# A Water Reuse System in Wetland Paddy Supports the Growing Industrial Water Needs

Yu-Chuan Chang, and Chen Shi-Kai



***Abstract*—**A water reuse system in wetland paddy was simulated to supply water for industrial in this paper. A two-tank model was employed to represent the return flow of the wetland paddy. Historical data were performed for parameter estimation and model verification. With parameters estimated from the data, the model was then used to simulate a reasonable return flow rate from the wetland paddy. The simulation results show that the return flow ratio was 11.56% in the first crop season and 35.66% in the second crop season individually; the difference may result from the heavy rainfall in the second crop season. Under the existent pond with surplus active capacity, the water reuse ratio was 17.14%, and the water supplementary ratio was 21.56%. However, the pattern of rainfall, the active capacity of the pond, and the rate of water treatment limit the volume of reuse water. Increasing the irrigation water, dredging the depth of pond before rainy season and enlarging the scale of module are help to develop water reuse system to support for the industrial water use around wetland paddy.

***Keywords*—**Return flow, water reuse, wetland paddy, return flow ratio (*RR*), water reuse ratio (*WRR*), water supplementary ratio*(WSR).*

## I. INTRODUCTION

NET water consumption in wetland paddy irrigation takes place in evapotranspiration $ET_{crop}(t)$ and the growth of plant bodies [7]. The other part of the irrigated water moves downstream after infiltrating into the soil or flowing directly into the adjacent drain [11]. The wetland paddy has a buffer function for water quality [9], and higher water reuse ratio in wetland paddys can reduce the net runoff load to zero [10]. Therefore, the water users in downstream areas have the opportunity to reuse the water.

Rainfall in Taiwan is abundant, but has a very uneven distribution over time. About 78% of the rainfall runs directly to the ocean without being utilized [8]. The storage of rainfall in wetland paddy by the bunds is like an effective rainwater cistern system during the wet season [5]. Since the water need in urban and industrial water use are growing, exploit reuse water from wetland paddy to provide the dramatic increase is critical.

For supplying a steady water resource, reuse the return flow from wetland paddy needs a large storage capacity to regulate the unstable discharge. Since the volume of return flow will increase with the area of paddy fields, the wetland paddy should be linked and collected through canal in large area. But the problems are a surcharge return flow may result in flood in downstream, and it is hard to concentrate through link canal in large scale.

In respect of delivering a reasonable return flow rate from wetland paddy under the existent pond with surplus active capacity, the Hsin-Hua irrigation office district under the jurisdiction of the Chia-Nan Irrigation Association was investigated. Through the simulation of return flow in wetland paddy, the suitable area of wetland paddy was reasonable estimated.

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## II. METHOD AND MATERIALS

### A. Methods

Fig. 1 describes the concept of water reuse between wetland paddy and industrial park, in which *I(t)* was the return flow rate from wetland paddy at time *t* ($m^3$ 10-days$^{-1}$); *O(t)* was the water treatment rate of purification unit ($m^3$ 10-days$^{-1}$); $DP_{max}$ was the maximum water storage of pond ($m^3$) and $DP_{min}$ was the minimum water storage of pond ($m^3$).

During the period of supplying water to industrial park through reusing return flow from wetland paddy, the water budget equation for the pond in Figure 1 can be described as

$$\Delta S = S(t+1) - S(t) = I(t) + R(t) - E(t) - O(t) \tag{1}$$

in which $\Delta S$ was the change in water storage in the pond from *t* to *t+1*, *S(t+1)* was the water storage at *t+1* ($m^3$), *S(t)* was the water storage at *t* ($m^3$), *R(t)* was the rainfall rate ($m^3$ 10-days$^{-1}$) and *E(t)* was the evaporation rate ($m^3$ 10-days$^{-1}$). Considered the maximum volume of pond $DP_{\max}$ ($m^3$) and the minimum volume of pond $DP_{\min}$ ($m^3$), the *S(t+1)* should be adjusted as follow.

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 $O_{wp}$ was the maximum water treatment rate in purification unit ($m^3$ 10-days$^{-1}$). *S(t+1)* and *O(t)* can written further 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 terms *R(t)* , *E(t)*, $DP_{max}$, $DP_{min}$ and $O_{wp}$ can be obtained from the investigation of the records. Owing to the consolidation of farm land in Taiwan, each standard lot connects with the irrigation ditch and drainage ditch. The return flow of each lot can be collect directly through drainage system. So the term *I(t)* in Equations (2), (3) and (5) can be expressed as

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

in which *A(t)* was the irrigation area at time *t* (ha), and *Y(t)* was the return flow rate per hectare (mm 10-day$^{-1}$).

Fig. 2 describes a two-tanks model simulate the water budget in wetland paddy [1], in which $ET_{crop}(t)$ was the evapotrnaspiratin rate of wetland paddy at time *t* (mm 10-day$^{-1}$), *G(t)* was the rate of downward percolation (mm 10-day$^{-1}$). *i* was the index corresponding to the tank (*i*=1,2), *j* was the index corresponding to the pipe on a tank (*j*=1,2,…,*J*), $H_L$ was the height of the first tank (mm), *H(i, j)* was the elevation of pipe *j* on tank *i* (mm), *h(i, t)* was the water level in tank *i* at time *t* (mm). *F(i, t)* was the horizontal discharge rater on tank *i* (mm 10-day$^{-1}$),and *G(i, t)* was the vertical discharge rater on tank *i* (mm 10-day$^{-1}$).

The terms *Y(t)*, *F(i,t)* and *G(i,t)* in Fig. 2 can be expressed as

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

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

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

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

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

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

in which *J* was the total number of pipes on a tank, and *C(i, j)* was the coefficient of pipe *j* on tank *i* (10-day$^{-1}$). Once the parameters *C(i, j)* and *H(i, j)* were solved using optimization techniques through historical records *Y(t)*, *W(t)*, *R(t)* and $ET_{crop}(t)$ in wetland paddy [6], we can then simulate *Y(t)* to find out the return flow rate from different irrigation area *A(t)*.

In order to evaluate the reasonable rate of return flow from wetland paddy and the reuse rate of return flow under existent pond, we applied several index below. First, the 'actual return flow ratio' (*RR*) was defined as the ratio of return water to the total water used in an irrigation system. When system management water was not included, the total used water was estimated as the sum of the water requirement multiplied by the area of paddy fields in each block, which can be written as

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

Furthermore, the 'water reuse ratio' (*WRR*) was defined as the ratio of reused water to the total 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*) was defined as the ratio of reused water to the total water need in Industrial Park, which can be written as

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

in which $O_{wn}(t)$ was the water need in Industrial Park at time *t*.

### B. Materials

The management area of Chia-Nan Irrigation Association location in the south-western part of Taiwan, covering Chia-Yi Hsien, Chia-Yi city, Tai-Nan Hsien, and Tai-Nan city which was bounded by the Taiwan central mountain range to the east, the Pei-Kang river to the north, the Erh-Jen river to the south and the Taiwan strait to the west, The climate of this area was sub-tropical with on average temperature of 21-24 $^{o}$C and annual Average rainfall of 1,600 mm which 80% of total concentrated in the wet season from May to September [2].

Fig. 3 shows the Southern Taiwan Science Park (STSP) was surrounded by the Hsin-Hua irrigation office district under the jurisdiction of the Chia-Nan Irrigation Association. The area of STSP was approximately 1,038 hectares and the water need was about 200 thousand ton per day. The average rate of water treatment in purification unit was 86 thousand ton per day in STSP. Considered flood control, the detention ponds with capacity 1,040 thousand ton was constructed, which was utilized as a regulating reservoir in rainy season [4].

In the area of Hsin-Hua irrigation office, irrigation water was diverted from WuShanTou reservoir through several irrigation systems. The area was approximately 33,600 hectares and the soil was almost sandy loam. Fig. 4 shows the average irrigation water *W(t)*, the average rainfall *R(t)*, and average drainage discharge *D(t)* from 1997 to 2006 [13]. The annual depth of average irrigation water was 1655 mm, and the annual depth of average drainage discharge was 1477 mm.

## III. Results and Discussions

### A. Calibrated the Parameters in Two-Tank Model

Based on the records in the Hsin-Hua irrigation office from 1997 to 2006, the parameters *C(i, j)* and *H(i, j)* can be determined using non-linear programming. The root mean square error (RMSE) between *Y(t)* and *D(t)* can achieves the minimum value 1.25, and the parameters *C(i, j)* and *H(i, j)* used in the simulations were presented in Table I. The pipe coefficient of the first tank will reach the maximum near the ground, and the pipe coefficient of the second tank will reach the maximum on the elevation of pipes at 40 mm to 60 mm. With the estimated parameters, the two-tank model was now ready for simulations.

### B. Simulated the Return Flow in Wetland Paddy

Fig. 5 shows both the simulated and actual historical drainage discharge, *Y(t)* and *D(t)*. The simulation drainage was good agreement with the actual data. The peaks of the simulated drainage were almost higher then actual drainage.

Fig. 6 shows both the simulated drainage discharge and downward percolation, *Y(t)* and *G(t)*. The volume of simulated drainage discharge was the triple of the volume of downward percolation. The peaks of simulated drainage and downward percolation occur in the same time.

### C. Estimated Return Flow Ratio (RR), Water Reuse Ratio (WRR), and Water Supplementary Ratio (WSR) in Irrigation Area

In order to find a reasonable return flow rate, the *RR*, *WRR*, and *WSR* were calculated at the range of irrigation area from 671 to 8,718 hectares in the first crop season and 665 to 8,642 hectares in the second crop season. The *RR* simulated by two-tank model in the second crop season (35.66%) was larger then in the first crop season (11.56%). The difference may be explained by examining the rainfall always results in overflow in the second crop season.

Figs. 7 and 8 show the *WRR* and *WSR* varied with the simulated irrigation area in the first and the second crop season. Within the simulated irrigation area in the first crop season, the *WSR* increases steeply from 671 to 6,036 hectares and moderate after 6,036 hectares. The *WRR* increases slightly from 671 to 2,012 and decreases after 6,036 hectares. Although the increase of the area can deliver more water into the water distribution system of industrial park, the active capacity of the pond and the water treatment rate of purification unit still limit the volume of reuse water. For reusing more water from return flow, the area of paddy field should be linked and collected through canal was 6,036 hectares. Within the simulated irrigation area in the second crop season, the *WRR* decreases steeply after 1,330 hectares in Fig. 8. The *WSR* increases from 665 to 1,994 hectares and moderate after 1,994 hectares. Consider the rainfall was heavy in the second crop season, an excess of return flow may cause flood in downstream. The suitable area can be linked and collected shouldn't larger than 1,994 hectares.

Fig. 9 shows the reasonable reuse flow rate corresponding with the area of 6,036 hectares in the first crop season and 1,994 hectares in the second crop season. Under the active capacity of existent pond and the water treatment rate in purification unit, the *RR* was 21.38%, the *WRR* was 17.14%, and the *WSR* was 21.56%. The volume of return flow was 18.74 million ton, and the volume of reuse water was 15.52 million ton. There still have the return flow of 3.2 million ton can't be reuse timely.

## IV. Summary and Conclusion

Limited land resources force the industrial development has to compete with the agricultural land use in Taiwan. In the wake of the large-scale industrial park developed, the water shortage was critical in local area. The wetland paddy has a buffer function for water quality and quantity is like an effective rainwater cistern system. Linking up a water reuse system in wetland paddy can support the even more water need for industrial use. Through the historical data and two-tank model, a reasonable return flow rate from the paddy field was determined in this paper. The simulated results were in good agreement with other historical data [12]. However, the pattern of rainfall, the active capacity of the pond, and the rate of water treatment limit the volume of reuse water and result in low ratio of *WRR* and *WSR*. Enhancing the water storage capacity in wetland paddy through deepwater management practice [3], increasing the active capacity of pond through dredging before rainy season, and constructing the purification unit in large scale module were help to develop the water reuse system to support the industrial water need in wetland paddy.

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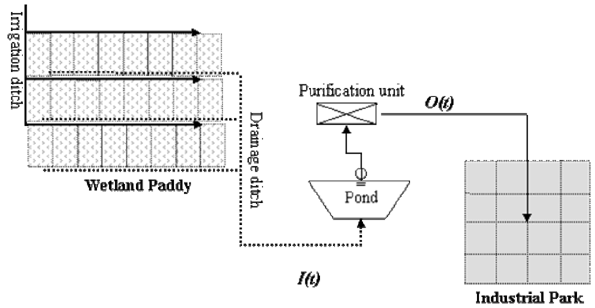


Fig. 1 The concept of water reuse between wetland paddy and industrial park

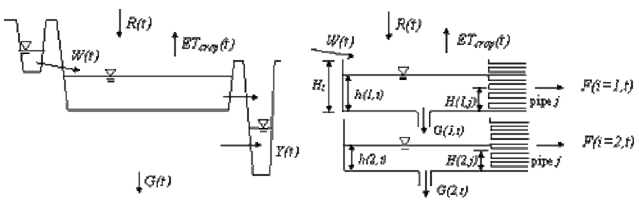


Fig. 2 Simulation of water budget in wetland paddy

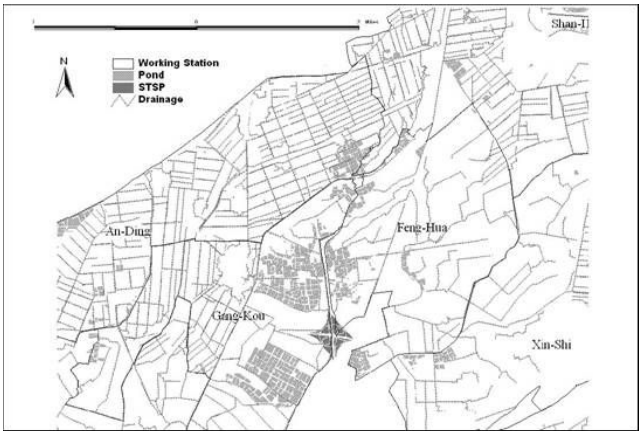


Fig. 3 The district of Hsin-Hua irrigation office around the Southern Taiwan Science Park (STSP)

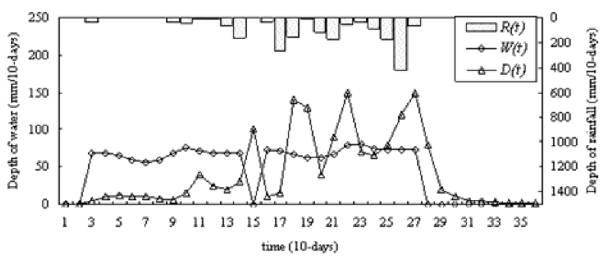


Fig. 4 The average rainfall, average irrigation water and average drainage discharge

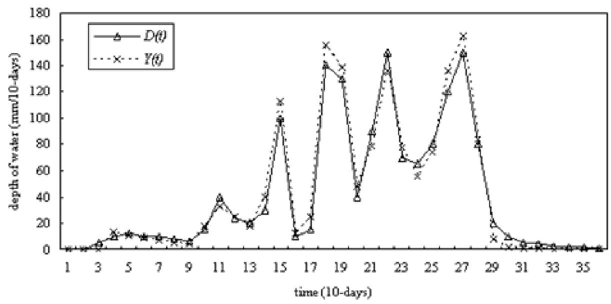


Fig. 5 The simulated and actual drainage discharge

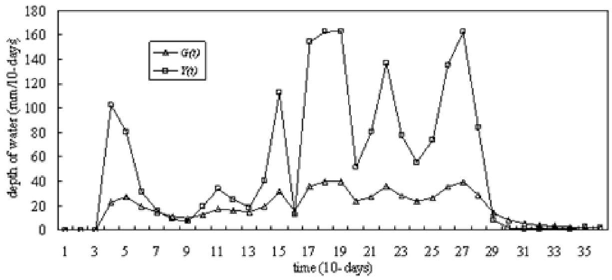


Fig. 6 The simulated drainage discharge and downward percolation, *Y(t)* and *G(t)*

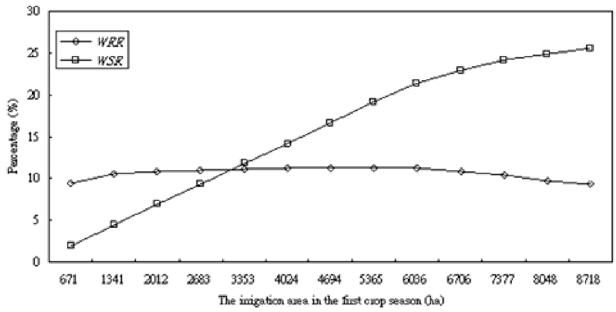


Fig. 7 The *WRR* and *WSR* in the first crop season

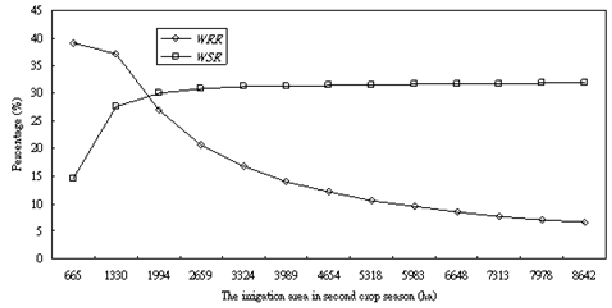


Fig. 8 The *WRR* and *WSR* in the second crop season

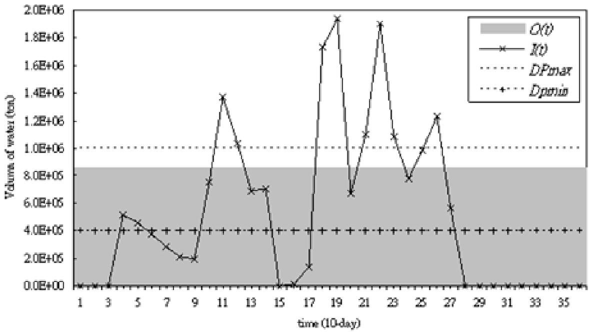


Fig. 9 The reasonable reuse flow rate and the water treatment rate