RECALCULATING WATER BALANCE OF CACABAN DAM SYSTEM [1]

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A B S T R A C T

The Cacaban dam system located at Central Java was constructed mainly for supplying water to irrigate 6628 ha of land. In the recent year, the water storage capacity of the dam is decreasing due to sedimentation flowing from the upper watershed. Recalculation of balance recalculation was focused on finding optimized water balance of water supply from the dam and demand for irrigation. Prediction of water availability at the dam was predicted by Mock hydrologic model and water demand for irrigation was calculated based on various cropping pattern. The period year of 2007-2008 was used for the recalculation. The result shows that water availability at the dam has decreased significantly in the recent year. In the same time, water demand for irrigation in dry season has increased. Calculated deficit water in the dry season has also increased. Optimizing water balance then was recalculated using modification of the cropping pattern presented by the various value of K meaning half monthly fixed coefficient of irrigation services, ranging from 0.3 to 0.5.

Key words: Cacaban dm system, water balance, water supply from dam, water demand for irrigation

I. INTRODUCTION

One of strategic asset of the government of Indonesia for food production, mainly rice is Cacaban dam system. Administratively, the system is located at Tegal district Central Java. It was constructed mainly for supplying water to irrigate 7439 ha of land. Other purposes are for flood control and fisheries (**Fig.1**). Area of the upper watershed of Cacaban dam is 60.66 km2. Design maximal storage capacity of the dam is 90 million cumec.

In the recent year, sedimentation flowing from the upper watershed to the dam has increased significantly. The water storage capacity of the dam become decreasing. In the same time, water demand for irrigating land is getting high especially in the second planting date PD-

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2) where the season is moving from the wet season to the dry season and in the third planting date (PD-3) in dry season. Using high variety of rice with shorter age and higher water consumptive use comparing the usual variety of rice gives contribution in increasing water demand of irrigation. Therefore, recalculation of water balance of the dam system is needed.

The objective of the study is directed to find optimized water balance of water supply from the dam and demand for irrigation. The benefit of the study can be used for decision makers to apply an integrated water resources management at the dam system.

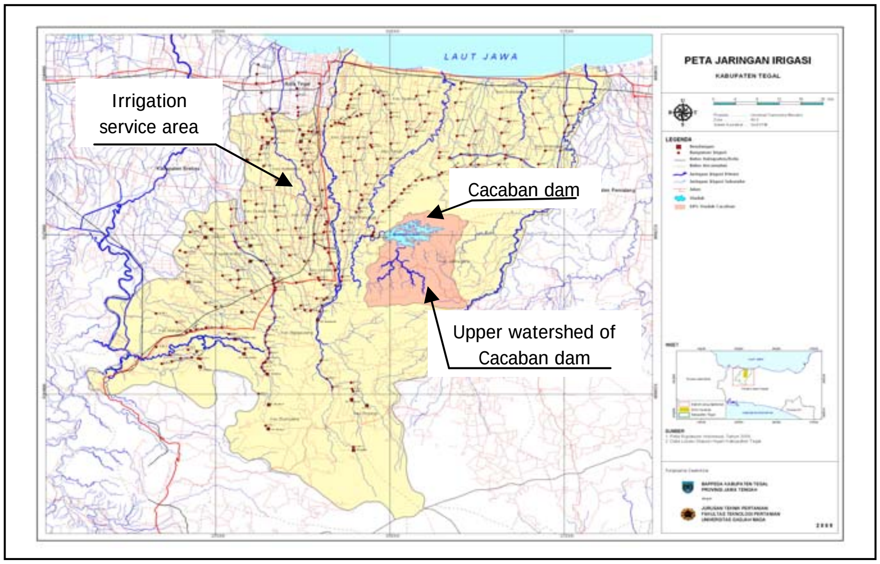

Fig. 1. Location of Cacaban dam and its irrigation service area

II. METHODOLOGICAL APPROACH

2.1. Water balance in the dam

Precision method for calculating water balance has been developed by researcher (Xi-Bin Ji, et al., 2007). Here, water balance in the dam is calculated following simple formula by:

$$I_i = V_i - V_{i-1} + O_i + P_i + E_i + Lp_i - H_i \quad \text{.........} \quad (1)$$

Water storage in i period is calculated using equation below:

$$V_i = V_{i-1} + I_i + H_i - P_i - E_i - Lp_i - O_i \quad \text{.........} \quad (2)$$

Where:

I_i : discharge inflow in i period

V_i : water reservoir volume in i period

V_{i-1}	:	water reservoir volume before i period
O_i	:	water supply in irrigation area from the dam in i period
P_i	:	percolation in reservoir inundation in i period
E_i	:	evaporation in i period
Lp_i	:	excess water on spillway in i period
H_i	:	rainfall in i period

2.2. Discharge inflow

Prediction water flowing to the dam is calculated by simple hydrologic model of Mock (Mock, 1973; Nurrochmad, 1998). The model is basically of rainfall-run-off model containing three tanks arranged in vertical position (**Fig. 2**). There are six parameters in the model. Model calibration of the parameter was conducted by trial and error.

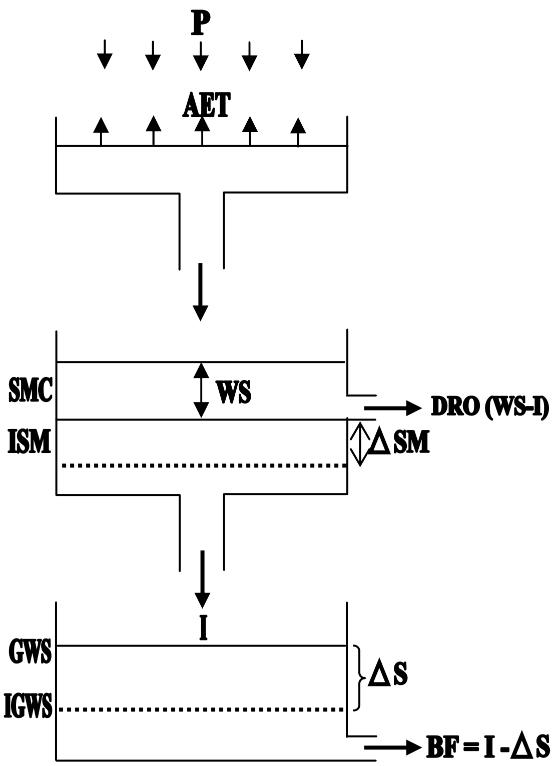

Figure 2. Model Structure of Mock

$$AET = CF \times ETO$$
$$ER = P - AET$$
$$WS = ER - \Delta SM$$
$$ISM = SM_{I-1}$$
$$ISM_{FEB} = SM_{JAN}$$
$$IGWS = GWS_{I-1}$$
$$IGWS_{FEB} = GWS_{JAN}$$
$$I = C_W \times WS = C_D \times WS$$
$$GWS = 0{,}5 \times (1+K) \times I + K \times IGWS$$
$$Q_{BAS} = I - \Delta S = I - (GWS - IGWS)$$
$$Q_{TOT} = DRO + Q_{BSF}$$

where :

P	= rainfall (mm)
CF	= crop factor
AET	= actual evapotranspiration (mm)
ER	= excess rainfall (mm)
DRO	= direct runoff (mm)
WS	= water surplus (mm)
ĀSM	= change of soil moisture (mm)
SMC	= soil moisture capacity (mm)
ISM	= initial soil moisture (mm)
ĀS	= change of ground water volume
IGWS	= initial ground water storage
GWS	= ground water storage

Average rainfall as main input of the model is calculated by polygon Thiessen. Average evapotranspiration is calculated by Cropwat formula developed by FAO. Observed discharge was converted from mid monthly water volume flowing to the dam (m^3) to discharge (m^3/sec).

Goodness of fit between observed and simulated discharge was measured by correlation coefficient (R) and volumetric error (%).

2.3. Irrigation water requirement

Irrigation water requirement is calculated by simple formulation which is usually applied by the local irrigation office at the study area. The following steps are applied in the calculation. Step-1 calculates crop water requirement in the field; Step-2 calculates water requirement in the intake of secondary system; and Step-3 calculates water requirement in the intake of the dam. The formula applied in the calculation can be written as follows:

CWR : land area x *pasten* value
WRS : CWR x tertiary factor, 1.33
TWL : WRS x 10%
TWR : KAPT + TWL
QA : QI x 80 %
C : QA/TKAB

Where:

CWR : crop water requirement in the field
WRS : water requirement in secondary system
TWL : water losses in main canal system
TWR : Total water requirement at main intake
QA : available discharge
QI : water for irrigation
C : Correction factori

Some elements of the formula are predicted by modified standard formula developed by Doorenbos and Puitt (1998) and James, Larry G (1988). **Table 1** show the *pasten* value for familiar crops usually cultivated in the study area.

Tabel 1. Crop water requirement using pasten value

crop	Growing time	*pasten* value (lt/dt/ha)	ET+P (mm)
paddy	Soil preparation for Planting Date (PD) -1	1.20	10.4
	Soil preparation for Planting Date (PD) -2	1.12	9.7
	Growing stage	0.73	6.3
	Flowering	0.82	7.1
	Fertilization	0.52	4.5
	Harvesting	0.00	0.0
sugarcane	Soil preparation	0.45	3.9
	Growing stage-1	0.80	2.6
	Growing stage-2	0.50	0.0
upland crops	crop with a lot of water needed	0.30	2.6
	Crop with little water needed	0.20	1.7

Note: *Pasten* value is half monthly fixed coefficient of irrigation services
ET = actual evapotranspiration; P = effective rainfall
Source: Local irrigation office of Cacaban dam system

III. RESULT AND DISCUSSION

3.1. Calibration process of discharge inflow

To understand hydrologic processes at the upper watersheds of Cacaban dam using the Mock model, data of 1987 was applied for calibration (**Fig. 3). Table 1** shows the optimal parameter of the model from the calibration process. Correlation coefficient (R) and error volume (EV) in the calibration gave 0.895 and 0.032, respectively. Meanwhile data of 1988 was used for verification of the model (**Fig. 4**) and giving value of R and EV was 0.833 and 0.10, respectively. From the result of calibration and verification process shows that the model is sensitive enough to simulate the discharge inflow flowing to the dam.

Table 1. The optimal parameter of the model from the calibration process

Parameter	unit	Symbol	Range		Cacaban dam
			Max	Min	Optimal parameter
Infiltration coefficient in rainy season	-	CWS	0.1	CDS	0.5
Infiltration coefficient in dry season	-	CDS	0.1	0.99	0.7
Initial soil moisture	(mm)	ISM	100	SMC	150
Soil moisture capacity	(mm)	SMC	100	300	180
Initial groundwater storage	(mm)	IGWS	50	1000	300
Groundwater recession constant	-	K	0.1	0.99	0.7

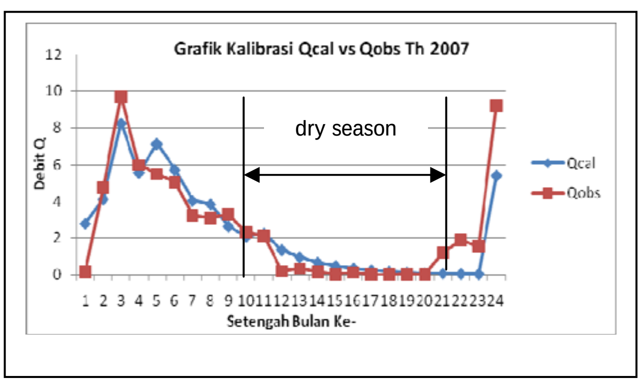

Fig. 3. Calculated discharge (Q_{cal}) and observed discharge (Q_{obs}) of Cacaban dam in calibration process

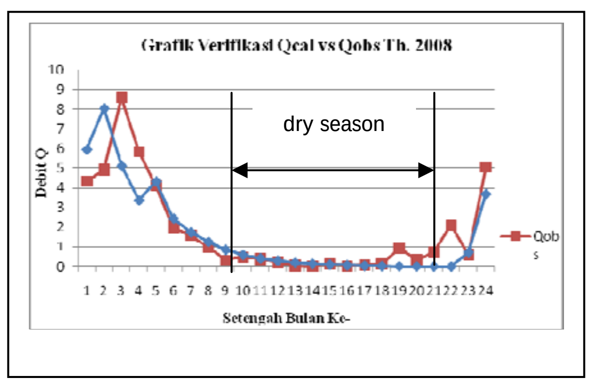

Fig. 4. Calculated discharge (Q_{cal}) and observed discharge (Q_{obs}) of Cacaban dam in verification process

3.2. Discharge inflow

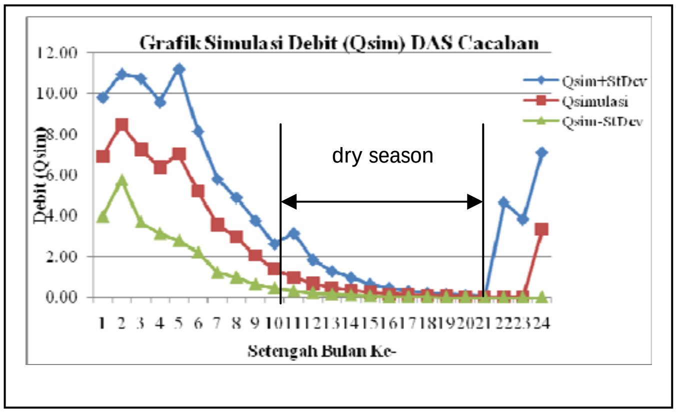

Fig. 5. Simulated discharge of half month basis using rainfall in 1993 to 2008

The consistency of the model was analyzed by running the model using rainfall in 1993 to 2008 as the input model. The fluctuation of rainfall on discharge inflow, average, average plus standard deviation and average minus standard deviation were used as the input model. The result is presented in **Fig. 5.**

The figure shows that the output of the model is still consistent. Discharge change at the rainy and dry season is still performed well by the model. In the dry season, the discharge inflow is very small. In three months before the dry season is completed, the discharge inflow is zero. It is the typical discharge inflow of small river at tropical monsoon climate. It is also has significantly affect to the water management of the dam.

3.3. Water storage

To understand the fluctuation of water storage in the dam, again hydrologic data of the year of 2007 and 2008 was used for water storage simulation. The simulated discharge flowing to the dam plotted in both time series and cumulative curve together with observed discharge. The result for the year 2007 and 2008 is presented in **Fig. 6** and **Fig. 7**, respectively. The figures indicate that cumulative both

As mentioned above that water storage capacity is 90 million m^3. From the two years simulation shows that the cumulative discharge simulations in 2007 and 2008 is 80 million m^3 and 60 million m^3, respectively. Both for two year simulations give cumulative discharge less than 90 million m^3. It means that the actual water storage capacity is less than the designed capacity. In the other word, those facts proved that water storage capacity of the dam is able to receive the total runoff from upper watershed of Cacaban dam even though sedimentation in the dam is getting higher. Therefore, it is reasonable that the water flowing to the spillway has never been overflow since the dam was constructed in 1958.

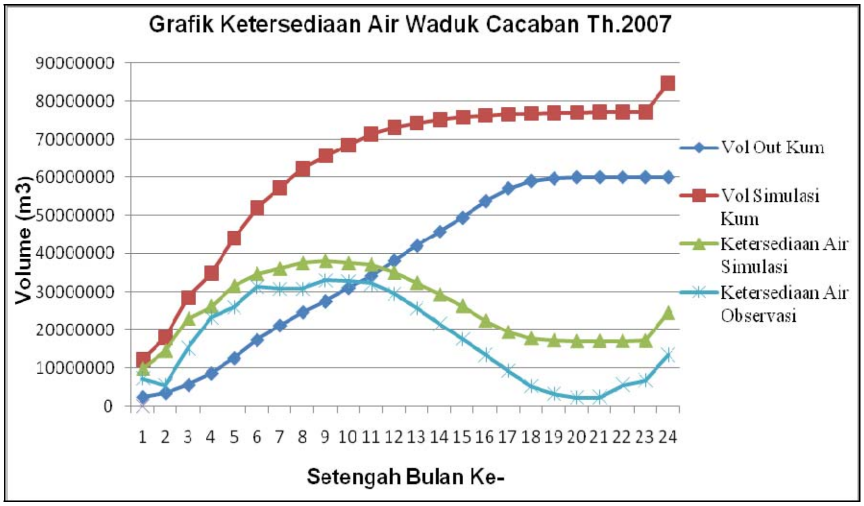

Figure 6. Water storage simulation of Cacaban dam in 2007

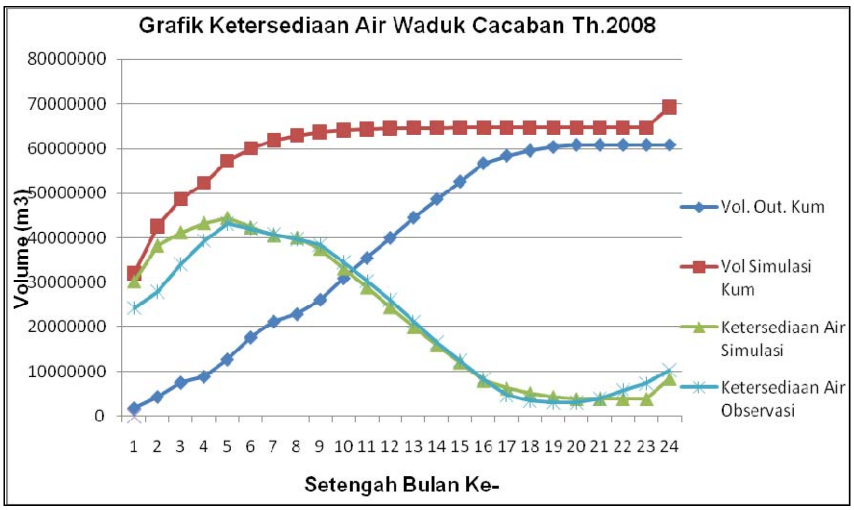

Figure 7. Water storage simulation of Cacaban dam in 2008

3.4. Climatic water balance

Climatic water balance has two components: rainfall and water requirement for crop (paddy). These two components were calculated in the time basis of half month in a full time of hydrologic cycles (a year). Based on the excising condition of plating date at the area study (**Table 2**), calculation of water requirement is divided by four groups. The results are plotted as shown in **Fig.8** to **Fig.11.**

From the figures indicate that the rainfall is not sufficient to cover crop water requirement, especially in the dry season for four group of different planting date. Each group of planting date has specific time of deficit and surplus of water. It proves that irrigation is needed, especially in the month of deficit water.

Table 2. Grouping in cropping pattern date of Cacaban irrigation common area

Group	Planting Date-2		Planting Date-3	
	First watering	Kind of first crops	First watering	Kind of first crops
I	November 1	wet season paddy	March 16	Dry season paddy, upland crops, TRS II
II	November 16	wet season paddy	April 1	Dry season paddy, upland crops, TRS II
III	December 1	wet season paddy	April 16	Sugarcane, TRS II
IV	December 1	wet season paddy	April 16	Upland crops, TRS II

Note: TRS II = Tebu Ratun Sawah (Ratoon sugarcane plated in irrigated rice field II)

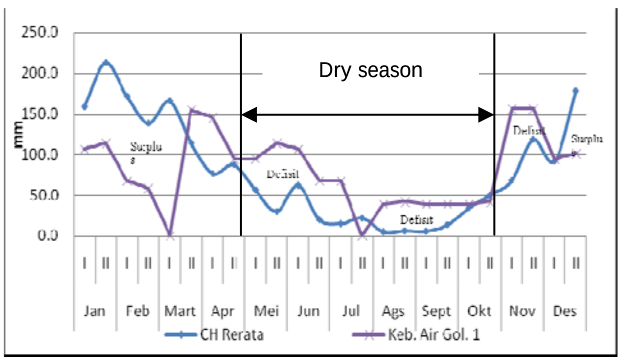

Figure 8. Climatic Water balance for Group 1

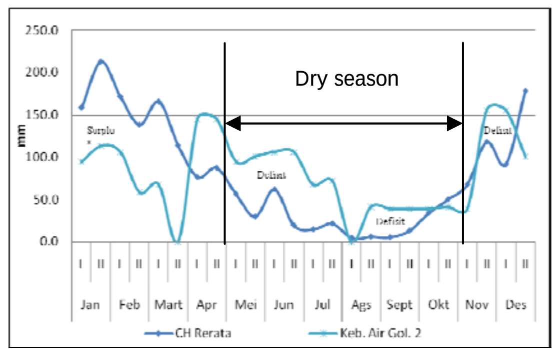

Figure 9. Climatic Water balance for Group 2

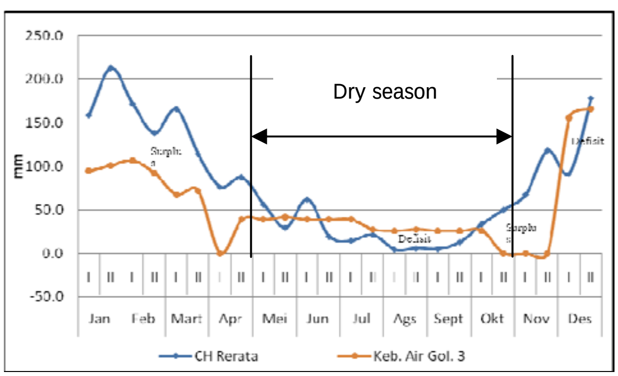

Figure 11. Climatic water balance for Group 3

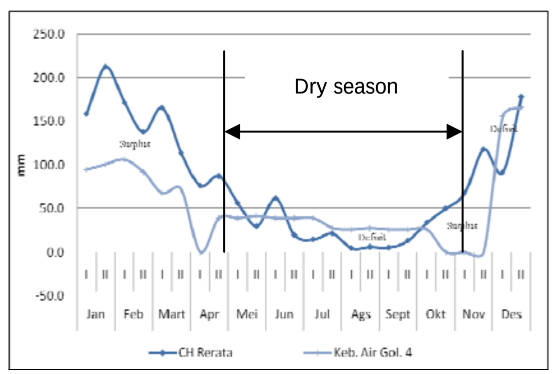

Figure 11. Climatic water balance for Group 4

In the context of recalculating water balance, the result of the climatic water balance also gives important information in making decision on developing schedule of irrigation services in Cacaban system. This area will be covered in the following discussion.

3.4. Water balance

Based on the calculation results as mentioned above recalculating of water balance for each group of plating date of the Cacaban system was carry out using the data of 2007 and 2008. The results for 2007 are presented in **Fig. 12** to **Fig. 15**. Meanwhile for 2008 are shown in **Fig. 16** to **Fig. 19**.

From the figures indicate that water shortage always appears in Planting Date-2 (transition of rainy season to dry season) and in Planting Date-3 (in the dry season). Peak water irrigation requirement happens when the farmers started doing soil preparation for paddy cultivation. Irrigation water requirement also tends to increase.

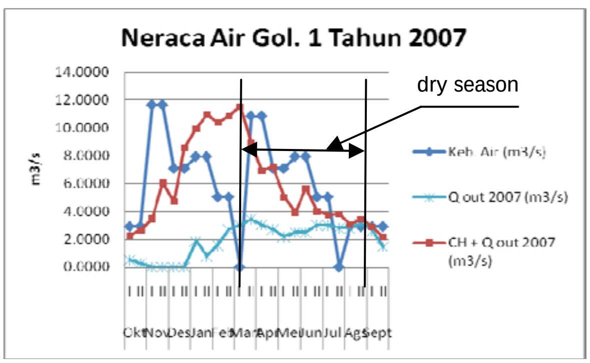

Figure 12. Irrigation water balance for Group 1 in 2007

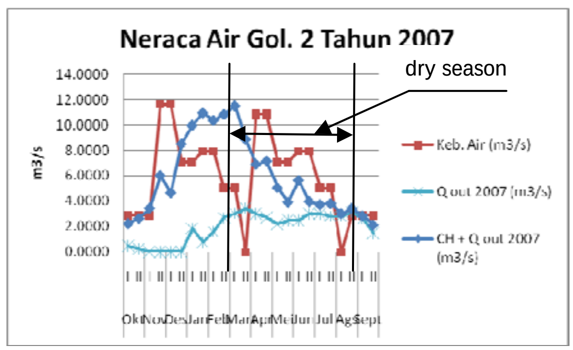

Figure 13. Irrigation water balance for Group 2 in 2007

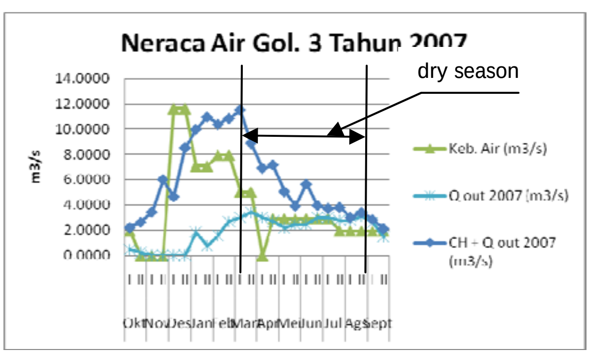

Figure 14. Irrigation water balance for Group 3 in 2007

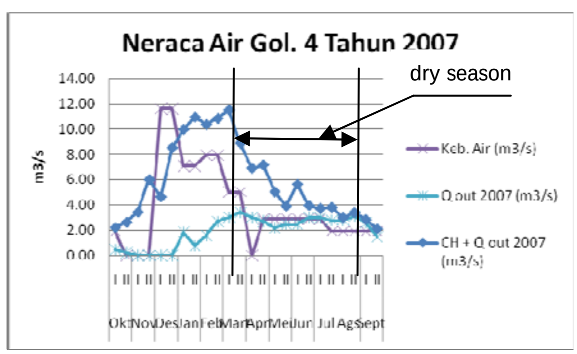

Figure 15. Irrigation water balance for Group 4 in 2007

Applying high yields variety of paddy with short age and need more water by the farmer gives contribution in increasing irrigation water requirement. In the same time, water storage capacity of the dam is decreasing due to sedimentation. Discharge inflow flowing to the dam basically does not change.

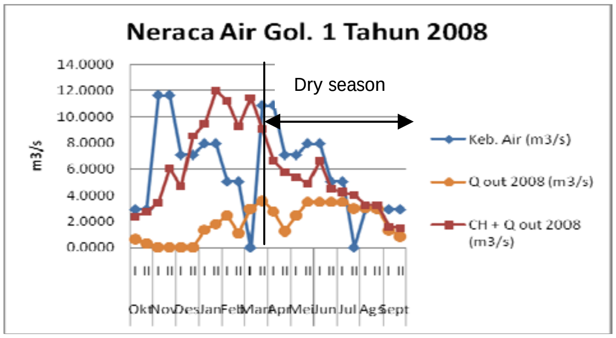

Figure 16. Irrigation water balance for Group 1

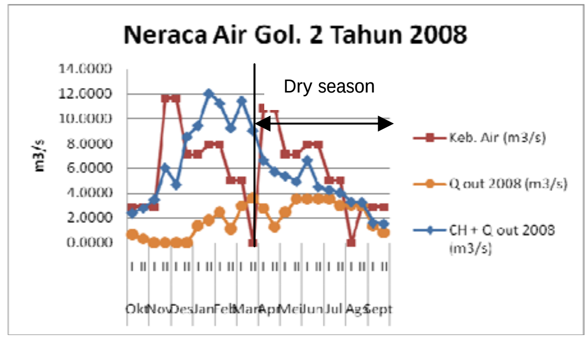

Figure 17. Irrigation water balance of Group 2

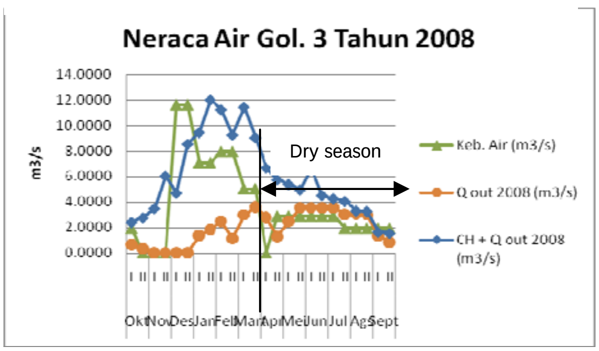

Figure 18. Irrigation water balance of Group 3

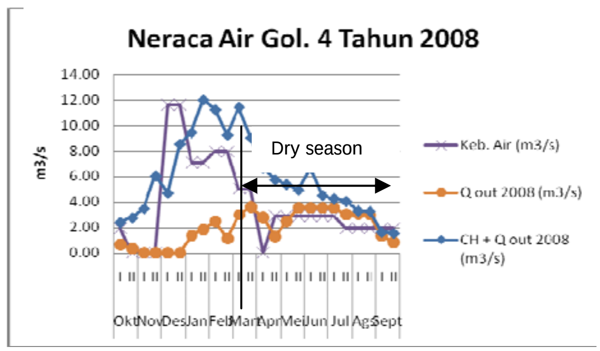

Figure 19. Irrigation water balance of Group 4

IV. SUMMARY AND CONCLUSION

4.1. Summary

The Cacaban dam system located at Central Java has irrigated common area of 6628 ha of land. Due to sedimentation flowing from the upper watershed, the water storage capacity of the dam is decreasing significantly.

Recalculation of water balance was needed and focused on finding optimized water balance of water supply from the dam and demand for irrigation. Recalculation was carried out with prediction of water availability at the dam was used by Mock hydrologic model and water demand for irrigation was calculated based on various cropping pattern. The period year of 2007-2008 was used for the recalculation.

The result shows that water availability at the dam has decreased significantly in the recent year. In the same time, water demand for irrigation in dry season has increased. Calculated deficit water in the dry season has also increased. Optimizing water balance then was recalculated using modification of the cropping pattern presented by the various value of K meaning half monthly fixed coefficient of irrigation services, ranging from 0.3 to 0.5.

4.2. Conclusion

1. Recalculation of water balance at the Cacaban dam irrigation system has been carried out. Using basic consideration of climatic water balance, the result shows that water surplus and shortage tends to follow the typical characteristics of tropical monsoon climate.
2. From the output side, in the rainy season, there is no need of irrigation. Water shortage happens in the planting date-2 and in planting date-3. Therefore, water supplying for irrigation has to be started in the planting date-2 where this season is the transition from rainy season to dry season and in planting date-3 where the season is the dry season. Water demand for irrigation in planting date-3 is much higher than demand in planting date-2.

3. From the input side, discharge inflow flowing to the dam was simulated well by a simple rainfall-runoff hydrologic model. The result show that basically the discharge inflow flowing to the dam, mainly in the rainy season does not change.
4. Using the discharge inflow simulation, the water storage capacity of the dam is about 60-80 million m^3. It is still less than design water storage capacity (90 million m^3). Therefore, water flowing to the spillway has never been overflow since the dam was constructed in 1958. Due to the degraded condition of the upper watershed of the dam, it gives significant contribution in increasing sedimentation in the dam. Moreover, the capacity of water storage of the dam tends to decreasing.

4.3. Recommendation

1. In the demand side, an innovation on increasing the efficiency of water irrigation is needed to be developed. Such as cultivation in optimal cropping pattern and System Rice Intensification (SRI) has potential to be introduced.
2. Increase the availability of water storage in the reservoir, developing inter watershed management is needed. Potentially, flowing water from Rambut watershed located at the Cacaban upper watershed is still possible.
3. In order to control sedimentation flowing to the dam, several methods of water resource conservation program at the degraded condition of Cacaban upper wathershed is urgent to be developed.

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