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A MODEL OF RETURN FLOW RECOVERY SYSTEM IN PADDY FIELD BASE ON GIS

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Key words: return flow, water reuse, paddy field, GIS.

ABSTRACT

In this study, return flow in a paddy field was simulated in order to supply reuse water to industries. Field experiment and historical data were obtained for a two-tank model parameter estimation and verification. The selected boundary of paddy fields was identified based on GIS. The simulation results showed that the reasonable reuse flow rate corresponding to the area of 6,036 ha in the first crop season and 1,994 ha in the second crop season. The volumes of the return flow and reuse water are 18.74×10^6 and 15.52×10^6 t, respectively. However, the pattern of rainfall, active capacity of the pond, and rate of water treatment restricted the amount of reuse water. An increase in the height of field's bunds, active capacity of pond, and scale of purification unit will aid in the development of water reuse systems around paddy fields.

I. INTRODUCTION

Of the total amount of water supplied to a paddy field, some part of it is lost due to evapotranspiration and some part is utilized for the growth of plants [1]. The remaining irrigation water flows downstream after infiltrating into the soil or directly flowing into adjacent drains [12]. The paddy field help maintain the quality of water [13], and higher water reuse ratio in paddy fields can reduce the net runoff to zero [11]. Therefore, water users in the downstream areas are able to utilize reuse water.

The rainfall in Taiwan is abundant; however, the rainfall distribution over time is highly uneven. Approximately 78% of the rainfall flows directly into oceans without being utilized [9]. The storage of rainwater in paddy fields by building bunds during the wet season is an efficient rainwater cistern system [7]. The water demand in urban and industrial areas is increasing and the reuse of return flow from paddy fields will help in meeting this demand.

In view of sustainable water management, reusing the return flow around paddy field can release the competition between water users. For a steady supply of water, the reuse of return flow from paddy fields should be stored in large storage reservoirs in order to regulate the irregular discharge. Since the volume of return flow increases with the area of paddy fields, drainage in paddy fields should be linked and concentrated to storage reservoirs. However, an increase in the return flow may result in floods in the downstream areas. Further, it is difficult to collect the return flow through building and linking canals on a large scale.

With regard to achieving an acceptable linking paddy fields scale, a paddy field with a natural pond with surplus active capacity in Hsin-Hua, where the irrigation office is situated, under the jurisdiction of the Chia-Nan Irrigation Association was studied. Through the simulation of return flow in the paddy field, a suitable area of the paddy field was satisfactorily estimated.

II. METHODS AND MATHERIALS

1. Methods

Fig. 1 describes the concept of water reuse from the paddy field in the industrial park, where $I(t)$ denotes the return flow rate from the paddy field at time t (m^3/10 days); $O(t)$, the water treatment rate of the purification unit (m^3/10 days); and DP_{max} and DP_{min}, the maximum and minimum water storage capacity of the pond (m^3), respectively.

During the reuse of the return flow from the paddy field in the industrial park, the water budget equation for the pond shown in Fig. 1 can be described as

$$\Delta S = S(t+1) - S(t) = I(t) + R(t) - E(t) - O(t) \qquad (1)$$

where ΔS indicates the change in the amount of water stored in the pond from t to $t + 1$; $S(t + 1)$ and $S(t)$, the amount of water stored at $t + 1$ and t (m^3), respectively; $R(t)$, the rainfall

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rate (m^3/10 days); and $E(t)$, the evaporation rate (m^3/10 days). Considering the maximum and minimum capacity of the pond, i.e., DP_{max} (m^3) and DP_{min} (m^3), respectively, $S(t+1)$ should be adjusted as given below.

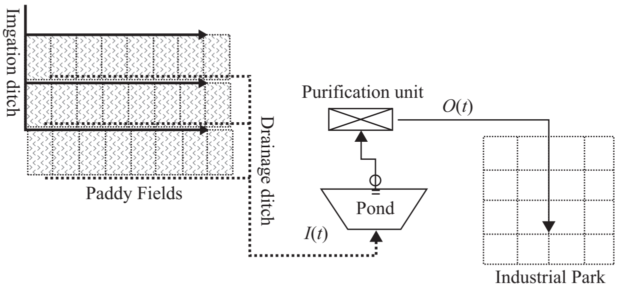

Fig. 1. Concept of water reuse from paddy fields in industrial park.

Suppose

$$S'(t+1) = S(t) + I(t) + R(t) - E(t) - O(t) \tag{2}$$

and

$$S''(t+1) = S(t) + I(t) + R(t) - E(t) - O_{wp} \tag{3}$$

where O_{wp} denotes the maximum water treatment rate of the purification unit (m^3/10 days).

Then, $S(t+1)$ and $O(t)$ can be given as

$$S(t+1) = \begin{cases} DP_{\max} & \cdots \quad S'(t+1) > DP_{\max} \\ S'(t+1) & \cdots \quad DP_{\min} < S'(t+1) < DP_{\max} \\ DP_{\min} & \cdots \quad S'(t+1) < DP_{\min} \end{cases} \tag{4}$$

$$O(t) = \begin{cases} O_{wp} & \cdots \quad S''(t+1) > DP_{\min} \\ S(t) + I(t) + R(t) - E(t) - DP_{\min} & \cdots \quad S''(t+1) < DP_{\min}, S''(t+1) + O_{wp} > DP_{\min} \\ 0 & \cdots \quad S''(t+1) < DP_{\min}, S''(t+1) + O_{wp} < DP_{\min} \end{cases} \tag{5}$$

The parameters $R(t)$, $E(t)$, DP_{max}, DP_{min}, and O_{wp} can be obtained from the investigation of the historical records [14]. Owing to the consolidation of farmlands in Taiwan, each standard lot is connected with an irrigation ditch and a drainage ditch. The return flow of each lot can be collected directly through the drainage system. Hence, the parameter $I(t)$ in Eqs. (2), (3), and (5) can be expressed as

$$I(t) = 10 \times A(t) \times Y(t) \tag{6}$$

where $A(t)$ is the irrigated area at time t (ha) and $Y(t)$ is the return flow rate per hectare (mm/10 days).

Fig. 2 shows the simulated tank model for the water budget in the wetland paddy field [3], where $ET_{crop}(t)$ denotes the evapotranspiration rate of the wetland paddy field at time t (mm/10 days); $G(t)$, the downward percolation rate (mm/10 days); i, the index corresponding to the tank ($i = 1, 2$); j, the index corresponding to the pipe on the tank ($j = 1, 2, \ldots, J$); H_L, the height of the first tank (mm); $H(i, j)$, the elevation of pipe j on tank i (mm); $h(i, t)$, the water level in tank i at time t (mm); and $F(i, t)$ and $G(i, t)$, the horizontal and vertical discharge rates, respectively, on tank i (mm/10 days).

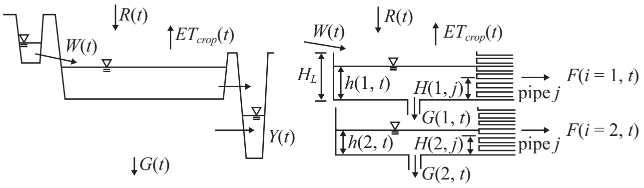

Fig. 2. Simulation of water budget in paddy field.

The parameters $Y(t)$, $F(i, t)$, and $G(i, t)$ indicated in Fig. 2 can be expressed as

$$Y(t) = \sum_{i=1}^{2} F(t,i) \tag{7}$$

$$F(i,t) = \begin{cases} \sum_{j=2}^{J} C(i,j) \times [h(i,t) - H(i,j)] + h(1,t) - H_L & \cdots \quad \text{for } i = 1 \text{ and } h(1,t) > H_L \\ \sum_{j=2}^{J} C(i,j) \times [h(i,t) - H(i,j)] & \cdots \quad \text{others} \end{cases} \tag{8}$$

$$h(i,t+1) = \begin{cases} h(1,t) + W(t+1) + R(t+1) - F(1,t) - ET_{crop}(t+1) - G(1,t) & \cdots \quad \text{for } i = 1 \\ h(2,t) + G(1,t) - F(2,t) - G(2,t) & \cdots \quad \text{for } i = 2 \end{cases} \tag{9}$$

$$h(1,t) = H_L \text{ when } h(1,t) \geq H_L \tag{10}$$

$$h(i,t) - H(i,j) = 0 \text{ when } h(i,t) \leq 0 \tag{11}$$

$$0 \leq \sum_{j=2}^{J} C(i,j) \leq 1 \tag{12}$$

where J denotes the total number of pipes on a tank and $C(i, j)$ denotes the coefficient of pipe j on tank i (/10 days). Once the parameters $C(i, j)$ and $H(i, j)$ are obtained by using the optimization techniques through the observed records of $Y(t)$, $W(t)$, $R(t)$, and $ET_{crop}(t)$ in the wetland paddy field [8], we can then simulate $Y(t)$ to determine the return flow rate for different irrigated areas $A(t)$ [10].

In order to evaluate the reasonable rate of return flow from wetland paddy field and the reuse rate of return flow considering the natural pond, we define several indices. First, the "actual return flow ratio" (*RR*) is defined as the ratio of the amount of return flow to the total amount of water used in an irrigation system. When water management system is not employed, the total amount of water used is estimated from the net amount of water required multiplied by the net area of the paddy fields in each block, which can be written as

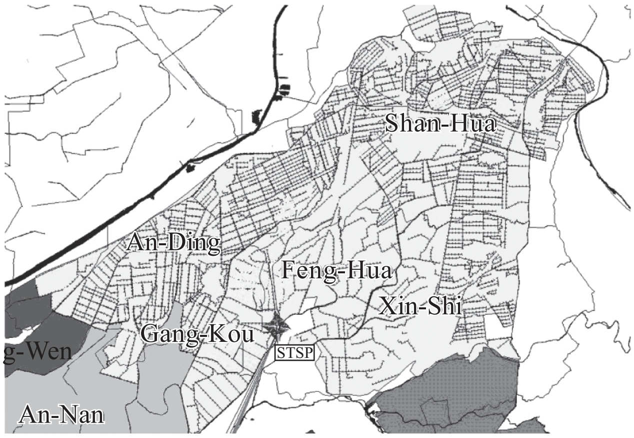

Fig. 3. District of Hsin-Hua around Southern Taiwan Science Park.

$$RR = \frac{\sum_{t=1}^{36} I(t)}{\sum_{t=1}^{36} W(t)} \times 100\% \tag{13}$$

Then, the "water reuse ratio" (*WRR*) is defined as the ratio of amount of reused water to the total amount of water used in an irrigation system, which can be written as

$$WRR = \frac{\sum_{t=1}^{36} O(t)}{\sum_{t=1}^{36} W(t)} \times 100\% \tag{14}$$

Finally, the "water supplementary ratio" (*WSR*) is defined as the ratio of the amount of reused water to the total water required in the industrial park, which can be written as

$$WSR = \frac{\sum_{t=1}^{36} O(t)}{\sum_{t=1}^{36} O_{wn}(t)} \times 100\% \tag{15}$$

where $O_{wn}(t)$ denotes the amount of water required in the industrial park at time t.

2. Materials

Fig. 3 shows the map of Southern Taiwan Science Park (STSP) surrounded by Hsin-Hua Irrigation Office (HHIO) under the jurisdiction of the Chia-Nan Irrigation Association. The area of HHIO is approximately 33,600 ha and the soil is almost loamy which has a subtropical climate with average temperature of 21-24°C and an annual average rainfall of 1,600 mm; 80% of the total rainfall is received in the wet season from May to September [5].

The lengths of drainage canals of HHIO are presented in Table 1 which collected the drainage discharge of 9 working groups.

Table 1. Lengths of drainage of Working Groups locate near STSP.

Location	Working Group	Irrigation Area (ha)	Subtotal Area (ha)	Length of Drainage (m)	Subtotal Drainage (m)
UP	Shan-Hua	3,694	9,738	162,031	769,364
	An-Ding	1,756		123,905	
	Gang-Kou	1,522		331,579	
	Feng-Hua	1,246		53,937	
	Xin-Shi	1,520		97,912	
DOWN	An-Nan	2,797	10,655	141,344	455,724
	Xin-Hua	2,593		179,613	
	Gui-Ren	2,764		79,715	
	Gong-Wen	2,500		55,052	

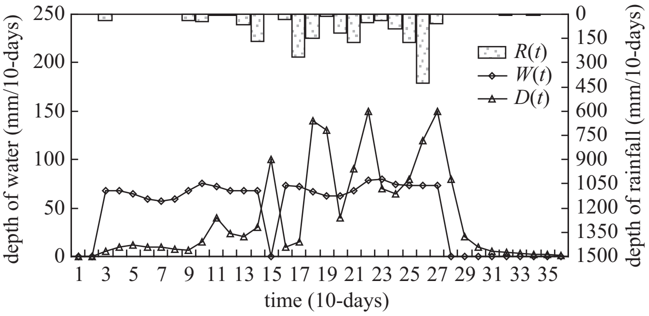

Fig. 4. Plot of average rainfall, average amount of irrigation water, and average amount of drainage discharge.

The area of STSP is approximately 1,038 ha and the amount of water required is approximately 200,000 t/day. The average rate of water treatment of the purification unit is 86,000 t/day in STSP. For flood control, detention ponds with a capacity of 1,040,000 t have been constructed, which are used as regulating reservoirs in the rainy season [4]. The main water source was planed to supply by reusing the return flow in the paddy field of HHIO.

The experimental tertiary unit, located in the area of HHIO is approximately 52 ha, irrigation water has been diverted from the Wushantou Reservoir through irrigation system. A rain gauge and a U.S. Weather Bureau Class A Land Pan were installed to record the rainfall and evaporation, respectively. The evapotranspiration was estimated using the crop coefficients recommended by FAO [6]. Standard 90° V-notch weirs were placed to measure the irrigation water and drainage discharge. Fig. 4 shows the average amount of irrigation water $W(t)$, average rainfall $R(t)$, and average amount of drainage discharge $D(t)$ from 2004 to 2006. The average annual depth of irrigation water is 1,655 mm, and the average annual depth of drainage discharge is 1,477 mm.

Table 2. Values of parameter of tanks used in simulations.

Pipe *j*	Elevation of pipe *j* $H(i, j)$	Pipe coefficient $C(i, j)$	
		First tank	Second tank
1	0	0.174	0.04
2	20	0.04368	0.07
3	40	0.04908	0.18
4	60	0.03677	0.19
5	80	0.02542	0.09
6	100	0.02452	0.07
7	125	0.02373	0.06
8	150	0.02319	-
9	175	0.02277	-
10	200	0.02246	-
11	225	0.0222	-
12	250	0.022	-
13	275	0.02183	-
14	300	0.21	-
15	0	0.3	0.3

III. RESULTS AND DISCUSSIONS

1. Calibration of Parameters in Two-Tank Model

On the basis of the observed records for the period 2004-2006 in experiment, the parameters $C(i, j)$ and $H(i, j)$ can be determined by nonlinear programming. The root mean square error (RMSE) in $Y(t)$ and $D(t)$ can attain the minimum value of 1.25. The parameters $C(i, j)$ and $H(i, j)$ used in the simulations are presented in Table 2. The pipe coefficient of the first tank will attain the maximum value near the ground, while that of the second tank will attain the maximum value at the elevation of 40-60 mm. With the estimated parameters, the two-tank model is now ready for the simulations.

2. Simulation of Return Flow in Paddy Fields

Fig. 5 shows both the simulated and actual drainage discharge, $Y(t)$ and $D(t)$, respectively. The simulated drainage shows a good agreement with the actual drainage according to the root mean square error (RMSE). The peaks of the simulated drainage are slightly higher then those of the actual drainage.

Fig. 6 shows both the simulated drainage discharge and downward percolation, $Y(t)$ and $G(t)$, respectively. The amount of simulated drainage discharge was the triple that of the downward percolation. The peaks of simulated drainage and downward percolation appear at the same time.

3. Estimation of Acceptable Linking Paddy Fields Scale

In order to find acceptable linking paddy fields scale, the *RR*, *WRR*, and *WSR* were calculated for an irrigated area of 600-9000 ha. The *RR* simulated using the two-tank model in the second crop season (35.66%) was higher than that in the first crop season (11.56%). The difference may be due to the heavy rainfall in the second crop season.

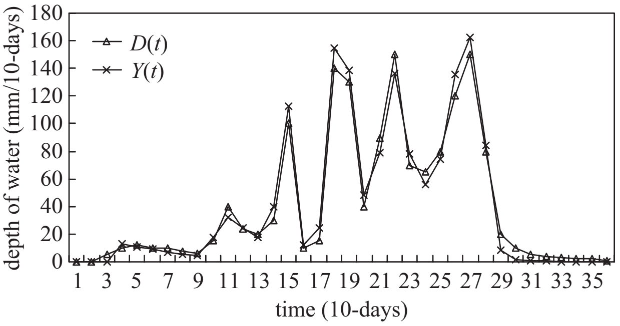

Fig. 5. Simulated and actual drainage discharge.

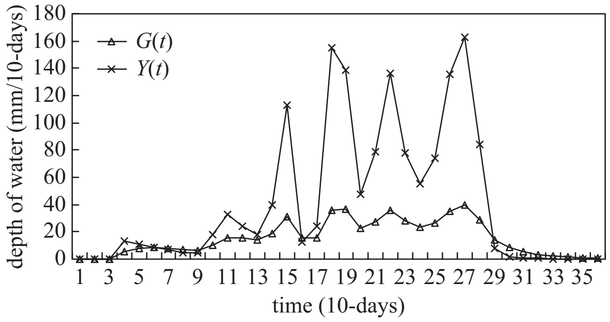

Fig. 6. Simulated drainage discharge and downward percolation.

Figs. 7 and 8 show the *WRR* and *WSR* varied in the simulated irrigated area in the first and the second crop seasons. Within the simulated irrigated area in the first crop season, the *WSR* increases rapidly from 671 to 6,036 ha and moderately after 6,036 ha. The *WRR* increases slightly from 671 to 2,012 and decreases after 6,036 ha. Although the increase in the area can deliver more water into the water distribution system of the industrial park, the active capacity of the pond and the water treatment rate of the purification unit still restrict the volume of reuse water. For increasing the volume of reuse water from the return flow, the area of paddy field that should be linked and collected through canals should be 6,036 ha in the first crop season. In the simulated irrigated area in the second crop season, the *WRR* decreases rapidly after 1,330 ha, as shown in Fig. 8. The *WSR* increases from 665 to 1,994 ha and is constant after 1,994 ha. Consider that the rainfall is heavy in the second crop season; an increase in the return flow may cause floods in the downstream area. The acceptable linking paddy fields scale should not exceed 1,994 ha in the second crop season.

Fig. 9 shows the reasonable reuse flow rate corresponding to the area of 6,036 ha in the first crop season and 1,994 ha in the second crop season. Considering the active capacity of the natural pond and the water treatment rate of the purification unit, the *RR*, *WRR*, and *WSR* are 21.56%, 21.38%, and 17.14%, respectively. The volumes of the return flow and reuse water are 18.74×10^6 and 15.52×10^6 t, respectively. Return flow of an amount of 3.2×10^6 t still cannot be reused appropriately.

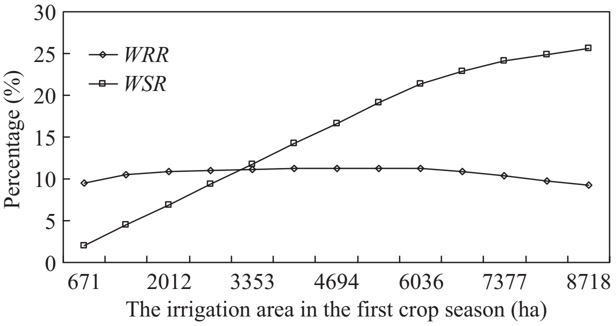

Fig. 7. ***WRR* and *WSR* in first crop season.**

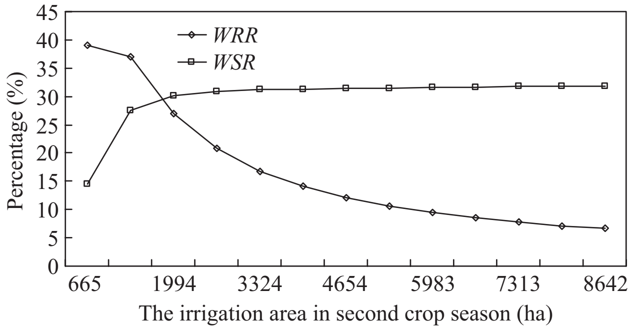

Fig. 8. ***WRR* and *WSR* in second crop season.**

Fig. 10 shows the selected paddy and drainage canals should be linked based on GIS through tracing the paddy field along drainage canal and accumulating the area amount to upward acceptable linking fields scale. The accumulate length of drainage canals are 607 km in the first crop season and 152 km in the second crop season. Since the irrigation scheme were practiced according to the boundary of working group which is indivisible, so the return flow reuse strategies should apply on the district of An-Ding, Gang-Kou, Feng-Hua and Xin-Shi in the first crop season and Feng-Hua and Xin-Shi in the second crop season. The strategies including separating the return flow from other land use drainage and constructing the linking canal between drainage canals.

IV. SUMMARY AND CONCLUSIONS

Due to limited land resources, the industries are forced to compete with agriculture in Taiwan. In the wake of a large industrial park being developed, the water shortage has become a critical issue in the local areas. The paddy fields help maintain the quality of water and are effective rainwater cistern systems. Linking up a water reuse system in paddy fields can aid in meeting the water requirements of industries. Through the experiment and two-tank model, a reasonable return flow rate from the paddy field was determined in this study. The simulated results were in a good agreement with the historical data. However, the pattern of rainfall, active capacity of the pond, and rate of water treatment restricted the volume of reuse water and resulted in low values of *WRR* and *WSR*. Enhancing the water storage capacity in paddy fields through deepwater practice [2], increasing the active capacity of ponds by dredging before the rainy season, and constructing purification units on a large scale will aid in the development of water reuse systems. This can be used to meet the water requirements of industries.

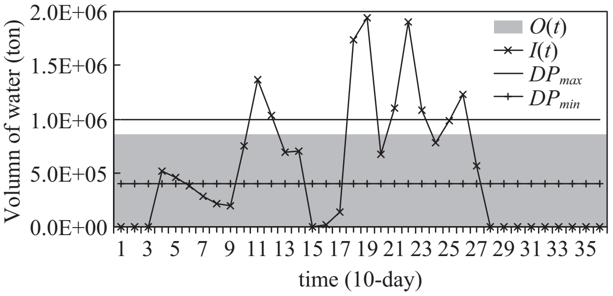

Fig. 9. Reasonable reuse flow rate and water treatment rate.

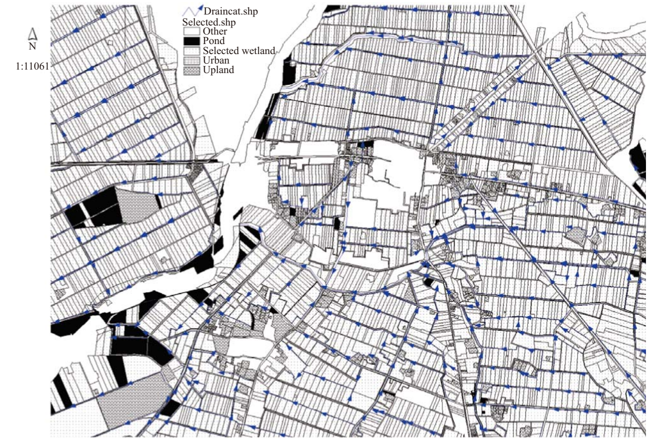

Fig. 10. Selected paddy fields for water reuse system based on GIS.

REFERENCES

1. Brouwer, C. and Heibloem, M., "Irrigation water needs," *Irrigation Water Management Training Manual*, No. 3, FAO, Rome, Italy (1986).
2. Chang, Y. C., Kan, C. E., Chen, C. T., and Kuo, S. F., "Enhancement of water storage capacity in wetland rice fields through deepwater management practice," *Irrigation and Drainage*, Vol. 56, pp. 79-86 (2007).
3. Chang, Y. C., Kan, C. E., Lin, G. F., Chiu, C. L., and Lee, Y. C., "Potential benefits of increased application of water to paddy fields in Taiwan," *Hydrological Processes*, Vol. 15, pp. 1515-1524 (2001).
4. Chen, C. N., Tsai, C. H., and Tsai, C. T., "Analysis on effect of detention-pond on reduction of flooding potential around the Tainan Scientific Base Industrial Park," *Journal of Chinese Institute of Civil and Hydraulic Engineering*, Vol. 19, No. 2, pp 189-198 (2007).
5. Chia-Nan Irrigation Association, *Study on Regional Optimal Allocation of Water Resource in the Area of Chia-nan Irrigation Association*, Wei-Qian Foundation, p. 94 (2002).
6. Doorenbos, J., "Guidelines for predicting crop water requirements," *FAO Irrigation and Drainage paper 24*, FAO, Rome, p. 141 (1977).
7. Hayase, Y., "Evaluation of paddy fields for flood control and a proposal of their enhancing project," *Journal of the Japanese Society of Irrigation*

Drainage and Reclamation Engineering, Vol. 62, No. 10, pp. 943-948 (1994).

8. Hayase, Y., Koseki, K., Waitriyeunyon, W., and Buddhapalit, A., “Development of hydrological information system in the upper Chao Phraya ricer basin,” *International Conference on Water Resources and Environment Research*, Kyoto, pp. 611-618 (1996).
9. Kuo, C. H., “Irrigation in Taiwan,” *Proceedings of the Sino-Japanese Workshop on Agricultural Engineering*, Taipei, Taiwan, pp. 1-5 (1994).
10. Mizutani, M., Hasagawa, S., Koga, K., Goto, A., and Murty, V. V. N., *Advanced Paddy Field Engineering*, The Japanese Society of Irrigation, Drainage and Reclamation Engineering (JSIDRE), p. 170 (1999).
11. National Institute for Rural Engineering, “Model analysis of runoff load reduction from paddy fields through recycling irrigation,” *National Institute for Rural Engineering*, Vol. 24, pp. 1-2 (2004).
12. Satoh, M. and Goto, A., “Water reuse system,” *Advanced Paddy Field Engineering*, The Japanese Society of Irrigation, Drainage and Reclamation Engineering (JSIDRE), pp. 149-173 (1999).
13. Sekiya, S., *Functions of Paddy Fields*, Ie No Hika Association, Tokyo, p. 644 (1992).
14. Taiwan Joint Irrigation Association, *Series of Taiwan Irrigation Association Report*, Taiwan Joint Irrigation Association, Taiwan, pp. 1-5 (2007).