

# THE INFLUENCE OF CLIMATE CHANGE ON THE RULE CURVE OF THE MENINTING RESERVOIR

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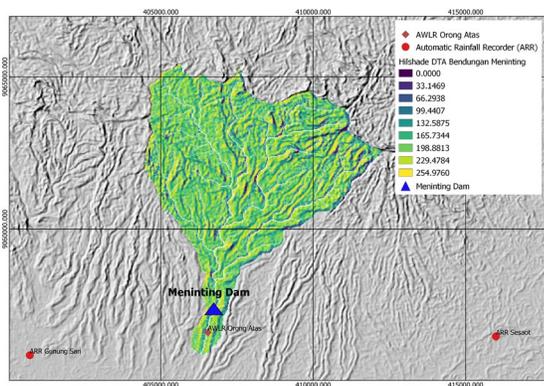
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## Graphical abstract



## Abstract

Climate change can affect the amount of rain intensity and inflow discharge into reservoirs. The Statistical Downscaling Model (SDSM) method is used to predict future rainfall data using GCM CanESM5 data under three greenhouse gas scenarios, namely SSP2.6, SSP4.5, and SSP8.5. Future rainfall projections show increasing values in the SSP4.5 and SSP8.5 scenarios in the 2030s and 2060s. The flow of inflow discharge into the reservoir can influence the value of annual cropping intensity and rule curve. Reservoir water availability was calculated by converting rainfall variations into discharge data using the F.J. Mock model. Inflow discharge for wet, dry, and normal years was then created using the Weibull method. Simulation discharge using the F.J. Mock method is compared with the measured discharge data. The results show good agreement with correlation values of 0.956. The highest total cropping intensity values for each discharge scenario in dry, normal, and wet years were 278%, 300%, and 300%. The success of optimizing reservoir operations can be seen from the k-factor value for irrigation water needs and domestic water, which meets the minimum limit requirements, namely 0.70 and 0.85, and the reliability of the reservoir in serving these water needs reaches 100%.

**Keywords:** Climate change, optimization, F.J Mock, SDSM – DC 4.2, rule curve

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## 1.0 INTRODUCTION

Climate change is a phenomenon whose impacts are currently felt in all parts of the world, including West Nusa Tenggara Province. The large absorption of long-wave radiation causes an increase in the earth's temperature due to the effects of greenhouse gases [1]. Climate change can cause disasters such as rising sea levels, crop failure, floods, and landslides, as well as other economic problems [2]. Several components of climate change, such as temperature, rainfall, humidity, evaporation, wind direction, and speed, are influenced by climate change. Changes in the amount and intensity of rain affect inflow into rivers and reservoirs, which are the source of reservoir water availability [3].

Global Climate Model (GCM) is the main component that can be used to predict global climate [4]. CanESM5 is one of the GCMs in Assessment Report 5, developed by the Canadian Center of Climate Modeling and Analysis (CCCma) [5]. Climate modeling with CanESM5 uses three future scenarios, namely RCP2.6, RCP4.5, and RCP8.5. The downscaling method using Statistical Downscaling Model (SDSM) software aims to approach the spatial resolution of GCMs, which is still quite coarse [6].

One area that has sufficient water resource potential to meet irrigation and domestic water needs in its region is West Lombok Regency. Utilizing the potential of water resources can be done by building a dam, namely the Meninting Dam. The development is planned to meet irrigation water needs in the Jangkok and Sesaot irrigation areas, covering an area of 1.559,29 ha and

domestic water needs of 150 l/s. Climate change can affect storage volumes during the rainy and dry seasons [7], so it is necessary to study the influence of climate change on the rule curve. In their research on optimizing reservoir operations, Agastya et al. (2022) stated that the rule curve is a system that includes the availability of water for downstream water needs and determines the magnitude of the reservoir benefits [8]. The study of the rule curve aims to minimize water shortages, which usually occur in the dry season, and excess water in the rainy season in an area [9].

## 2.0 METHODOLOGY

### 2.1 Study Location

One of the developments in water infrastructure in West Nusa Tenggara Province is the Meninting Dam. Geographically, this dam is located at coordinates 8°31'11" south latitude and 116°9'10" east longitude. Meninting Dam is located between two sub-districts, Gunungsari and Sesaot. This dam has a water catchment area of 32.77 km<sup>2</sup> and is in the Meninting River basin. The length of the main river in the Meninting Dam catchment area is 10.09 km. In Figure 1, you can see a map of the locations of the Meninting Dam, the Automatic Rainfall Recorder (ARR) Gunungsari and Sesaot, and the Automatic Water Level Recorder (AWLR) Orong Atas.

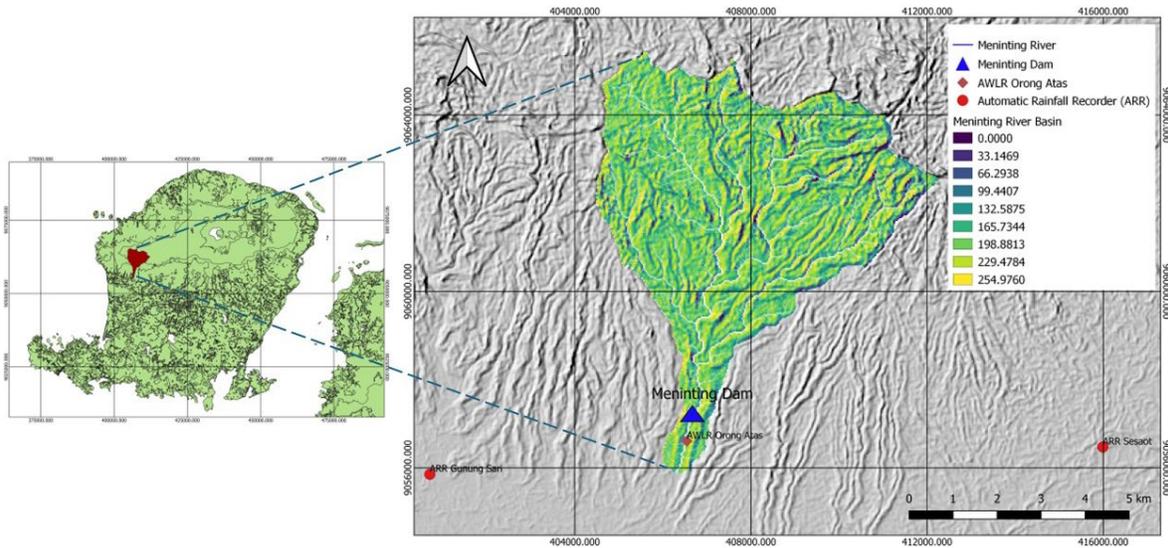


Figure 1 Map of the Catchment Area at Meninting Reservoir, West Lombok Regency, West Nusa Tenggara Province, Indonesia

### 2.2 Meninting Dam Technical Data

The Meninting Dam was planned with a zonal type of random earth filled with a vertical core. The main dam structure has a height of 74 m from the base of the foundation, a peak width of 15 m, a peak length of 418 m, and the top of the dam is at an elevation of +202.00 m. The maximum reservoir capacity is 12.18 MCM, with a pool area of 53.6 ha. The elevation of the spillway building is +196.00 m with storage of 9.91 MCM. The base elevation of the intake building at this dam is +168.00 m with a tunnel-type concrete construction. Figure 2 shows the characteristics curve of the Meninting Reservoir.

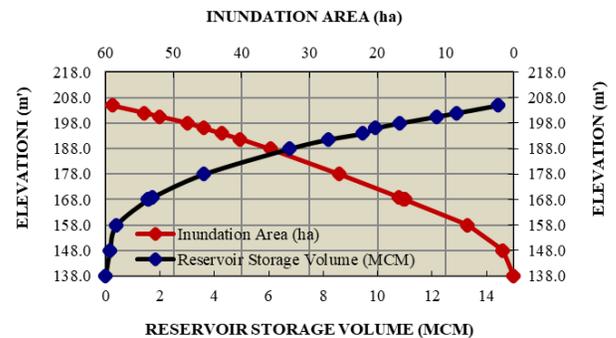


Figure 2 Characteristics Curve of the Meninting Reservoir

### 2.3 Statistical Downscaling Model (SDSM) 4.2

Statistical Downscaling Model (SDSM) 4.2 software can be used to create high resolution climate change scenarios [10]. The SDSM application can conduct a downscaling process by developing a multiple linear regression model between several predictor variables selected based on temperature and rainfall indicators [11]. The Statistical Downscaling Model is a combination of a transfer function model and stochastic

weather generator approach using two types of data, namely local predictive data (observed rain) and large-scale predictor data (NCEP) [12]. The downscaling parameters ( $\alpha_j$ ,  $\beta_j$ ) are obtained through the least squares method of predicting the NCEP/NCAR re-analysis predictor variables. The previously selected predictors are used for the weather generation process. The Weather Generator at the model calibration process stage is carried out for historical periods using NCEP and GPM data [13]. This weather generation process allows the SDSM regression model to produce 100 ensembles of weather variables scaled down from the weather generator and scenario generator processes. The selection of ensembles is based on a statistical scenario with the smallest RMSE value close to zero and the highest regression coefficient value, namely one. The method used to assess the performance of each ensemble uses the following statistical parameters:

Root Mean Square Error (RMSE) [14]:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_{obs} - x_{pred})^2} \quad (1)$$

Where  $x_{obs}$  is measured rain data,  $x_{pred}$  is predicted rain data, and  $n$  is the amount of data.

Correlation Coefficient (R) [15]:

$$r = \frac{\sum_{i=1}^n (x_{obs} - \bar{x}_{obs})(x_{pred} - \bar{x}_{pred})}{\sqrt{\sum_{i=1}^n (x_{obs} - \bar{x}_{obs})^2 \sum_{i=1}^n (x_{pred} - \bar{x}_{pred})^2}} \quad (2)$$

where  $\bar{x}_{obs}$  is the average of measured rain data,  $\bar{x}_{pred}$  is the average of predicted rain data, and  $n$  is the amount of data.

#### 2.4 F.J Mock Method

The F.J Mock method considers the amount of incoming and outgoing water and soil storage water. The method for calculating the transfer of rainfall variation into discharge is done by multiplying the total runoff by the area of the water catchment area [16]. Parameters that influence the evapotranspiration value are plant type, number of rainy days, and soil surface [17]. Five parameters that can describe the characteristics of a river basin are the percentage of land use, infiltration coefficient, soil moisture capacity, initial storage, and recession factor ( $k$ ) [18]. The  $k$  value ranges from 0.4 – 0.7 to produce an appropriate flow.

#### 2.5 Irrigation Water Needs

The value of irrigation water requirements can be influenced by several factors, namely plant type, area of irrigation, cropping pattern, percolation, crop coefficient, land preparation, consumptive use, and water requirements at the intake gate [19]. The value of irrigation water requirements for paddy and secondary crops can be calculated using the following equation [20]:

$$\text{Paddy plants} : NFR = ETc + P - Re + WLR \quad (3)$$

$$\text{Secondary crops} : NFR = ETc + P - Re \quad (4)$$

Where NFR is the water demand in paddy fields, ETC is the consumptive use value (mm), Re is the effective rainfall

(mm/day), and WLR is the replacement of the water layer (mm/day).

#### 2.6 Optimization

Optimization method calculations in water resources can be used to optimize potential water availability to meet irrigation and domestic water needs [21]. The optimization method is designed to solve planning models with constraints to obtain optimal results [22]. The calculation method for optimizing reservoir operations has three important elements, namely:

- Decision Variables are the values obtained and provide optimal results for the objective function targeted in the optimization process [23].
- Objective Function, namely the equation to be optimized and the implementation of the targeted goal. The objective function equation is used to obtain the maximum crop area percentage (%), namely [24]:

$$Z = \sum_{j=1}^n C_j X_j \quad (5)$$

$$Z = C_1 X_1 + C_2 X_2 + \dots + C_j X_j \quad (6)$$

Where  $Z$  is the objective function (optimization value),  $C_1, C_2, C_3, \dots, C_i$  are the objective function parameters,  $X_1, X_2, X_3, \dots, X_n$  are the decision variables (optimization objective variables) and  $n$  are the number of variables.

- Constraints, namely a mathematical formula, must be met with reliability requirements to obtain optimal goals [25]. The constraint function in optimizing reservoir operations can be formulated as follows:

$$A_{11} X_1 + A_{12} X_2 + \dots + A_{1j} X_j \leq b_1 \quad (6)$$

$$A_{21} X_1 + A_{22} X_2 + \dots + A_{2j} X_j \leq b_2 \quad (7)$$

$$A_{ij} X_1 + A_{ij} X_2 + \dots + A_{ij} X_j \leq b_i \quad (8)$$

Where  $A_{ij}$  are the constraint parameters (coefficients),  $b_1, b_2, \dots, b_m$  is the constraint parameters (capacity),  $m$  is the number of constraints, and  $n$  is the number of decision variables.

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Future Rainfall Projections

The Statistical Downscaling Model (SDSM) analysis results are used to get future rainfall projections. The climate model used in CanESM5 with greenhouse gas SSP2.6, SSP4.5, and SSP8.5. The data period used for the calibration process is 1993-2023. This analysis used NCEP/NCAR re-analysis data and GCM CanESM5 data for the historical period. Calibration calculations produce 100 ensembles; then, the ensemble average value is used to evaluate the model's performance using Root Mean Square Error (RMSE) [26]. The RMSE values for NCEP/NCAR and CanESM5 range between 11.889 and 14.247, as seen in Table 1.

**Table 1** Calibration Period RMSE Value

Rain Data Type	Rainfall (mm)	RMSE
Observation		
Existing	5.350	
NCEP	5.180	11.889
CanESM5 Historical	5.508	14.247

The validation process was calculated using rainfall data for 2004 – 2014 with GCM CanESM5 data for the greenhouse gas scenarios SSP2.6, SSP4.5, and SSP8.5. The RMSE value in the validation calculation is greater than the RMSE value in the calibration stage. The results of calculating the RMSE value in the validation period are shown in Table 2 below.

**Table 2** Validation Period RMSE Value

Rainfall Type	Rainfall		RMSE
	Ensemble	Rainfall (mm)	
Observation			
Existing		5.458	
SSP2.6	14	5.508	14.247
SSP4.5	16	5.841	14.849
SSP8.5	12	5.819	14.927

**Table 3** Comparison of Annual Rainfall Based on The SSP2.6, SSP4.5, and SSP8.5 Scenarios with Existing Conditions

Type of Rainfall	Rainfall (mm)		% Change	Information	Period (mm)	% Change	Information
	Existing	2040			2060		
SSP2.6	2024.31	2008.93	-0.759	Decrease	2014.57	-0.481	Decrease
SSP4.5	2024.31	2234.29	10.37	Increase	2296.52	13.45	Increase
SSP8.5	2024.31	2283.62	12.81	Increase	2663.53	31.58	Increase

### 3.3 Meninting Reservoir Water Availability

The optimization results of the F.J. Mock method to obtain optimal watershed parameter values are shown in Table 4 and

### 3.2 Analysis of Future Rain Data

An analysis of future rainfall will be carried out in 2024 – 2063, and the projection will be adjusted to the useful life of the reservoir in the Meninting Reservoir. The rainfall projection period is divided into two future periods, namely the periods 2024 – 2043 and 2044 – 2063. Determining the length of the period depends on the length of available rainfall data, namely twenty years. In this modeling, it is assumed that there will be no change in temperature. Temperature is considered to follow the current trend; apart from rain, it is considered the same. In the 2040 period, the highest increase in annual rainfall was observed rainfall, with SSP8.5 at 12.81% and the smallest at SSP2.6 at -0.759%. In the 2060 period, the highest annual rainfall increase value was obtained at 31.58% at an observed rainfall of 8.5, and the smallest value was SSP2.6 at -0.481%. Based on the calculation results, it is known that the SSP8.5 value has a higher value. This conclusion shows that the threat of future water shortages in the Meninting Reservoir may occur, so a rule curve is needed to optimize reservoir water availability. A comparison of annual rainfall values based on the SSP2.6, SSP4.5, and SSP8.5 scenarios with existing conditions can be seen in Table 3.

Figure 3. Evaluation of the similarity of calculated discharge can be seen from the correlation coefficient (R) value, which is 0.956, and the difference in annual flow volume (%), which is 0.

**Table 4** Meninting River Watershed Parameters Calibration Results using the F.J Mock Method

River Basin Parameters	Symbol	Optimal Value	Objective Function Value
1. Area of the river basin (km <sup>2</sup> )	A	32.77	
2. Wet season infiltration coefficient	WIC	0.25	Correlation Coefficient (R)
3. Dry season infiltration coefficient	DIC	0.40	
4. Initial Soil Moisture (mm)	ISM	100.00	
5. Soil Moisture Capacity (mm)	SMC	100.00	Volume Error
6. Initial Groundwater Storage (mm)	IGWS	769.94	0.000
7. Groundwater Recession Constant	K	0.79	

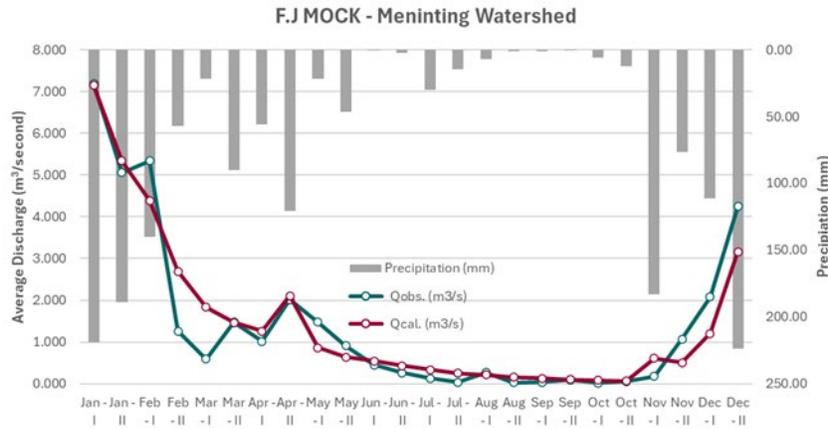


Figure 3 F.J Mock method calibration results between measured and calculated discharge

The inflow discharge is used as input to optimize reservoir operations at the Meninting Reservoir. The SSP2.6 inflow discharge scenario for a wet year is 4.894 m<sup>3</sup>/s in the middle of the second month of January, and the smallest dry year inflow discharge is 0.077 m<sup>3</sup>/s in the middle of the second month of October. The largest SSP44.5 inflow discharge value was in a wet year, namely 5.841 m<sup>3</sup>/s, while the smallest inflow

discharge value was in a dry year, 0.096 m<sup>3</sup>/s. The SSP8.5 inflow discharge scenario for a wet year is 6.617 m<sup>3</sup>/s in the first month of February, and the smallest dry year inflow discharge is 0.112 m<sup>3</sup>/s in the middle of the first month of October. The results of inflow discharge modeling for wet, dry, and normal years can be seen in Figure 4.

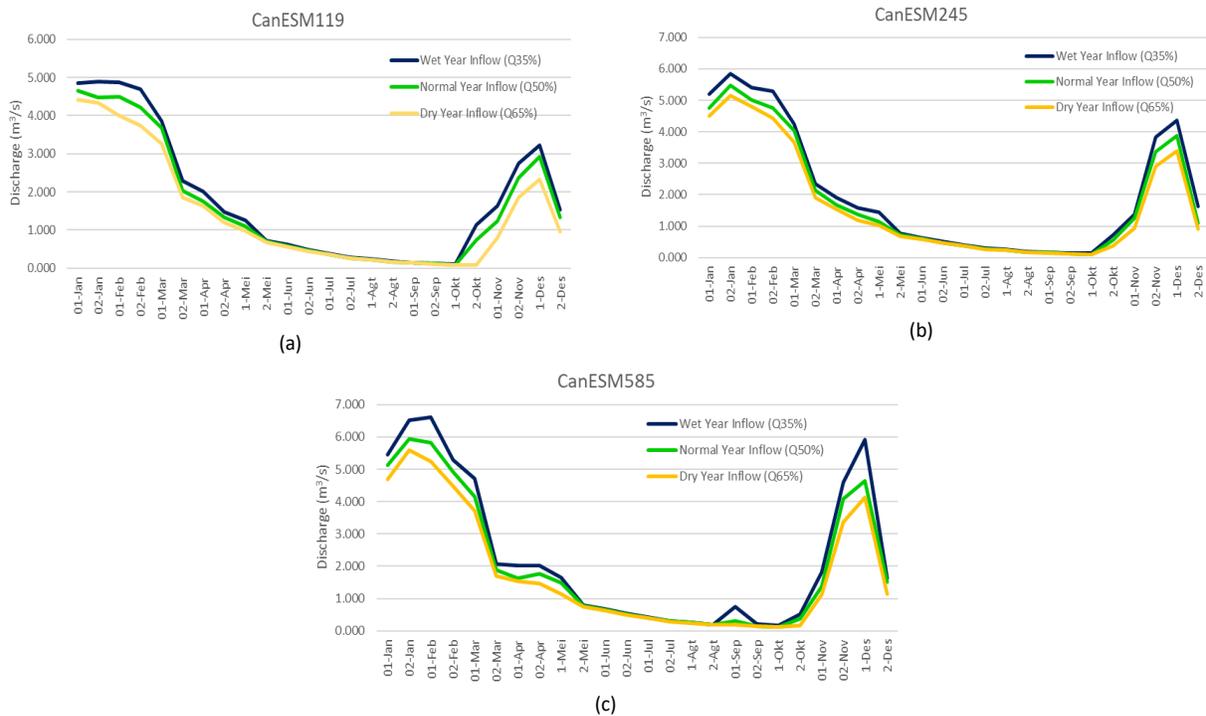


Figure 4 Future Projections of Inflow Discharge for Wet, Dry and Normal Years (a) CanESM119, (b) CanESM245, and (c) CanESM585

### 3.4 Irrigation and Domestic Water Needs

The basic concept of utilizing potential water availability for irrigation development is to meet irrigation water needs covering an area of 454 ha in the Penimbung and Ketapang Orong irrigation areas. The distribution area of the Jangkok supply system covers an area of 1.065 ha, which will replace the irrigation discharge at Sesaot Weir. The cropping pattern

used is Paddy – Paddy – Secondary Crops with a planting schedule of November – I and November – II. The Meninting Reservoir is planned to supply domestic water requirements of 150 l/s. Table 5 shows the need for irrigation water and domestic water. The highest need for irrigation water occurs during the November – I and November – II planting schedules, namely 1.334 l/s/ha and 1.477 l/s/ha, respectively.



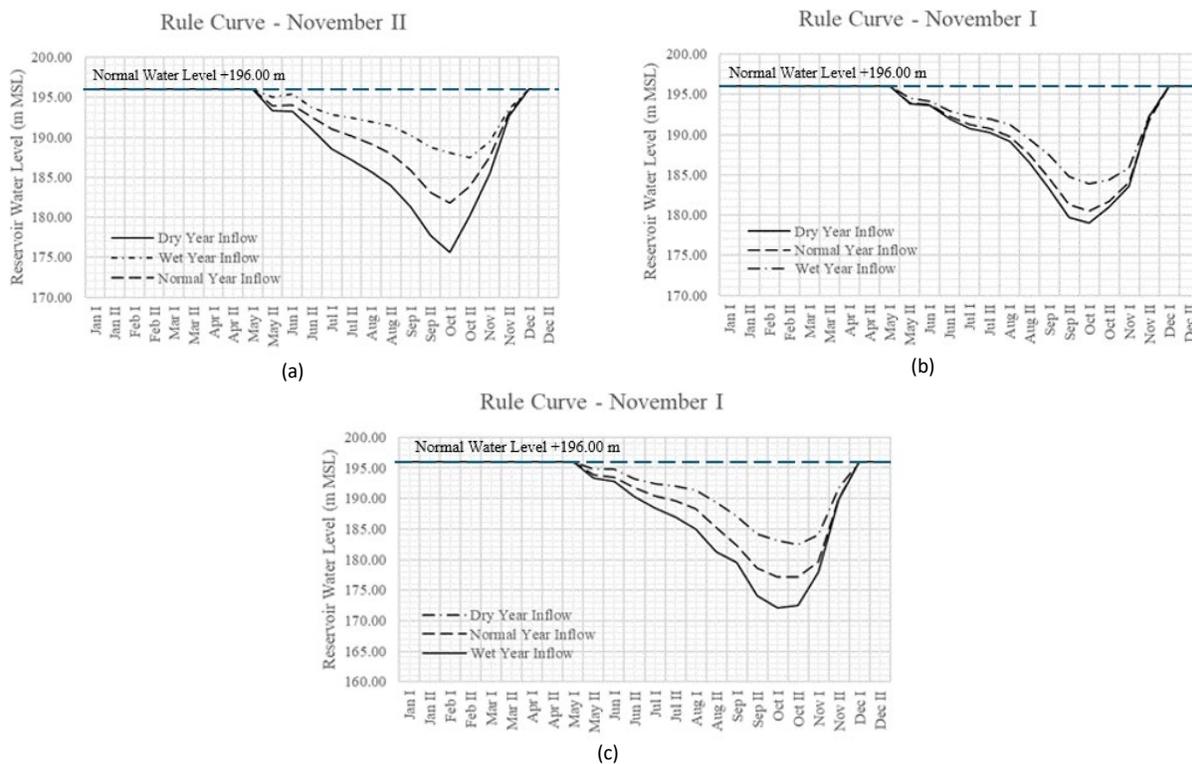
**Table 8** Results of Optimizing the Operation of the Meninting Reservoir using SSP4.5 Scenario Data

Indicator		Dry Year Inflow		Normal Year Inflow		Wet Year Inflow	
		MT - I	MT - II	MT - I	MT - II	MT - I	MT - II
		Nov I	Nov II	Nov I	Nov II	Nov I	Nov II
Total cropping intensity	%	278%	269%	300%	300%	300%	300%
The area of irrigation	ha	4331.62	4196.69	4677.87	4677.87	4677.87	4677.87
Irrigation k-factor	-	0.95	0.98	1.00	1.00	1.00	1.00
Domestic water k-factor	-	0.85	0.85	0.85	0.85	0.85	0.85
Minimum storage volume	MCM	4.692	4.093	4.108	3.007	4.574	4.160
Maximum storage volume	MCM	9.910	9.910	9.910	9.910	9.910	9.910

**3.6 Rule Curve**

Guidelines for the rule curve are prepared at the beginning of the reservoir’s operation. It is reviewed at least once every five years based on developments in reservoir conditions and changes in its use. The rule curve is implemented as an

operating zone rule curve. Creating a rule curve requires that the upper and lower normal operating limits curve back to their initial position. Figure 6 displays the rule curve used in the Meninting Reservoir.



**Figure 6** Rule Curve in the Meninting Reservoir with Scenarios (a) SSP2.6, (B) SSP4.5, and (c) SSP8.5

**4.0 CONCLUSION**

Based on the results of future rainfall projections in observed rainfall, it is known that there will be a decrease for one future period under the three Representative Concentration Pathways scenarios, namely RCP2.6 and an increase in RCP4.5 and RCP8.5. The measured discharge and calculated discharge calibrated showed a correlation of 0.956 and a volume error of 0.00. The planting schedule that shows the highest total cropping intensity results occurs in November – I. The highest total cropping intensity values in each scenario of dry, normal, and wet year inflow discharge were 278%, 300%, and 300%.

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## Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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