Application of Complex Tank Model for Evaluating Performance of Water Operation in a Reused Water Irrigation System

Fukuda, Tetsuro
Laboratory of Irrigation and Water Utilization Engineering, Faculty of Agriculture, Kyushu University

Jayadi, Rachmad
Laboratory of Irrigation and Water Utilization Engineering, Faculty of Agriculture, Kyushu University

Nakano, Yoshisuke
Laboratory of Irrigation and Water Utilization Engineering, Faculty of Agriculture, Kyushu University

Kuroda, Masaharu
Laboratory of Irrigation and Water Utilization Engineering, Faculty of Agriculture, Kyushu University

https://doi.org/10.5109/24320

出版情報：九州大学大学院農学研究院紀要. 44 (1/2), pp.189-198, 1999-11. Kyushu University

J. Fac. Agr., Kyushu Univ., **44** (1·2), 189–198 (1999)

Application of Complex Tank Model for Evaluating Performance of Water Operation in a Reused Water Irrigation System

Tetsuro Fukuda, Rachmad Jayadi, Yoshisuke Nakano, Masaharu Kuroda

Laboratory of Irrigation and Water Utilization Engineering, Faculty of Agriculture,
Kyushu University, Hakozaki, Higashi-ku, Fukuoka 812–8581, JAPAN
(*Received July 30, 1999 and accepted August 24, 1999*)

A case study on the performance of irrigation water operation was conducted using data collected at a reused water irrigation system of low–lying paddy area with creek networks, located in the Oide district, Saga plain, Kyushu, Japan. The complex Tank model was applied for simulating the daily cyclic water in the system. Results showed that the system performed the remarkable irrigation water conservation. This phenomenon was marked by the great values of ratio of water use (*Rwu*), in which the calculated values for all of blocks were over 100% for paddy season of 1997. It was found that the total return flow in usual fine day and heavy rain day of paddy season were 10 and 80 mm/day, respectively. It was also proven that the effective return flow contributed significantly as reusable irrigation water. This interesting point was shown by the high values of the ratio index of the effective return flow to the amount of usable water in creek network (*Riu*) that ranged of 0.5–0.86. The study clarified that the recycle use of irrigation water accumulatively occurred at the lower block of creek networks.

Key words: *Tank Model, Return flow, Ratio of water use, Ratio index of the effective return flow*

INTRODUCTION

The delivery and management of water resources for agricultural purpose require an estimate of hydrologic data and physical characteristics of the cultivated area. These data are needed for obtaining the accurate information concerning water balance and cyclic water that is crucial for operations of water allocation and drainage control in an irrigation system. If return flow exists, actual water operation has to be evaluated by considering reused water factor. The existence of return flow is one of the most significant characteristics of paddy field irrigation system. Therefore, to evaluate return flow and take it into consideration in system operation is of great importance.

This study was addressed to assess the applicability of complex Tank model for evaluating performance of water operation in an irrigation system of low–lying paddy area with creek networks. The model was first calibrated through fitting of the actual and simulated runoff from creek networks, and then the obtained model parameters were used for simulating daily cyclic water as well as return flow components. Second, analysis of water use efficiency obtained by the simulation results was made for identifying the valuable factors affecting performance of water operation in the system.

METHODS

The Surveyed Area

The study was carried out at a low–lying paddy area with creek networks being a part of the Kase River Irrigation System. The surveyed area is situated at an artificially reclaimed area located at the Oide district of Saga plain facing the Ariake bay on the island of Kyushu, southwest Japan. Irrigation water for the Kase River Irrigation System, including water supply for the Oide district is taken from the Kawakami diversion through main canal system in which the water flows to the delivery gates to each block of creek network. **Fig. 1** shows a map of locations of field surveys on flow discharges at the main canal system, creek water depths and water qualities. The layout of irrigation system is represented in **Fig. 2**.

The considered area consists of five blocks named **C**, **D**, **E**, **F** and **G**, being a part of the eleven blocks of paddy area as shown in **Fig. 2**. **Table 1** describes a brief quantitative physical data of each block of the surveyed area.

The table shows that paddy fields occupy the dominant part of area compared to the

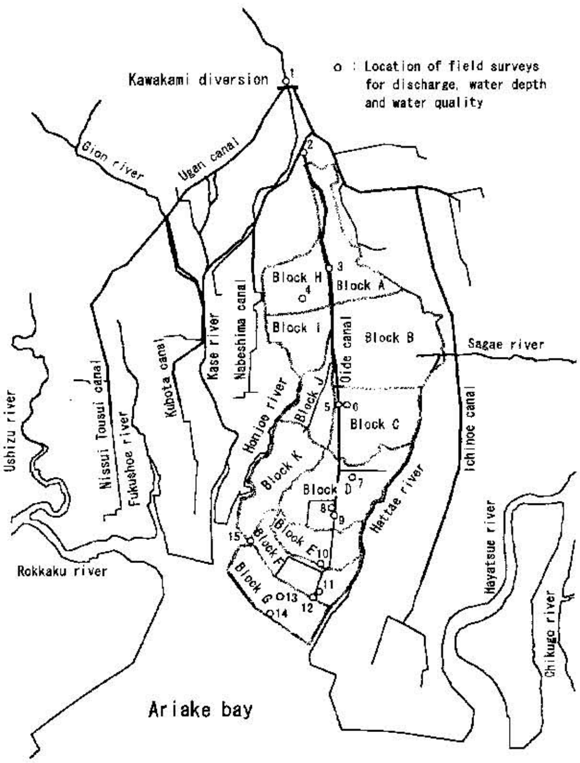

Fig. 1 Locations of field surveys

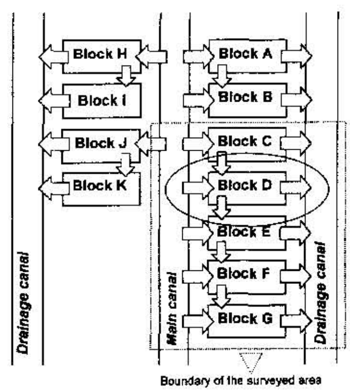

Fig. 2 Schematic layout of irrigation system

Table 1. Land use and creek networks at the surveyed area (after field surveys of 1997)

Block	Paddy fields (ha)	Upland fields (ha)	Green houses (ha)	Settlement area (ha)	Population (person)	Creek Length (m)	Creek Area (m^2)	Creek Volume (m^3)
C	324	15	8	155	2,257	30,851	166,330	473,125
D	393	28	14	104	1,519	41,818	384,003	480,354
E	195	6	14	57	829	21,205	194,722	243,580
F	285	21	9	21	312	26,186	240,464	300,799
G	314	28	6	11	162	27,849	255,727	319,892

other types of land utilization. Settlement area and the number of population decrease from the upper block to the lower block. The areas of creek network vary from around 5 to 10% of the occupied paddy field area at each block. Assuming the daily water consumption for paddy plots at about 15 mm/day, the storage capacities of creek networks are equal to the amount of water demand for the period of 7–10 days.

Development of Complex Tank Model

The study is focussed on irrigation water operation at creek–fields system that characterized by the existence of return flow from the cultivated and non–cultivated areas to creek networks as illustrated in **Fig. 3**. The delivered water from the main canal system is temporarily stored into creek storage. Since water level in creek is always lower than the irrigated fields, a pumping system of irrigation water is usually applied for both paddy plots and greenhouse.

Percolation and seepage water that have disappeared from paddy plots appear again in creek storage. Excess water due to over supply of irrigation water and abundant rainfall flows through surface drainage pipes installed beneath the levees. These returned water perform surface runoff and seepage runoff return flows stored in creek networks as

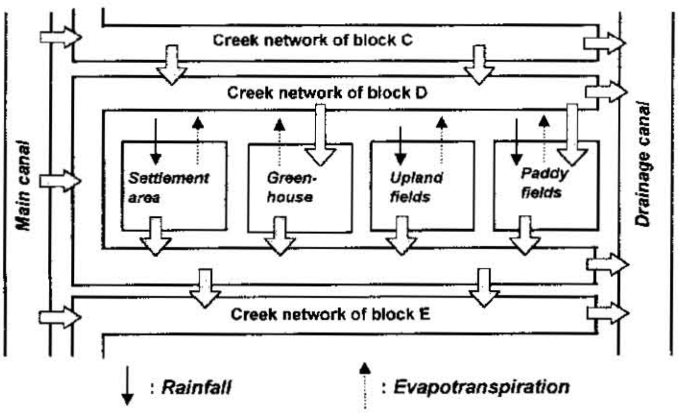

Fig. 3. Schematic representation of return flow in a creek–fields system

reusable irrigation water.

From **Fig. 2**, it can be seen that reuse mechanism of return flow is performed not only within the creek–fields system of each block, but also among the blocks in which runoff from the upper block flows as irrigation water supply to the lower block of creek networks. Therefore, besides the runoff components of each block, flow from a block to its lower field through creek networks is also a significant data for evaluating water operation in the irrigation system.

The water balance approach is well known as a method for analyzing and evaluating return flow. In this study, complex Tank model was developed for analyzing the reuse mechanism of irrigation return flow in the surveyed area (Jayadi, Fukuda and Kuroda 1998). For each block of the surveyed area, the model consists of six sub Tank models that each applicable for paddy fields, upland fields, greenhouse, settlement area, main canal and the creek network as shown in **Fig. 4**. The model formulation is a continuous work for developing the previous model (Kuroda and Fukuda, 1996), in which the current model considers also the runoff components originate from non–paddy fields. The optimized parameters of the model that are height of outlet, constant of the outlet and initial water depth in each sub Tank were obtained through model calibration using the Standardization–Davidon–Fletcher–Powell method (Kadoya and Nagai, 1980). For the whole system there were 157 values of parameter that have been defined using an optimization procedure described in the following section.

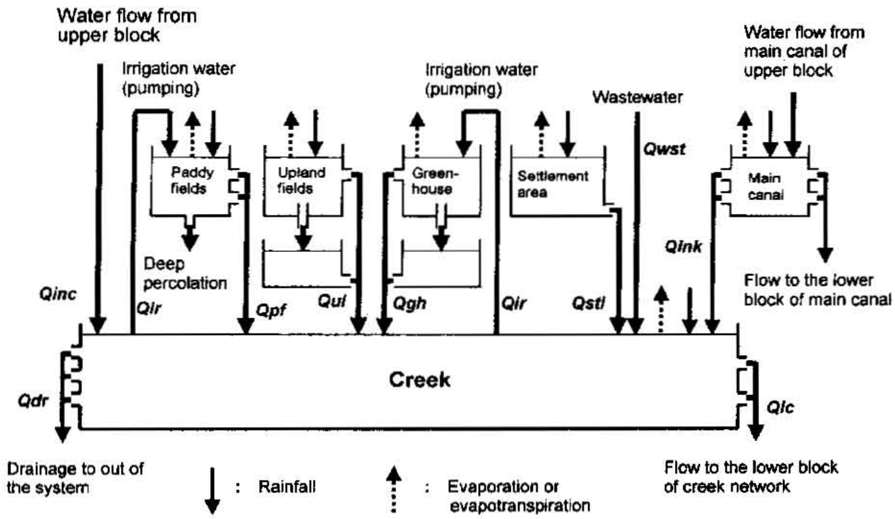

Fig. 4. Structure of the complex Tank model for a creek–fields system

Procedure for Calibrating Complex Tank Model

Regarding there were large number of parameters had to be found, the application of the Standardization–Davidon–Fletcher–Powell method for calibrating complex Tank model was run through a sequential optimization approach from the upper block to the lower block, successively. Based on the recorded data of creek water depths, the actual daily runoff discharge in each creek–network (*Qro*) was approximated using a procedure of calculation as explained in **Fig. 5**, equations (1) and (2).

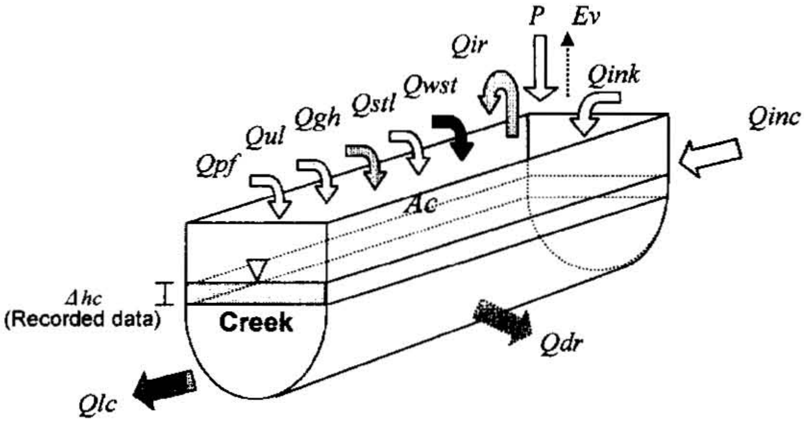

Fig. 5. Schematic representation of inflow and outflow in the creeks

$$\sum Rflow = Qpf_i + Qul_i + Qgh_i + Qstl_i + Qwst_i \quad (1)$$

$$Qro_i = Qlc_i + Qdr_i$$
$$= \sum Rflow_i + P_i + Qink_i + Qinc_i - Qir_i - Ev_i - \Delta hc_i \cdot Ac_i \quad (2)$$

in which *Ac* is the average area of creek storage at water surface, and Δhc is change in the observed creek water depth. *Qpf*, *Qul*, *Qgh*, *Qstl* are the calculated runoff from paddy fields, upland fields, greenhouse and settlement area, respectively. *Qwst* is wastewater flow from settlement area and *P* is the daily rainfall. *Qinc* is water flow from the upper block of creek networks and *Qink* is water supply from the main canal. *Qir* is irrigation water supplied to paddy fields and greenhouse. *Qdr* is drainage from creek network to outside of the system. *Qlc* is runoff to the lower block of creek network. *Ev* is evaporation from creek storage. Subscript i means the day of concerning calculation period.

Afterwards, observing the actual and the simulated daily runoff discharges from creeks the outputs of Tank model parameters were examined. In this case, the discharge of total runoff to the outside of the concerning block (*Qro*) was used for examining accuracy of the model. The model calibration was carried out by minimizing the value of an objective function $\boldsymbol{J}$ as shown in Equation (3).

$$J = \frac{1}{n} \sum_{i=1}^{n} \frac{|Qro_i - Qrob_i|}{\sqrt{Qrob_i}} \tag{3}$$

in which n is number of days of calculation period, Qro_i and $Qrob_i$ are the calculated and actual runoff in the i^{th} day of concerning calculation period, respectively.

RESULTS AND DISCUSSION

Performance of The Simulated Daily Runoff in Creeks

Having optimized values of complex Tank model parameters, simulations of the daily runoff from creek networks and return flow components could be conducted. **Fig. 6** displays performance of the simulated daily runoff from creek networks based on the observed input data of 1997. Results show that the optimized parameters provide the calculated runoff that is close to the actual ones. The daily runoff fluctuated wider in the period of paddy season, i.e., from the beginning of June until the middle of October, than its non–paddy season. To assure the validity of the model, the calculated runoff from each sub Tank model has to be analyzed. The procedure of analysis is described in the

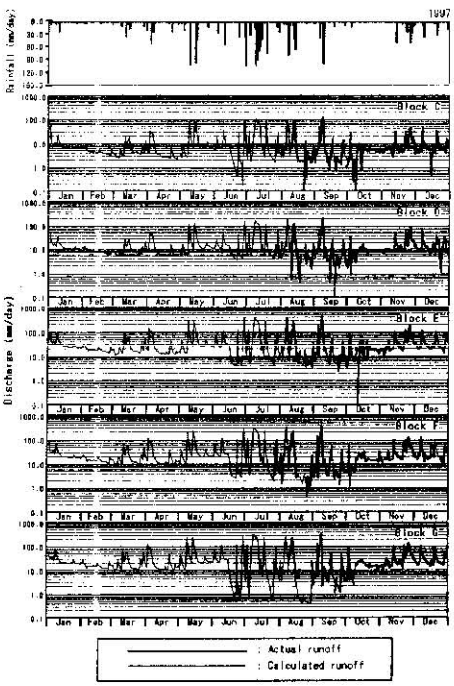

Fig. 6. The actual and calculated daily runoff from creek networks

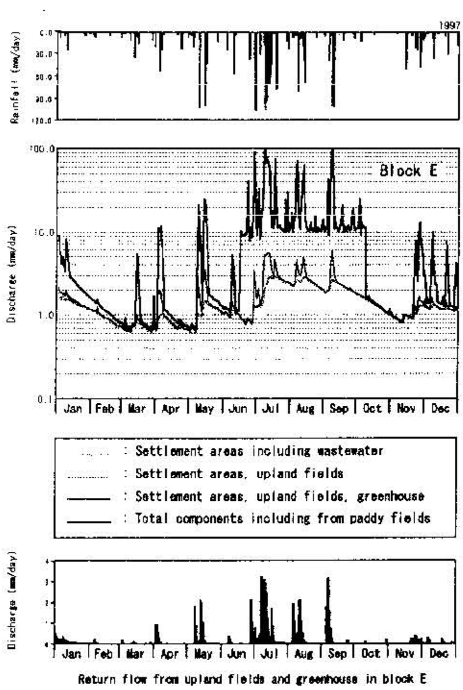

Fig. 7. Performance of the simulated runoff components in block E

following explanation.

In order to pay close attention to output of complex Tank model, the corresponding runoff from each type of land use needs to be evaluated. Example of simulation output of such runoff components in cumulative amount is given for block **E** as shown in **Fig. 7.** The unit of mm/day was derived with respect to the occupied area of paddy fields in each block. The figure clearly shows that the runoff from paddy fields was the dominant part of return flow components. It can also be observed that return flow from paddy fields similarly fluctuates to the amount of the daily rainfall. Return flow from upland fields and greenhouse took a value up to 3 mm/day in a day with abundant rainfall. The runoff from greenhouse is the minor part of return flow component due to the small–occupied area compared to those in the other fields. In addition, the irrigation water supplied to greenhouse is usually just a little amount of water for maintaining soil moisture within the field capacity, so that the runoff appears as low discharge of intermittent subsurface flow. It was found that in usual fine day of paddy season, the total return flow was about 10 mm/day, while in heavy rain day the value could reach 80 mm/day.

Assessment of Return Flow Characteristics

Figs. 8 and **9** depict results of simulation on flow distribution of water cycle in the whole system. The figures show the value of each flow component in mm/day calculated in the average value of daily flows obtained by simulation run for paddy season and non–paddy season of 1997. The unit of mm/day was derived with respect to the occupied area of paddy fields in each block. The unit of discharge for the main canal (mm/day) was defined with reference to the total paddy fields area of the study site.

It can be seen from the figures that the returned water from paddy fields took the dominant part of return flow for both paddy and non–paddy seasons. In the period of non–paddy season, paddy fields change to be a cultivated area for upland crops, such as wheat, barley and onion, in which the rain feed irrigation seems to be enough for such kind of crops. Because of there was mostly no irrigation water supplied to paddy fields during non–paddy cultivation period, the amount of return flow was strongly affected by the rainfall. This phenomenon was indicated by the decrease in the amount of return flow, because the returned water appeared as low rate of seepage runoff only.

The same characteristics of return flow were also obtained for upland fields. The returned water from upland fields decline with the decrease in the amount of rainfall. This tendency was verified by the low discharge of return flow during non–paddy cultivation.

As has been discussed in the previous section, due to the small size of occupied area and the limited irrigation water supply, the returned water from greenhouse appeared as insignificant amount of return flow component. During non–paddy season, greenhouse agriculture was cultivated more intensively than its in paddy season that resulted in increase of irrigation water supply through pumping system as well as increase in the amount of return flow.

Return flow from settlement area depends on the amount of rainfall, the value of runoff coefficient and size of the area. In this study, we considered an assumption that the drainage area of settlement in all of blocks was uniformly. Therefore, the value of return flow varied only with the size of occupied area for settlement. Return flow

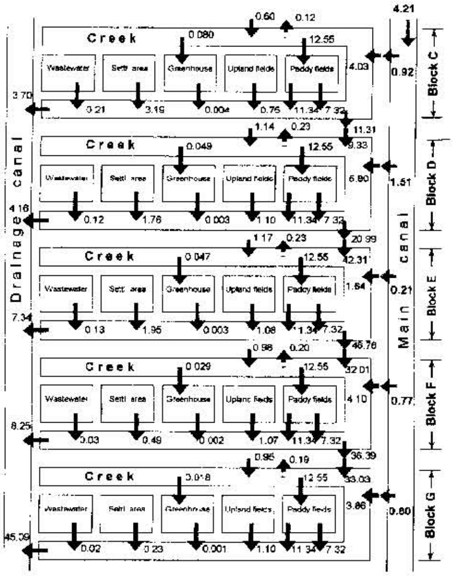

Fig. 8. Flow distribution of cyclic water for paddy season of 1997

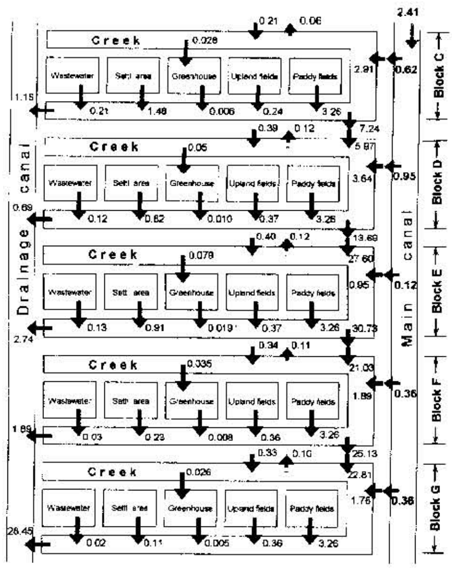

Fig. 9. Flow distribution of cyclic water for non–paddy season of 1997

originated from wasted water was just a constant amount of returned water obtained by the multiplication of number of population and individual domestic water demand. For the analysis we used 300 l/day per population of the domestic water demand.

Observing the results shown in **Figs. 8** and **9**, all of the identified actual phenomena were realized by the analysis of the characteristics of return flow in the surveyed area.

Performance of The Irrigation System Obtained by The Existing Water Operation

In order to elucidate how much the actual operation of irrigation system conserved water resources, it is necessary to apply several quantitative measures of performance of water operation. In this study, we used ratio of water use (Rwu) defined as the total amount of water supply for the irrigated area taken from creek storage, divided by the amount of water allocated from the main canal to creek network.

We evaluated also ratio index of effective return flow to the amount of usable water in creek network (Riu). The effective return flow was defined as the total amount of returned water in a concerning block including flow from the upper block, reduced by the amount of water flowed out of creek storage. The usable water in creek network is the summation of effective return flow and water supply from the main canal. This ratio index is useful for observing the contribution of return flow as reusable irrigation water, thought that the available water in creek storage consisted of original irrigation water supplied from main canal and returned water to concerning block including return flow from upper block reduced by the amount of water flows out of concerning creek network.

It is interesting to clarify the composition of return flow from paddy fields (Rp),

Table 2. Characteristics of return flow and performance of water use during paddy season of 1997

Index	Block				
	C	**D**	**E**	**F**	**G**
Rwu	3.134	2.172	7.681	3.068	3.256
Riu	0.659	0.501	0.859	0.650	0.673
Rp (%)	81.79	60.25	29.09	35.70	35.18
Rnp (%)	18.21	9.63	4.93	3.05	2.55
Rub (%)	0.00	30.12	65.97	61.25	62.27

non–paddy fields (*Rnp*) as well as flow from the upper block (*Rub*) in each concerning block. These fraction ratios were stated in percentage value of each return flow component, respectively. As the study was focused on paddy plant as the main crop, these measures were calculated exploiting the results of simulation run for paddy season of 1997. The results of calculation are summarized in **Table 2**.

Surprisingly, the total amount of irrigation water applied to paddy fields and greenhouse was much higher than the actual amount of water supply delivered from the main canal to creek network. This interesting feature was marked by the great values of *Rwu* in each block that was higher than one. The implication is that the actual measured efficiency of water use was over 100%. The most effective water use was found in block **E**, with the value of *Rwu* was 7.681. The reason is that the area of paddy cultivation in block **E** is much lower than it's in block **D** with the result that block **E** receives a large amount of return flow from block **D** through the creek network.

Observing values of *Riu* as drawn in **Table 2**, it could be noticed that return flow contributed a significant amount of water available in creek network. The results clearly explain that in all of blocks the amount of return flow were more than half of water stored in creek. Similar to the obtained result for *Rwu*, block **E** performed the largest value of *Riu*, showing the highest yield of irrigation water conservation.

The value of *Rp* varied with the area of paddy cultivation in each block and ranged of 29.09–81.79%. In this case block **E** performed the lowest percentage value of *Rp*. It was caused by the small area of paddy fields in block **E** compared to the others and there was a large amount of water flowed from block **D** as return flow component of block **E**. The value of *Rnp* was characterized by the data of settlement area. The value decreased with both the area and number of population.

Return flow from the upper block (*Rub*) seems to increase in the lower block as shown in **Table 2**. It indicates that the returned water was accumulated at the downstream part of the area. It has to be noticed that there was no runoff from the upper block to the creek network of block **C**, as shown by 0% value of *Rub*. In block **C**, return flow originates from its concerning area only, because of this block is isolated to the upper block of cultivation area (block **B**).

CONCLUSIONS

In this study, complex Tank model was proposed and has been demonstrated to clarify the reuse mechanism of irrigation return flow. Concerning the existence of creek networks, the model proved possibility of identifying the characteristics of return flow related to the efficiency of irrigation water use.

The actual operation of the irrigation system in the surveyed area showed a successful effort in conserving the irrigation water resources for paddy rice cultivation. The performance of water operation was marked by the considerably great values of the ratio of water use (*Rwu*), in which the calculated values for all of blocks were over 100%.

It was also proven that the effective return flow contributed significantly as reusable irrigation water. This interesting phenomenon was characterized by the high values of ratio index of the effective return flow to the amount of usable water in creek network (*Riu*).

Concerning return flow components, the results showed that runoff from paddy fields appear more dominantly than the returned water originated from non–paddy fields. The percentage value of return flow from the upper block tended to increase toward the downstream area, showing the recycle use of irrigation water accumulatively occurred at the lower block of creek networks.

REFERENCES

M. Kuroda and T. Fukuda 1996 Reuse Mechanism of Irrigation Return Flow and Water Quality Maintenance in Low Lying Paddy Area, *Transactions of the 16th Congress on ICID*, vol. 1C, pp. 167–180.

Nagai, A. and M. Kadoya 1980 *Journal of JSIDRE*, vol. 48, pp. 851–856 (in Japanese).

R. Jayadi, T. Fukuda and M. Kuroda 1998 Reuse Mechanism of Irrigation Return Flow and Its Impact on Water Quality, *Proceeding of the 11th Congress of APD–IAHR*, vol. 1, pp. 221–230.