The Role of Agriculture and Irrigation in Lake Basin Management

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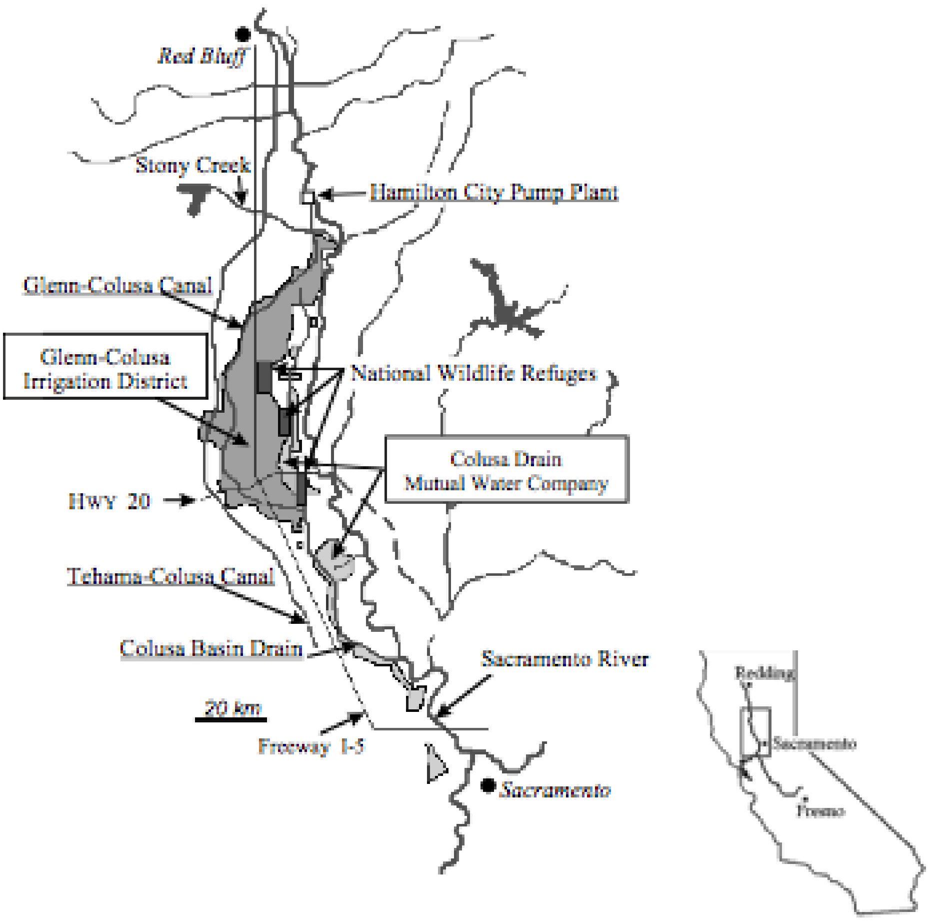
1. Control of Farmland Drainage and Lake Water Quality

Agriculture is the largest water use sector in most of the river and lake basins of the world. Farmland in irrigated regions diverts much water from water resources like rivers and lakes, and discharges drained water including surface runoff and seepage into drainage canal or directly into rivers or lakes. Especially, paddy fields usually divert much water and most of applied water is discharged to drainage canals or seeps into deep groundwater. Drainage water from farmland usually contains many nutrients and agrochemicals, which induce downstream water contamination and pollution. In the case that lakes or other closed waterbodies is located in the downstream of an irrigated area, nutrients from farmland accelerate eutrophication of them.

To control the impacts of nutrient runoff from farmland on lake water quality, there are possible measures in various levels or scales of water management practices in the agricultural regions: in farm plots, on-farm level and in water use district level. In this paper, to show the significance of farmland return-flow on downstream water quality improvement, two examples in the paddy irrigation region are introduced. One example is the case in California, USA of regulation on water holding on farms after application of pesticides not to discharge the chemicals to the downstream river which is source of domestic water for large population.

The other example introduces the effects of recycling use of farmland drainage for paddy irrigation in the Lake Biwa Basin of Shiga, Japan. There, recycling irrigation reduces the effluent nutrient loads in to the Lake Biwa, where eutrophication has been the serious environmental problem.

Figure 1. Location and outline of the Colusa Basin



2. Case Study I in the Sacramento Valley of California, USA

2.1 Introduction

The 170,000 ha of rice production in the Sacramento Valley have been a successful system. But in the past thirty years or so, several regulations and policies for environmental and ecological improvements have been imposed on irrigated agriculture, in particular, paddy irrigation and rice production. These regulations are increasingly constraining the regional water supply and water use in the west side of the Sacramento Valley, notably the Colusa Basin area (**Fig. 1**). This case study describes discharge limitations on rice pesticides in runoffs which is one of four major regulations and policies implemented there (discharge limitations on rice pesticides in runoffs, protection of juvenile salmon with fish screens at river intakes and reduced screen approach velocity, restriction on rice straw burning and water needs to promote straw decomposition, and water supply for wildlife refuges).

2.2 Rice Production and Water Management in the Sacramento Valley

More than 90 percent of the 190,000 ha of rice in California is grown in the Sacramento Valley. Rice is the major crop in the Colusa Basin, the case study area. The irrigation water for rice is obtained mainly by diversions from the Sacramento River system and delivered into continuously flooded paddies with reuse of runoff waters at downstream sites. The rice growers are organized into water districts/companies to handle water supply and drainage in their service areas.

The rice paddies usually consist of laser-leveled or contour-levee checks. In the conventional flow-through irrigation system, water is serially introduced into the topmost to the bottommost check and spilled into a drain ditch (Hill et al., 1991). Water depth in checks is regulated by weirs. The spilled water is typically recaptured for downstream rice paddies before final outflow into the Sacramento River system. Rice is sown by airplanes usually in late April on flooded paddies and harvested in late September. The flood water depth is regulated to promote rice growth and control weed growth. Herbicides are also used to control weeds.

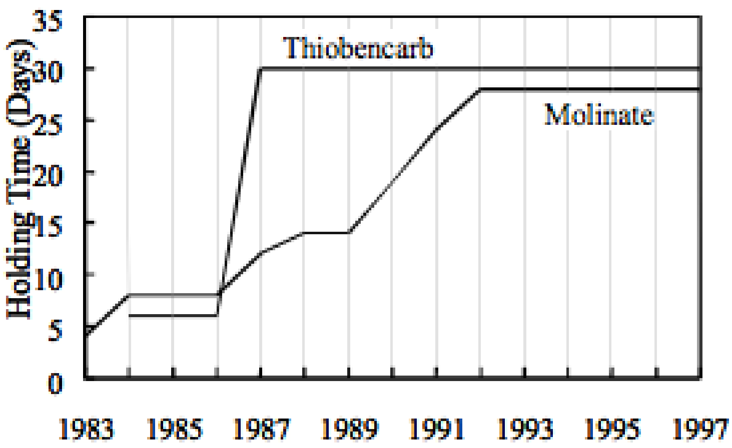
Since the Sacramento River system is the major source water in California for municipal, agricultural and fish and wildlife uses, much attention is given to the management and use of this river flow in the upstream rice growing areas.

2.3 Pesticide Regulation

The runoff of herbicide residues in the flow-through irrigation system previously resulted in occasional fish kills in drains and imparted a bitter taste to the water treated for drinking water at downstream Sacramento City. To mitigate fish kills and taste problems, California Environmental Protection Agency (Cal EPA) established guidelines for major rice herbicide residues and set performance goals in the Sacramento River and tributary drains (Lee et al., 1993). To meet these concentration and load limits, flood waters in paddies had to be held in the fields for a certain number days after chemical application. As shown in **Fig.2**, the number of water holding days for each target herbicide became more stringent from about a week in 1984 to about a month in 1992.

For instance, the peak concentration of molinate (Ordram) in the Sacramento River downstream near the city of Sacramento was over 20 (gL^{-1} in 1984 and gradually decreased to about 7 (gL^{-1} in the mid 1980s, lower than the performance goal of 10 (gL^{-1}, and now is less than 1 (gL^{-1}. In contrast, the peak molinate concentration in the Colusa Basin Drain (CBD) at Highway 20 in the rice growing area was over 100 (gL^{-1} in 1984, decreased slightly in the mid 1980s and decreased further in the 1990s, but at times exceeded the performance goal of 10 (gL^{-1}. However, fish kills in the CBD have been eliminated. The maximum concentration of thiobencarb (Bolero, Abolish) in the Sacramento River near Sacramento City had also decreased in the 1980s and since then it has been less than 1.0 (gL^{-1} detection limit. The incidences of drinking water taste problems have been eliminated.

Figure 2. Required Rice Herbicide Holding Time in Sacramento Valley



Source: Cal EPA

While the regulation with water holding is succeeding in controlling herbicide runoffs, it has increased flood water and soil salinity in some rice fields in the lower Colusa Basin, affecting seedling establishment and rice yields (Scardaci et al., 1996). Where serious salinity damage is expected, plans are being made to allow the grower to release spill water through a special permit.

3. Case Study II in the Lake Biwa Basin of Japan

This chapter depends on the following persons for providing with useful materials and helpful suggestions. Kimihito Nakamura, Takehide Hama and Toru Mitsuno of Kyoto University (Hama et al., 2007).

3.1 Introduction

Lake Biwa of Shiga Prefecture, which is the largest lake in Japan, has been seriously contaminated since the 1970s. For improvement of water quality of the Lake Biwa, Shiga Prefecture is promoting environmentally-sound farming including financial support by direct payments to the farmers for environment management practices and activities.

Recycling or reuse of farmland drainage for irrigation of paddy fields, hereafter referred as Recycling Irrigation (RI), is recognized as one of the measures for reducing the impacts of agriculture on water contamination. The RI means reuse of drainage water as irrigation water by pump-up. It was designed originally for water saving (Kudo et al., 1995; Takeda et al., 1997; Takeda and Fukushima, 2006). The RI can reduce effluent loadings such as SS, nitrogen, phosphorous, and so on, because water reuse reduces effluent water quantity itself (Kaneki, 1989; Takeda et al., 1997; Feng et al., 2004; Hitomi et al., 2006).

The actual impacts and contribution of the recycling irrigation have been investigated in a low-lying paddy field district in the eastern bank of Lake Biwa since 2004 by Dr. Hama and others of Kyoto University Group. They assess the effects of effluent loadings reduction of SS by the recycling irrigation are assessed (Hama et al., 2005). In this section, their investigations mainly of 2006 and the findings are outlined.

3.2 Recycling of farm drainage

The investigated district is located in the eastern bank of the Lake Biwa. The district is adjacent to an inner lake on the west side. **Fig. 4** shows the outline of the district. The total land area is about 150 ha and most of the area is used as paddy field. About one third of the paddy field area

Figure 4. Outline of the Konohama District

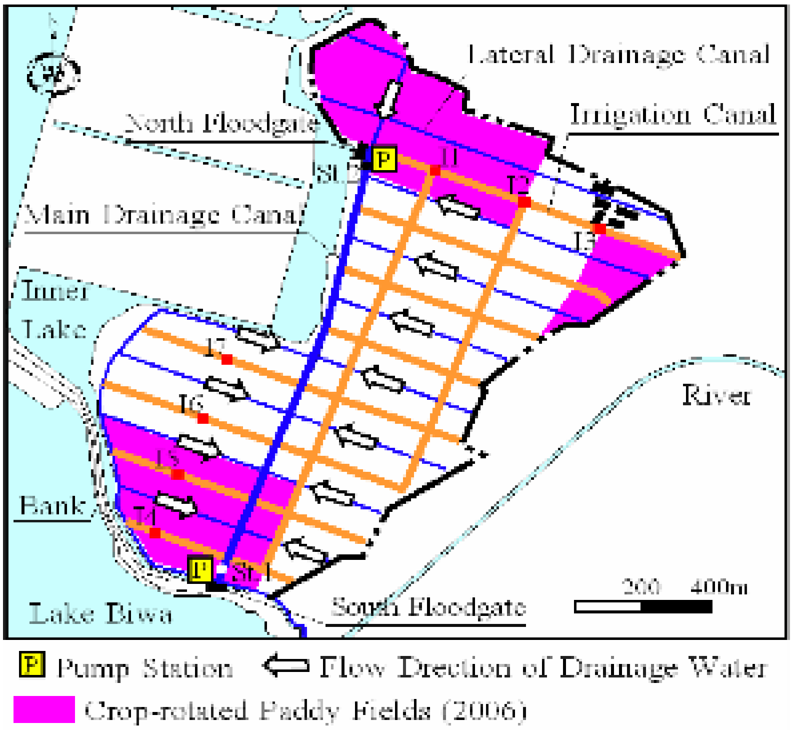
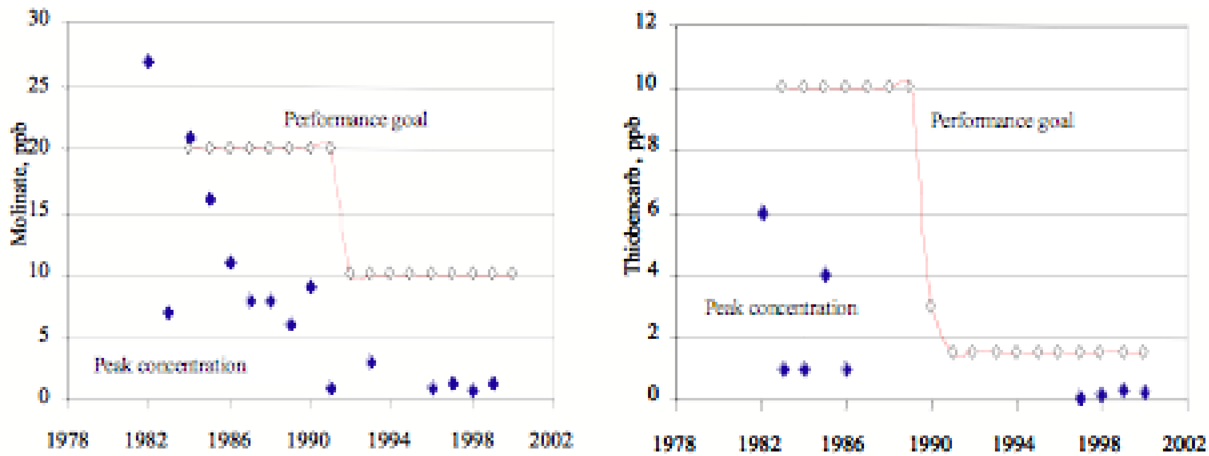


Figure 3. Water holding times for rice pesticides in the field are successful in meeting performance goals; no bitter taste in drinking water at Sacramento City and reduced fish kills in rice drains.



a. Molinate in Sacrament City water intake

b. Thiobencarb in Sacrament City water intake is converted to other crops, mainly to winter wheat and subsequently soy bean.

There are 14 lateral drainage canals and a main drainage canal in the district. The main drainage canal is about 1.5 km long and cuts the district from north to south. Additionally, the main drainage canal is modified by vegetation to trap more sediment than a normal drainage canal lined with concrete. Runoff from paddy fields flows into the main drainage canal through each lateral drainage canal and flows out through north and south floodgates.

In the district, two pump stations are installed at both ends of the main drainage canal. The irrigation system is classified into two types by the way of water intake of irrigation water; recycling irrigation (RI) system and conventional irrigation system, which is called Gyaku-sui irrigation (hereafter abbreviated as "GI") system.

Irrigation water is taken from the main drainage canal in the RI system. On the other hand, in the GI system, irrigation water is supplied by pumping directly from Lake Biwa via pipeline, which is connected to the north pump station. **Fig. 5** shows the schematic diagrams of the irrigation system. The RI was implemented from the beginning of puddling season to the mid-summer drainage (RI period), while the GI was carried out from the mid-summer drainage to the end of the irrigation period (GI period). The RI period and the GI period have almost same days, about 60 days.

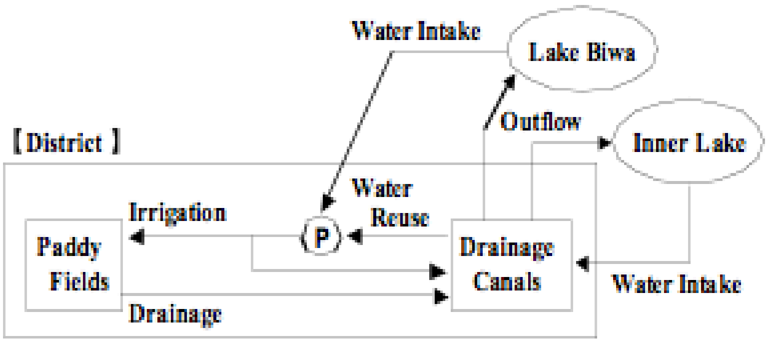
3.3 Measurements of water balance and water quality

The investigation was carried out on a weekly basis in the irrigation period. Water qualities were investigated at the following points, including the drainage canals, the irrigation canals, two paddy plots and the inner lake. Turbidity, flow velocity, water depth, EC, pH, and water temperature were measured at these points. At the same points, water was sampled and then the water quality was measured in the laboratory. The measurements of water quality were suspended solids (SS), total nitrogen (TN), total phosphorous (TP), NH_4-N, NO_3-N, NO_2-N, and PO_4-P.

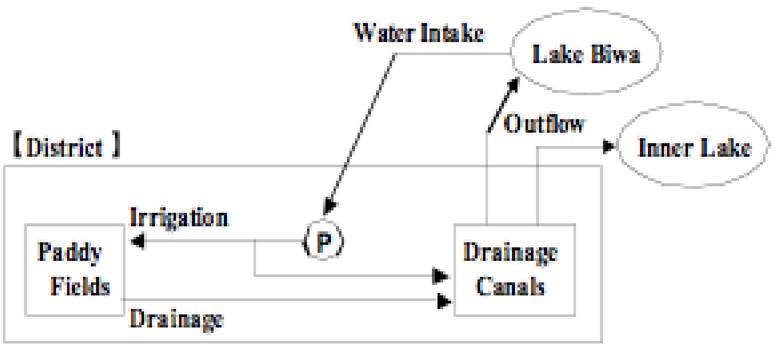
The flow discharge at both floodgates was measured with a flow meter. The amount of rainfall was measured with a rain gauge at the south pump station. Evapotranspiration was estimated by the Penman method. The amount of pumped water was estimated from the working time of the pumps and flow rate of sucked water. In addition, water balance of two paddy plots in the district was observed by measuring intake and drainage of water into/out of the plots.

3.4 Contribution of recycling to deduction of nutrient loads to the downstream lake

Figure 5. Schematic Diagrams of the RI and GI Systems



(a) RI: Recycling irrigation system



(b) GI: yaku-sui irrigation system (conventional irrigation system)

a. Characteristics of effluent loadings

The operation started on April 24 and the stopped on August 31 which is the irrigation season of 2006 with the RI period and the GI period are from April 24 to June 25 and from June 26 to August 31, respectively. The mid-summer drainage season, from June 26 to July 7, is included in the GI period.

Figure 6 shows daily variations in outflow and rainfall in the irrigation period in 2006. It is found that the outflow did not happen except rainy days in the RI period and the outflow of about 15mm d^{-1} happened even in fine days in the GI system. Therefore, it is confirmed that the RI system could reduce the outflow from the district.

Figure 7 shows seasonal variations in concentrations of SS, TN, and TP of the drainage water sampled at the south end of the main drainage canal. Concentrations were

Figure 6. Daily Variations in Outflow and Rainfall in the Irrigation Period

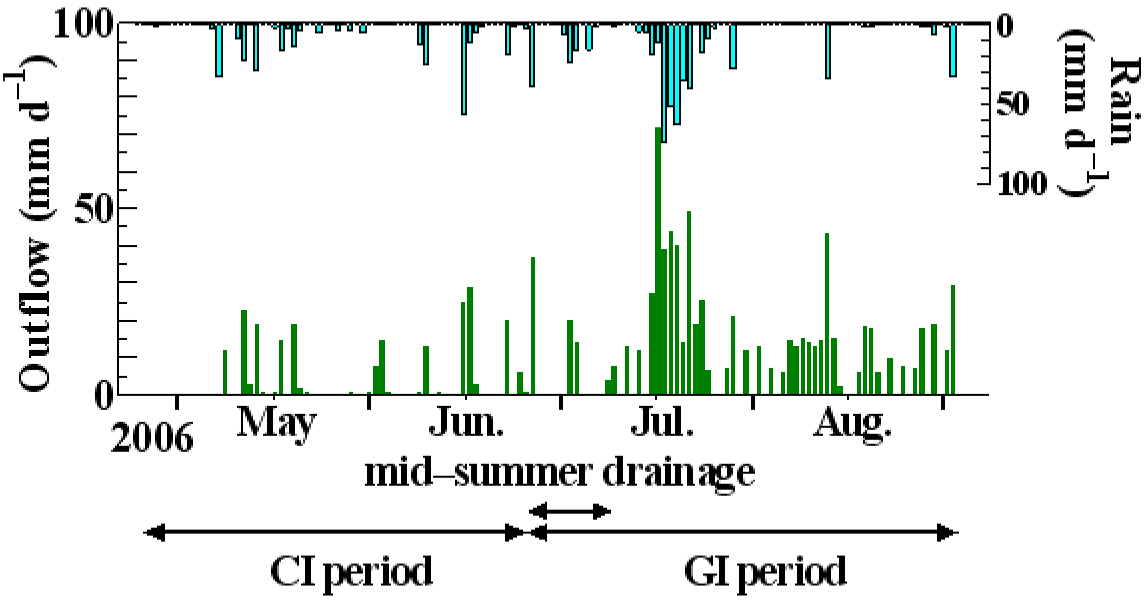


Figure 7. Seasonal Variations in Concentrations of SS, TN, and TP at the South End of the Main Drainage Canal in the Irrigation Period

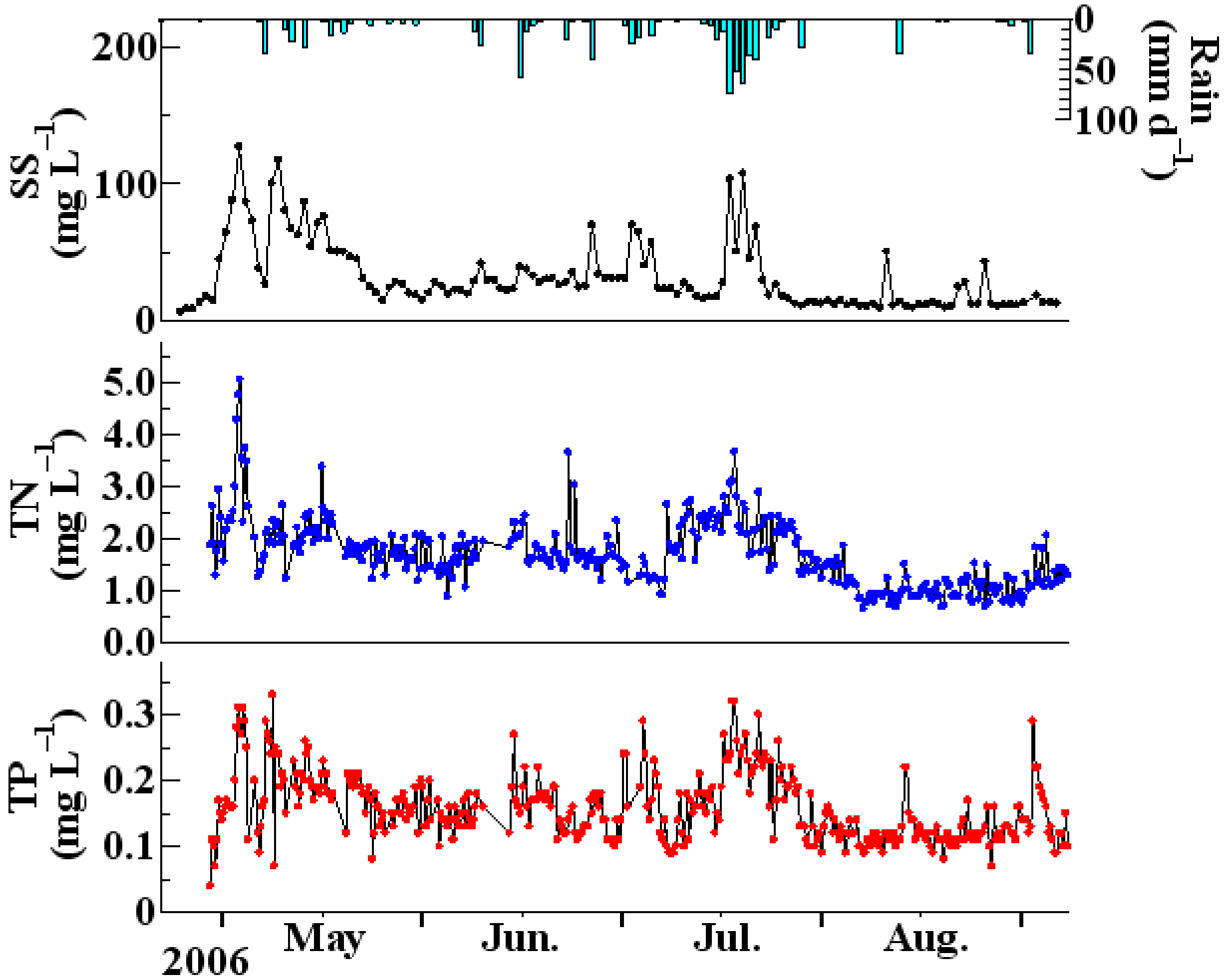


Figure 8. Seasonal Variations in Effluent Loadings of SS, TN, and TP from the District in the Irrigation Period

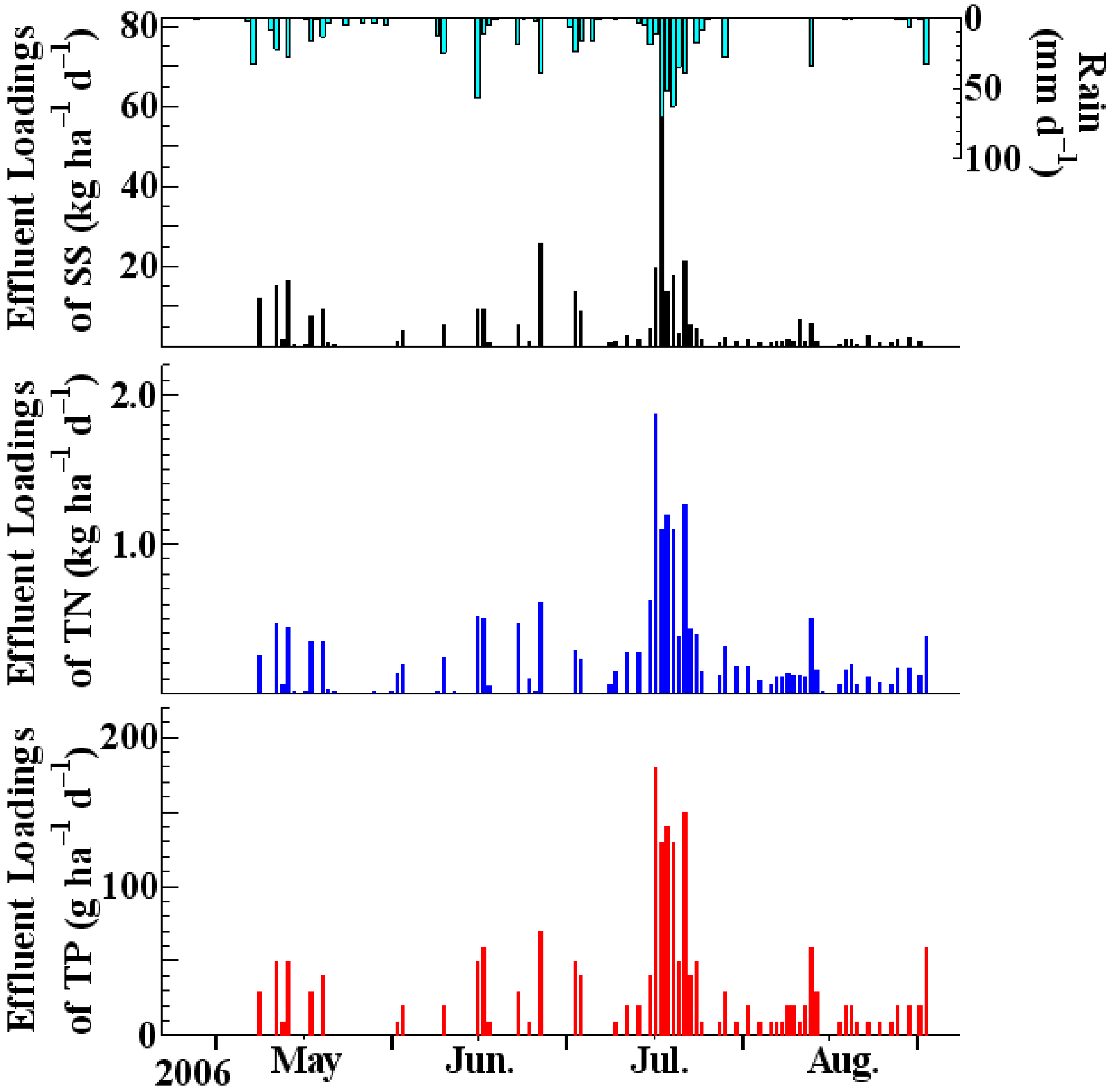
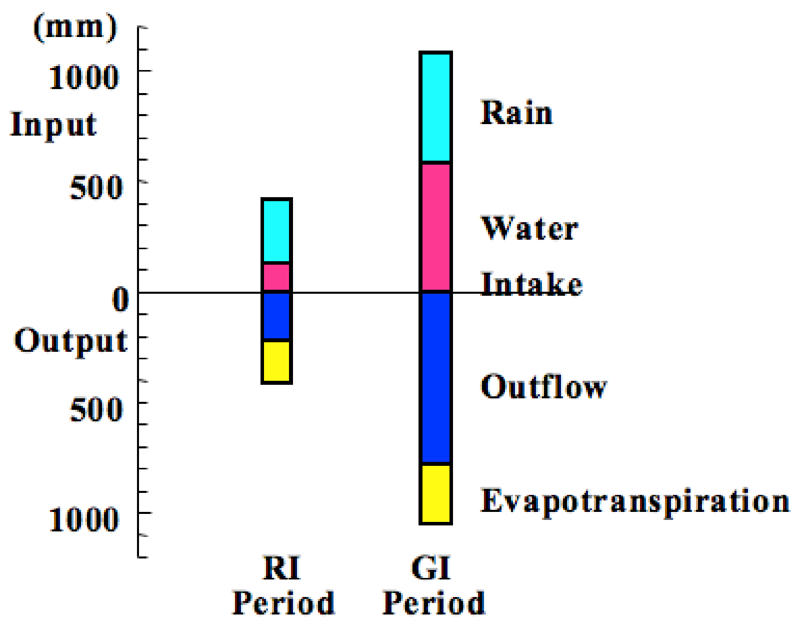


Figure 9. Water Balances in the RI and GI Periods in 2006



high during the puddling season and in rainy days. Each concentration showed almost same variation trend. Especially, there are a clear correlation between SS and TP. The percentage of in TN and TP in particulate state were about 50% and 70%, respectively.

Figure 8 shows variations in effluent loadings of SS, TN, and TP from the district in the irrigation period in 2006. As is the case with the outflow of water shown in Figure 6, there were less effluent loadings in the RI system, whereas from 0.1kg ha^{-1} d^{-1} to 0.2kg ha^{-1} d^{-1} of TN flowed out in the RI system. However, the effluent loadings in the RI system were much less than that in the rainy events because the concentrations of SS, TN, and TP shown in Figure 7 were low in the RI system and

Figure 10. Monthly Pumped Water and Surplus Irrigation Water in 2006

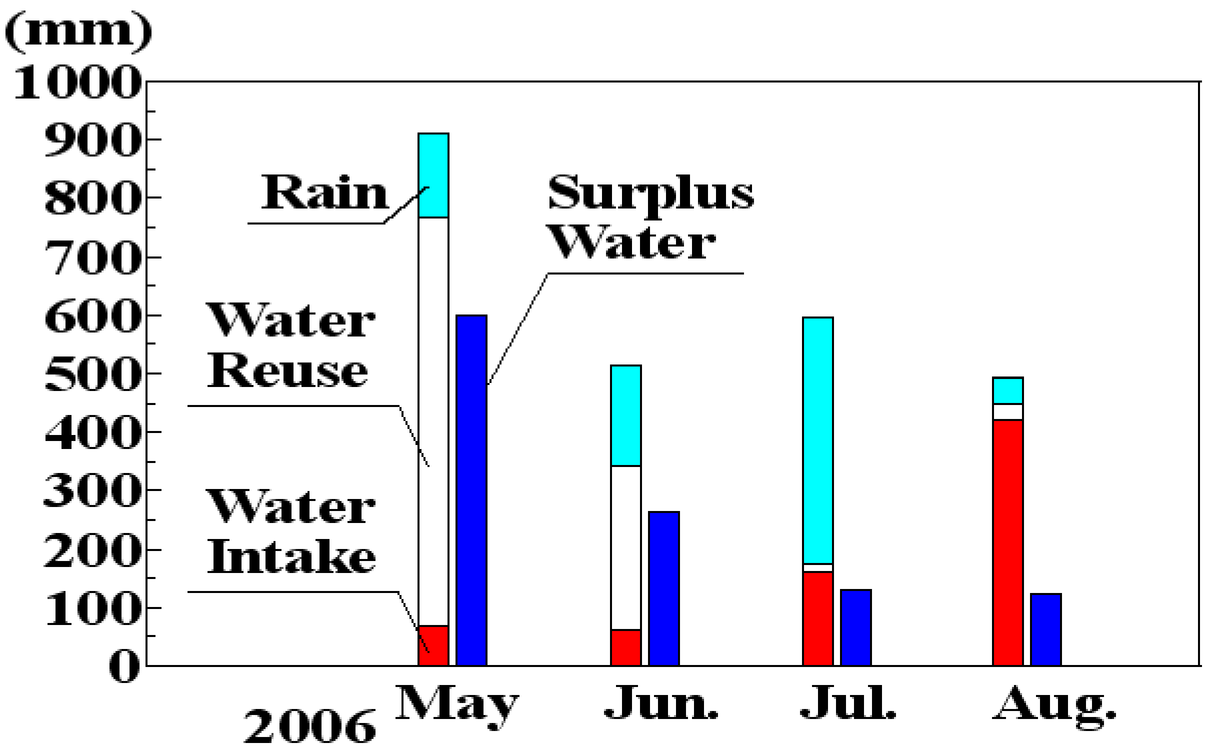


Table 1. Mass Balance of RI (CT in this table) and GI Periods in 2006

(unit : kg ha $^{-1}$)

Item	Period	Input			Output
		Intake	Rain	Fertilizer	Outflow
SS	CI [1]	4	3	-	110
	(Puddling season [2])	(2)	(2)	-	(66)
	GI [3]	18	5	-	250
	(July Rain [4])	(0)	(3)	-	(110)
	Total	22	8	-	360
TN	CI	1.1	1.4	15	4.4
	(Puddling season)	(0.6)	(0.7)	(13)	(2.1)
	GI	4.5	4.7	36	14
	(July Rain)	(0.0)	(2.4)	(0.0)	(5.1)
	Total	5.6	6.1	51	18
TP	CI	0.1	0.0	14	0.4
	(Puddling season)	(0.0)	(0.0)	(12)	(0.2)
	GI	0.3	0.1	0.0	1.6
	(July Rain)	(0.0)	(0.1)	(0.0)	(0.7)
	Total	0.4	0.1	14	2.0

Note) [1] CI = from 24 April to 25 June, [2] Puddling season = from 24 April to 31 May, [3] GI = from 26 June to 31 August, and 4) July Rain = from 17 July to 21 July.

Figure 11. Flow Diagrams of SS (kb ha^{-1} d^{-1}), TN (g ha^{-1} d^{-1}), and TP (g ha^{-1} d^{-1}) in the Irrigation Systems

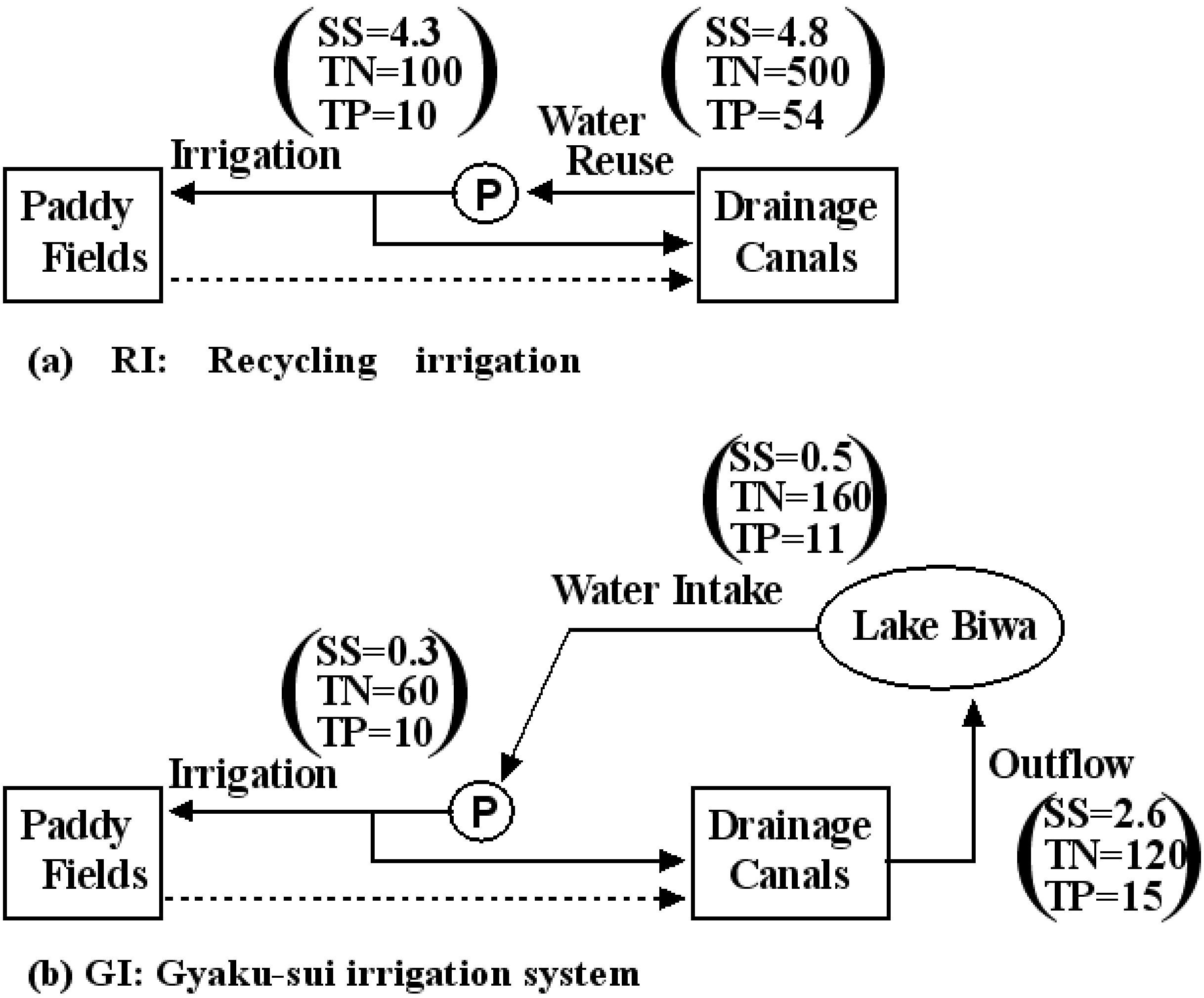


Figure 12. Inflow of Water into a Paddy

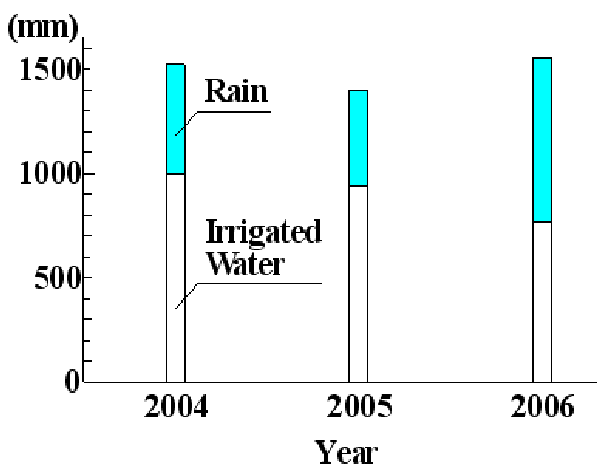
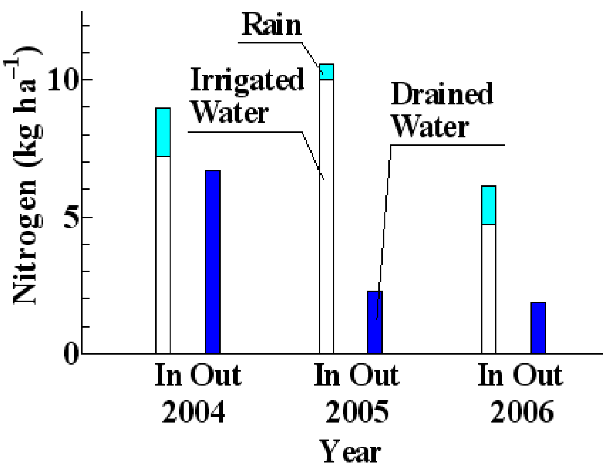


Figure 13. Nitrogen Input and Output in a Paddy Plot in the RI



both of the outflow and the concentration became high in the rainy events.

b. Water and mass balances

Figure 9 shows water balances in the RI and GI periods in 2006, respectively. It was assumed that percolation is very small compared with the outflow, because the district is a riparian low-lying basin. The amount of water intake in the RI period was less than that in the GI period because the water intake from outer water resource (an inner lake on the west side) was carried out as complementary one in the RI system. The water reuse rate, R_{RI}, which is defined below as equation (1), was about 88% on average in the RI period in 2006.

$$R_{RI} = V_{RI} \ / \ V_P \qquad (1)$$

where, V_{RI} is the amount of water reuse and V_P is the amount of pumped water.

It is confirmed again that the outflow in the RI period was less than that in the GI period, as seen in Figure 6. This is mainly because that surplus irrigation water is stored in the main drainage canal and does not become the outflow in the RI system.

Figure 10 shows rain, irrigation water, and surplus irrigation water in each month in the irrigation period. From May to June, the surplus irrigation water accounted for about 80% of the pumped water, which is the sum of water reuse and complementary intake. In August, the percentage of the surplus water was about 30%, because of dry weather.

Table 1 shows mass balances of SS, TN, and TP in each period in 2006. The effluent loadings ("Outflow" in Table 1) of SS, TN, and TP in the RI period were only 80%, 50%, and 40% of those in the GI period except the effluent loadings by the heavy rain in mid-July, respectively. Therefore, it is shown that the RI system can also reduce the effluent loadings of SS and nutrients.

Figure 11 shows flow diagrams of loads of SS, TN, and TP in the RI (except the puddling season) and GI systems. Each diagram was calculated under the condition that there were no input of rain and fertilizer in the calculation period. It is indicated that the RI system can reduce the effluent loadings of SS by 2.6kg ha^{-1} d^{-1}, TN by 120g ha^{-1} d^{-1}, and TP by 15g ha^{-1} d^{-1} in comparison with the outflow in the GI system. In the GI system, however, net outflow loads (outflow load minus inflow load) of TN and TP were negative. This proves that the district absorbs TN and TP.

The estimation of reduction effect of the RI system, described above, assumed the implementation of the GI in the RI period under the same condition as the actual GI period. This, however, may underestimate the potential reduction effect.

Similarly, the potential reduction effect of the RI system during the puddling season can be clarified by considering hypothetical implementation of the GI. The potential reductions are estimated by multiplying the surplus water in the RI period by each average concentration in the drainage water in the GI period. As a result, it is found that the (minimum) potential reductions of effluent loadings of TN, and TP during the puddling season in 2006 were about 170g ha^{-1} d^{-1} and 17g ha^{-1} d^{-1}, respectively. In addition, we made another assumption that the concentrations of SS, TN, and TP in the drainage water would equal to values measured in the actual RI period even if the GI were conducted. On this assumption, the potential reduction effects are estimated by using the concentrations in the RI period. This assumption may give the upper limit of the potential reduction. As a result, the (maximum) potential reductions of effluent loadings of TN and TP during the puddling season were about 380g ha^{-1} d^{-1} and 30g ha^{-1} d^{-1}, respectively.

c. Impacts of meteorological factors

As shown in Table 1, the outflow by rainy events was also large. Especially, in the case of SS, more than 60% of total outflow occurred in the rainy events.

Figure 12 is the inflow of water into a paddy plot in three years and shows the relationship between rainfall and irrigated water. It is suggested that the total amount of input to a plot is constantly about 1500mm, which equals to 12.5 mm d^{-1} on average in the irrigation period. This is because the farmers control well the amount of irrigated water into their paddy plots. This complementary relationship between rainfall and irrigated water means that the amounts of rainfall have influence not only on the increase of the effluent loadings, but also on the decrease of the chance to conduct RI. For instance, rainfall of 25mm on 9 June, which generated the effluent loadings of TN of 240g ha^{-1}, reduced the chance to return TN of 200g ha^{-1} to a paddy plot.

Figure 13 shows input (except fertilizer) and output of nitrogen in a paddy plot in the RI period. The net outflows (output minus input) of 3 years were all negative. Therefore, it is indicated that the paddy plot played a role of removal of nitrogen in the RI period. As referred to above, however, there seems to be inverse relationship between rainfall and the net outflow.

d. Contribution of recycling irrigation

The measurements and analyses introduced in this section realize the actual effect of recycling irrigation system for loading reduction. Compared with the conventional irrigation system, the cyclic irrigation system reduced the outflow of SS by 2.6kg ha^{-1} d^{-1}, TN by 120g ha^{-1} d^{-1}, and TP by 15g ha^{-1} d^{-1}. Therefore, the recycling irrigation is to be recognized as one of useful water management practices to reduce effluent loadings from paddy irrigation scheme. The reduction effect of recycling irrigation, however, depended largely on the meteorological factors, as larger rainfall might decrease the reduction effect of the recycling irrigation system.

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