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Rotational irrigation scheduling in rice paddy with the operation rule curve of irrigation reservoir

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Abstract

The state of drought was evaluated by the water level in irrigation reservoir. From the present water level and operation rule curve, it could be determined when to restrict the irrigation water supply and how to decide the amount of deficient irrigation water. With the help of the operation rule curve and weekly rainfall forecasting, the system of rotational irrigation scheduling in rice paddy during irrigation season has been proposed to mitigate the damage of drought more reasonably. The system could be also utilized as a software program of the tele-control works for irrigation water supply.

1. Introduction

The principle management rule of irrigation reservoir is to accelerate the water use and supply water fully when water is sufficient, but to restrict the water use and supply water deficiently in order not to stop the irrigation activity even when water is scarce. But, the full irrigation has been a traditional pattern of irrigation even in the drought season.

In the sense, it is important for the water managers to know when to restrict the water supply and how to decide the amount of deficient irrigation water with regards to the rice growing stage and reservoir storage volume. But, proper operation rule of irrigation reservoir in the drought is not available.

In the study, the system of rotational irrigation scheduling in rice paddy was developed with the operation rule curve and the weekly rainfall forecasting. The system would be practically utilized as a software of the tele-control system for the automation facilities like Tele-metering and/or Tele-control installed in the irrigation reservoir.

2. Materials and methods

2.1 Summary of the Yedang reservoir

The Yedang reservoir has the watershed area of 37,360ha and its irrigation area is 8,788ha. The reference storage curve and the restricted release curve are made by analyzing hydrologic data(rainfall, reservoir water level, pan evaporation, temperature, relative humidity, sunshine duration, wind speed, and irrigated area) of past 30 years.

Table 1. Summary of the Yedang reservoir

Item	Unit	Value	Item	Unit	Value
Watershed area	Ha	37,360	Irrigation area	ha	8,788
Total storage	ha-m	4,710	Effective storage	ha-m	4,607
Full water level	El.m	22.5	Dead water level	El.m	14.5
Flood control level	El.m	21.5	Flood control volume	MCM	10

Fig.1. Yedang reservoir

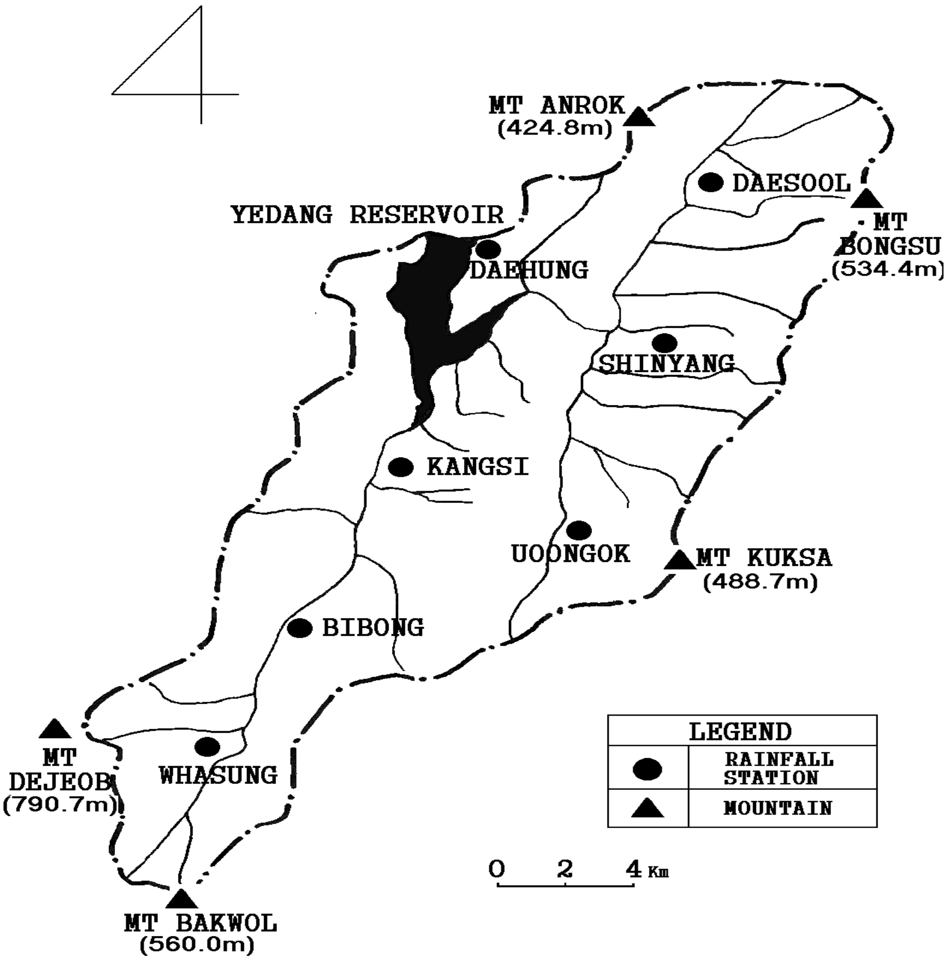


Fig.2. Watershed map of the Yedang reservoir

2.2 Operation rule curve

There are two kinds of irrigation methods in rice paddy. One is a full irrigation or a simple release irrigation to supply water as much as it needed if water is available. The other is a deficient irrigation or a restricted release irrigation to reduce the amount of irrigation water in order not to stop the supply of irrigation water even in a serious drought season.

The operation rule curve indicates the guideline when to restrict the supply and how to decide the amount of deficient irrigation water. The operation rule curve includes the reference storage curve and restricted release curve.

Reference storage curve

The amount of water deficit in a day or period in the equation 1 can be calculated by subtracting the gross of duty water from the inflow. Storage volume needed to meet the amount of water deficit can be added up from the end to the beginning of irrigation season in a reversed order. In this manner, a sequence of needed storage volumes in a certain day can be obtained from the 30 years of data available. Reference storage volume on that day and then reference storage curve which has a 10 years of frequency can be obtained in a irrigation reservoir.

$$DEF(i) = INF(i) - GDW(i) \quad (1)$$
$$STV(i) = STV(i+1) - DEF(i) \quad (2)$$
$$STV(i) < 0, STV(i) = 0 \quad (3)$$

where, i : day, INF : Inflow, GDW : Gross duty of water, DEF : Water deficit, STV : Storage volume

Restricted release curve

Water supply in a certain day should be restricted to keep the reservoir not to be empty during the irrigation season when the water level in the irrigation reservoir drop down to the level of reference storage curve. The ratio of restriction is determined with regards to the rice growing stage and present storage volume.

$$DEFS(i) = INF(i) - (1 - S) GDW(i) \quad (4)$$
$$STV(i) = STV(i+1) - DEFS(i) \quad (5)$$
$$STV(i) < 0, STV(i) = 0 \quad (6)$$

where, DEFS : Water deficit with restricted release ratio

2.3 Rotational irrigation system

The rotational irrigation system was proposed to overcome the severe drought by saving water.

Establish the drought warning scenario by the storage ratio

The drought warning scenario was established by the operation rule curve and present water level in the irrigation reservoir. For example, if the water level is located above the restricted release ratio of 0%, the state of drought assumed to be "Stand-by". If the water level is located below the restricted release ratio of 10%, the state of drought is assumed to be "Notice". If the water level is located between the restricted release ratio of 10 to 30%, the drought stage is assumed to be "Warning". If the water level is located between the restricted release ratio of 30 to 50%, the drought stage is assumed to be "Danger". If the water level is located below the restricted release ratio of 50% or higher, the state of drought is assumed to be "Special danger".

Propose the rotational irrigation system

With the help of information in the Internet regarding to climate forecasting and the restricted release ratio in the operation rule curve, the rotational irrigation system would be proposed and applied to mitigate the serious damage of drought more reasonably and practically.

If the state of drought is "Notice", it is enough to irrigate water with the amount of 10% reduction. But if the state of drought are "Warning", "Danger", and "Special danger", some special drought schemes of the rotational irrigation system should be introduced to overcome the serious drought as shown in the Table. 2.

Case 1. If the state of drought is "Warning", the irrigation area is divided into 3 blocks with the supply system of 4 day-on and 2 day-off, rotationally. In this case, irrigation water would be supplied with the amount of 20% reduction.

Case 2. If the state of drought is "Danger", the irrigation area is divided into 2 blocks with the supply system of 3 day-on and 3 day-off, rotationally. In this case, irrigation water would be supplied with the amount of 40% reduction.

Case 3. If the state of drought is "Special danger", the irrigation area is divided into 3 blocks with the supply system of 2 day-on and 4 day-off, rotationally. In this case, irrigation water would be supplied with the amount of 60% reduction.

Table 2. Drought warning scenario and rotational irrigation system

Operation rule curve	Restricted release ratio	State of drought	Water Supplied area	Water supply system
0% or lower	0%	Stand-by	whole area	Normal supply
0~10%	10%	Notice	whole area	10% restricted supply
10~30%	20%	Warning	3 blocks	4 days-on, 2 days-off
30~50%	40%	Danger	2 blocks	3 days-on, 3 days-off
50% or higher	60%	Special danger	3 blocks	2 days-on, 4 days-off

3. Result and discussion

With the help of information on the weekly rainfall forecasting and the restricted ratio by operation rule curve, the rotation irrigation system on the irrigation district map prepared by GIS could be proposed and applied to mitigate the serious damage of drought more reasonable and practically.

3.1 Reference storage curve

The drawing process of reference storage curve in a frequency of 10 years was shown in the Fig.3. The average infiltration of 3mm/day and management loss of 20% were applied for the hydrologic data of past 30 years(1966~1995).

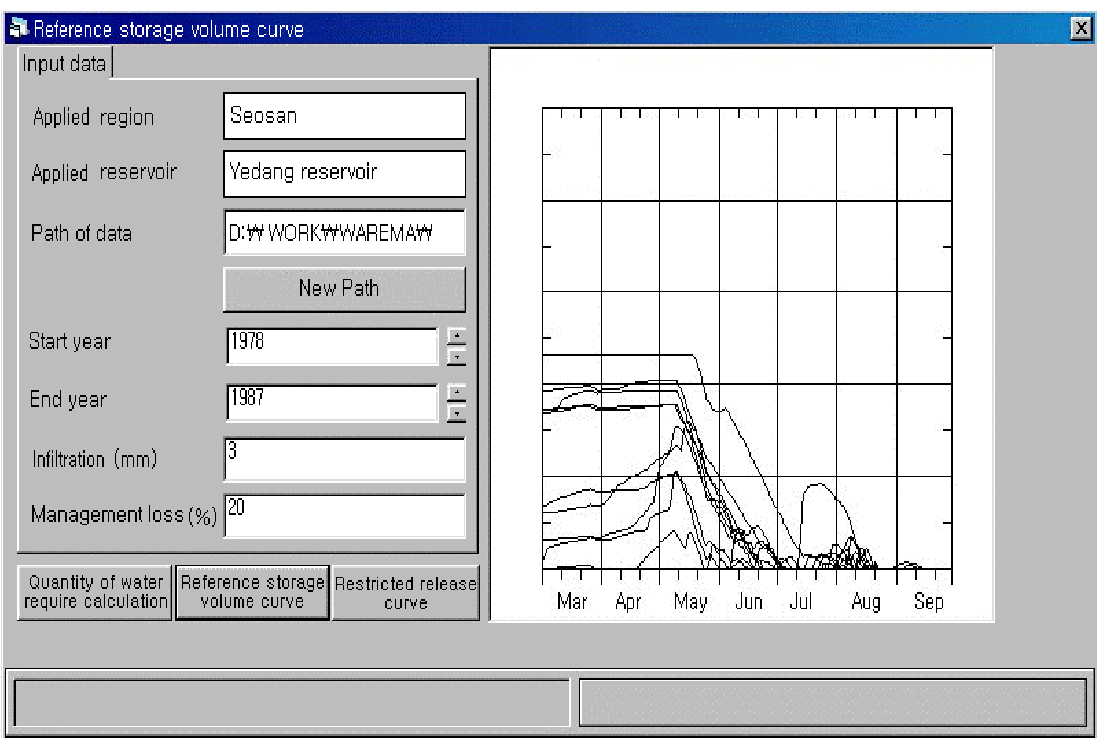


Fig.3. Drawing process of reference storage curve in the Yedang reservoir

3.2 Restricted release curve

The operation rule curve in the Yedang reservoir was shown in Fig.4. The restricted release ratio was proposed with regards to the growth period and storage ratio.

Table 3. Restricted release ratio by growth period and storage ratio in the Yedang reservoir

Growth Period	Restricted ratio (%)				Growth Period	Restricted ratio (%)			
	10	30	50	70		10	30	50	70
4. 1	87.2	63.3	39.5	15.8	7. 1	11.0	7.9	5.0	2.2
6	88.2	64.5	40.9	17.2	6	8.0	5.7	3.3	1.1
11	89.0	65.5	42.0	18.5	11	3.3	2.3	1.4	0.5
16	89.5	66.3	43.0	19.7	16	16.7	10.3	5.0	0.4
21	89.5	66.4	43.3	20.2	21	17.3	11.2	5.9	1.9
26	89.3	66.4	43.6	20.7	26	20.6	12.4	7.1	2.5
5. 1	89.1	66.5	43.8	21.2	8. 1	20.2	13.5	6.8	3.1
6	88.9	66.5	44.1	21.6	6	16.0	10.3	5.8	2.0
11	87.0	65.2	43.4	21.5	11	9.7	6.8	3.8	0.8
16	77.3	57.7	38.4	19.1	16	6.0	3.9	1.8	0.1
21	68.6	50.3	32.4	15.9	21	0.3	0.0	0.0	0.0
26	55.8	41.1	26.3	11.6	26	0.6	0.0	0.0	0.0
6. 1	49.5	39.7	23.9	11.1	9. 1	3.6	1.7	0.5	0.0
6	44.4	33.1	21.8	10.5	6	4.3	2.8	1.4	0.3
11	37.6	28.1	18.6	9.1	11	4.5	3.0	1.4	0.5
16	30.1	22.4	14.8	7.1	16	0.0	0.0	0.0	0.0
21	23.2	17.2	11.3	5.3					
26	17.3	12.8	8.4	3.9					

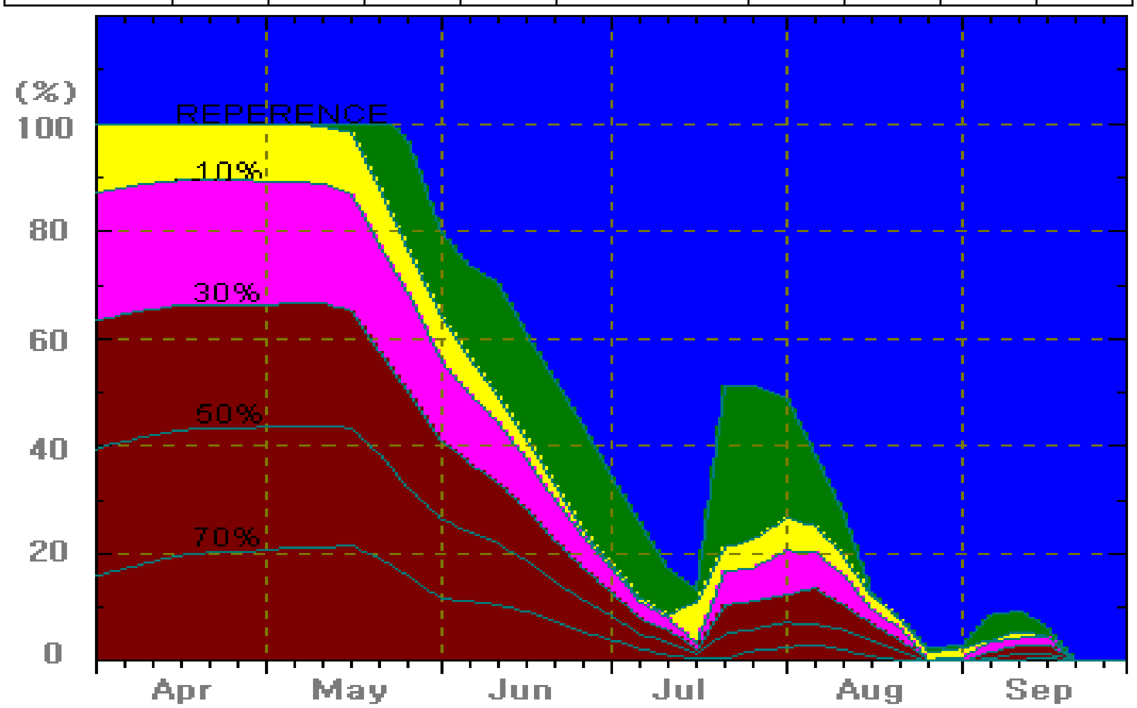


Fig.4. Reference storage and restricted release curve in the Yedang reservoir

3.3 Rotational irrigation system

The rotational irrigation system on the 2 blocks and 3 blocks in the Yedang reservoir were shown in the Fig.5. and Fig.6.

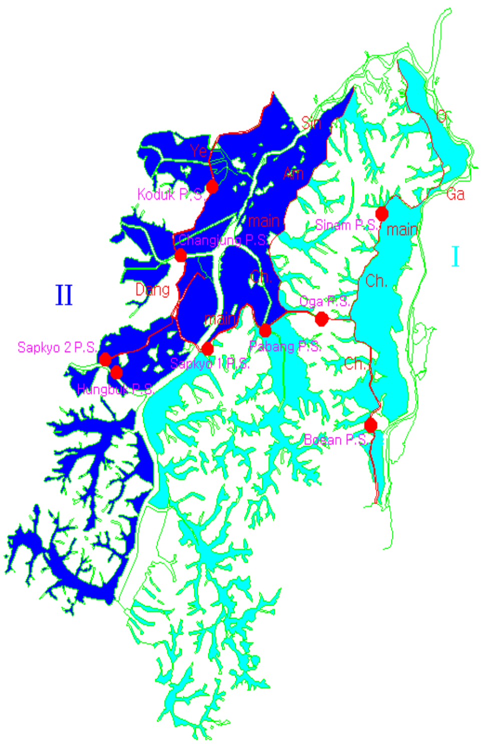


Fig.5. Rotational irrigation system on the 2 blocks

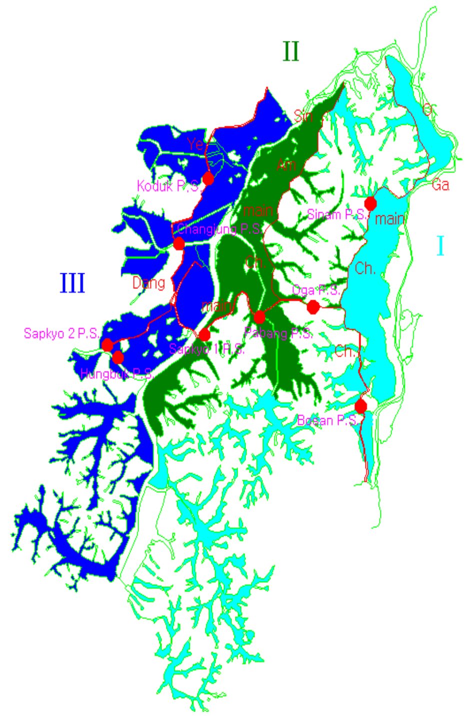
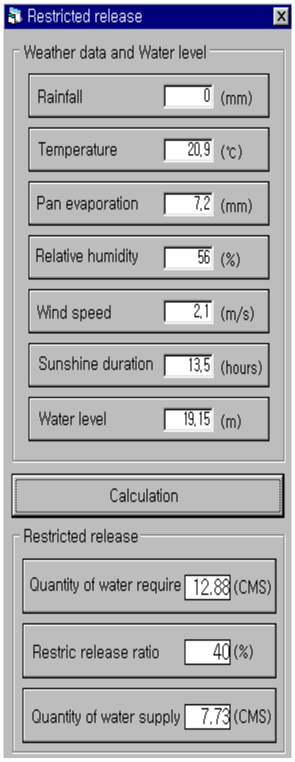


Fig.6. Rotational irrigation system on the 3 blocks

3.4 Rotational irrigation model

The quantity of water required on that day could be calculated from the regional weather data (Rainfall, temperature, pan evaporation, relative humidity, wind speed, and sunshine duration, etc.). And the restrict release ratio and discharge of water will be proposed from the present storage ratio. If the weather conditions are a rainfall of 0 mm, a temperature of 20.9 , a pan evaporation of 7.2mm, a relative humidity of 56%, a wind speed of 2.1m/s and a sunshine duration of 13.5hours in June 5, the quantity of required water is 12.88m^3/s as in Fig.7.



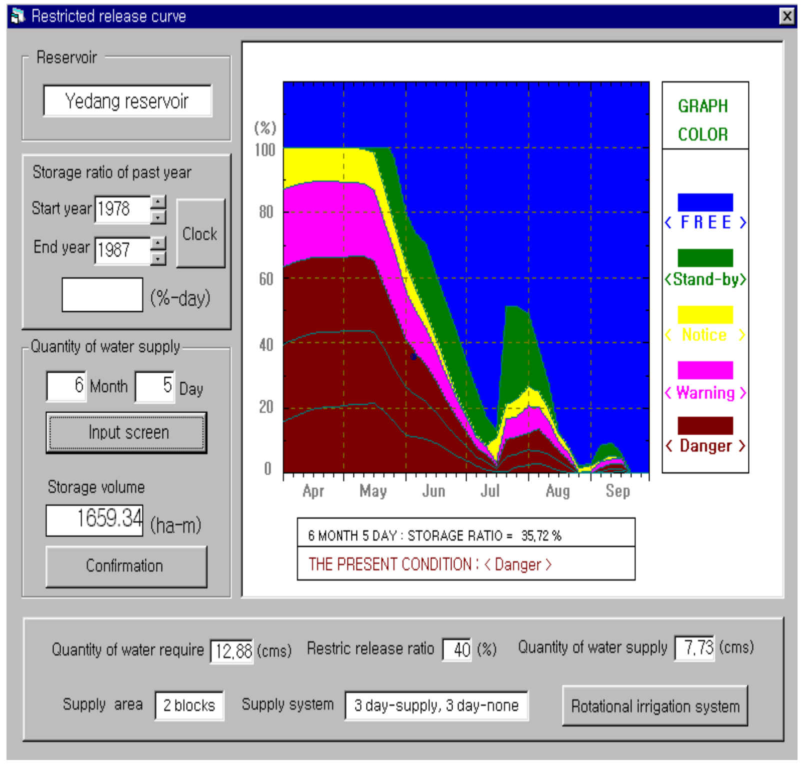


Fig.7. Input screen Fig.8. Proposed rotational irrigation system and discharge of water supply

Before the rotational irrigation system is determined, rainfall expected in the weekly weather forecasting should be taken into account.

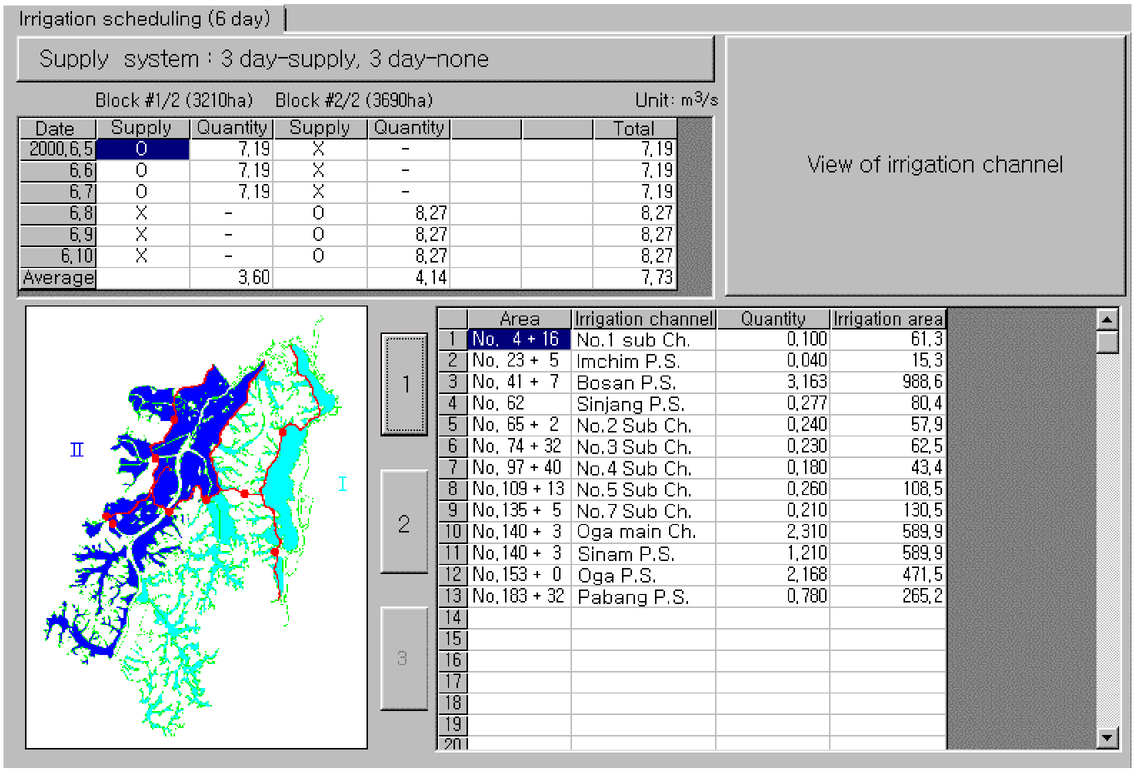
No rainfall expected in the weekly weather forecasting

Case 1. If the storage ratio is 49%, water level would be El.+20.0m and the restricted release ratio would be 20%. In this case, the state of drought assumed to be "Warning". The discharge of irrigation water is reduced to $10.3m^3/s$ and the system of rotational irrigation would be 4 days-on and 2 days-off on the 3 blocks.

Case 2. If the storage ratio is 35.7%, water level would be El.+19.15m and the restricted release ratio would be 40% from the operation rule curve. In this case, the state of drought assumed to be "Danger". The discharge of irrigation water is reduced to $7.73m^3/s$ and the system of rotational irrigation would be 3 days-on and 3 days-off on the 2 blocks as shown in Fig.8.

Case 3. If the storage ratio is 23.7%, water level would be El.+18.2m and the restricted release ratio would be 60%. In this case, the state of drought assumed to be is "Special danger". The discharge of irrigation water is reduced to $515m^3/s$ and the system of rotational irrigation would be 2 days-on and 4 days-off on the 3 blocks.

But, if the sufficient amount of rainfall is forecast in the coming week, there would be no need to operate the rotational irrigation and the full irrigation is available even in the above mentioned cases.



Block #1/2 (3210ha) Block #2/2 (3690ha) Unit: m³/s

Date	Supply	Quantity	Supply	Quantity			Total
2000,6,5	O	7,19	X	-			7,19
6,6	O	7,19	X	-			7,19
6,7	O	7,19	X	-			7,19
6,8	X	-	O	8,27			8,27
6,9	X	-	O	8,27			8,27
6,10	X	-	O	8,27			8,27
Average		3,60		4,14			7,73

	Area	Irrigation channel	Quantity	Irrigation area
1	No. 4 + 16	No.1 sub Ch.	0,100	61,3
2	No. 23 + 5	Imchim P.S.	0,040	15,3
3	No. 41 + 7	Bosan P.S.	3,163	988,6
4	No. 62	Sinjang P.S.	0,277	80,4
5	No. 65 + 2	No.2 Sub Ch.	0,240	57,9
6	No. 74 + 32	No.3 Sub Ch.	0,230	62,5
7	No. 97 + 40	No.4 Sub Ch.	0,180	43,4
8	No.109 + 13	No.5 Sub Ch.	0,260	108,5
9	No.135 + 5	No.7 Sub Ch.	0,210	130,5
10	No.140 + 3	Oga main Ch.	2,310	589,9
11	No.140 + 3	Sinam P.S.	1,210	589,9
12	No.153 + 0	Oga P.S.	2,168	471,5
13	No.183 + 32	Pabang P.S.	0,780	265,2
14				
15				
16				
17				
18				
19				
20				

Fig.9. Daily schedule of 3 days-on and 3 days-off system and the discharges of irrigation channel

Rainfall expected in the weekly weather forecasting

It is assumed that the if the amount of weekly forecast rainfall exceeds that of expected rainfall, there would be no need to operate the rotational irrigation system and the deficient irrigation is unnecessary. The expected amount of rainfall to escape from the serious drought can be calculated as follows.

The required storage volume can be obtained by subtracting the present of storage ratio(35.7%) from the reference storage ratio(57.8%) of June 5 in the operation rule curve, and then the effective rainfall to refill this storage volume will be 27.3mm.

$$Qs = \frac{(57.8 - 35.7)}{100} \times \frac{(4{,}607 \times 10^4)}{(37{,}360 \times 10^4)} \times 10^3 = 27.3\text{mm}$$

Meanwhile, Umax which is the maximum depth of available storage in the Yedang watershed was 320mm in the DAWAST model. Because, WSU which is the depth of soil moisture on June 5 is 136mm, Sa which is the depth of effective storage become 184mm. It means that the soil moisture condition of watershed is extremely dry.

The total rainfall can be calculated from the SCS formula.

$$P^2 - (0.4Sa + Qs)P + 0.04Sa^2 - 0.8SaQs = 0$$

$$P = \frac{0.4Sa + Qs + \sqrt{(0.4Sa + Qs)^2 - 4(0.04Sa^2 - 0.8SaQs)}}{2}$$

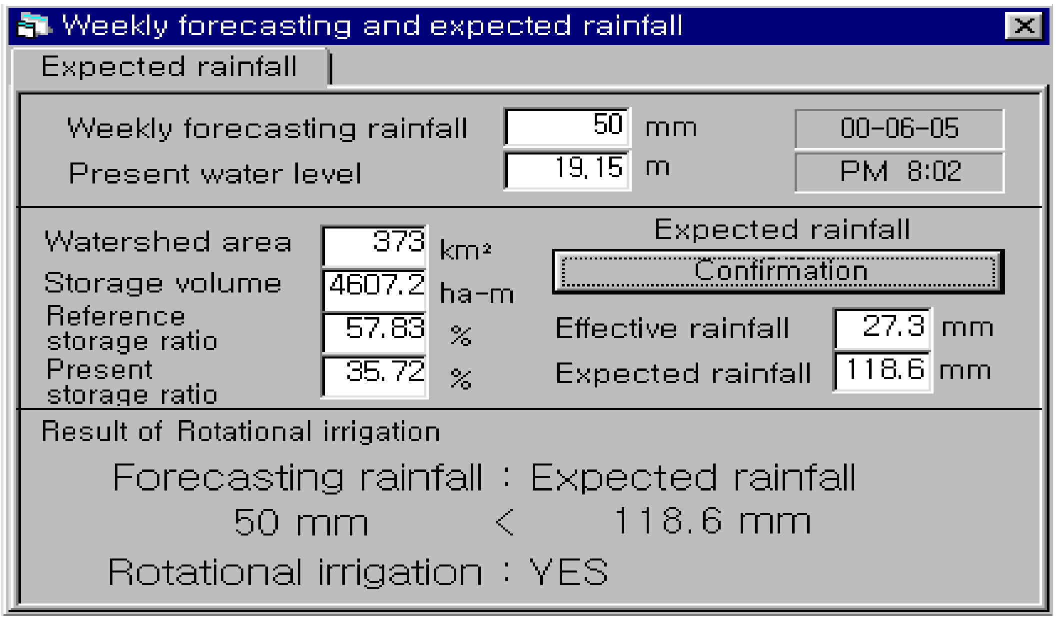


Fig.10. Weekly forecasting rainfall and expected rainfall

In the example shown in Fig.10, the weekly forecast rainfall of 50mm does not exceed that of expected rainfall of 118.6mm, the system of rotational irrigation should be adopted as shown in Fig.9.

4. Conclusions

The concept of rural water, which originally focused on the supply of irrigation water for rice, has now been widened to include irrigation water for dry crops, livestock water and regional water for domestic, industrial, and instream flow in the rural area.

The comprehensive counteracts to overcome the water shortage are the drought evaluation technique, saving water by deficit irrigation and system of rotational irrigation, pipeline system of irrigation canal, regulation pond system, balanced storage management, and dam construction, etc. However, dam construction has become more difficult due to an increase in construction costs and the environmental and ecological issues. Consequently, considerable amount of rural water should be afterwards supplied with the saved water. The most favorable technique to save water is to introduce the rotational irrigation system.

But, there is no proper operation rule of irrigation reservoir for the rotational irrigation system, water managers have difficulties when to restrict the water supply and how to reduce the amount of irrigation water during the serious drought period. Drought forecasting by advanced technique is much more reasonable than by the traditionally experienced method. With the help of information on the weekly rainfall forecasting and the restriction ratio in the operation rule curve, rotation irrigation system has been proposed and applied to mitigate the serious damage of drought more reasonably and practically.

Rotational irrigation scheduling in rice-paddy with the operation rule curve and the weekly rainfall forecasting for the drought control of irrigation reservoirs was developed in the study and could be utilized as software program to install TM/TC system for irrigation water supply by automation facilities.

Acknowledgment

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