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Optimizing the Use of Meninting Multipurpose Reservoir Water in West Lombok District

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ABSTRACT The construction of the Meninting Reservoir was planned with the objective of meeting the irrigation and domestic water demands on Lombok Island. It served as a multipurpose reservoir, with a maximum storage volume of 12.18 million m^3, mainly for supplying irrigation and domestic water. The reservoir had considerable potential for water availability, which could be used to supply water to the South Lombok region with limited water availability but had agricultural land potential. Therefore, this study aimed to evaluate the potential of Meninting Reservoir water availability and its optimum utilization for irrigation and domestic purposes. The irrigation water demand for 1,559.29 ha and domestic water demand of 150 ls^{-1} was fulfilled by Meninting Reservoir. Water availability in this Reservoir was estimated with the F.J. Mock method of rainfall-runoff model using 25 years of daily rainfall data from Gunung Sari and Sesaot rain gauge stations. The calibration process of the rainfall-runoff parameters models employed observed discharge data from the Aiknyet water level gauge station. The formula for optimizing reservoir water release was prepared using the linear programming method based on operational water level limits, inflow discharge, irrigation, and non-irrigation water requirements, including domestic water. The optimal average annual cropping intensity was 203.96%, 215.87%, and 241.41% for dry, normal, and wet years, respectively. The service reliability of irrigation and domestic water demands reached 100% for all inflow discharge conditions. The k-factor value met the minimum limit of 0.70 and 0.85 for irrigation and domestic water demands, respectively.

KEYWORDS Optimization, Water Balance, Linear Programming, Cropping Intensity, Reliability

1 INTRODUCTION

Meninting Reservoir is located in the river basin of Meninting, which has a catchment area of 32.77 km^2. This basin has sufficient water potential to meet the water demand of West Lombok Regency, both for irrigation and domestic purposes. Specifically, the construction of this reservoir was planned to address the water demand of 1,559.29 ha of land for irrigation and 150 ls^{-1} for domestic use (PT. Indra Karya, 2014). The potential availability of water in the reservoir can help mitigate the reduction in spring discharge. However, this issue affects the water imbalance between irrigation and domestic water demands and can reduce its potential availability. To address this problem, an optimization scheme was proposed for the reservoir release in order to fulfill domestic water demand and maximize crop intensity.

It is important to note that Meninting Reservoir is planned as part of the National Strategic Project to have a maximum storage volume of 12.18 million m^3. The initial storage capacity is planned to be 9.4 million m^3, with a dead storage capacity of 1.59 million m^3 (PT. Indra Karya, 2014). This storage can be used to meet the water demand of southern Lombok Island, where water availability is lacking. To optimize its performance, an irrigation water allocation optimization method was employed (Jayadi et al., 2019). Kumlasari (2015) reported that planning and implementation of reservoir operations are crucial for organizing the optimal release of reservoir water. According to Lund and Guzman (1999), this practice follows guidelines based on the characteristics of each reservoir. Krishna et al. (2018) also explained that the released water discharge was determined by the reservoir operation rules to maintain the storage eleva-

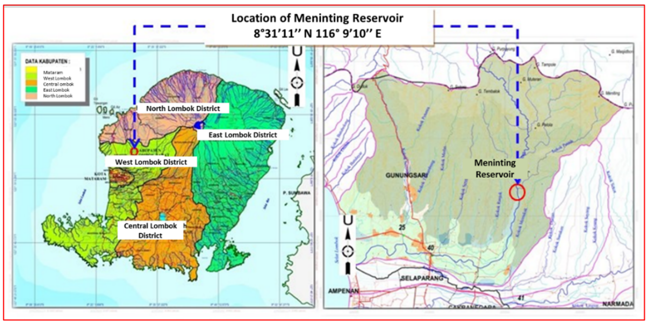

Figure 1 Location of Meninting Reservoir (modified from PT. Indra Karya, 2014)

tion in the design period. This means that operation patterns are very important in simulation modeling based on the function and type of the reservoir operating system (Hadthya et al., 2020). To obtain optimal problem-solving results, linear program optimization method was used (Samosir et al., 2015). The calculation of the optimization of the reservoir water release arrangements using the linear program method is crucial to maximizing the intensity of annual planting, the value of the k-factor, and the reliability of service for irrigation and domestic water demands (Jayadi, 2012).

2 METHODS

2.1 Study Site Description

Meninting Reservoir, which spans an area of 32.77 km² and has a 10.08 km long Meninting River as its source, is situated administratively between Bukit Tinggi and Gegerung Villages in West Lombok Regency. Geographically, it is located at coordinates 8'31'11" N and 116'9'10" E. A map illustrating the exact location of the reservoir on Lombok Island is shown in Figure 1, sourced from the final planning report of PT. Indra Karya (2014).

2.2 Data Availability

The data used in this study were collected from Balai Wilayah Sungai Nusa Tenggara I and The Meteorology, Climatology, and Geophysics Agency (BMKG) of Indonesia, specifically from West Lombok District. The secondary data utilized were described below.

(a) Technical data of Meninting Reservoir.
(b) Daily rainfall data from Gunung Sari and Sesaot automatic rainfall recorder stations (ARR) (1995-2018).
(c) Climatological data of Mataram meteorological station located in Kopang (2016-2020).
(d) Observed discharge data from Aiknyet automatic water level recorder (AWLR) (1994-2018).
(e) Irrigation demand data for two irrigation areas, namely Penimbung (454 ha) and Sesaot (1065.29 ha).
(f) Domestic water demand (150 ls^{-1}).

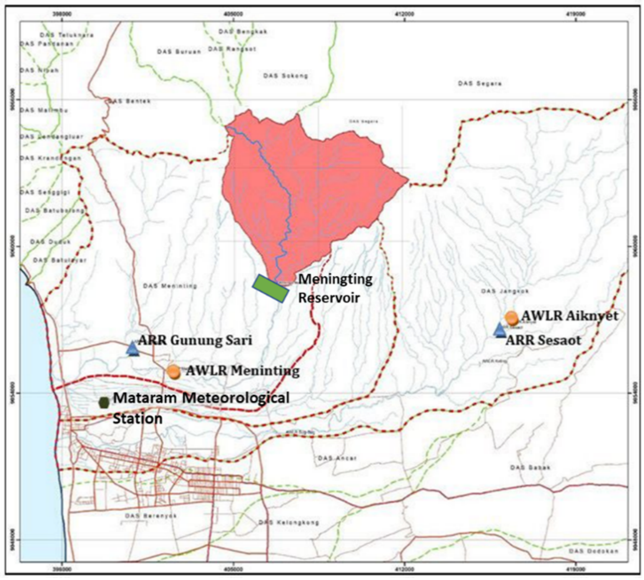

Figure 2 Hydrological station of Meninting Reservoir (modified from PT. Indra Karya, 2014)

Figure 2 showed the location map of the hydrological station of Meninting Reservoir, which had been modified from the final planning report of PT Indra Karya in 2014.

2.3 Reservoir Water Availability

There was a lack of discharge data for the rivers around Meninting Reservoir plan site. To estimate the half-monthly average discharge of the river, the F.J. Mock method of a rainfall-runoff simulation model was used. This model relied on input parameters from Meninting watershed, which were assumed to be similar to those of the Aiknyet watershed, as shown in Figure 2. The parameters of the Aiknyet watershed were established through a calibration process that utilized rainfall data from the Sesaot and Gunung Sari ARR, along with corresponding discharge data observed at the Aiknyet AWLR. The rainfall-runoff calculation was determined by catchment area characteristics, rainfall data, and evapotranspiration data. The wet and dry season infiltration coefficients, initial soil moisture and its capacity, initial groundwater storage, and groundwater recession constant, were all part of the catchment area parameters. The following equations were used in the rainfall-runoff calculation (Mock, 1973).

$$\Delta E = \frac{PET.m(18-n)}{20} \tag{1}$$

$$AET = PET - \Delta E \tag{2}$$

Where ΔE represents the difference between potential evapotranspiration and actual evapotranspiration (mm), PET indicates potential evaporation (mm), m is the percentage of unvegetated land (%), n denotes the number of rainy days, and AET is actual evapotranspiration (mm).

$$ER = P - AET \tag{3}$$

Where ER is excess rainfall (mm) and P represents monthly precipitation (mm).

$$WS = ER - SM \tag{4}$$

Of which WS indicates excess water (mm) and SM is soil moisture (mm).

$$I = DIC \times WS; I = WIC \times WS \tag{5}$$

$$DRO = WS - 1 \tag{6}$$

In the equation above, I denotes infiltration (mm), DIC and WIC denote the infiltration coefficient in dry and wet seasons, respectively, while DRO indicates the runoff (mm).

$$GWS = 0.5 \times (1+K) \times 1 + K \times IGWS \tag{7}$$

$$BF = 1 - (GWS - IGWS) \tag{8}$$

Where GWS is groundwater storage (mm), K represents soil recession factor, IGWS is initial groundwater storage (mm), and BF denotes baseflow (mm).

$$TRO = DRO + BF \tag{9}$$

$$Qcal = \frac{A \times TRO \times 1000}{H \times 24 \times 60 \times 60} \tag{10}$$

From the above equation, TRO represents total runoff (mm), Qcal is the calculated runoff discharge (m^3 s^{-1}), A denotes catchment area (km^2), and H is the number of days in a calculation month.

2.4 Irrigation and Domestic Water Requirements

To estimate irrigation water demand, several factors were considered, such as evapotranspiration, irrigation area, crop coefficient, group system, cropping pattern, percolation, irrigation efficiency, land preparation, and rainfall (Direktorat Jenderal Sumber Daya Air, 2013). In Meninting irrigation area, a cropping pattern of paddy-paddy-secondary crops was used, with a planting schedule for the first week of November (I), the second week of November (II), and the first week of December (III). To calculate the irrigation water requirements for both paddy and secondary crops, Equations 11 and 12 could be utilized.

$$Paddy = NFR = ETC + P - Re + WLR \tag{11}$$

$$Secondarycrops = NFR = ETC + P - Re \tag{12}$$

Discharge of water demand at the intake gate could be calculated using Equation 13.

$$DR = \frac{NFR}{EI} \tag{13}$$

Where DR is water demand at the intake (ls^{-1} ha^{-1}), NFR represents water demand in paddy fields (ls^{-1} ha^{-1}), and EI denotes irrigation efficiency (%). It is important to reiterate that Meninting Reservoir was designed to cater to the domestic water supply needs of various areas, including Batu Layar District and Gunung Sari District in the northern part of West Lombok Regency. According to PT. Indra Karya (2014), the total demand for water in these areas was estimated to be around 150 ls^{-1}.

2.5 Reservoir Inflow Discharge Scenario

Ensuring proper inflow discharge scenarios was very important in order to prevent critical conditions from occurring at the end of operations and to ensure sufficient reservoir storage. These scenarios were categorized into three groups, namely dry, normal, and wet years, each with a specific probability. According to Pusdiklat Sumber Daya Air dan Konstruksi (2017), the probability of wet year inflow discharge was equal to or exceeded 35%, the normal was 50%, and the dry was 65%. To evaluate these scenarios, the Weibull method was employed, utilizing equation 14 as described by Soemarto (1995).

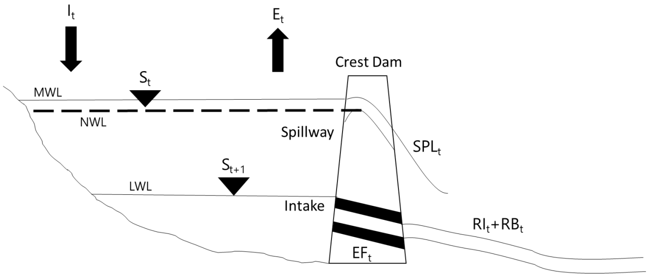

Figure 3 Illustration of reservoir operation simulation

$$P(x) = m/(n+1)\times 100 \quad (14)$$

Where P(x) is the exceedance probability value (%), m denotes the data sequence number from largest to smallest, and n represents the number of data.

2.6 Reservoir Simulation and Optimization Model

The analysis of the reservoir system under varying conditions was conducted through reservoir release regulation (Wurbs, 1993). This simulation model depicted the behavior of the reservoir and assessed its operational performance, but could not optimize the result (Chou et al., 2020). To achieve efficient reservoir operation, an optimization model was integrated with a simulation model based on its water balance (Ngo, 2006). The water balance equation involved the inflow, outflow, and reservoir storage as shown in Equation 15.

$$S_{t+1} = S_t + I_t - E_t - EF_t - RI_t - RB_t \quad (15)$$

From the above equation, St+1 represents the reservoir storage volume (MCM), St is the reservoir storage at the beginning of the period (MCM), It denotes the inflow (MCM), Et indicates the evaporation (MCM), EFt is environmental water release (MCM), RIt is irrigation water release (MCM), and RBt is domestic water release (MCM). An illustration of the reservoir operation simulation could be seen in Figure 3.

To enhance reservoir calculations, the linear program optimization method was utilized. According to Goodarzi et al. (2014), this method was designed to maximize and minimize linear functions. The optimization model used comprised three important components, namely the objective function, decision variables, and constraints (Montarcih and Hoesein, 2010).

Table 1. Aiknyet watershed parameters

Watershed Parameters	Unit	Symbol	Calibration result
Watershed area (km^2)	km^2	A	32.770
Infiltration coefficient in the wet season	–	WIC	0.450
Infiltration coefficient in the dry season	–	DIC	0.650
Initial soil moisture (mm)	(mm)	ISM	200.000
Soil moisture capacity (mm)	(mm)	SMC	250.000
Initial groundwater storage (mm)	(mm)	IGWS	860.000
Groundwater recession constant	–	K	0.980

(a) Decision Variablec
Some decision variables in reservoir operation optimization with linear programs include:
RIt : irrigation water release (MCM)
RBt : domestic water release (MCM)
ATi : planting area (ha)

(b) Objective Function
The objective function of this study was to maximize the intensity of annual planting in Meninting irrigation area.

(c) Constraint
The constraints in this linear program optimization calculation were the release of irrigation water, domestic water, reservoir storage volume, and reservoir water level.

3 RESULTS & DISCUSSION

3.1 Reservoir Water Availability Analysis

The rainfall data were collected from Gunung Sari and Sesaot ARR for the recorded period of 1994 to 2018. To determine the hydrologic characteristic of the Aiknyet watershed, calibration was performed using Excel “Solver” as shown in Table 1.

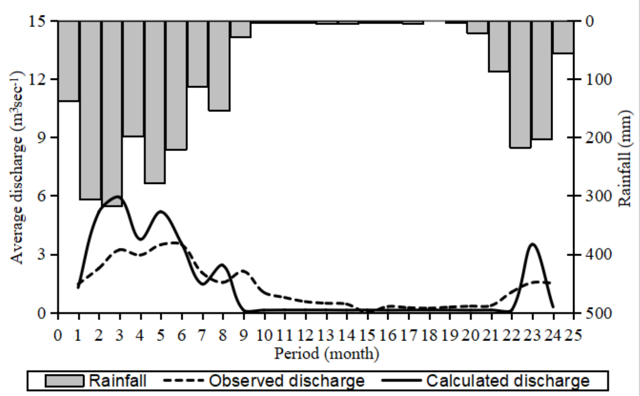

Figure 4 Parameter calibration graph

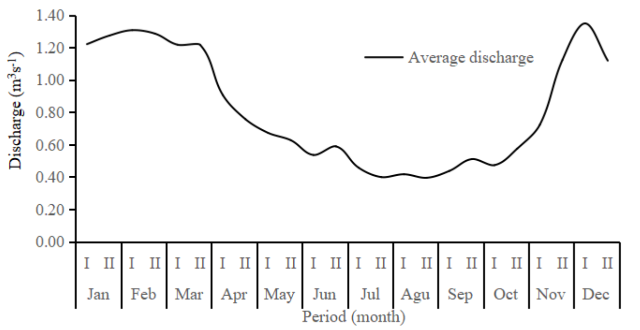

Figure 5 Average discharge of Meninting Reservoir

The Aiknyet watershed parameters were used to calibrate the observed discharge in 2014. The calibration results showed a strong correlation between the observed and calculated discharge, as reflected by the correlation coefficient of 0.846 as shown in Figure 4. Furthermore, the calibrated Aiknyet watershed parameters could be employed to simulate the half-monthly discharge in Meninting watershed.

Figure 5 showed the results of calibrating the Aiknyet River basin parameters using rainfall-runoff model simulation for estimating the mid-month mean discharge at Meninting Reservoir plan site.

3.2 Reservoir Inflow Discharge Scenario

Based on the analysis, a dataset spanning 25 years of inflow discharge from 1994 to 2018 was obtained. The data were used to generate three inflow discharge scenarios, namely normal, wet, and dry years, showing probabilities of 50%, 35%, and 65%, respectively. These parameters were analyzed using the Weibull method by sorting the inflow discharge values from largest to smallest. The inflow graphs for normal, wet, and dry years, presented bi-monthly, could be seen in Figure 6.

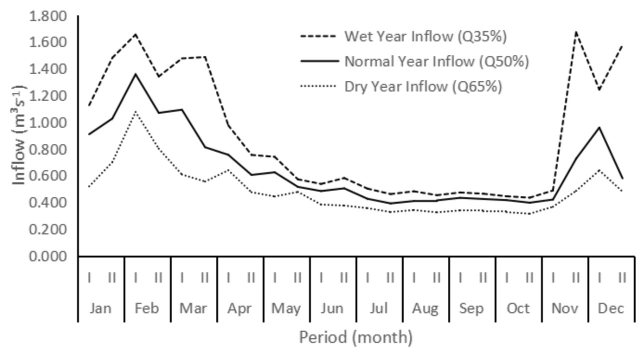

Figure 6 Inflow graph for dry, normal, and wet years in Meninting Reservoir

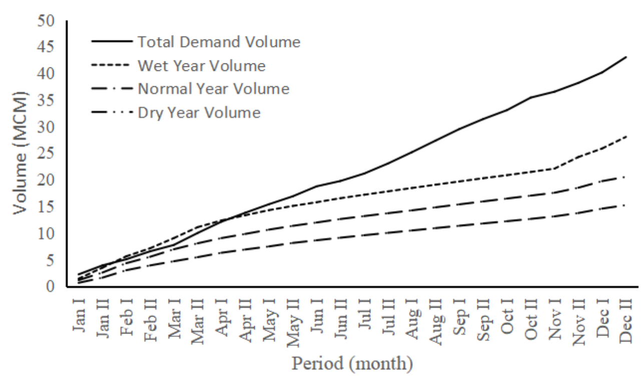

Figure 7 Global water balance of water availability and total water demand

Table 2. Realization of planting area

Wet year	Normal year	Dry year
991.030 (ha) 65.23%	726.196 (ha) 47.80%	538.975 (ha) 35.48%

The graph depicting the inflow for dry, normal, and wet years showed that the largest inflow discharge values were 1,074 $m^3\ s^{-1}$, 1,356 $m^3\ s^{-1}$, and 1,670 $m^3\ s^{-1}$, respectively. After conducting simulation analysis using the F.J. Mock method, an average annual inflow of 20.547 million m^3 was obtained into Meninting Reservoir, while the total water demand target was 42.987 million m^3. To determine the ability to meet water demand, a global water balance analysis had to be conducted. Figure 7 showed the annual global water balance, depicting the cumulative annual water demand and the total cumulative annual water availability.

Table 3. Irrigation water requirement value in Meninting Area

Half Monthly	Water demand unit (l/sec/ha)			Half Monthly	Water demand unit (l/sec/ha)		
	PS-I	PS-II	PS-III		PS-I	PS-II	PS-III
Jan I	1.047	1.289	1.913	Jul I	0.610	0.563	0.732
Jan II	0.701	0.971	1.469	Jul II	0.800	0.648	0.780
Feb I	0.485	0.444	1.296	Aug I	0.971	1.040	1.155
Feb II	0.776	0.276	1.288	Aug II	0.944	0.962	1.165
Mar I	0.508	1.011	0.926	Sep I	1.000	1.016	1.330
Mar II	0.970	0.671	1.051	Sep II	0.853	0.891	1.156
Apr I	0.978	0.995	0.911	Oct I	0.751	0.811	1.107
Apr II	0.751	0.833	1.195	Oct II	1.021	0.627	0.813
May I	0.716	0.791	1.172	Nov I	0.464	0.667	0.700
May II	0.609	0.882	1.220	Nov II	0.738	0.376	1.004
Jun I	0.848	0.715	1.190	Dec I	0.899	0.970	1.044
Jun II	0.411	0.716	0.859	Dec II	1.261	1.327	1.928

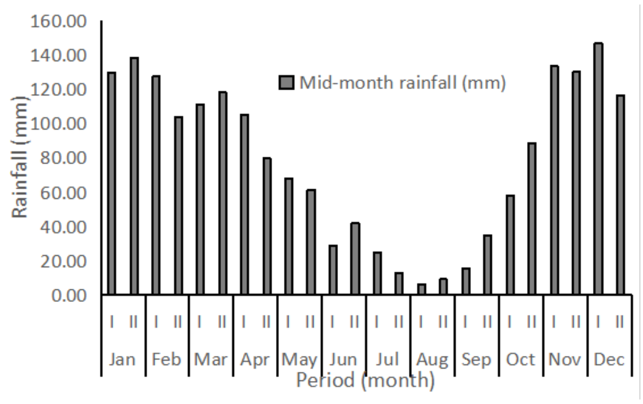

Figure 8 Half-monthly rainfall at Meninting Reservoir catchment area

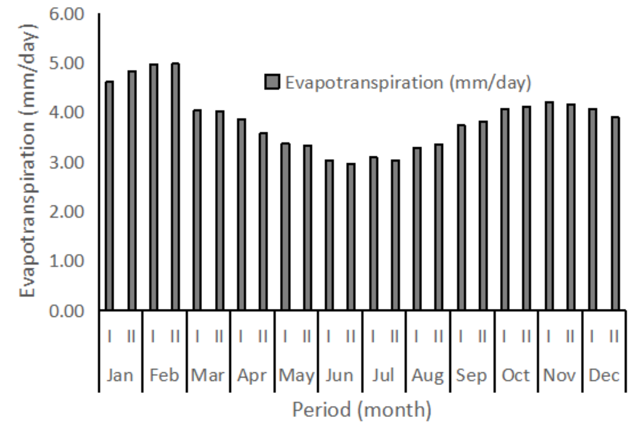

Figure 9 Half-monthly evapotranspiration at Meninting Reservoir catchment area

Figure 7 clearly showed that the available water was insufficient to meet the water demand for inflow discharge in wet, normal, or dry years. This means it was not possible to achieve the existing planting area of 1,559.29 ha. Table 2 displayed the actual maximum planting area for the wet, normal, and dry years of inflow.

3.3 Rainfall and Evapotranspiration

The average value of half-month rainfall, as depicted in Figure 8, was utilized in computing the irrigation requirements for both paddy and secondary crops.

The temperature, humidity, sun duration, and wind speed data collected from Kopang station were used to compute evapotranspiration. The results of the calculation aided in determining irrigation water requirements. The largest value in February was recorded in February at 4.98 mm/day, and the smallest was in June at 2.96 mm/day. Figure 9 showed the evapotranspiration value at Meninting Reservoir.

3.4 Irrigation Water Demand in Meninting Irrigation Area

Meninting Reservoir was used to provide irrigation water for an area of 1,559.29 ha, which was divided into two irrigation zones, namely Penimbung and Sesaot. For example, the Penimbung irrigation area used a cropping pattern of

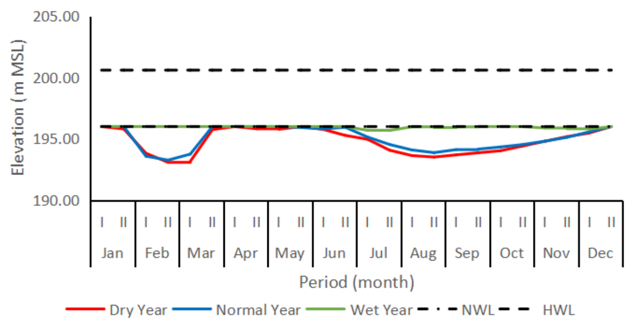

Figure 10 Rule curve of Meninting Reservoir for the November II planting schedule period

paddy-paddy-secondary crops, covering an area of 454 ha, while Sesaot employed a planting pattern paddy-paddy (50%)/secondary crops (50%)-paddy (50%)/secondary crops (50%), covering an area of 1,065 ha. Irrigation water requirements were calculated based on the planting schedule of November I, November II, and December I. Table 3 displayed the irrigation water requirements for each planting schedule. Planting Schedule I began in early November, Planting Schedule II started in mid-November, and Planting Schedule III started in early December. The highest irrigation water requirement for each planting schedule was 1.261 ls^{-1} ha^{-1}, 1.327 ls^{-1} ha^{-1}, and 1.928 ls^{-1} ha^{-1}, respectively.

3.5 Reservoir Optimization Results

The irrigation and domestic water demand values served as a benchmark for optimizing the utilization of reservoir water. The review of reservoir water utilization was based on water availability during dry, normal, and wet years. The optimization results showed that the maximum annual cropping intensity reached 228%, 239%, and 297% for dry, normal, and wet years, respectively. The irrigation area that could be served included 1,229.35 ha, 1,736.15 ha, and 2,947.44 ha for dry, normal, and wet years, respectively. The reliability of irrigation and domestic water demand reached 100% for all three years. The minimum limit required for the k-factor value was achieved at 0.70 for irrigation and 0.85 for domestic water demand. Tables 4, 5, and 6 displayed the optimization results using the November I, November II, and December I planting schedules for the scenarios of inflow discharge in the dry, normal, and wet years, respectively.

3.6 Rule Curve

The optimized use of reservoir water indicated that planting schedule option II provided the maximum cropping intensity while maintaining a reasonable fluctuation pattern in reservoir water levels. Additionally, the optimization of reservoir release with the planting schedule option II ensured that the k-factor values for both irrigation and domestic water met the constraint of not being less than 0.7 and 0.85, respectively. Figure 10 showed the rule curve of Meninting Reservoir for the selected planting schedule, highlighting several operational limits of reservoir water level. The normal water level (NWL) represented the highest allowable reservoir water level needed to meet water demand, while the high water level (HWL) denoted the maximum controlled reservoir water level during the flood period.

4 CONCLUSION

Based on the analysis of Meninting Reservoir water availability using the F.J. Mock method, it was discovered that the storage volume required for dry, normal, and wet years was 15.250 million m^3, 20.547 million m^3, and 28.040 million m^3, respectively. The optimization analysis of Meninting Reservoir water utilization produced effective guidelines for reservoir operation and could be used as a reference for operating the reservoir. The maximum annual cropping intensity was found to be 228%, 239%, and 297% for dry, normal, and wet years, respectively. The reliability of irrigation and domestic water service was determined to be 100% for all inflow discharge scenarios. This conclusion was based on the annual cropping intensity, irrigated area, and k-factor values that met the minimum limit requirement of 0.70 and 0.85 for irrigation and domestic water demand, respectively. Consequently, Meninting Reservoir rule curve could be used to develop the annual plan for reservoir operation.

DISCLAIMER

The authors declare no conflict of interest.

Table 4. Dry year flow optimization result

Indicator	Nov I			Nov II			Des I		
	PS-I	PS-II	PS-III	PS-I	PS-II	PS-III	PS-I	PS-II	PS-III
Crop intensity (%)		228%			220%			164%	
Actual planting area (ha)	538.98	538.98	151.40	538.98	538.98	106.19	422.55	328.03	133.77
Total planting area (ha)		1229.35			1184.14			884.35	
Irrigation water k factor	0.89	0.80	0.81	0.89	0.80	0.80	0.82	0.81	0.80
Domestic water k factor	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Irrigation water reliability (%)		100%			100%			100%	
Domestic water reliability (%)		100%			100%			100%	

Table 5. Normal year flow optimization result

Indicator	Nov I			Nov II			Des I		
	PS-I	PS-II	PS-III	PS-I	PS-II	PS-III	PS-I	PS-II	PS-III
Crop intensity (%)		234%			239%			174%	
Actual planting area (ha)	726.20	726.20	249.54	726.20	726.20	283.75	611.81	611.81	41.20
Total planting area (ha)		1701.93			1736.15			1264.83	
Irrigation water k factor	0.88	0.85	0.87	0.90	0.76	0.70	0.90	0.90	0.90
Domestic water k factor	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Irrigation water reliability (%)		100%			100%			100%	
Domestic water reliability (%)		100%			100%			100%	

Table 6. Wet year flow optimization result

Indicator	Nov I			Nov II			Des I		
	PS-I	PS-II	PS-III	PS-I	PS-II	PS-III	PS-I	PS-II	PS-III
Crop intensity (%)		219%			297%			208%	
Actual planting area (ha)	991.03	991.03	190.75	991.03	991.03	965.38	991.03	991.03	75.08
Total planting area (ha)		2172.81			2947.44			2057.14	
Irrigation water k factor	0.90	0.90	0.95	0.90	0.90	0.81	0.89	0.80	1.00
Domestic water k factor	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Irrigation water reliability (%)		100%			100%			100%	
Domestic water reliability (%)		100%			100%			100%	

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