water depth is shown as Fig. 11 and Fig. 13.In Fig, 13, the result showed that the pond irrigation afforded more water for paddy field and pond water depth in second crop is decreased more slowly than Fig.8 at beginning stage which has no rainfall.

The variation of water level of pond storage is shown as Fig. 12 and Fig. 14. When reservoir and weir plus the rainfall can afford the water demand, the water level of pond storage is not decreased obvious. In beginning stage of second crop, the water shortage is happened, and pond is needed to transport great quantity water to paddy field. The rainfall can increase the water level of pond storage and saving the water for next irrigation.

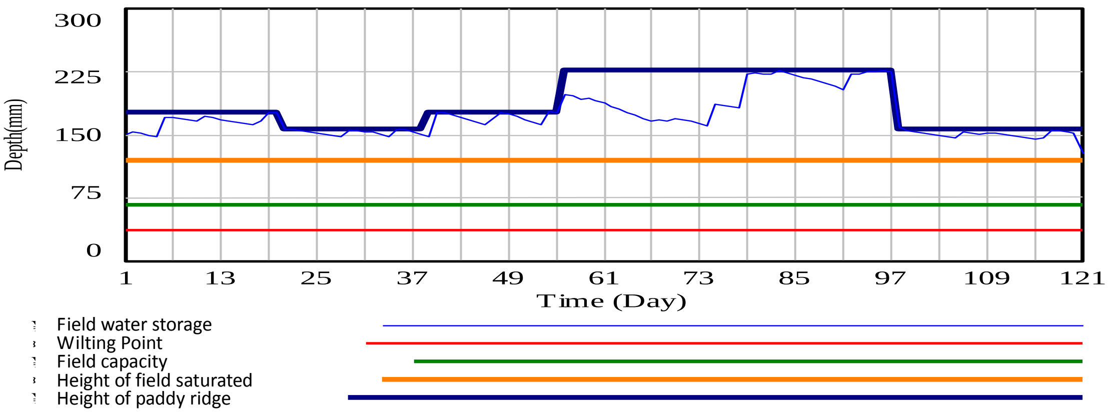

Figure 11. The average field water depth with pond irrigation(first crop)

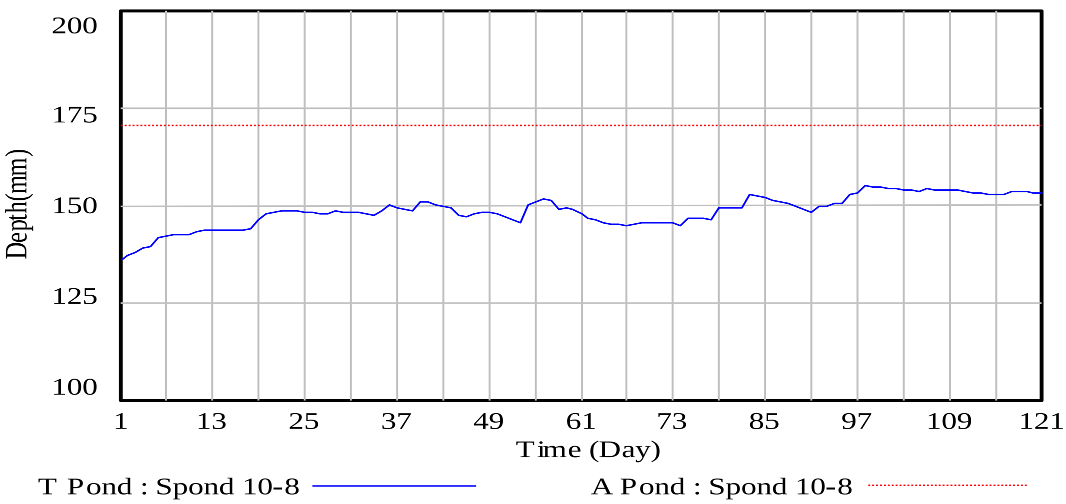

Figure 12. The water level of pond storage (first crop)

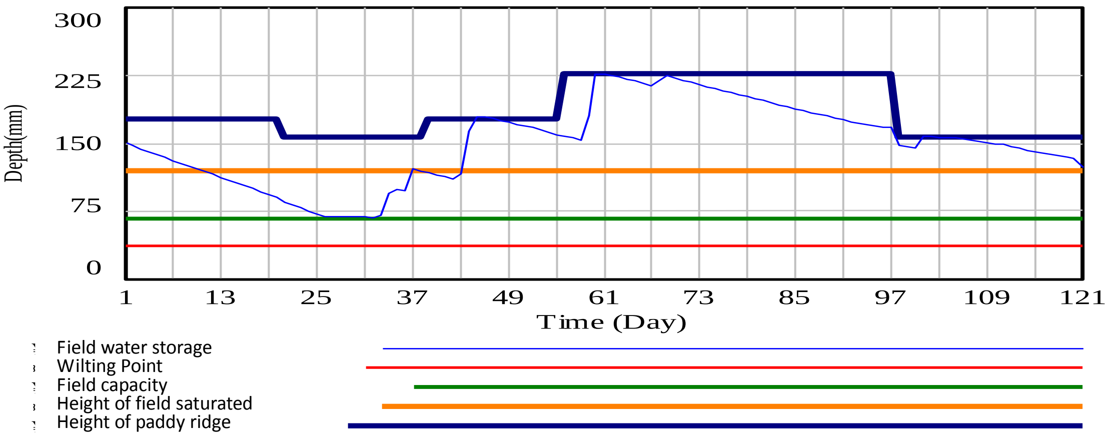

Figure 13. The average field water depth with pond irrigation(second crop)

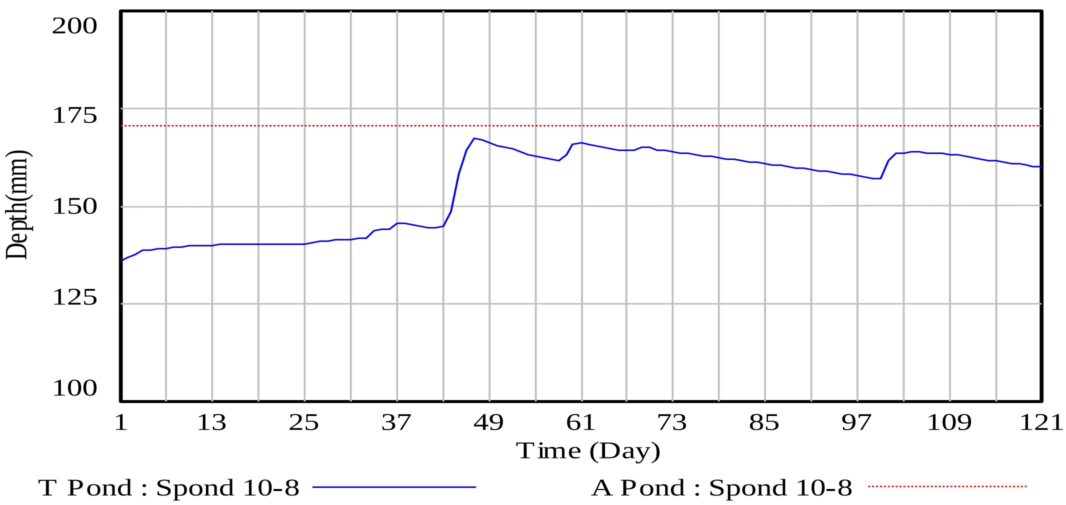

Figure 14. The level of pond storage (second crop)

CONCLUSIONS

This research investigated into the influence of irrigation water requirement with the irrigation operation including channel supply, wire supply and pond supply. Taoyuan Channel #2 Feeder in North Taiwan was selected as the study area. The agriculture irrigation system model was established by adapting Vensim model and the irrigation water supply data in 2008 was applied.

The simulation result showed that outflow occurred with two main parameters: rainfall, when rainfall is big enough, outflow can be happen; otherwise is paddy ridge changed. The rate of outflow in second crop is higher than that in first crop. The rainfall is hard to store in fields due to typhoon or torrential rainfall and usually happened in second crop. Adding the pond irrigation system into the agricultural irrigation system can afforded more water for paddy field and be an importance role at water shortage stage which has no rainfall. The pond irrigation system improved stable irrigation and saving the water from rainfall for irrigation.

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