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Simulation Analysis of Base Year Operation Pattern Method of Marangkayu Reservoir East Kalimantan Province

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Abstract

Marangkayu is a multi-purpose dam that serves irrigation water needs for a functional area of 1,500 hectares and provides raw water supplementation of approximately 450 liter per second. One of the requirements for impounding certification involves the preparation of an operational guideline for the dam. Therefore, this study aims to analyze the reservoir operation pattern by simulating water availability and demand. The reservoir operation pattern is determined through simulations based on calculations of water inflow, water demand, and losses, constrained by the reservoir's storage capacity. The simulation calculations employ the baseline year method, which includes dry years, normal years, and wet years. Reservoir water availability simulations are conducted under three conditions: dry year (probability of being equaled or exceeded 65%), normal year (probability of being equaled or exceeded 50%), and wet year (probability of being equaled or exceeded 35%). The results of this study indicate that the simulation of Marangkayu reservoir's operation pattern for dry, normal, and wet conditions can sufficiently meet the water needs for a functional irrigation area of 1,500 hectares with a cropping pattern of rice–rice–secondary crops, raw water demand of 450 liter per second, and river maintenance flow of 0.848 m³/second.

Keywords: Marangkayu Dam; reservoir operation pattern; baseline year; inflow; outflow; engineering

1. Introduction

Marangkayu Dam is a multi-purpose dam that meet the demand for irrigation water. It has a functional area of 1,500 Ha and a raw water supply of ± 450 liter per second. Marangkayu Dam is geographically located at the coordinates 117023'52.64" E and 006'34.69" S. The location of the Marangkayu Dam is shown in Figure 1.

To support the management of the Marangkayu Dam, simulations are needed regarding the availability and demand of reservoir water by simulating the reservoir operation pattern. One of the requirements for the certification of the first filling of the reservoir is the completion of the reservoir operation guidelines document with the reservoir operation pattern (Kementerian PUPR, 2017). Therefore, it is necessary to prepare a reservoir operation pattern for The Marangkayu Dam.

Reservoir operation is collecting river water in a reservoir and then releasing the collected water for various specific purposes. (Samosir et al., 2015). The reservoir operation pattern is a system for managing the availability of water for various downstream needs and determining the benefits that can be obtained from the reservoir (Ubaidah M.I et al., 2020). The reservoir operation pattern is used as a guideline that regulates the operating periods of the reservoir, where the outflow must meet the regulations to ensure that the elevation remains as planned (Soetopo, 2010). The reservoir operation

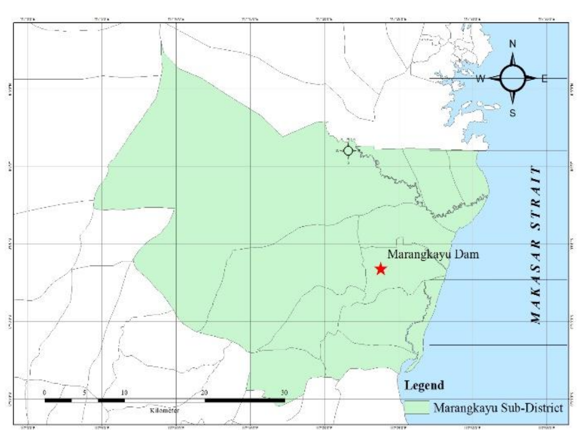

Figure 1. Location of Marangkayu Dam

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pattern is prepared since the beginning of the reservoir operation and is reviewed every 5 (five) years to adapt to the development of conditions, such as changes in the benefits or functions of the reservoir (Farida & Andajani, 2019). The reservoir operation pattern is obtained by analyzing the reservoir operation simulation.

Reservoir operations simulation is a quantitative process performed to model water inflow, water demand, and losses constrained by reservoir storage capacity to obtain the reservoir operations pattern over a specified period. The output from the simulation results will be used as a reference to assess whether the inflow can be used to review the failures generated by the output of a modeling process in optimization to be closer to the existing natural phenomena (Kementerian PUPR, 2017).

The purpose and objective of this study are to simulate the operation of Marangkayu Reservoir in meeting the demand for raw water and irrigation water in base year conditions, namely wet year (with probability of reaching or exceeding 35%), normal year (with probability of reaching or exceeding 50%), and dry year (with probability of reaching or exceeding 65%) with a functional irrigated area demand of 1,500 hectares with a cropping pattern of rice - rice - secondary crops, raw water demand of 450 liter per second, and river maintenance water demand with 95% mainstay discharge.

2. Materials and Methods Used

The data used in this analysis are secondary data obtained from the Kalimantan IV River Basin Center. The required data include hydrological data, namely rainfall data for 23 years (2001 - 2023), dam technical data, arch capacity (H-V-A curve), climatological data obtained from Aji Pangeran Tumenggung Pranoto Meteorological Station for 9 years (2015 - 2023), and the characteristics of the Marangkayu watershed.

The preparation of reservoir operating models begins with the collection of data, such as hydrologic data (precipitation, dam engineering, arch capacity (H-V-A) curve, climatology, and watershed characteristics).

Rainfall information is used in various hydrological studies, water resource management, and climate-related research (Wang et al., 2019). Rainfall data collection faces several challenges. One of the main problems is the limitation of spatially and temporally accurate rainfall observation data. Available rainfall time series data are often limited, with an uneven distribution of rain stations and an insufficient number of observers (Andari, 2024).

The rainfall data used in this study are Global Precipitation Measurement (GPM) satellite rainfall data, as there is no 10-year rainfall data series available in the Marangkayu watershed. For hydrological analysis, the GPM data must first be evaluated and adjusted. The evaluation aims to assess the suitability between GPM rainfall data and ground station rainfall data and to correct GPM rainfall data based on the characteristics of the two rainfall data (Dzisofi Amelia et al., 2021). This correction of GPM rainfall data was carried out on rainfall data around Marangkayu Dam obtained from Kanaan Rain Station, Santan Baru Rain Station, and Sei Siring Rain Station.

In hydrologic modeling, GPM rainfall correction refers to the process by which model parameter values are systematically adjusted or optimized to achieve parameter values that provide the best estimates. The parameter being adjusted is the correlation coefficient. The correlation coefficient indicates the strength of the relationship between two variables, with values ranging from -1 to 1. A negative correlation coefficient (-1) indicates that the variables are inversely related, while a positive correlation coefficient (1) indicates that the variables have a comparable relationship (Sanjaya et al., 2022).

Water balance is a comparison between the potential availability of water and the demand for water in an area over a period (Dengo et al., 2016). The study of water availability and demand aims to analyze whether there is an excess (surplus) or shortage (deficit) of water in the study area, especially in certain months (Andita & Lipu, 2020).

Analysis of water availability in the Marangkayu Reservoir catchment using the 15-day FJ Mock method. The FJ Mock method combines climatic data (mainly rainfall) with the characteristics of the watershed to estimate the resulting runoff discharge. The main components of the FJ Mock method calculation are rainfall and evapotranspiration calculations, land surface water balance, and soil storage (Sachro et al., 2013). The probability of reliable runoff is calculated using the Weibull method for base year conditions, namely wet year, normal year, and dry year.

Water demand includes the amount of water needed to overcome evaporation, water loss, and to meet the water needs of plants. It includes calculations that take into account the amount of water provided by nature through rainfall and the contribution of water from the soil. The water need of Marangkayu Reservoir includes the irrigation water need, where the irrigation water need is the total amount of water needed to overcome evaporation, water loss, as well as to meet the water needs of plants, taking into account the amount of water provided by nature through rainfall and the contribution of water from the soil (Priyonugroho, 2014).The functional irrigated area is ± 1,500 hectares, with a rice-rice - secondary cropping pattern starting in the October period. The raw water requirement according to the

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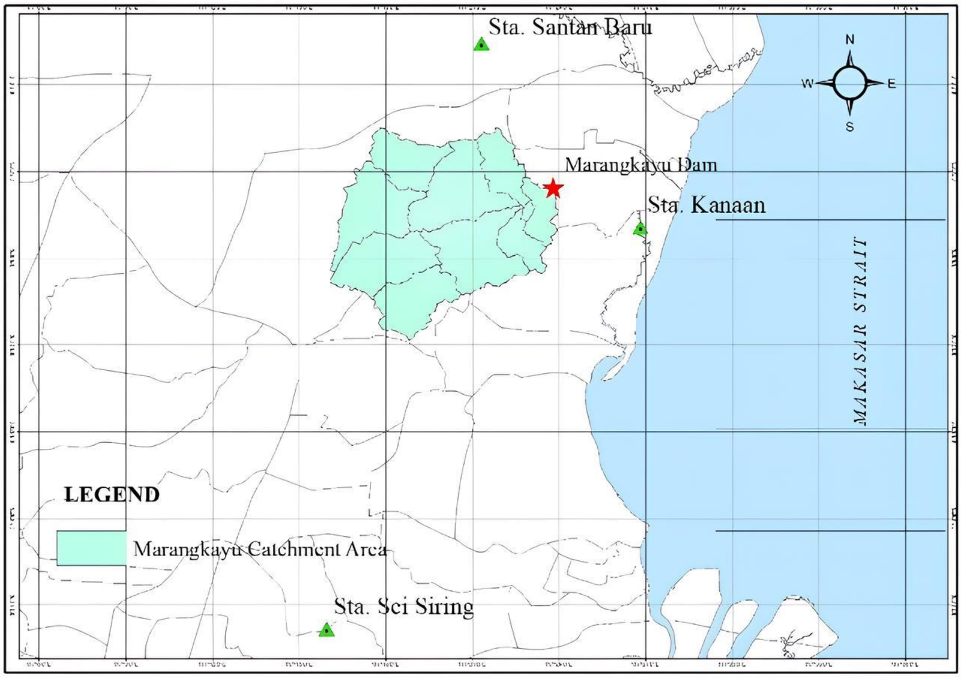

Figure 2. Coordinates of the ground stations STA Kanaan, STA. Santan Baru and STA. Sei Siring

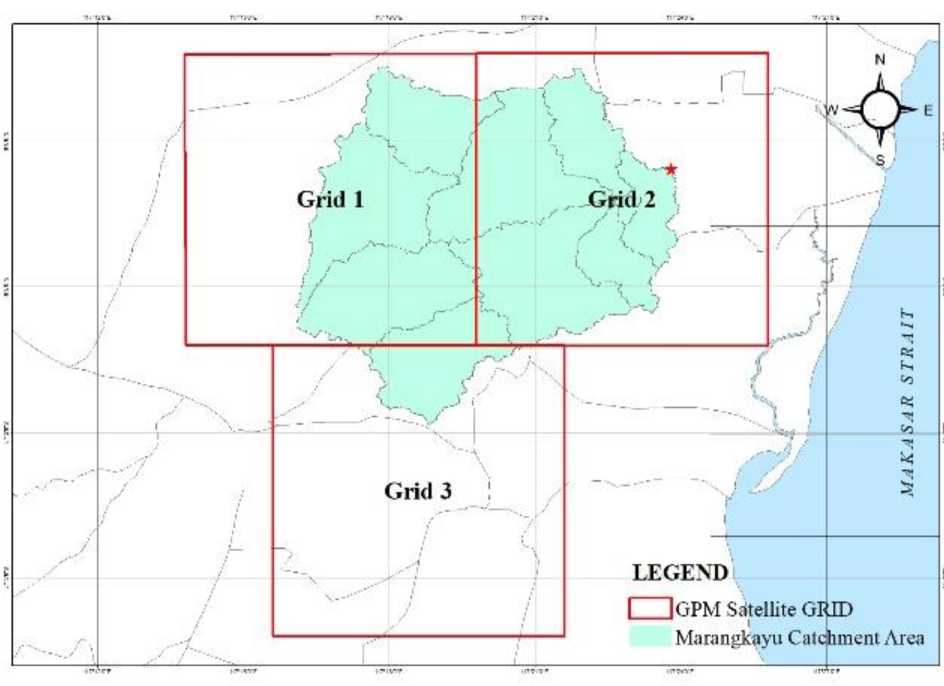

Figure 3. GPM Marangkayu Satellite Grid

Kalimantan River Basin IV planning document is 450 liter per second with details of 200 liter per second for Bontang City and 250 liter per second for Kutai Kertanegara Regency and river maintenance requirement according to the mainstay discharge of 95%.

The reservoir operation pattern is obtained by conducting simulations based on the calculation of water inflow, water demand, and losses with the limitations of reservoir storage capacity (Maulana et al., 2020). Simulations are carried out in three conditions, namely in

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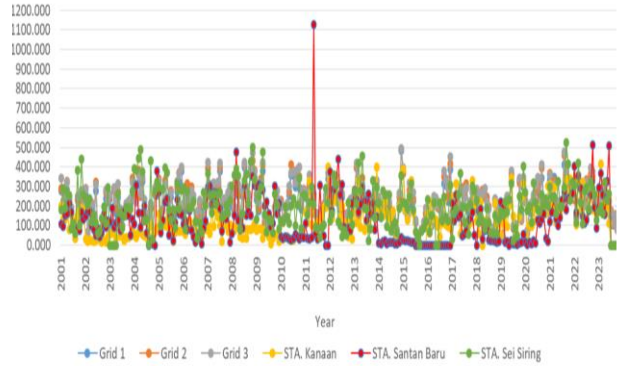

Figure 4. Rainfall Data of Each Ground station and GPM Satellite

wet years, normal years and dry years. The water balance simulation is done by trial and error, where the water level at the beginning of the period is the same as the water level at the end of the period. From the simulation results, the operating curves for wet years, normal years and dry years were obtained.

The simulation of reservoir operation patterns is based on the water balance equation (Equation 1).

$$I - O = \frac{ds}{dt} \quad (1)$$

With I being the inflow discharge (m^3/s), O being the outflow discharge (m^3/s), and $\frac{ds}{dt}$ being the change in storage (m^3/s).

The detailed reservoir water balance analysis can be calculated using the following Equation 2.

$$S_{t+1} = S_t + I_t - E_t - SP_t - Rl_t \quad (2)$$

With S_t, S_{t+1} is the reservoir storage at a certain period, I_t is the inflow discharge during period t, E_t is the water loss due to evaporation during period t, SP_t is the water runoff through the spillway during period t and Rl_t is the water release in the reservoir according to the operating pattern.

3. Results and Discussion

3.1 Rainfall Data Analysis

The closest rainfall stations to the catchment area of the Marangkayu Reservoir are the ground stations STA. Kanaan, STA. Santan Baru, and STA Sei Siring as shown in Figure 2. None of the 3 (three) ground station rainfall stations are located in the Marangkayu catchment, so rainfall analysis was performed using Global Precipitation Measurement (GPM) satellite data.

GPM Satellite rain data with a spatial resolution of 0.1^0 x 0.1^0 degrees required 3 grids to cover the entire Marangkayu catchment. The GPM Marangkayu Satellite Gridfor Marangkayu is shown in Figure 3. Rainfall data for 2001 - 2023 for each ground station and GPM satellite grid can be seen in Figure 4.

The GPM satellite rainfall data was evaluated against the ground station rainfall data using the correlation coefficient parameter. The value of the correlation coefficient between the ground station and the GPM satellite is shown in Table 1.

STA. Sei Siring has a correlation value (r) > 0.6, which means that the rain data from the GPM satellite has

Table 1. Correlation Coefficient Between Ground Station and GPM Satellite

Rainfall	Correlation		
	Sta. Santan Baru	Sta. Kanaan	Sta. Sei Siring
Grid 1	0.2768	0.3384	0.6316
Grid 2	0.2611	0.3184	0.6262
Grid 3	0.2473	0.3203	0.6404

Table 2. Error value Before and After Correction

Error Value	Sei Siring		
	Grid 1	Grid 2	Grid 3
Before Correction	0.02697	0.02652	0.02892
After Correction	0.00828	0.00791	0.00863

Table 3. Outlier test for the Corrected Rainfall Data of Grid 1, Grid 2, and Grid 3

Satellite	Grid 1	Grid 2	Grid 3
Data Max	151.22	179.48	139.34
Data Min	64.1	52.23	76.33
Upper Limit	186.5	189.17	161.51
Lower Limit	56.69	54.45	62.49
Results	**Accepted**	**Accepted**	**Accepted**

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Table 4. Consistency Test of Grid 1, Grid 2, and Corrected Grid 3

Satellite	Grid 1	Grid 2	Grid 3
$Q/\sqrt{n}$ Calculate	0.38	0.4	0.44
$R/\sqrt{n}$ Calculate	0.68	0.69	0.79
$Q/\sqrt{n}$ Table		1.42	
$R/\sqrt{n}$ Table		1.63	
Results	**Consistent**	**Consistent**	**Consistent**

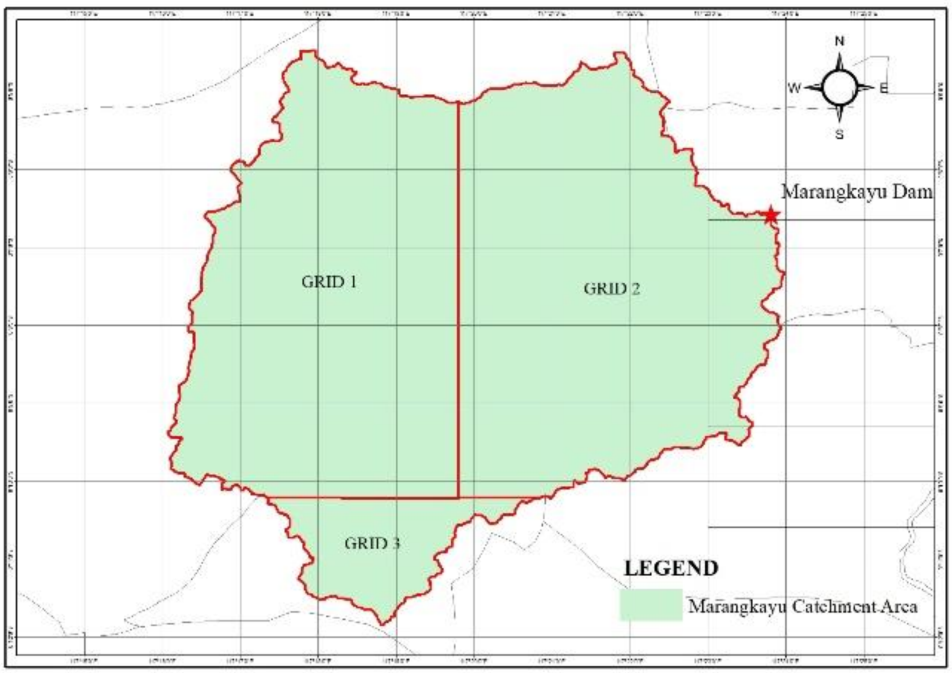

Figure 5. The impact of the individual grids on the water catchment area of Marangkayu

a strong relationship with the rain data from the STA. Sei Siring, while for STA. Santan Baru and STA. Kanaan has a low correlation value with the GPM satellite rain data.

Correction of GPM satellite rain data with Sei Siring rain station is done by multiplying the daily rain data by the correction coefficient to reduce the error value between GPM rain data and ground station data. The results of the correction based on the error value of the GPM satellite rain data against the Sei Siring rain station data can be seen in Table 2.

After the correction between the GPM satellite rain data and the Sei Siring rain station, the error value was reduced, then the corrected GPM rain data using the Sei Siring rain station rain data is tested using the outlier test and consistency test.

The purpose of the outlier test is to determine whether the data is acceptable as part of the data set or

Table 6. Parameter values for FJ Mock calculation

Parameters	Value	Description
Open land factor (m)	30%	Agricultural area
Soil moisture capacity (SMC)	200 mm	Dominant soil type - clay
Koefisien infiltrate	0.4	Dominant soil type - clay
Ground flow recession factor (k)	0.5	Dominant soil type - clay
Watershed area	60.40 Km^2	
Heavy rainfall flow factor (PF)	30%	Dominant agricultural land

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Table 5. Area of Each Individual Grid's Influence on the Marangkayu Catchment Area

Rain Station	Area (Km^2)	Coefficient
Grid 1	57.178	0.45
Grid 2	61.209	0.48
Grid 3	9.576	0.07
Total	**127.963**	**1**

whether it should be examined for possible errors. Data that is considered an outlier is data that has a value that is very far from the mean or median and is often considered unusual or deviant data. In this study, the outlier test uses the Grubbs and Beck method. The results of the outlier test for the corrected rainfall data of grid 1, grid 2, and grid 3 can be seen in Table 3.

Grid 1 and Grid 3 have data between the upper limit and the lower limit, while Grid 2 has data below the lower limit. On the basis of the outlier test by the Grubbs and Beck method, it is explained that the data below the lower limit can be discarded directly, while the data above the upper limit should be considered for discard. Based on the outlier test analysis according to Table 3, it is determined that Grid 1, Grid 2, and Grid 3 are acceptable.

The consistency test is performed to ensure that the rain data collected from different stations are consistent and reliable. The Rescaled Adjusted Partial Sums method was used to perform the consistency test in this study. The consistency test results of Grid 1, Grid 2, and Grid 3 rain data corrected to 99% reliability are shown in Table 4.

The values $Q/\sqrt{n}$ calculate and $R/\sqrt{n}$ calculate are smaller than $Q/\sqrt{n}$ Table and $R/\sqrt{n}$ Table so it is stated that the rain data of Grid 1, Grid 2, and Grid 3 are consistent.

3.2 FJ Mock Model - Analysis of Water Availability

The rainfall data used is 15 daily corrected GPM satellite rainfall data from 2001 - 2023, the calculation of flow discharge using the FJ Mock Method for each year for 23 years. In this analysis, 15 daily rainfall data needed to be converted into 15 daily low-flow discharges. Based on the results of rainfall data correction there are 3 (three) grids so it is necessary to do hydrological analysis to determine the average rainfall.

The regional rainfall is calculated on the basis of the influence of each of Grid 1, Grid 2, and Grid 3 on the

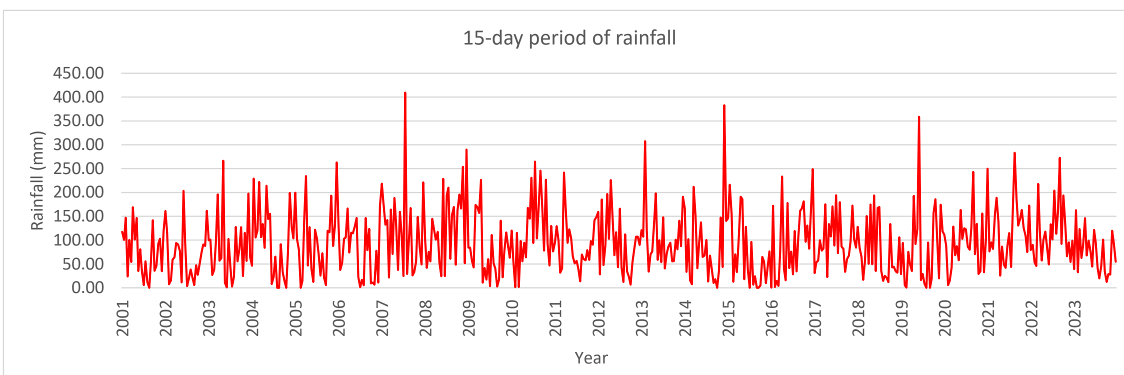

Figure 6. Regional Rainfall Graph from 2001 - 2023

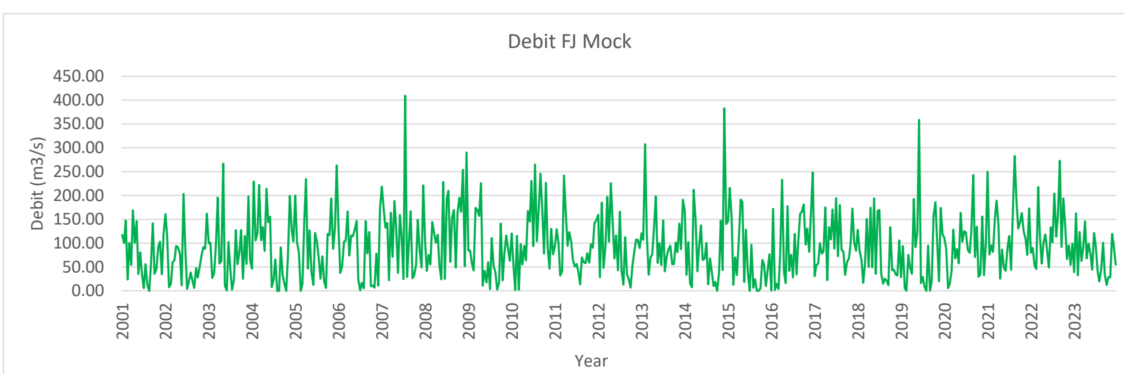

Figure 7. The low flow discharge analysis of the FJ Mock method with a 15-day period from 2001 - 2023

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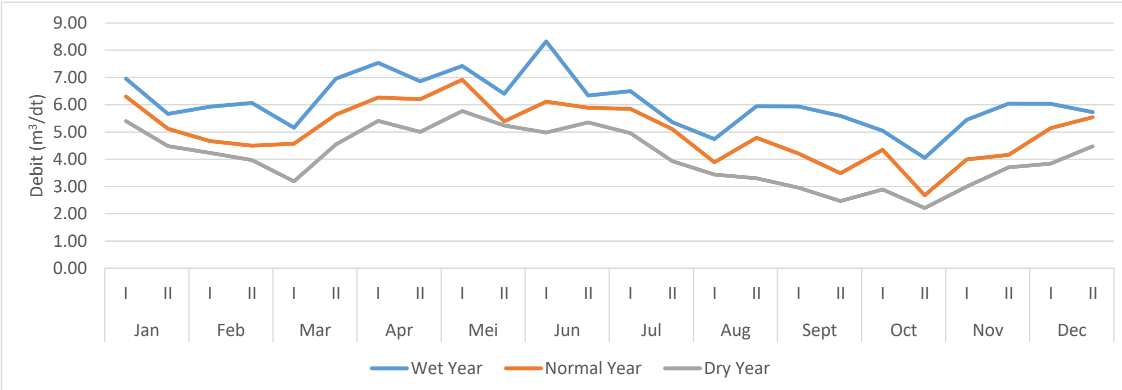

Figure 8. Recapitulation of Reliable Discharge in Wet Year, Normal Year, and Dry Year Conditions

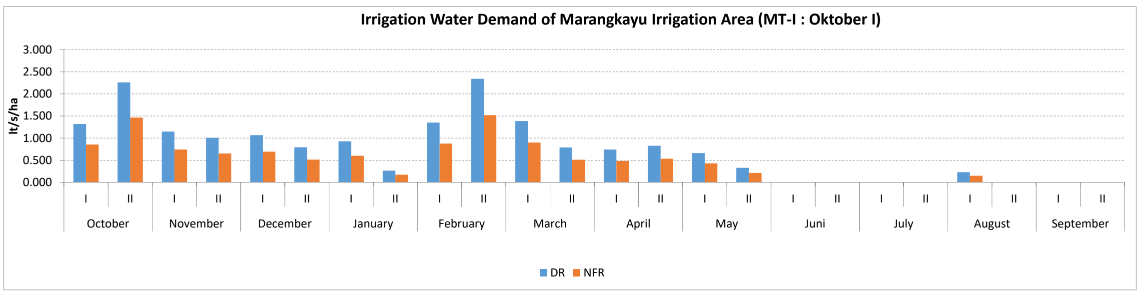

Figure 9. Marangkayu Irrigation Demand Discharge

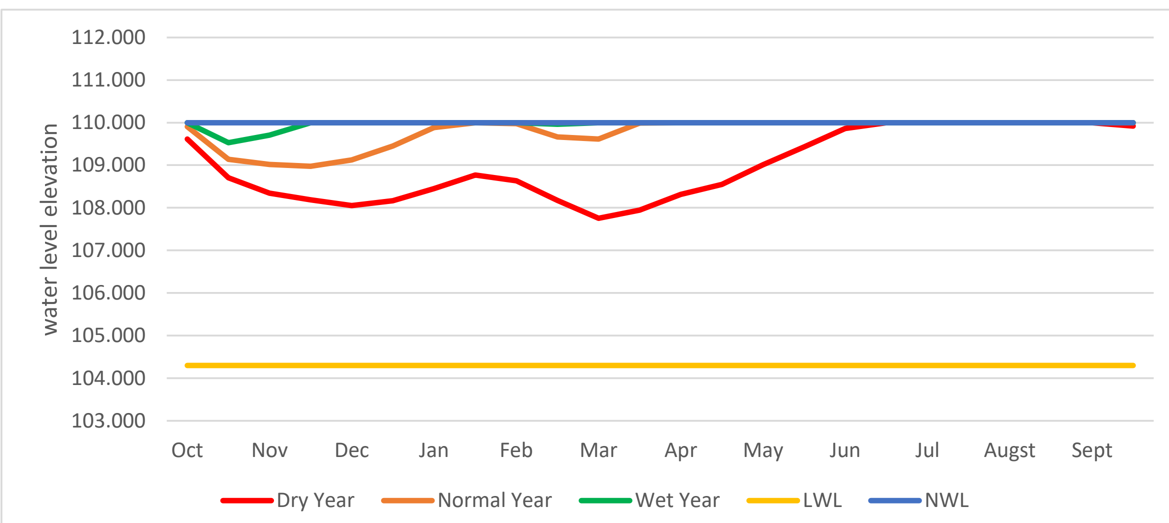

Figure 10. Simulated Base Year Operating Pattern of Marangkayu Reservoir

water catchment area of Marangkayu. The influence of each grid on the Marangkayu DTA is shown in Figure 5. The influence of each of the grids on the catchment area of Marangkayu has a different area. The area of each individual grid's influence on the Marangkayu catchment area can be seen in Table 5.

As a basis for the FJ Mock model runoff calculation, the amount of each grid influence is used to calculate the regional rainfall in the Marangkayu catchment. The results of calculating the regional rainfall for 2001 - 2023 are presented in a graph that can be seen in Figure 6. The calculation of runoff using the FJ Mock method requires several parameters, such as the value of the open area factor (m), soil moisture capacity (Soil Moisture Content), infiltration coefficient, groundwater flow recession factor (k), heavy rainfall flow factor (PF),

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and Marangkayu catchment area. The values of the parameters that were used for the calculation of the FJ Mock can be seen in Table 6. The results of the low flow discharge analysis of the FJ Mock method with a 15-day period from 2001 - 2023 are displayed in graphical form which can be seen in Figure 7.

3.3 Reliable Discharge Analysis

Calculation of the mainstay runoff using the runoff duration curve method with the Weibull probability formula for three conditions, namely, dry year conditions (probability of reaching or exceeding 65%), normal year (50%), and wet year (probability of reaching or exceeding 35%). Figure 8 shows a recapitulation of the mainstay runoff for wet, normal, and dry year conditions. The average wet year discharge was 6.09 m^3/s, the average normal year discharge was 5.03 m^3/s, and the average dry year discharge was 4.12 m^3/s.

3.4 Water Demand Analysis

3.4.1 Irrigation Water Demand

Irrigation water demand is calculated on the basis of the rice - rice – secondary cropping pattern (October I) with a period of 15 days for a functional irrigation area of 1,500 hectares. Figure 9 shows the irrigation water demand for each period. The period from October to May requires irrigation water from the intake (DR), while the period from June to December tends not to require irrigation water from the intake (DR).

3.4.2 Raw Water Demand

In this study, according to the planning document, the allocation of raw water demand for Kutai Kertanegara Regency is 250 liter per second and Bontang City is 200 liter per second with a total raw water demand of 450 liter per second (Balai Wilayah Sungai Kalimantan IV, 2024).

3.4.3 River Maintenance Water Demand

The water required to maintain the river is obtained by averaging the 95% probability of the main stem flow, which is 0.848 m^3/dt.

3.5 Reservoir Water Balance Simulation

The base year simulation is implemented by modeling water inflows, water demands, and losses or water losses with reservoir storage capacity constraints to obtain reservoir operating patterns throughout the specified time period.

The Marangkayu Reservoir operation simulation also consists of the upper, normal, and lower limits of reservoir operations. The minimum operation level is at elevation + 104.30 and the upper limit of operation is at the normal water level elevation of + 100.00 so that if the reservoir water level is above the normal level, flood operations are carried out, while if the reservoir water level is below the low water level, it is necessary to carry out drought alert. The base year simulation of the Marangkayu Reservoir operation pattern can be seen in Figure 10.

The simulation results of the Marangkayu Reservoir operation show that the water level during the period is above the low water level or remains ineffective storage, which means that the reservoir is able to meet water needs throughout the base year period.

4. Conclusion

Simulation of the Marangkayu Reservoir operation pattern using the base year method, namely with the conditions of inflow discharge in wet years, normal years, and dry years, is able to meet the water needs for irrigation of 1,500 hectares with a rice - rice - secondary cropping pattern, raw water needs of 450 liter per second, and river maintenance of 0.848 m^3/dt. Reservoir storage elevation in dry year conditions decreased by 0.08 m, from 110.00 to 109.92 so that outflow optimization is needed to keep the initial storage elevation of the period equal to the final storage elevation of the period, while in normal and wet years the reservoir storage elevation remains at 110.00 elevation, this is because the inflow discharge in normal and wet years tends to be greater than the outflow discharge.

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