MANAGEMENT OF IRRIGATION SYSTEMS FOR RICE DOUBLE CROPPING CULTURE IN THE TROPICAL MONSOON AREA

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ABSTRACT

In the tropical monsoon area, the existence of a reservoir ensuring water supply for the dry season by storing excess water during the wet season is indispensable for the practice of rice double cropping. Water management in an irrigation system with a reservoir should be functioning effectively from the water source to the terminal lots. The irrigation system ought to be operated so as to distribute timely the required irrigation water to the fields. Water saving attempt at the terminal level should contribute to the reduction of the dependence on reservoir water. Management of the conveyance and distribution system has a significant meaning in connecting the supply and demand organically. The time lag of water running in the system which is an important factor determining the loss of irrigation water in the system itself ought to be kept in mind all the time for the dam operation. In this paper, several aspects which ought to be considered for improving the management of irrigation systems with a reservoir are discussed based on the studies which were carried out in the Muda Irrigation Scheme of Malaysia and the dry zone area of Sri Lanka.

Components of water management in water consumption

In terminal paddy fields, water requirement must make provision for the loss due to evapotranspiration (ET), seepage, percolation and runoff. These losses can be divided into two parts, i.e. unavoidable losses and avoidable losses. ET, percolation and normal seepage are unavoidable losses. Runoff and seepage due to over-irrigation, uneven distribution and poor farm management can be considered as avoidable losses and should be minimized by proper management. In this chapter, only avoidable losses are discussed.

1 General trend of field intake

Generally, a farmer tends to introduce as much water into his field as possible and to drain the excess water off. This trend becomes increasingly conspicuous when the terminal irrigation and drainage system is improved and water can be easily controlled in each individual field.

In the tertiary development area of the Muda Irrigation Scheme, fields located in the upper stream of the terminal irrigation canal tend to retain a large quantity of water. Conversely, fields located downstream tend to retain a small quantity of water. Namely, fields located in the upper stream can easily take in a large quantity of water due to the hydraulic gradient between the tertiary canal and fields. Accordingly, fields located downstream are compelled to take in a small quantity of water (KITAMURA *et al.*, 1984). A similar trend was recognized in the dry zone area of Sri Lanka (KITAMURA, 1984).

2 Seepage and runoff

According to the water balance study (Table 1) in the tertiary development area of the Muda Irrigation Scheme, the average daily runoff and seepage accounted for 4.4 mm/day or 41.5% of the average daily water consumption amounting to 10.6 mm/day during the supplementary supply period in the off-season of 1984 (KITAMURA *et al.*, 1984). The characteristics of runoff including seepage in a tertiary development area, of which the canal

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Table 1 Water balance in the ISA A, SCRBD5b during the 1984 off-season (Unit: mm), Muda area, Malaysia

Period	Days	Water supply			Water consumption		
		IR[1]	RF[2]	Total	ET[3]	VS[4]	DR[5]
Presaturation supply (39 days)							
1 - 10 March	10	97.0	5.0	102.0	24.2	78.7	-0.9
11 - 20 March	10	101.9	47.4	149.3	37.4	48.7	63.2
21 - 31 March	11	92.0	54.6	146.6	50.4	52.3	43.9
1 - 8 April	8	73.7	43.1	116.8	40.6	2.5	73.7
Sub-total	39	364.6	150.1	514.7	152.6	182.2	179.9
(%)		70.8	29.2	100.0	29.6	35.4	35.0
Supplementary supply (145 days)							
9 - 20 April	12	16.6	309.2	325.8	55.9	45.4	224.5
21 - 30 April	10	0.0	41.7	41.7	57.7	-97.1	81.1
1 - 10 May	10	39.0	48.2	87.2	55.0	4.1	28.1
11 - 20 May	10	55.2	82.5	137.7	56.5	26.1	55.1
21 - 31 May	11	29.5	31.7	61.2	59.2	-5.9	7.9
1 - 10 June	10	19.4	123.9	143.3	41.7	36.9	64.7
11 - 20 June	10	19.5	78.2	97.7	63.5	-10.4	44.6
21 - 30 June	10	0.0	60.4	60.4	58.8	-3.1	4.7
1 - 10 July	10	7.6	24.3	31.9	62.2	-41.7	11.4
11 - 20 July	10	11.0	187.1	198.1	47.7	46.3	104.1
21 - 31 July	11	0.0	71.0	71.0	60.6	-37.5	47.9
1 - 10 August	10	0.0	87.0	87.0	56.8	0.0	30.2
11 - 20 August	10	0.0	17.1	17.1	51.9	-73.9	39.1
21 - 31 August	11	0.0	18.4	18.4	50.0	-54.3	22.7
Sub-total	145	197.8	1180.7	1378.5	777.5	-165.1	766.1
(%)		14.3	85.7	100.0	56.4	-12.0	55.6
Total	184	562.4	1330.8	1893.2	930.1	17.1	946.0
(%)		29.7	70.3	100.0	49.1	0.9	50.0

1) IR: irrigation supply
2) RF: rainfall
3) ET: evapotranspiration
4) VS: variation of total existing water in field
5) DR: drainage including seepage and percolation

density is 25 m/ha, during the growing period of rice plants can be shown by the multiple regression model represented by Eq (1) in Table 2. Fig. 1 shows the statistical unit hydrograph during the growing period of rice plants in the off-season. It is obvious from the hydrograph that the water supply in the previous day exerts an influence on the runoff of the next day, although the water supply in a given day does not affect appreciably the runoff in the same day. The maximum time lag between water supply and runoff is 7 days in this case. The runoff characteristics from fields depend on farmers' field management as well as topography and canal density. For economical water use, the time lag between the water supply and its peak runoff should be kept as long as possible when the drainage problem is not critical.

In the dry zone area of Sri Lanka, the average daily runoff accounted for 6.2 mm/day or 16.7% of the average daily water consumption during the growing period of rice plants in the 1979 Yala season and 15.7 mm/day or 38.7% in the 1979/80 Maha season (KITAMURA and EZAKI, 1983; KITAMURA, 1984). The high runoff during the Maha season can be ascribed to the inadequate use of rain water in fields. Namely, farmers frequently continue to introduce water into their fields without controlling the inlet regardless of the weather. Thus, in this case, valuable rain water is treated as excess water and drained off.

Table 2 Multiple regression models for runoff, variation of TEW[1], and water requirement in the tertiary development area, Muda Irrigation Scheme, Malaysia

Items	Equations	MCC[2]	Variables	
Runoff	Y(t)=0.338+0.012X(t)+0.202X(t-1)+0.117X(t-2) +0.091X(t-3)+0.056X(t-4)+0.025X(t-5) +0.030X(t-6)+0.024X(t-7) ..... (1)	0.766	Y(t):	estimated runoff including seepage on date t(mm)
			X(t):	total water supply on date t(mm) X(t)=IR(t)+RF(t) IR(t): irrigation supply on date t(mm) RF(t): rainfall on date t(mm)
Variation of TEW[1]	VS(t)=-6.338+1.029X(t)-0.223X(t-1)-0.157X(6-2) ..... (2)	0.930	VS(t):	variation of TEW[1] on date t(mm)
			X(t):	water supply on date t (including rainfall) (mm)
			X(t-i):	water supply on date t-i (including rainfall) (mm)
Water requirement	X(t)=6.159+0.217X(t-1)+0.153X(t-2)+0.972VS(t) ..... (3)	0.930	X(t):	water requirement on date t (mm)
			X(t-i):	water supply on date t-i (including rainfall) (mm)
			VS(t):	variation of stored water aimed at on date t (mm)

Note: 1) TEW: Total existing water = standing water + existing water in the soil.
2) MCC: Multiple correlation coefficient.

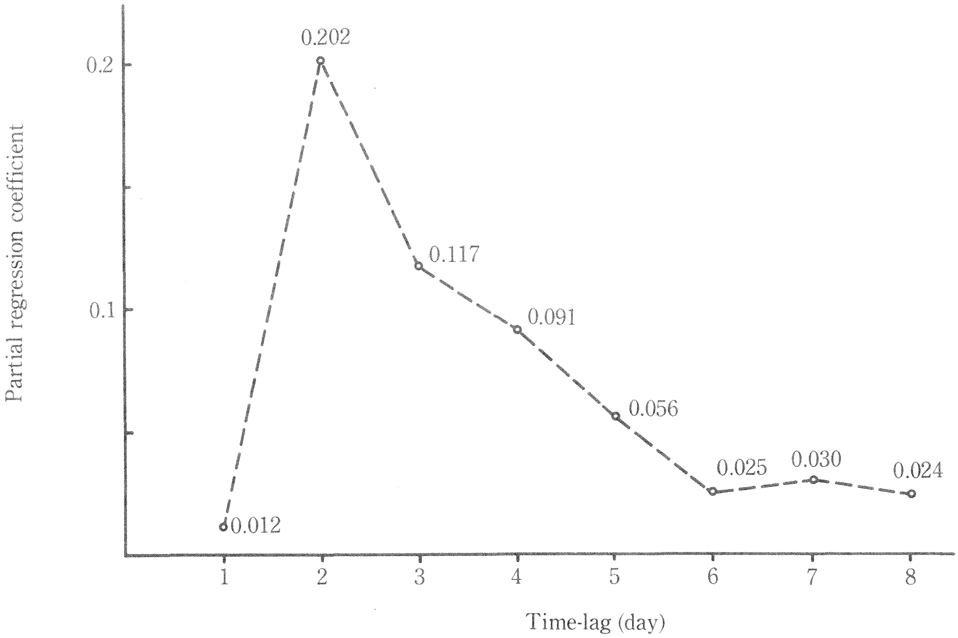

Fig. 1 Statistical unit hydrograph for paddy field runoff (including seepage) in the tertiary development area of the Muda Irrigation Scheme, Malaysia.

3 Economical water management and land consolidation

As an economical irrigation method, intermittent irrigation is usually adopted during dry spells in the dry zone area of Sri Lanka. In the Rajangana Scheme, intermittent irrigation is commonly adopted in the Yala season. Based on the water balance study carried out during the growing period of rice plants in the 1979 Yala season in the Rajangana Scheme, surface runoff of nearly 500 mm was observed. Based on this study, intermittent irrigation did not appear to be a suitable measure for saving water. When intermittent irrigation is practiced, each lot should substitute its plot-to-plot irrigation method for the ponding irrigation method so as to avoid waste of water. However an ordinary lot is irregularly divided into a large number of small plots by dykes of poor quality in the dry zone (for example, 52 plots/0.7 ha in Lot No. 219 of Tract 2 in L.B. of the Rajangana Scheme, 110 plots/2 ha in Lot No. 6 of Tract 2 in the Dewa huwa Scheme). It is very difficult to control irrigation water in each plot due to the large number of plots. In the case of the Dewa huwa Scheme, it took more than two hours for two persons working actively to interrupt the water movement of 110 plots in a 2.0 ha lot. Namely, it is physically impossible to interrupt the water movement and to substitute plot-to-plot irrigation for ponding irrigation in each plot even though the intermittent irrigation method is adopted. This would result in a considerable surface runoff. Under the current conditions of terminal fields, intermittent irrigation is not advantageous. In order to promote economical water management in a terminal field, land consolidation should be given priority.

The effectiveness of land consolidation on economical water management was investigated by comparing a consolidated lot with an adjacent non-consolidated lot in the Dewa huwa Scheme. Based on the investigation, the advantages of land consolidation for economical water management were as follows:

(1) Land consolidation enables to achieve proper water management by rearranging and converting "a large number of small and irregularly distributed plots" into "a small number of large and well distributed plots" in a lot. Accordingly, consolidation work in paddy fields further increases the benefit of the application of the intermittent irrigation method.

(2) In the process of implementation of land consolidation, paddy soil compacted and puddled by heavy machinery results in the reduction of percolation and dyke-leakage.

In addition to the above advantages for economical water management, land consolidation leads to the improvement of land and labor productivity and conservation, etc.

4 Tertiary development and farm management

At present, the tertiary development project (Muda II project) which aims at increasing the canal density from a level of 10 m/ha to 30-35 m/ha in a fifteen year period is making good progress. The main purpose of the Muda II project is to promote water movement and to decrease the water requirements by shortening the presaturation period physically by increasing the canal density. Actually, the water balance study carried out in the SCRBD5b Muda II block during the off-season of 1984 confirmed that the tertiary system fulfilled its above-mentioned function (KITAMURA *et al.*, 1984). However, due to the considerable delay in the field activities, such as land preparation, transplanting, and direct sowing, the effect on rice cropping has not been demonstrated. Namely, the supplementary supply period following the presaturation period is often prolonged resulting in the increase of water consumption. It is necessary that the farmers realize that good farm management is essential for the successful performance of the tertiary system. Land improvement including the construction of a terminal irrigation and drainage system (hardware) should be followed by proper farm management (software).

5 Tentative proposal for water management in the Muda II block

Based on the water balance study carried out in the SCRBD5b Muda II block (KITAMURA, 1985), the regression equation (2) in Table 2, which depicts the relationship between the water supply and the variation of total existing water (TEW) for the supplementary supply period, was derived. Based on equation (2), the movement of water supplied in paddy fields can be analyzed very precisely. The first constant term on the right hand side of the equation refers to the sum of evapotranspiration and percolation. The second term refers to the direct increment of TEW during the day in relation to the water supply on the same day. The third and fourth terms refer to the decrease of TEW during the day by surface runoff and seepage of the water supplied on the previous day and two days before, respectively. Eq(2) can be transposed and arranged as Eq(3) (Table 2). This equation can be used for the calculation of the water requirement of a given day. In Eq(3), X(t-1) and X(t-2) are known and VS(t) is the variation of stored water aimed at in the field on a given day. Eq(3) can be readily applied for the water management during the supplementary supply period in the Muda II block. As an equation for water management, Eq(3) should be modified in proportion to the improvement of farmers' management. However, under the present farm management level, Eq(3) can be applied tentatively for water management in the Muda II blocks under similar conditions to those prevailing in SCRBD5b.

Components of water management for water supply

1 Reservoir inflow

Rice double cropping culture in the tropical monsoon area depends upon the volume of water stored in a reservoir (KITAMURA and NAKAYAMA, 1985). This is especially true for the dry season crop, which cannot be planted without receiving an adequate supply of water from the dam due to the low amount of rainfall during this season.

In the Muda Scheme, the 1978 off-season crop had to be cancelled over the entire Muda area for this reason, and in 1983 and 1984, half of the Muda area could not obtain irrigation water for the off-season crop. In recent years, the shortage of reservoir water which has occurred annually, is one of the most serious constraints on the establishment of stable rice double cropping culture in the Muda area. Therefore, it is very important for the proper management of an irrigation system to evaluate the potential of reservoirs for irrigation supply in the Muda area and to determine the difference between the designed annual inflow and actual annual inflow, quantitatively. Exceedance probability of actual annual inflow was plotted on the basis of fourteen year data together with that of the designed annual inflow, as shown in Fig. 2.

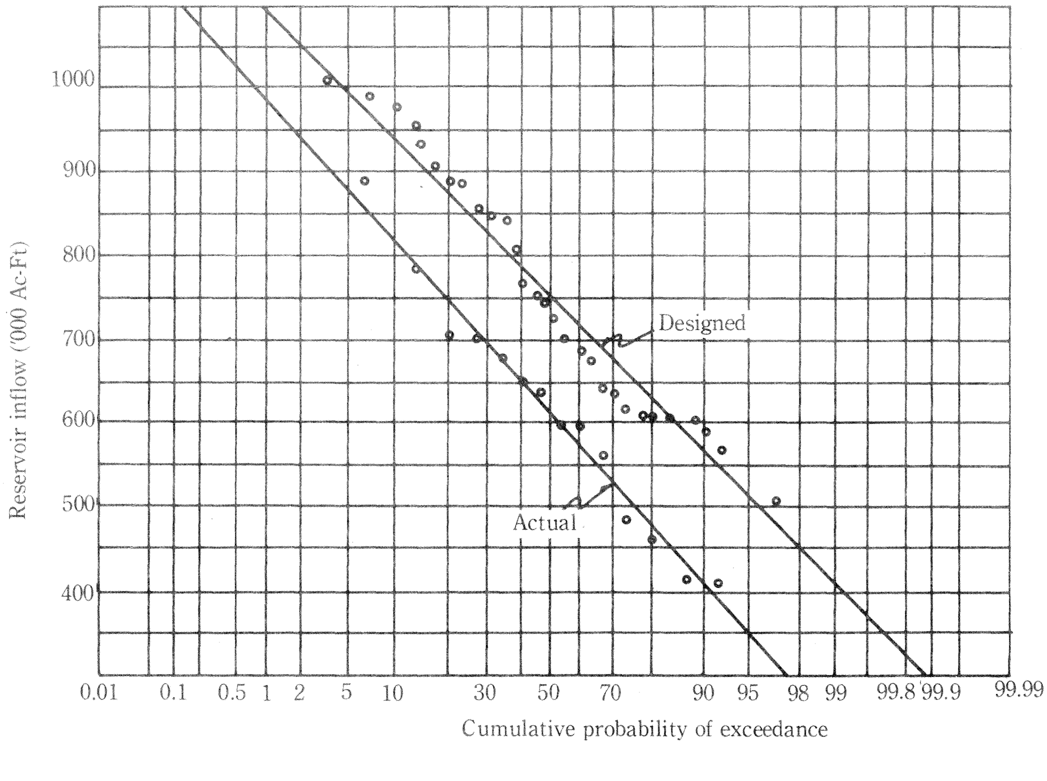

Fig. 2 Exceedance probability of reservoir inflow, Muda and Pedu Dams, Malaysia.

According to Fig. 2, it is expected that the actual inflow from the catchment area of the dams will be only 600×10^3Ac.Ft ($740\times10^6m^3$ or 640.7 mm) in contrast to the designed annual inflow of 750×10^3Ac.Ft ($925\times10^6m^3$ or 800.9 mm) in a normal year with a probability of exceedance of 50%. Undoubtedly, the actual inflow is 20% lower than the originally designed inflow. Namely, a stricter dam management is required so as to compensate for the deficiency of water resources as well as the adoption of water recycling measures, effective use of uncontrolled river flow and rainfall, etc.

Runoff percentage in the catchment area of the two dams ranges between 20% and 37%. Rainfall loss, i.e. the difference between the amount of rainfall and runoff ranges from 1,300 to 1,900 mm/year or from 3.6 to 5.2 mm/day. This amount of rainfall loss is consumed in the form of evapotranspiration from the catchment area (Fig. 3).

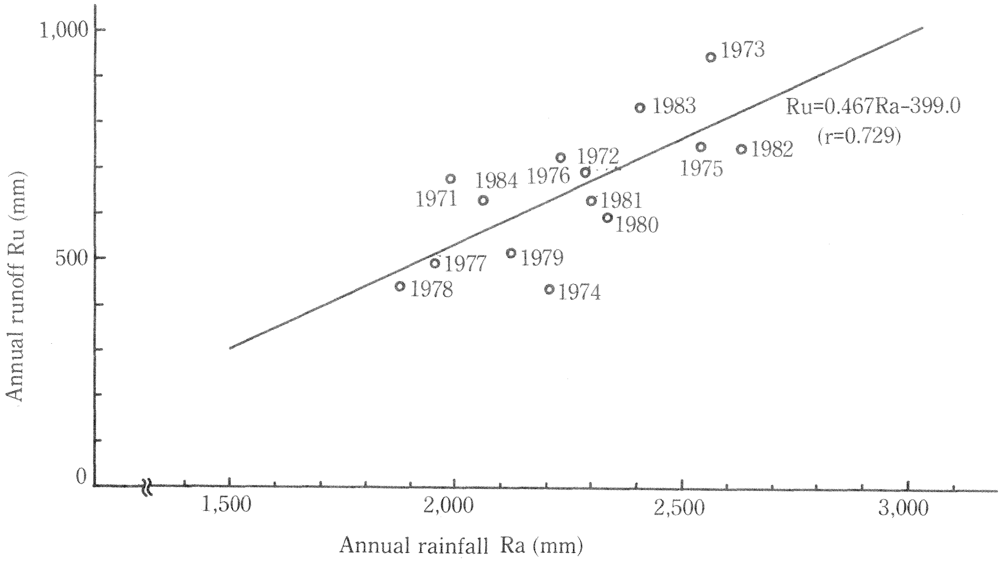

Fig. 3 Relationship between annual rainfall and annual runoff in the catchment area of Muda and Pedu Dams (Muda Irrigation Scheme, Malaysia).

Schedule of water release from the reservoir should be set up over a long period of time in considering the water demand, rainfall amount in the irrigation area and reservoir inflow. For the setting of the schedule of water release from the reservoir, it is necessary to design a runoff forecasting system. From the rainfall-runoff analysis, the multiple regression equations (4)—(7) in Table 3 were derived. These equations can be used for the setting of the schedule of water release from the reservoir by forecasting the runoff.

2 Uncontrolled river flow (side flow)

The uncontrolled river flow (side flow) should be used for irrigation as effectively as possible so as to save reservoir water. As a general rule, the uncontrolled river flow has to be introduced into the irrigation area prior to the reservoir water. If the time lag of water flowing in the conveyance and distribution system is L hours, the water from the reservoir should be released L hours earlier than the start of demand. As the uncontrolled river flow has to be estimated earlier than the reservoir release, the runoff forecasting system plays a very important role. In the Muda Irrigation Scheme, a telemetry system has been set up recently for the effective use of uncontrolled river flow. However, the runoff forecasting system has not been developed yet. Rainfall-runoff analysis was carried out in the adjacent dam basin of which area is almost the same as the catchment area of the uncontrolled river flow (KITAMURA and NAKAYAMA, 1985). The runoff forecasting equations for various periods are shown in Table 3.

Table 3 Multiple regression models for runoff in the catchment area of Muda and Pedu Dams, Malaysia

Items	Equations	MCC[1]	Variables	
Monthly runoff	Ru(t)=-111.688+0.286r(t)+0.103r(t-1)+0.122r(t-2)+0.105r(t-3) +0.080r(t-4)+0.064r(t-5)+0.044r(t-6)+0.075r(t-7)...(4)	0.882	Ru(t): r(t-i):	estimated runoff during the one-month period t (mm) actual rainfall during the one-month period t-i (mm) (i=0, 1, ... 7)
10-day runoff	Ru(t)=-10.921+0.200r(t)+0.047r(t-1)+0.041r(t-2)+0.018r(t-3) +0.013r(t-4)+0.029r(t-5)+0.032r(t-6)+0.032r(t-7) +0.044r(t-8) ..... (5)	0.786	Ru(t): r(t-i):	estimated runoff for a period of 10-day t (mm) actual rainfall for a period of 10-day t (mm) (i=0, 1, ... 8)
5-day runoff	Ru(t)=-5.206+0.164r(t)+0.066r(t-1)+0.014r(t-2)+0.012r(t-3) +0.019r(t-4)+0.014r(t-5)+0.008r(t-6)+0.011r(t-7) +0.001r(t-8)+0.023r(t-9)+0.014r(t-10)+0.010r(t-11) +0.004r(t-12)+0.028r(t-13)+0.020r(t-14)+0.013r(t-15) +0.027r(t-16) ..... (6)	0.766	Ru(t): r(t-i):	estimated runoff for a period of 5-day t (mm) actual rainfall for a period of 5-day t-i (mm) (i=0, 1, 2, ... 16)
Daily runoff	Ru(t)=-0.1829+0.09727r(t)+0.06308r(t-1)+0.02087r(t-2) +0.01152r(t-3)+0.01062r(t-4)+0.00843r(t-5) +0.00819r(t-6)+0.00698r(t-7)+0.00355r(t-8) +0.00473r(t-9)+0.00330r(t-10)+0.00361r(t-11) +0.00595r(t-12)+0.00414r(t-13)+0.00012r(t-14) +0.00054r(t-15)+0.00110r(t-16)+0.00581r(t-17) +0.00674r(t-18)+0.00543r(t-19)+0.00276r(t-20) +0.00536r(t-21)+0.00581r(t-22)+0.00275r(t-23) +0.00653r(t-24)+0.00742r(t-25)+0.00732r(t-26)..... (7)	0.700	Ru(t): r(t-i):	estimated runoff on date t (mm) actual rainfall on data t-i (mm) (i=0, 1, 2, ... 26)

Note: 1) MCC: Multiple correlation coefficient.

These equations seem to be applicable as a tentative runoff forecasting system.

3 Rainfall in the irrigation area

Rainfall plays an important role in the operation of rice double cropping, because rainfall brings water directly to the paddy fields without any time lag. Thus, rainfall is more effective than irrigation water which involves conveyance loss and time lag from the reservoir to the paddy fields. Rainfall should be used in the paddy fields prior to reservoir water. In order to determine when water should be released from the reservoir, the average amount of rainfall in an irrigation area should be calculated as early as possible. However, it is very difficult to determine the average rainfall in a large irrigation area located in the tropical monsoon area, due to the rainfall characteristics. The rainfall is quite erratic, especially in the dry season. Localized rain is one of the characteristics of the rainfall pattern in the tropical monsoon area. Thus, it is necessary to analyse factors including location dependence, locational variations, and locational correlation of rainfall quantitatively. In the Muda area, the changes in the correlation coefficient with the distance of rainfall between two among nine rainfall stations were analyzed, as shown in Fig. 4. (KITAMURA *et al.,* 1984). Based on the rapid decrease of the correlation coefficient with the distance shown in Fig. 4, it is possible to determine the rainfall

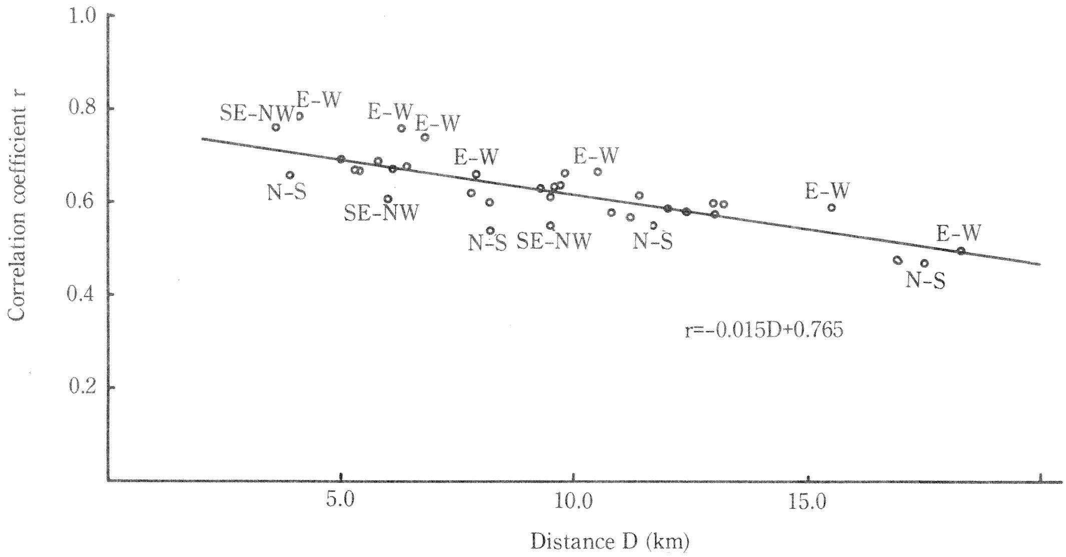

Fig. 4 Changes of correlation coefficient with distance in daily rainfall (Tunjang Drain Basin, Muda Irrigation Area, Malaysia).

characteristics in the Muda area where localized rain prevails. It is remarkable that the extent of the significance of linear correlation changes depends on the locational relation (direction) as well as the distance. In particular, in the case of the locational relation of the East and West directions, the linear correlation is becoming more highly positive. On the other hand, the linear correlation is becoming more negative for the locational relation of the North and South directions. It seems that this trend is closely related to the travelling direction and expanse of clouds which send rain. Such rainfall characteristics should be clarified and ought to be reflected for proper water management.

Management of conveyance and distribution system

1 Conveyance and distribution losses

1) Natural losses

It is very important to evaluate the natural losses such as seepage, percolation and evaporation losses in the conveyance and distribution system for the practical operation of an existing irrigation system as well as for the planning and design of a new irrigation project, especially in the tropical monsoon area, as most of the canals are made of earth. According to the study on the natural losses in earth canals carried out in the dry zone area of Sri Lanka, some trends are summarized as follows (Fig. 5) (KITAMURA, 1984; KITAMURA and EZAKI, 1984).

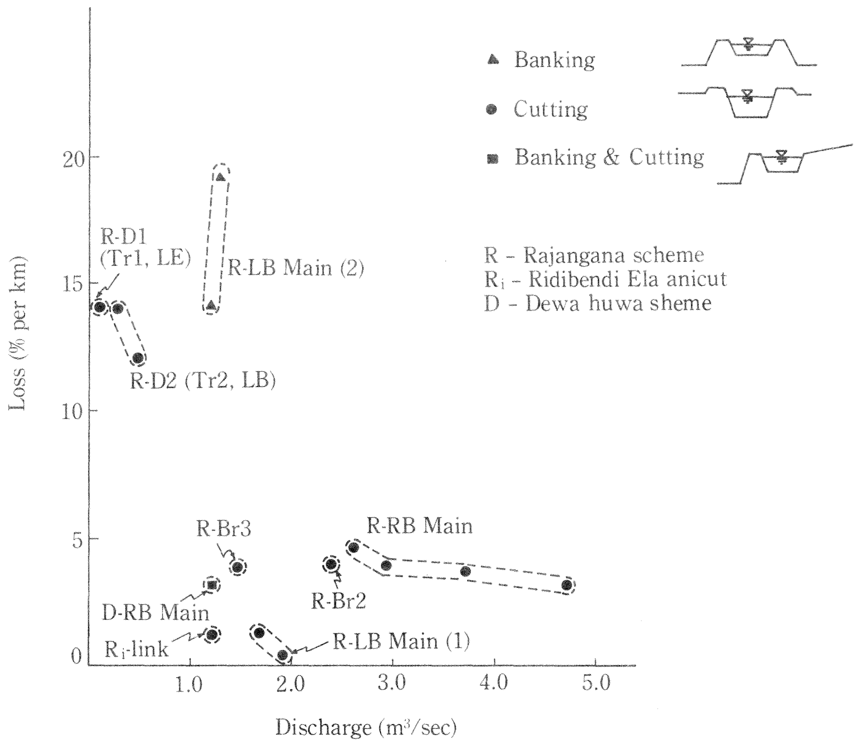

Fig. 5 Relationship between discharge and conveyance loss in irrigation channel in the dry zone, Sri Lanka.

(1) The natural losses in cut canals with a designed discharge of more than 1.0 m^3/sec which were constructed on reddish brown earths ranged from 0.5 to 4.7%/km with an average of 2.95%/km. Since a series of investigations on natural losses were carried out during a dry spell, the figures listed above are on the safe side for irrigation planning. If the canal runs on lowland as is the case for the Link Channel to Nikaweratiya, the losses decrease and average 1.0%/km.

(2) In the case of banked canals, the loss rate is higher than in cut canals for the following two reasons:

(a) The hydraulic gradient of seepage flow, i.e. the difference between the water level of the canal and that of the groundwater table, in a banked canal is usually larger than that of cut canals.

(b) Compaction is not effective enough to control seepage and percolation in many banked canals. Therefore, it is very important for the construction and maintenance of banked canals to control compaction.

(3) In small canals where the design discharge is less than 1.0 m^3/sec, the loss rate tends to be high owing to the lack of adequate operation and maintenance.

(4) The natural losses are in inverse proportion to the discharge in the same canal.

2) Operational loss

In addition to the natural losses, operational loss should be taken into account, especially in an irrigation area with a long conveyance and distribution system such as the Chao Phraya-Meklong Project in Thailand and the Muda Irrigation Project. The time lag of water flowing in the system is an important factor which determines the loss of irrigation water in the system itself. The flowing time of water from the reservoir to the irrigation area is about 5 days in the Chao Phraya-Meklong Project (Royal Irrigation Department, 1982) and 27 hours in the Muda Project (KITAMURA *et al.,* 1984). Operational loss increases with the repeated release and interruption of release of water from the reservoir. Operational loss for release can be calculated by the following equation (refer to Fig. 6):

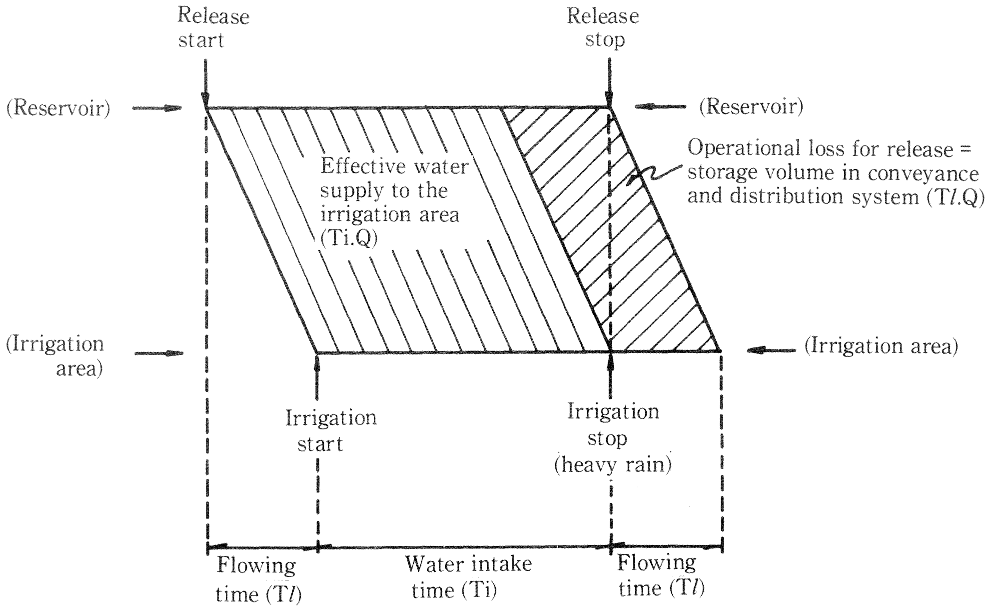

Fig. 6 Operational loss for release (under constant discharge).

$$O.L(\%) = \frac{Tl.Q}{(Ti + Tl).Q} \times 100 = \frac{Tl}{Ti + Tl} \times 100 \quad \ldots\ldots (8)$$

where O.L : operational loss for release (%)

Q : average release discharge
Ti : necessary hours for release to meet the water demand in the irrigation area
Tl : flowing time of water in conveyance and distribution system

For example, when water release from a reservoir is interrupted after three days of continuous release due to rain in the irrigation area of the Muda Scheme, the operational loss for this release, which can be calculated by Eq(8), amounts to 27.3%. The most effective measure to reduce the operational loss in the conveyance and distribution system is to build a proper regulating reservoir in an appropriate area of the system. In the Aichi Irrigation Project of Japan, the operational loss in the main canal, whose total length is 112 km, was reduced from 35% to 5% by the construction of a regulating reservoir (YUKAWA, 1972). However, it is very difficult to identify a suitable area ensuring the necessary storage capacity in the tropical monsoon zone. Even in the Muda Scheme, a suitable area for the construction of a regulating reservoir can not be easily found. Therefore, the storage function of all the canals, drains and paddy fields should be used effectively in future so as to store the water released from the reservoir that is usually drained to the sea, which requires the farmers' understanding and cooperation in the whole irrigation area.

2 Existing problems and measures to improve the management of conveyance and distribution systems

Based on the investigation on impartiality of water distribution among diversion works in the secondary canals as well as the main canals in the dry zone area of Sri Lanka, the following trends were confirmed (KITAMURA, 1984; KITAMURA and EZAKI, 1984).

(1) Diversion works located in the upper stream of main and secondary canals take in a large quantity of water in comparison with those located downstream (Fig. 7a).
(2) Diversion works supplying a small area take in a larger quantity of water than those supplying a large area (Fig. 7b).

The first trend is due to the considerable difference between the actual coefficient of roughness of the canal and the designed coefficient of roughness. Namely, while the designed coefficient of roughness was 0.025, the actual coefficient of roughness was 0.038 in the Branch Channel 2, and 0.037 in the Branch Channel 3 respectively, in the Rajangana Scheme. These actual values of coefficient of roughness were even larger than the designed value for natural river. To keep the impartiality in water distribution, the coefficient of roughness should be maintained at the designed level by appropriate management. The second trend is due to the structure of small diversion works of which gate-opening can be adjusted only in limited stages. For impartial water distribution, all diversion works should be improved in order that their gate-opening can be adjusted continuously.

In the Muda area, usually one operator is in charge of a major structure such as regulator and diversion works in order to operate the structure at specific intervals. Actually, the gate operation of each structure is performed every four hours if necessary in the daytime, i.e. 7.00 am, 11.00 am, and 3.00 pm (Muda Agricultural Development Authority, 1977). It seems that there are two problems in this operation rule. One is the uniformization of the operation time in the entire Muda area, the other is the short interval, i.e. only four hours, between the operation time in the daytime. If all the irrigation structures are simultaneously operated in the entire Muda area, the flow of all the canal system changes to an unsteady condition instantaneously. In this case, even if the gates are adjusted for the required discharge at each structure, the discharge changes immediately far from the originally adjusted discharge. Therefore, it is important to manage irrigation structures in due consideration of the locational relations of all the structures and water flowing time in a series of conveyance and

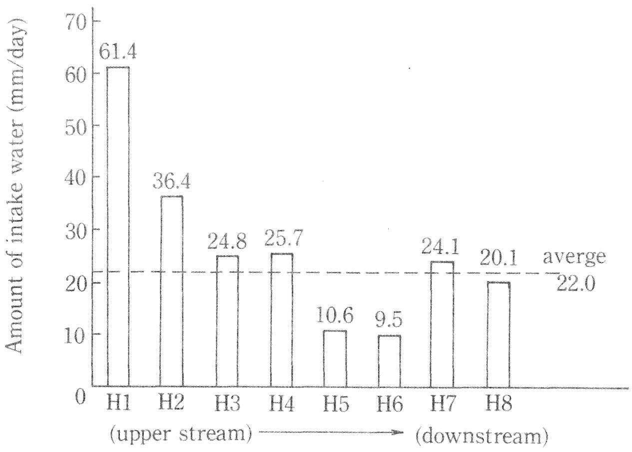

Fig. 7a **Amount of intake water at the head of each distributary channel, Jan. 10-11, 1980 (Maha). (High Level Main Channel, Nachchaduwa, Sri Lanka).**

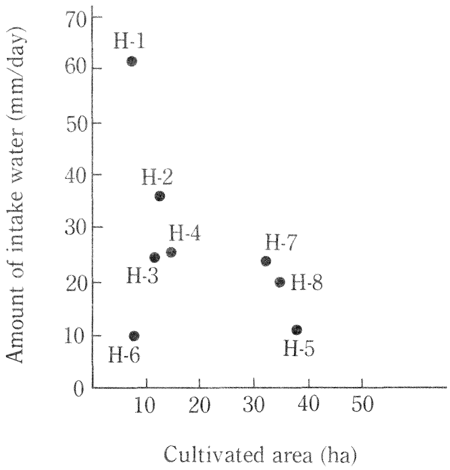

Fig. 7b **Relationship between amount of intake water and cultivated area, Jan. 10-11, 1980 (Maha). (High Level Main Channel, Nachchaduwa, Sri Lanka).**

distribution systems. It frequently takes more than four hours for the flow to become steady after the gate adjustment. Based on simulations of the gate operation of the regulators in the northern Canal, when the flow passes over the gate under the condition of perfect overflow, the water level and the discharge become steady in a comparatively short time (within three hours). However, when the flow at the gate is under a submerged condition, it takes five or six hours for it to become steady (YOSHINO and TANJI, 1986). Accordingly in such a case, the next gate operation will be performed under unsteady flow conditions. The interval between the gate operations should be determined after due consideration based on a large number of simulation analyses. In each structure, the flow condition should be considered as well as the flowing time for determining the time and interval of operations.

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Discussion

Perez, A.T. (ADB): 1. Following your detailed study of the amount of water available in the Muda scheme reservoirs, is there enough irrigation water to achieve the full potential for 200% cropping intensity? 2. Could the improvement of the irrigation efficiency in the primary and secondary canals increase the supply of irrigation water to achieve the full potential of targetted cropping intensity? For example, could the lining of the main and secondary canals help reduce the conveyance loss?

Answer: 1. It seems that there is not enough irrigation water to achieve the full potential for 200% cropping intensity under the present conditions of water resources. Two alternatives could be proposed, namely to develop new water resources, which is costly or to promote water recycling in the irrigation area. 2. I believe that it will be very difficult to achieve the full potential of targetted intensity by only increasing the irrigation efficiency in the primary and secondary canals. Other measures such as the recycling of water, effective use of side flow should be adopted concurrently. Also more research in this field is essential.