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ARTICLE

The reasonable scale of water reuse system in irrigation area: a case study of Chitong irrigation district in Taiwan

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Abstract The aim of this study is to assess the potential of the irrigation return-flow in a water reuse system, for the supply of other local water users. Both field survey and water-budget analysis were conducted, and the Chitong irrigation district in Taiwan was selected as the case study area. The results indicate that through the regulation of a pond with the effective capacity of 20,000 m^3, a stable supply of 10,000 CMD of reuse water can be generated if the return-flow from the irrigation area of 200 hectares, which is about the size of a rotation plot, is intercepted. However, as the irrigation and effective rainfall are low from December to March, which are considered high risk for water supply, the irrigation return-flow decreases accordingly, and a series of responding measures are also suggested.

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Introduction

Despite the increase in water demand in agricultural and non-agricultural sectors, the construction of large-scale dams has become more difficult. As a result, how to increase the efficiency of existing irrigation systems has drawn much attention recently. A growing concern about water reuse has been studied in Taiwan and in other countries (Barker 1995). In order to develop a stable and effective water reuse system, the availability of return-flow in terms of quantity and quality should be surveyed. In particular, the features and layout of the facilities, as well as the operation and management systems, should be studied.

Agriculture in Taiwan is based primarily upon rice paddy, which requires considerable amount of water for irrigation. After developing for hundreds of years, the water storage and distribution systems have been well established (Chang et al. 2007). In the mean time, the irrigation return-flow, which is a product out of irrigation, has become a targeted auxiliary water source in recent years due to its stability in quantity, controllability in quality, and less cost in treatment. However, the reuse of the irrigation return-flow is constrained by factors such as geography, topography, as well as locations. As a result, the utilization of return-flow is restricted mostly in the agriculture sector, and is not easy to be adopted by other sectors.

Based on the Integrated Water Resources Management Program of Taiwan, the average amount of total return-flow in the irrigation area of Taiwan during 1997–2001 was estimated to be 2.79 billion tons, while the return rate was 24.4%. Among the 2.79 billion tons of return-flow, there were 2.14 billion tons of traditional agricultural return-flow which was

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repeatedly used as the irrigation water, and the remaining 0.65 billion tons of reusable return-flow was available (Taiwan WRA (Water Resources Agency) 2008; Taiwan AERC (Agricultural Engineering Research Centre) 2008).

Until recently, in an attempt to meet various regional water demands by establishing a mechanism on the reuse of return-flow for various local sectors, experts and scholars have prompted different ideas for the increase of return-flow in irrigation areas (Friend and Coutts 2006; Hayase and Kadoya 1993; Hayase 1994; Oad et al. 1997; Satoh and Okamoto 1985; National Institute for Rural Engineering (NIRE) 2004). This mechanism is to be achieved by enhancing water efficiency while no large water resources development projects are to be promoted. As a result, the aim of this study is to assess the potential of return-flow reuse system in paddy fields by conducting both field survey and water-budget analysis for the supply of other local water users.

In order to fully develop the return-flow reuse system under current conditions, the irrigation district of Chitong Work Station of Yunlin Irrigation Association in southern Taiwan was chosen as the case study area, and relevant field survey and analysis were conducted in this study. For simulation models, the Tank Model (Sugawara et al. 1974; Hayase et al. 1996; Chang et al. 2001) has been commonly used in Taiwan and Japan to simulate the water budget in irrigation areas, it is thus adopted in this study to simulate the return-flow in water reuse system. Meanwhile, for the constant supply of return-flow, various water management strategies in the irrigation area would be simulated as well. And using four indices to assess the effects of these strategies, the guidelines for the water management of the reuse of return-flow were prepared.

Methods and materials

Method

The reasonable scale of water reuse system

The concept of water reuse system between irrigation area and industrial park is illustrated in Figs. 1 and 2, in which *I(t)* is the return-flow from irrigation area at time t (m^3 10-days^{-1}), *O(t)* is the outflow from pond through collecting return-flow (m^3 10-days^{-1}), DP_{max} is the maximum water storage of pond (m^3), and DP_{min} is the minimum water storage of pond (m^3). Here the unit of 10-days is used as it is a local accustomed irrigation period in Taiwan.

During the period of supplying water to industrial park through reusing return-flow, the equation for the water budget of pond, as shown in Fig. 1, can be described as

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

in which ΔS is the change in water storage in pond from t to $t+1$, $S(t+1)$ is the water storage at $t+1$ (m^3), $S(t)$ is the water storage at t (m^3), $R(t)$ is the rainfall (m^3 10-days^{-1}), and $E(t)$ is the evaporation (m^3 10-days^{-1}). Considering the active capacity of pond, the $S(t+1)$ should be adjusted as follows.

Let

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

and

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

where $S'(t+1)$ is the value of water storage in time t which can only supply *O(t)* to purification unit, $S''(t+1)$ is a value of water storage in time t which can supply the maximum water treatment discharge O_{wp} (m^3 10-days^{-1}) to purification unit. *S(t + 1)* and *O(t)* can further be written as

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

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

The terms $R(t)$, $E(t)$, DP_{max}, DP_{min}, and O_{wp} can be obtained from the survey of historical records. Owing to the consolidation of farm land in Taiwan, each standard lot is connected with both the irrigation ditch and drainage ditch. The return-flow of each lot can thus be collected directly through the drainage system, so the term $I(t)$ in Eqs. 2, 3, and 5 can be expressed as

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

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

In order for the stable supply of irrigation water, the regulation by the remaining effective capacity of the current field pond is needed. Therefore, based on the effective capacity of the current field pond while the water balance

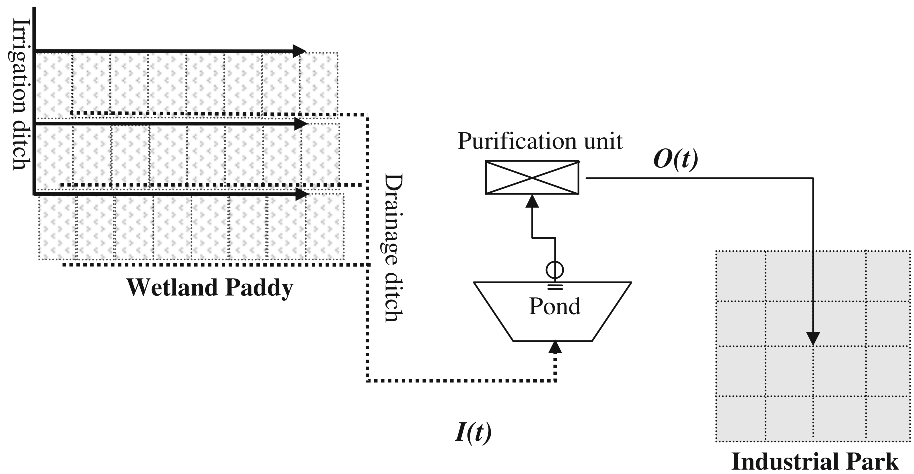

Fig. 1 Conceptual diagram of the reuse of irrigation return-flow

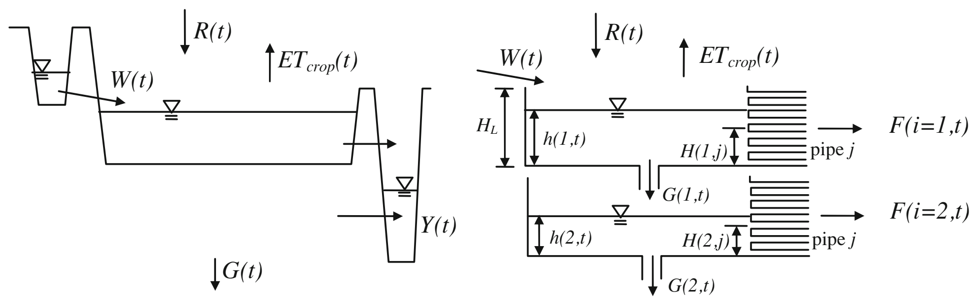

Fig. 2 Simulation of water budget in wetland paddy

equation was used under the condition that the demand for reuse water being satisfied, the appropriate area needed for the collection of irrigation return-flow is estimated, as shown in Eq. 7:

$$\sum_{t=1}^{36} O_{\mathrm{wn}}(t) \leq \sum_{t=1}^{36} \sum_{j=1}^{J} I(j,t) \tag{7}$$

where $O_{\mathrm{wn}}(t)$ is the water demand of the water users, $I(j,\ t)$ is the irrigation return-flow from different irrigation area, and j is the neighboring ditch number of the water users. Then using sensitivity analysis, the relationship between various areas and the amount of reuse water can be obtained.

The simulation of irrigation return-flow

The Modified Tank Model (Sugawara 1974; Hayase 1994) was adopted in this study to simulate the irrigation return-flow. The parameters in the model could be obtained by calibrating the field observation data versus the simulated flow with the optimal numerical model. The historical data needed include the cropping pattern of the Irrigation Association, evapotranspiration, irrigation, and field drainage. The root mean square error between the simulated flow and the field drainage was set as the objective function to estimate the optimal set of parameters using the Steepest Method, and the irrigation return-flow under various field water use conditions was simulated.

The simulation of the water budget in an irrigation area with a two-tanks model is depicted in Fig. 2 (Chang et al. 2001), in which $W(t)$ is the irrigation water of irrigation area at time t (mm 10-day^{-1}), $ET_{\mathrm{crop}}(t)$ is the evapotranspiration (mm 10-day^{-1}), $G(t)$ is vertical percolation (mm 10-day^{-1}), i is the index corresponding to the tank ($i = 1$, 2), j is the index corresponding to the pipe on a tank ($j = 1$, 2,…, J), H_{L} is the height of the first tank (mm), $H(i, j)$ is the elevation of pipe j on tank i (mm), $h(i, t)$ is the water level in tank i at time t (mm). $F(i,\ t)$ is the horizontal discharge on tank i (mm 10-day^{-1}), and $G(i,\ t)$ is the vertical discharge 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

$$Y(t) = \sum_{i=1}^{2} F(t,\ i) \tag{8}$$

$$F(i,t)=\begin{cases}\sum_{j=2}^{J} C(i,j)\times[h(i,t)-H(i,j)]+h(1,t)-H_L & \cdots \text{ for } i=1 \text{ and } h(1,t)>H_L\\ \sum_{j=2}^{J} C(i,j)\times[h(i,t)-H(i,j)] & \cdots \text{ others}\end{cases} \tag{9}$$

$$h(i,t+1)=\begin{cases}h(1,t)+W(t+1)+R(t+1)-F(1,t)-ET_{crop}(t+1)-G(1,t) & \cdots \text{ for } i=1\\ h(2,t)+G(1,t)-F(2,t)-G(2,t) & \cdots \text{ for } i=2\end{cases} \tag{10}$$

$$h(1,t)=H_L \text{ when } h(1,t)\geq H_L \tag{11}$$

$$h(i,t)-H(i,j)=0 \text{ when } h(i,t)\leq 0 \tag{12}$$

$$0\leq\sum_{j=2}^{J} C(i,j)\leq 1 \tag{13}$$

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

The water budget of the irrigation plot of rice paddies is illustrated in Fig. 3, in which $ET_{crop}(t)$ is the evapotranspiration (m/day) at time t, $D(t)$ is the surface water depth (m), B is the groundwater level (m), $P(t)$ is the vertical percolation (m/day), $S_P(t)$ is the lateral seepage (m^3/day), $R(t)$ is the rainfall (m/day), and $W(t)$ is the amount of irrigation (m/day).

In the case with no rainfall nor irrigation, i.e., $R(t)$ and $W(t)$ being zero, the water budget of the rice paddies can be expressed with the following equation:

$$-\frac{d[A\times D(t)]}{dt}=S_p(t)+A\times P(t)+A\times ET_{crop}(t) \tag{14}$$

where A is the irrigation area in hectares (ha), and $S_P(t)$ is expressed as

$$S_p(t)=nLD(t) \tag{15}$$

in which n is a coefficient related to ridge width (m/day), L is the length of the ridge over which lateral seepage occurs (m).

Substituting Eq. 15 into Eq. 14 will result in:

$$-\frac{d[AD(t)]}{dt}=nLD(t)+AK_a\frac{D(t)+B}{L_a}+AET_{crop}(t) \tag{16}$$

where K_a is the permeability coefficient (m/day), and L_a is the average distance of vertical percolation.

The solution for Eq. 16 is:

$$D(t)=[D(0)+M(t)]\exp(-tN)-M(t) \tag{17}$$

in which $D(0)$ is the initial surface water depth (m).

$$M(t)=[E_T(t)+(BK_a)/L_a]/N \tag{18}$$

$$N=(nL)/A+K_a/L_a \tag{19}$$

Under the same condition of no rainfall and irrigation with $R(t)$ and $W(t)$ being zero, and the first tank of the water budget can be expressed as:

$$\begin{aligned}-\frac{dh(1,t)}{dt}&=F(1,t)+G(1,t)+AET_{crop}(t)\\ &=C(1,1)h(1,t)+\left[\sum_{j=2}^{J}C(1,j)\right][h(1,t)-H(1,j)]\\ &+ET_{crop}(t)=\left[\sum_{j=1}^{J}C(1,j)\right]h(1,t)-\left[\sum_{j=2}^{J}C(1,j)\right]H(1,j)\\ &+ET_{crop}(t)=\alpha h(1,t)+\alpha\beta(t)\end{aligned} \tag{20}$$

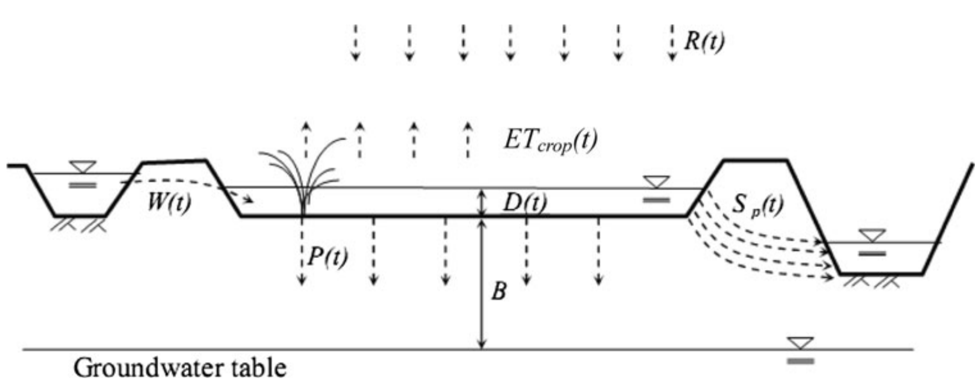

Fig. 3 Schematics of water budget components in a paddy field

where

$$\alpha = \sum_{j=1}^{J} C(1,j) \tag{21}$$

$$\beta(t) = \frac{\left[-\sum_{j=2}^{J} C(1,j)\right] H(1,j) + ET_{\mathrm{crop}}(t)}{\alpha} \tag{22}$$

And the solution for Eq. 20 is

$$h(1,t) = [h(1,0) + \beta(t)]\exp(-t\alpha) - \beta(t)\ . \tag{23}$$

Comparing Eqs. 17 and 23, it can be found that both equations have the same mathematical form. Thus, the variation of the water level of the first tank, $h(1, t)$, can be represented by the variation of the field water depth, $D(t)$, and the following relationship can be obtained from Eq. 20:

$$\left.\frac{\mathrm{d}\left[-\frac{\mathrm{d}h(1,t)}{\mathrm{d}t}\right]}{\mathrm{d}h(1,t)}\right|_{h(1,t)\leq H_{\mathrm{L}}} = \alpha = \sum_{j=1}^{J} C(1,j) = \left.\frac{\mathrm{d}\left[-\frac{\mathrm{d}D(t)}{\mathrm{d}t}\right]}{\mathrm{d}D(t)}\right|_{D(t)\leq H_{\mathrm{L}}}\ . \tag{24}$$

Consequently, the orifice coefficient of the first tank can be estimated by means of the variation of the surface water depth, as shown in Eq. 25:

$$\begin{aligned} C(1,j) &= \sum_{j=1}^{j} C(1,j) - \sum_{j=1}^{j-1} C(1,j) \\ &= \left.\frac{\mathrm{d}\left[-\frac{\mathrm{d}D(t)}{\mathrm{d}t}\right]}{\mathrm{d}D(t)}\right|_{D(t)\ <\ H(1,j+1)} - \left.\frac{\mathrm{d}\left[-\frac{\mathrm{d}D(t)}{\mathrm{d}t}\right]}{\mathrm{d}D(t)}\right|_{D(t)\ <\ H(1,j)} \end{aligned} \tag{25}$$

The reasonable reuse rate of return-flow

In order to evaluate the reasonable reuse rate of return-flow under the existing pond, several indices were applied as follows.

a. Return rate [$RR(n)$]: A ratio between irrigation return-flow and the total water used in the irrigation district, and can be expressed as:

$$RR(n) = \frac{\sum_t^T I(t)}{\sum_t^T W(t) + ER(t)} \times 100\% \tag{26}$$

where $W(t)$ is the amount of irrigation (m^3 10-days^{-1}), and $ER(t)$ is the effective rainfall (m^3 10-days^{-1}).

b. Water reuse rate [$WRR(n)$]: The ratio of the reuse water to the total water used in the irrigation district, and is expressed as:

$$WRR(n) = \frac{\sum_t^{\mathrm{T}} O(t)}{\sum_t^{\mathrm{T}} W(t) + ER(t)} \times 100\%\ . \tag{27}$$

c. Water supply rate (WSR): Ratio of the reuse water to the quantity of water treated in the water treatment plant, and can be expressed as:

$$WSR = \frac{\sum_t^{\mathrm{T}} O(t)}{\sum_t^{\mathrm{T}} O_{\mathrm{wn}}(t)} \times 100\% \tag{28}$$

where $O_{\mathrm{wn}}(t)$ is the quantity of water treated in the water treatment plant (m^3 10-days^{-1}).

d. Local water rate [$LWR(n)$]: The ratio of local water usage before and after irrigation return-flow being reused, and can be expressed as:

$$LWR(n) = \frac{\sum_t^{\mathrm{T}} W_p(t) + O_{\mathrm{wnp}}(t) - O(t)}{\sum_t^{\mathrm{T}} W(t) + O_{\mathrm{wn}}(t)} \times 100\% \tag{29}$$

where $W_{\mathrm{p}}(t)$ is the irrigation water after reusing (m^3 10-days^{-1}) and $O_{\mathrm{wnp}}(t)$ is the quantity of water treated in the water treatment plant after reusing (m^3 10-days^{-1}).

In this study, the indices mentioned above would be estimated based on field observations, historical data with relevant analysis, and the simulation of the optimum management set of water use strategies would then be carried out.

Study material

In Yunlin County (Fig. 4), agriculture and fishery used to be the major industries. However, the industrial structure has been changing dramatically since the introduction of important projects in this area, including the offshore industrial park, and the science-and-technology industrial park, etc. This change has benefited Yunlin County in terms of employment opportunities and local economy, nonetheless, agriculture still plays an important role in this area.

Current development of agriculture

The Yunlin Irrigation Association is responsible for the irrigation activities in Yunlin County. The present irrigation area of Yunlin Irrigation Association is approximately 64,807 hectares (Taiwan Joint Irrigation Association, 2006), and the main sources for the irrigation water are from Choushui River, Chingshui River, and Beigang River. The average annual rainfall ranges from 1,000 to 1,500 mm, yet rainfall occurs mostly from May to September. Due to the unstable water supply, the Irrigation Association has been trying to develop backup water resources for irrigation purposes by collecting return-flow, and extracting deep groundwater.

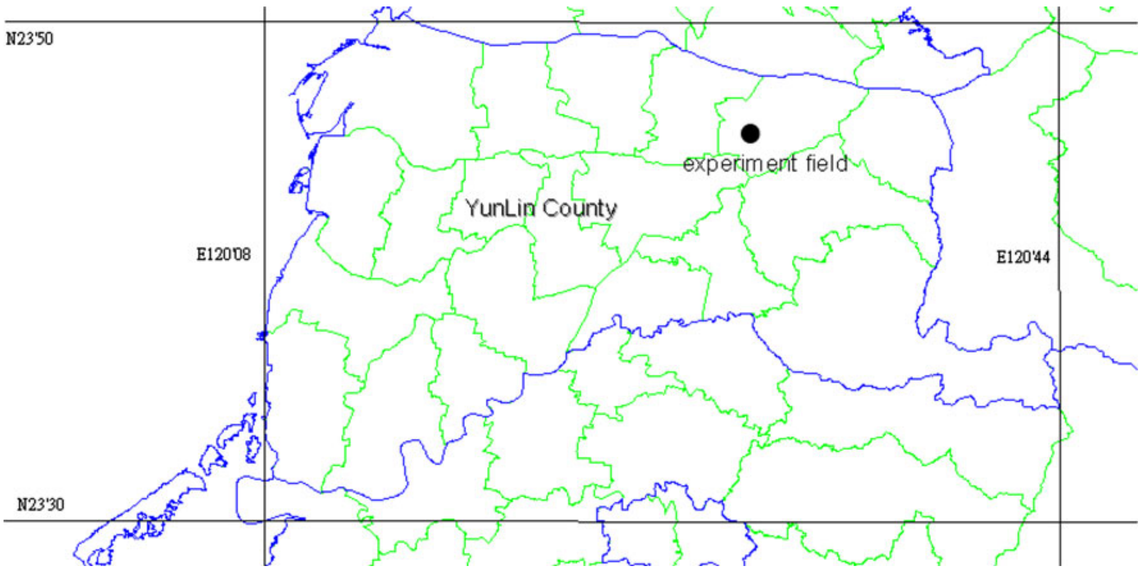

Fig. 4 The location of study area

Estimation of current agriculture return-flow in Yunlin County

The potential of agricultural return-flow in Yunlin County is expected to be high from June to October, yet shortage is very likely during November and May (Taiwan WRA (Water Resources Agency) 2008). Based on the relationship between the potential of annual agricultural return-flow and actual irrigation water in Yunlin County, the ratio of the return-flow to the irrigation water ranges approximately from 30 to 88% during June–October when there is more return-flow, and is between 0 and 50% during November to May. The trend of this distribution is similar to that of wet and dry seasons in Yunlin County. It is presumed that there is more rainfall during wet seasons, which would result in more effective rainfall and actual irrigation, and the potential of return-flow increases accordingly.

In terms of stable supply of water resources, a conservative estimation on the potential of return-flow in this area reveals that there is a significant difference between wet and dry seasons. This indicates a very unstable condition when return-flow is to be developed for the irrigation purposes in Yunlin County. Since the maintaining of a stable supply of water resources is not only a primary task of every industry, but also a necessary condition for industrial production and competition, all possible measures regarding the stable supply of return-flow during wet and dry seasons have to be strengthened, especially when return-flow is considered a source for industrial purposes. These measures may include the effective collection of agricultural return-flow, and taking engineering factors into account on the construction of storage facilities, such as the ponds or reservoirs.

Results and discussions

Water quality of return-flow

The investigation of water quality was conducted after applying pesticide and fertilizer for 4 times at two check points. The items of water quality investigation included suspended solids (SS), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorous (TP), and the results of June–November, 2009 is summarized in Table 1.

Since the irrigation water was detained in paddy fields, the time for the settling of sediments in the irrigation water was longer. As a result, the SS level in the outflow was expected to be lower. However, this phenomenon was not revealed in this study possibly because the observation time was too short. Instead, higher SS values were observed in some points as the soil in the field block was carried away by the outflow. It should be noted that the TN (total nitrogen) and TP levels in the outflow increased significantly when fertilizers or pesticides were applied, but remained constant during normal periods. Nonetheless, the quality of return-flow still conforms to the class C of

Table 1 Water quality variations before and after irrigation

Items (mg l^{-1})	Irrigation		Return-flow	
	Check point 1	Check point 2	Check point 1	Check point 2
SS	7 ± 4	11 ± 4	29 ± 19	4 ± 2
COD	2.3 ± 0.8	2.3 ± 0.2	7.5 ± 2.2	3.7 ± 0.9
TN	1.29 ± 0.17	1.23 ± 0.29	1.06 ± 0.35	1.18 ± 0.05
TP	0.06 ± 0	0.06 ± 0.01	0.12 ± 0.06	0.14 ± 0.07

surface water quality standard in Taiwan, and the purpose for industrial water use is allowed.

Calibration of the parameters of Tank Model

In order to simulate the variation of irrigation return-flow, flow data observed during June–November, 2009 were adopted. The root mean square error (RMSE) was applied as the prediction index, and the parameters of the Tank Model were obtained using the steepest method. The simulation results reveal that a better outcome is obtained when RMSE equals 0.825, as shown in Fig. 5.

Simulation of annual irrigation return-flow

The calibrated parameters are then used to simulate the water budget for each component in the selected irrigation area from 2004 to 2009 based on the annual irrigation plans of the Irrigation Association, as shown in Table 2 and Fig. 6.

From Table 2, it can be seen that the value of annual irrigation water ranges between 3,021 and 3,764 mm, while the annual rainfall ranges between 1,739 and 1,976 mm, the annual evapotranspiration between 2,665 and 3,155 mm, the annual vertical percolation between 269 and 432 mm, and the annual lateral seepage between 1,837 and 1,967 mm. It can also be observed that the vertical percolation is significantly less than the lateral seepage, and the ratio of 5:1 was found between the annual lateral seepage and the depth of annual vertical percolation.

As shown in Fig. 6, the total input water to the irrigation area is the sum of irrigation water and rainfall. It can also be observed from Fig. 6 that the lateral seepage increases slightly with total input water, while the vertical percolation remains almost the same. This phenomenon can be explained by the existence of a hard pan, which is formed beneath the paddy fields as a result of plowing practices, and is commonly found in Taiwan and Japan. The vertical percolation in the paddy field is retarded by the hard pan.

Table 2 The water budget of each simulated component during 2004–2009

Component (mm)	Year					
	2009	2008	2007	2006	2005	2004
Irrigation water	3,021	3,398	3,264	3,586	3,273	3,764
Effective rainfall	1,948	1,976	1,865	1,833	1,745	1,739
Evapotranspiration	2,665	3,020	2,860	3,155	2,835	3,050
Vertical percolation	412	432	328	407	269	405
Lateral seepage	1,837	1,967	1,897	1,877	1,884	1,958

Exceedance probability of annual irrigation return-flow

The χ^2 Goodness-of-Fit was used in this study to test the probability density function of the annual irrigation return-flow. The results showed that the simulated average annual irrigation return-flow could be fitted by a normal distribution with a mean of 4.26 mm and standard deviation of 1.75 mm, and the exceedance probability is illustrated in Fig. 7.

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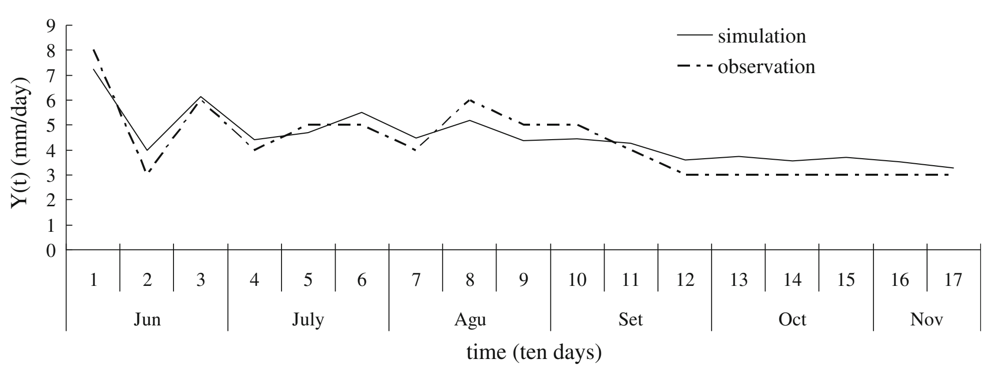
It can be observed from Fig. 7 that the daily irrigation return-flow is approximately 3 mm when the exceedance probability is 0.8. However, when the exceedance probability reaches 0.75, the daily irrigation return-flow is approximately 3.8 mm, which is equivalent to one half or one-third of the average daily irrigation of 9.4 mm.

Relationship between the collection area and reuse efficiency of the return-flow

Let the daily water reuse be 10,000 tons (10,000 CMD), then through sensitivity analysis to simulate the case when the collection area for the return-flow is increased from 50

Fig. 5 Simulation of the irrigation return-flow



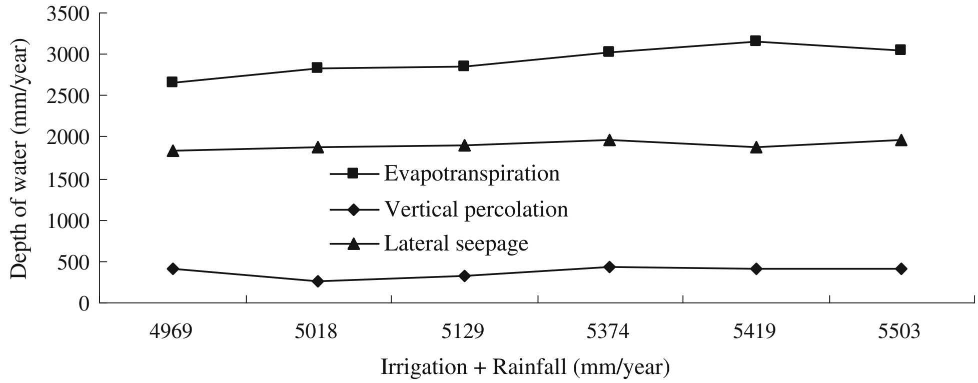


Fig. 6 The relationship between simulated components of water budget

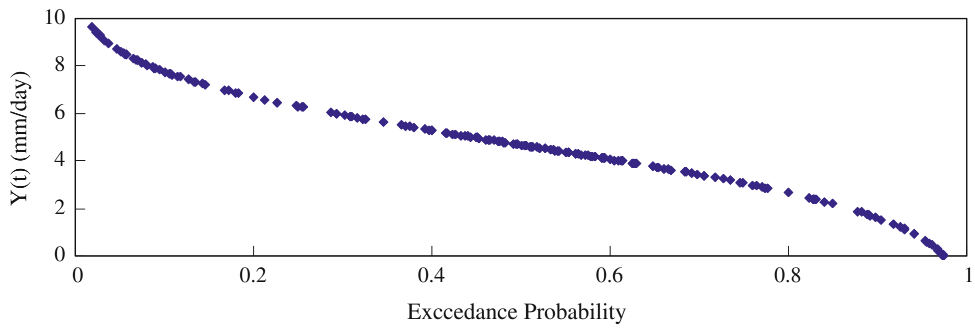


Fig. 7 Exceedance probability distribution of return-flow

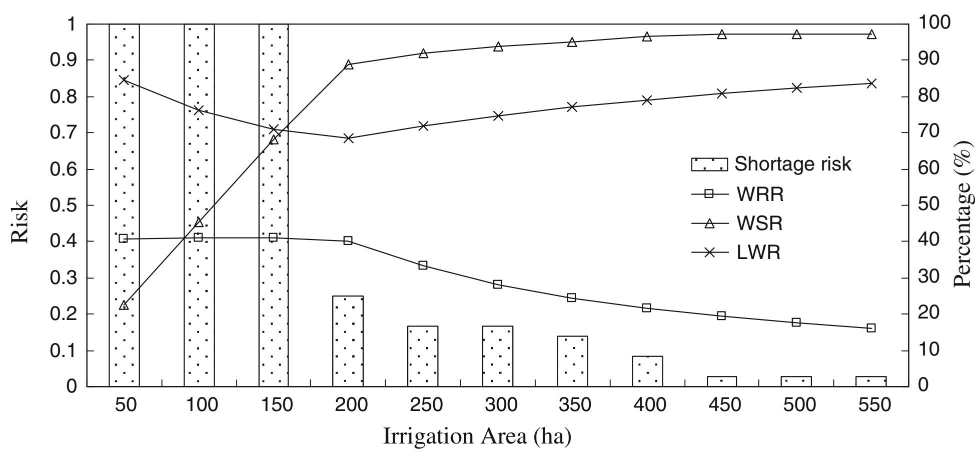


Fig. 8 Scale of water reuse system on shortage risk, WRR, WSR, and LWR

hectares to 550 hectares, the variations in water shortage risk, WRR, WSR, and LWR under a stable supply of reuse water can be shown in Fig. 8.

It can be seen from Fig. 8 that, for those water users with 10,000 CMD demand to be supplied by reuse water, all 36 periods (ten-days) of the whole year will be in water shortage when the collection area for irrigation return-flow is less than 150 hectares. When the collection area reaches over 200 hectares, there will be only 20% for the risk of water shortage. And when the area is over 450 hectares, the ratio for water shortage is no longer declining.

The WRR has the same trend in relation to the water shortage risk. This result seems to demonstrate that when the return-flow collection area is too small, the benefit on the reuse of return-flow is limited as the amount of return-flow is much lower when compared with the demand for reuse water.

With regards to the WSR, it increases significantly at the beginning when the collection area starts to increase from 50 hectares. However, when the area is over 200 hectares, WRR no longer increases. This phenomenon is speculated to be connected with the presumed capacity of the regulatory pond (effective capacity of 20,000 tons).

The LWR implies that when the collection area reaches 200 hectares, the water usage for the reuse system of total return-flow decreases to a minimum. However, when the

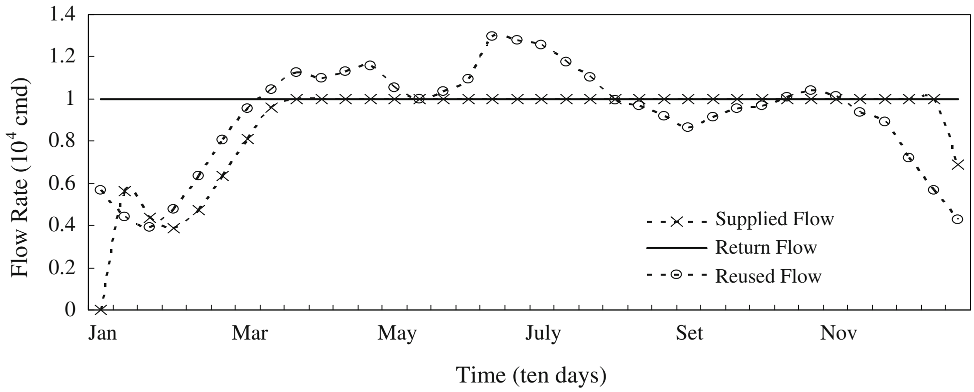


Fig. 9 Stable water supply of the reuse of irrigation return-flow

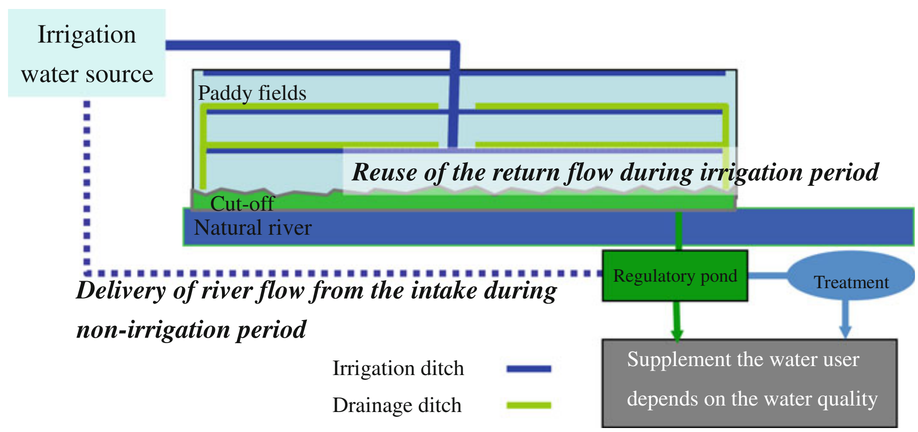


Fig. 10 Measures for the security supply of water resources

collection area increases, the agricultural water use, which takes the irrigation water into account, also increases, and the total water use in the return-flow reuse system slowly increases.

Since the main purpose of a return-flow reuse system is to provide a stable water supply, the scale in terms of collection area for the return-flow in the study area is suggested to be managed at approximately 200 hectares (about the size of a rotational plot). This suggestion is made under the assumption that the annual effective rainfall is approximately 940 mm, current cropping and irrigation systems are to be followed, and daily supply of 10,000 tons of reuse water is to be provided. The simulation of the water supply is shown in Fig. 9.

Measures to secure the stable supply of water resources

It can be observed from Fig. 9 that the timing for the best reuse of return-flow is from the middle of March to early December. During this period of time, the quantity of irrigation return-flow is plentiful, and could be effectively supplied to those in demand via proper facilities. From mid-December to early-March, both the irrigation water and effective rainfall are comparatively low, and the irrigation return-flow is reduced accordingly. Therefore, it is considered the high risk period of water supply is from mid-December to early-March, and corresponding measures should be taken to secure the stable supply of water resources for local water users.

Besides using return-flow during irrigation period, following measures are suggested as shown in Fig. 10.

(1) When fallow or ceased-irrigation is practiced, the original irrigation water is shifted to meet the demand.
(2) Yunlin is located in the southern half of the Choshui alluvial plain, where the groundwater resources is abundant, so emergency pumps could be installed during droughts or when surface water supply is insufficient.
(3) Make optimal use of the regulatory ponds.

Conclusions

In this study, a reuse system for the irrigation return-flow is proposed. The basic unit for the system is the rotational plot of the rice paddy fields, and the purpose of the system is to collect the return-flow following irrigation. It is found in this study that through the regulation of a pond with the effective capacity of 20,000 m^3, a stable supply of 10,000 CMD of reuse water resource can be generated when the collection area is augmented to 200 hectares, which is about the size of a rotational plot. Regarding water quality, although there is variation in the water samples collected during the study period, the quality of return-flow still conforms to the class C of surface water quality standard in Taiwan for which the industrial water use purpose is allowed. Overall speaking, disregarding the extreme water use scenario, there is indeed the potential to use irrigation return-flow as a source for the water supply of other local water users. This implies that return-flow can be appropriately distributed through a variety of management strategies, which would lead to the stabilization of local water supply and demand, and the reliability of food production is further secured.

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