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OPTIMIZATION OF THE MRICA RESERVOIR MANAGEMENT AT [1]BANJARNEGARA REGENCY USING A DETERMINISTIC DYNAMIC PROGRAM (FOR ELECTRICITY PRODUCTION AND IRRIGATION WATER)

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ABSTRACT
Siltation becomes the Mrica reservoir's main problem that causes the reduction of the effective storage capacity of the dam, so it cannot function properly. This research aims to obtain the optimal Reservoir Operating Rules that can produce maximum electrical power in hydropower and fulfill the irrigation water requirements as designed according to the existing reservoir capacity. The optimization method used in this research is a Deterministic Dynamic Program, assuming the event occurs as a certain occurrence. In this procedure, the existing constraints divide into multi-stages with decision variables at each stage. The analysis starts from a backward to a forward recursive to get the water storage and release maximum used as a recommendation to design the effective Reservoir Operation Rules. It was simulated using three scenarios, including Scenario 1 (Q IR optimization=actual); Scenario 2 (Q IR optimization=design); and Scenario 3(Q IR generate optimization=demand). Based on the benchmarking analysis results, the percentage of design, actual, and optimized Reservoir Operation Rules were 98.08%, 98.29%, and 99.04%, respectively, which indicates the design Reservoir Operational Rules performance is not better than others. Besides that, Scenario 2 has the highest profit of Rp 76350527181 and fulfills regulation No. 7 of 2004 concerning water resources.

Keywords : Optimization, Reservoir, Management

1. INTRODUCTION

The electricity consumption in Indonesia increases significantly every year. However, the electricity supply in Indonesia so far still relies on non-renewable power plants. Based on data from the Indonesian Ministry of Energy and Mineral Resources, from 2015 to 2020, the enormous amount of electricity usage is still dominated by electricity sourced from Coal Power Plants [1]. One alternative to reducing dependence on coal-fired power plants is through renewable resource power plants, such as hydroelectric power plants (PLTA). Hydropower is built using hydropower, usually found in dams or reservoirs. One example of a reservoir that functions as a power generator in Indonesia is the Mrica Reservoir in Banjarnegara. In addition, Mrica Reservoir is also used to fulfill irrigation water needs. However, The Mrica reservoir has a crucial problem related to silting. It happens due to the much material carried by the river sedimented at the reservoir's bottom and caused a rapid decrease in reservoir capacity [2]. As a result, the release issued by the Mrica reservoir is less than optimal in its operation. Therefore, we need water resource modeling in the form of optimization to help overcome the problems of water system configuration that are so complex and have a non-linear relationship between variables. The

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optimization of the management of the Mrica reservoir in this study uses a deterministic dynamic program method for optimization targets in the form of hydropower electricity production and irrigation water. The output of this research is realistic and optimal regulation of reservoir water release output to obtain adequate and reliable reservoir operation rules. In addition, this study also determined the reservoir operation pattern with the most optimal profit and following the provisions contained in Law no. 7 of 2004 concerning water resources.

There have been several previous studies related to reservoir optimization use a dynamic deterministic program. In 2012, Nurmansyah conducted research on the application of the Bellman dynamic program for a case study of the Saguling water reservoir at constant electricity prices and fluctuating electricity prices. In this condition, the comparison between Bellman's optimal profit and the operating profit of the constant discharge reservoir is minimal; that is, the added profit is only about 3.2%, so it can be concluded that under these conditions, the Bellman dynamic program does not provide added profit compared to the constant discharge operation [3]. Ritonga (2015) carried out a study on the application of dynamic programs in the East Lombok Regency to determine a simulation of cropping pattern planning. The simulation results show that the best planting schedule for East Lombok Regency is Planting Season I starting in January II, Planting Season II starting in May II, and Planting Season III starting in October II. Based on the simulation, it can be predicted that the projected value of production profits will increase by 20.49% [4]

In 2015, Purnamasari conducted research in the Kedungombo Reservoir. In this study, the optimization method is optimization with a non-linear program and the completion of the formulation using a solver in Microsoft Excel by utilizing reservoir capacity and inflow discharge. Based on the results of optimization of the Kedungombo reservoir using a simulation of the operation of the reservoir for ten years (2005-2015), in the existing condition, the electric power generated is 1,253,410.40 kW and the electric power after optimization is 1,514,572.63 kW which has increased by 20, 8%. In 2016, Nuf'a et al. researched water optimization of the Gondang reservoir using a deterministic dynamic method. From the optimization that has been carried out, there is an increase in irrigation intensity and profits, namely the irrigation intensity before optimization from 175% to 228.57%, and irrigation gains from IDR. 539,371,00 to IDR. 702,830,000,00. In 2004, Azmeri et al. analyzed water availability and the operating system of the Sukawana-Cimahi Reservoir with a deterministic dynamic method. In this study, the deterministic dynamic program only uses one inflow at each stage for one calculation. The water balance simulation in this study was carried out to try various uses of water demands, including drinking water, irrigation, industry, and PLTMH from 2003 to 2028 with two discharge alternatives, namely Q80 and Q50. The results of optimization of reservoir operations with deterministic dynamic programs produce reservoir operation patterns for wet, normal, and dry years, respectively. Storage in January and December is at a maximum elevation of 1475 m. From May to September, there was a decrease in the water level in the reservoir. Based on the water allocation simulation calculation, the reservoir storage volume has increased from 2003 to 2028 [5].

In 2008, Natalia P.R conducted a research entitled Formulation of Reservoir Curve Rule Using a Deterministic Dynamic Program Model in Sermo Reservoir. The rule curve obtained shows that the operational performance of the reservoir in the field can still be improved. The existing rule curve of the Sermo Reservoir in 2008 shows that the realization of the release in the field is closer to the rule curve resulting from the

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optimization. Resmi et al. (2015) studied optimizing the Wonogiri reservoir operating pattern using the Deterministic Dynamic Program with the help of CSUDP. Based on the study's results, it can be concluded that the actual operation of the reservoir is not yet optimum, with only 29% reliability. The most optimal operation of the Wonogiri reservoir is using a rule curve resulting from the optimization with 51% reliability [6].

2. STUDY LITERATURE

2.1. Basic equation of reservoir water balance

The basic equation for simulating the water balance in the reservoir is a function of input, output, and reservoir storage which can be formulated according to equation 1.

$$I - O = \frac{ds}{dt} \tag{1}$$

Where I is inflow discharge (m3/s), O is outflow discharge (m3/s), and ds/dt is delta storage (m3/s). Equation 1 in detail can be written as Equation 2.

$$St+1 = St + Rt - Et - Lt - Ot - OS \tag{2}$$

Where St is reservoir storage in period t, St+1 is reservoir storage in period t+1, It is reservoir inflow in period t, Rt is rainfall in reservoir surface, in period t, Et is the water losses due to the evaporation in period t, Lt is the water losses due to seepage and leakage, Ot is the total of water demand, and OS is the spillway outflow [7].

2.2. Dynamic Programming

Dynamic programming is one of the optimization techniques used to solve a double-step problem, where to solve the problem, it is necessary to form a recursive equation. What is meant by double-step problem solving is that initially, the problem is solved in one stage, then two stages, and then continued until all stages are completed [8]. Dynamic programming generally solves problems in stages involving exactly one optimization variable. The computations at the different stages are linked through recursive computations to produce the optimal possible solution for the entire problem. To formulate a problem involving optimal decision-making (maximum or minimal) into a Dynamic program model, it is necessary first to define the five essential elements of a dynamic program model, as shown in Figure 1.

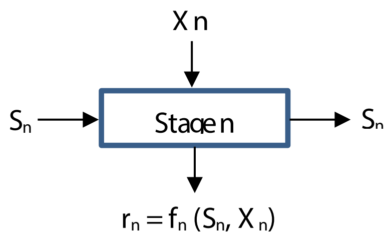

Figure 1. Dynamic program transformation [9]

Where Sn-1 is input state, Sn is output state, Xn is decision, and rn is return function, f (Sn , Xn). Therefore, a gradual decision chain scheme can be drawn according to Figure 2.

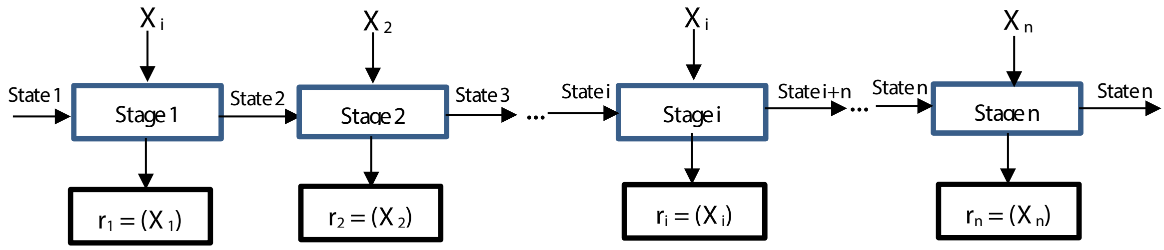

Figure 2. Gradual decision chain scheme [9]

The recursive equations commonly used to solve dynamic programming are forward recursive and backward recursive equations. In forward recursive, the calculation is carried out forward, starting from the first stage to the last stage (n), while backward recursive is the calculation starting from the last stage (n) and continuing backward to stage 1. The results obtained from both recursion are the same. Most dynamic program calculations use backward recursion. However, forward recursion supports computational efficiency in some instances involving time-span decision-making, such as inventory and production planning.

2.3. Deterministic dynamic program

A deterministic dynamic program is a dynamic programming method applied to deterministic problems, where the state at the next stage is entirely determined by the state or decisions made at the current stage. The basic structure diagram of a deterministic dynamic program is shown in Figure 3. In its development, dynamic programs can be categorized as deterministic dynamic programs and stochastic dynamic programs. A deterministic dynamic program treats phenomena that occur as certain occurrences. In contrast, the stochastic dynamic program considers the nature of uncertainty in its primary input through flow [10].

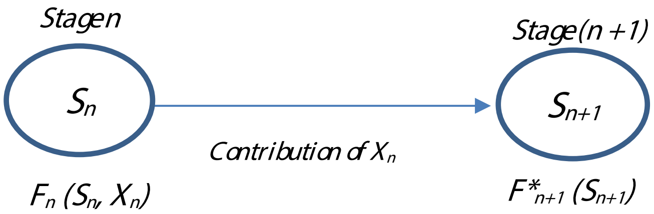

Figure 3. The basic structure of a deterministic dynamic program [9]

2.4. Optimization formula

Optimization in this study was carried out to maximize the value of electrical energy. The optimization objective function is given in equation 3.

$$Max\ Z = \frac{1}{n}\sum_{i=1}^{n} P(i) \quad (3)$$

where P(i)= Electricity generation in the period i, Z = objective function value, i = sequence of reservoir operation periods, namely the middle of the month i, and n = number of periods under review (24 periods/year). The power equation used in hydroelectric power is according to equation 4.

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$$P = \eta \; x \; 9.8 \; x \; H_e \; x \; Q \; x \; \rho \qquad (4)$$

where P is electricity generation, η = turbine-generator efficiency, H_e is effective fall height (m), Q is hydropower discharge (m^3/s), and ρ = Density of water (Kg/m^3)

3. METHODOLOGY

3.1. Study area

The research location is in the General Sudirman Reservoir, well-known as the Mrica Reservoir. Mrica Reservoir is located in Bawang District, Banjarnegara Regency, at coordinates 109006'00" - 110007'49" East Longitude and 7017'04" - 7047'07" South Latitude. The map of the research location is shown in Figure 4.

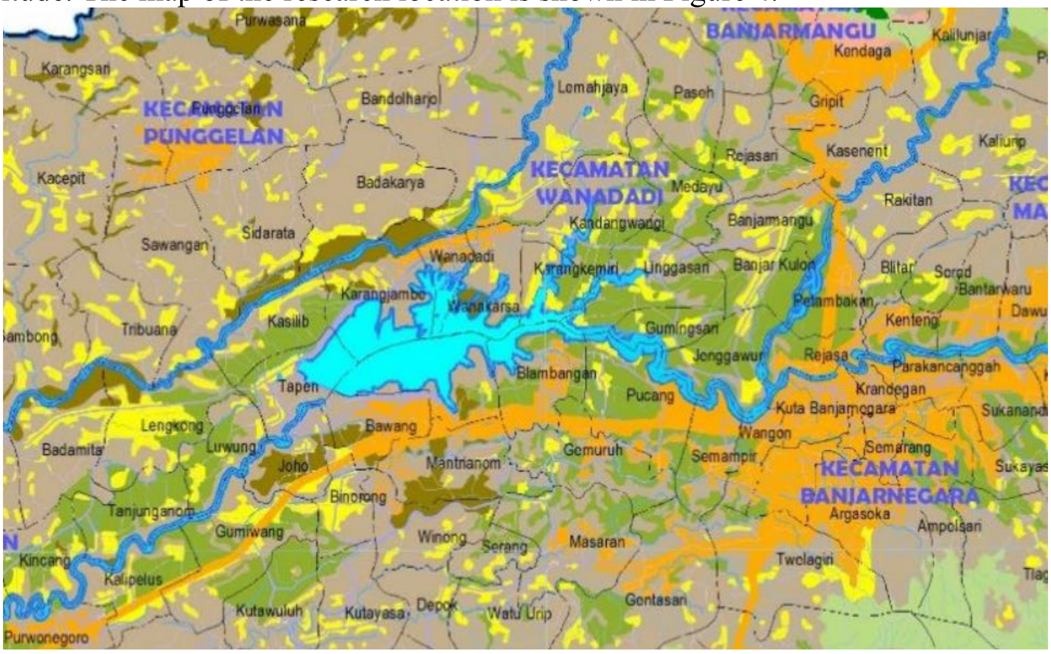


Figure 4. The map of the research location (sources: Pusadataru, 2017)

3.2. Data

The research location is in the General Sudirman Reservoir, well-known as the Mrica Reservoir. Mrica Reservoir is located in Bawang District, Banjarnegara Regency, at coordinates 109006'00" - 110007'49" East Longitude and 7017'04" - 7047'07" South Latitude. The map of the research location is shown in Figure 1. The data used in this study is secondary data, consisting of daily average inflow-outflow discharge data, daily average reservoir operation pattern, daily average reservoir actual elevation, sedimentation rate, echo sounding and evaporation, and technical data from reservoirs Mrica. In addition, data on irrigation needs in the Banjarcahyana irrigation area is also needed. The data obtained from PT. Indonesia Power UBP MRICA and the Department of Public Works, Water Resources and Spatial Planning, Central Java Province.

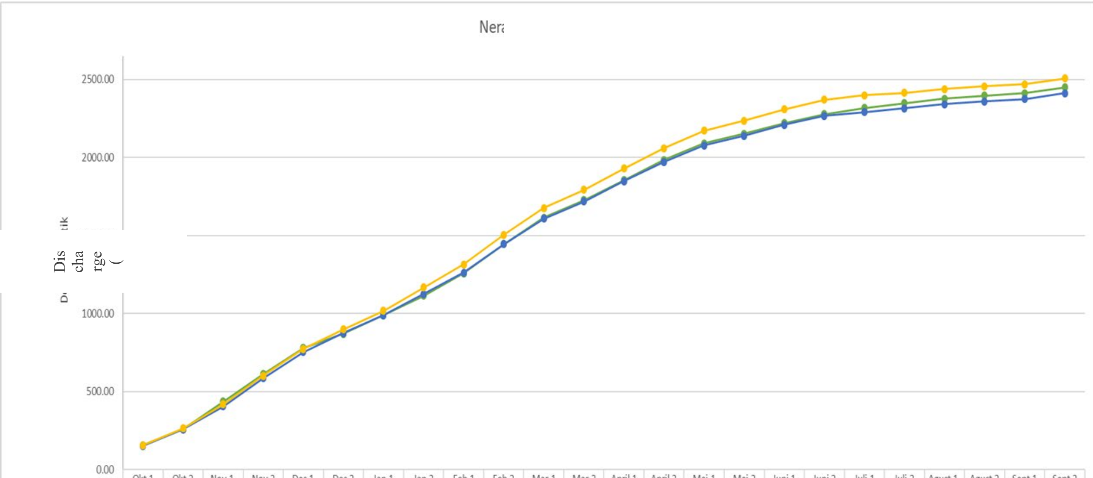
3.3. Analysis method

The analysis in this study was the optimization using a deterministic dynamic program to obtain an operating pattern that can further optimize water availability for water demands, especially for electricity generation and irrigation water needs. The data that has been collected is analyzed for inflow, outflow, and water balance. Then, the results of the three analyses are used as input in the optimization process using a deterministic program in Microsoft Excel. The result of the optimization is the reservoir operation rules. The reservoir operation rules resulting from the optimization still need to be benchmarked and simulated first. Benchmarking was applied by comparing and measuring an operating pattern process against other processes to get the operating pattern with the best performance. After the optimization process is complete, then proceed with the simulation. The simulation aims to see the ability of the reservoir operation pattern between the optimization and actual results to meet the water demand in the Mrica reservoir in the form of a percentage of performance efficiency and check storage. After the benchmarking and simulation process is complete, the next step is verifying the operating pattern; at this stage, three scenario options are applied in this study. In Scenario 1, reservoir release is carried out by equating the irrigation and actual release rates (QIR optimization = Actual). In Scenario 2, the reservoir release is carried out by equating the amount of irrigation release with the planned irrigation needs (Q IR Optimization = demand). In Scenario 3, the release of the reservoir is carried out by equating the magnitude of the power plant release and the actual demand ((Q Optimation generator = demand).

4. RESULT AND DISCUSSIONS

4.1. Water Balance Analysis Result

The water balance often referred to as the Water Usage Index, is the ratio between water use and availability and is usually displayed on a graph. The water balance graph shows the cumulative results of the average inflow, average outflow, and average demand. In this research, the water balance graph of the Mrica reservoir illustrates the actual condition of the amount of water available in the reservoir during the year, as shown in Figure 5. Figure 5 shows the comparison between the cumulative inflow and the actual cumulative outflow of the Mrica Reservoir, where there was a surplus from July-2 to September-2, while from October-1 to June-2, the results were relatively stable. It is different from the results of the comparison of cumulative inflow to cumulative demand, which shows a deficit throughout the year except for October-1 to December-1, so based on this, it shows that there is a need for an operating pattern so that the release outflow obtained meets the release demand.



	Okt 1	Okt 2	Nov 1	Nov 2	Des 1	Des 2	Jan 1	Jan 2	Feb 1	Feb 2	Mar 1	Mar 2	April 1	April 2	Mei 1	Mei 2	Juni 1	Juni 2	Juli 1	Juli 2	Agust 1	Agust 2	Sept 1	Sept 2
Kumulatif Inflow	157.81	261.52	435.99	612.15	779.37	871.34	990.05	1114.80	1258.71	1446.01	1613.90	1727.89	1855.66	1985.62	2089.77	2151.70	2219.19	2278.06	2317.73	2348.06	2377.15	2396.29	2412.76	2449.50
Kumulatif outflow	153.17	258.07	407.09	587.58	752.98	875.50	989.93	1125.73	1261.96	1444.23	1608.65	1718.88	1847.61	1970.50	2077.77	2139.18	2208.80	2265.60	2289.92	2315.80	2341.23	2359.37	2374.02	2412.00
Kumulatif demand	157.34	265.43	418.79	602.96	772.98	899.40	1018.26	1167.11	1316.05	1505.47	1676.93	1794.22	1930.47	2058.93	2171.29	2235.81	2308.67	2370.08	2398.89	2414.31	2438.97	2455.38	2468.19	2506.09

Figure 5. Water balance graph of Mrica Reservoir in 2017

4.2. Reservoir characteristic of Mrica dam

Reservoir storage characteristics describe the relationship between elevation - reservoir volume - inundation area, commonly called the reservoir curve or reservoir capacity curve. (Linsley, 1985:164). Based on the results of the reservoir characteristics of the Mrica Reservoir from 2008 to 2001, it shows that there is silting in the Mrica Reservoir, which causes the characteristic reservoir data to change yearly. The silting process in the Mrica reservoir is shown with a decrease in the volume and area of the Mrica reservoir shown in Table 1. The silting of the reservoir can reduce the effective storage capacity of the reservoir, which will affect the function of the reservoir. Therefore, proper operation and maintenance are needed to help optimize the reservoir's function.

Table 1. Reservoir Characteristics of Mrica Reservoir in 2008-2016

Year	Elevation 224.5		Elevation 225		Elevation 228		Elevation 231	
	Volume	Area	Volume	Area	Volum e	Area	Volume	Area
2008	31.85	2.844	34.72	3.05	45.69	4.44	64.05	8.26
2009	27.99	2.67	31.67	2.87	41.96	4.21	59.29	8.26
2010	23.44	2.51	28.62	2.69	38.23	3.99	55.24	8.259
2011	21.82	2.34	25.57	2.5	34.51	3.76	49.92	8.26
2012	20.68	2.17	22.53	2.32	30.78	3.54	45.78	8.26
2013	13.8	2	19.48	2.13	27.05	3.32	43.3	8.26
2014	11.09	1.83	16.43	1.95	23.33	3.09	41.59	8.26
2015	7.63	1.658	13.38	1.77	19.6	2.87	37.23	8.26
2016	7.63	1.49	10.34	1.58	15.87	2.64	33.59	8.26

4.3. Optimization of Reservoir Operating Rules

Reservoir optimization is carried out to increase the effectiveness of reservoir operations. This study's optimization program calculation process consists of three stages, namely data input, backward recursion, and forward recursion. The final result of the optimization is used in preparing the reservoir operation pattern, which is displayed in the Rule Curve of the Reservoir Operation Zone. The operating zone is bounded by the standard upper curve, the normal curve, and the lower standard limit curve. In principle, the reservoir operation pattern describes the schedule for filling and discharging reservoir water to maintain a constant water level. The rule Curve of the operating zone of the Mrica reservoir in this study is shown in Figure 6.

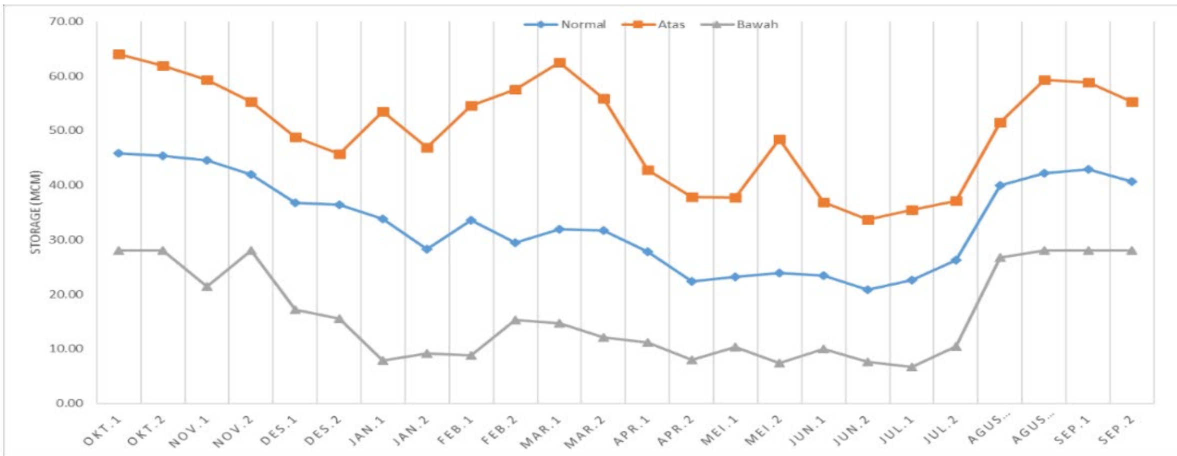


Figure 6. Storage Fluctuation curve for the standard upper, normal, and lower standard limit curves.

Based on Figure 4, the operation pattern of the Mrica reservoir can be arranged in such a way. Suppose the reservoir water level is not following the plan but is still within the boundaries of the operating zone. In that case, the operation of the reservoir is still considered as planned. However, short-term adjustments need to be made as needed. If the reservoir water level is above the "upper normal operating line," it means that there is excess water that can be flowed downstream. For hydropower dams, each water discharge is principally passed through a turbine. If the water level is below the "lower normal operating line," the water discharge must be reduced.

4.4. Benchmarking and Simulation of Reservoir Operation Rules

Benchmarking is to compare the methods and practices for performing processes [11]. While, benchmarking aims to increase the knowledge of best practices. In this study, benchmarking is carried out to gain insight into the performance conditions of the reservoir operating rule so that an optimal reservoir operation pattern can be obtained following the predetermined objectives. Three reservoir operation rules will be benchmarked in this research: the actual reservoir operation rule in 2017, the reservoir operation rule design, and the reservoir operation rule based on the optimization result. The results of the comparison of performance benchmarking in this study are shown in Figure 7.

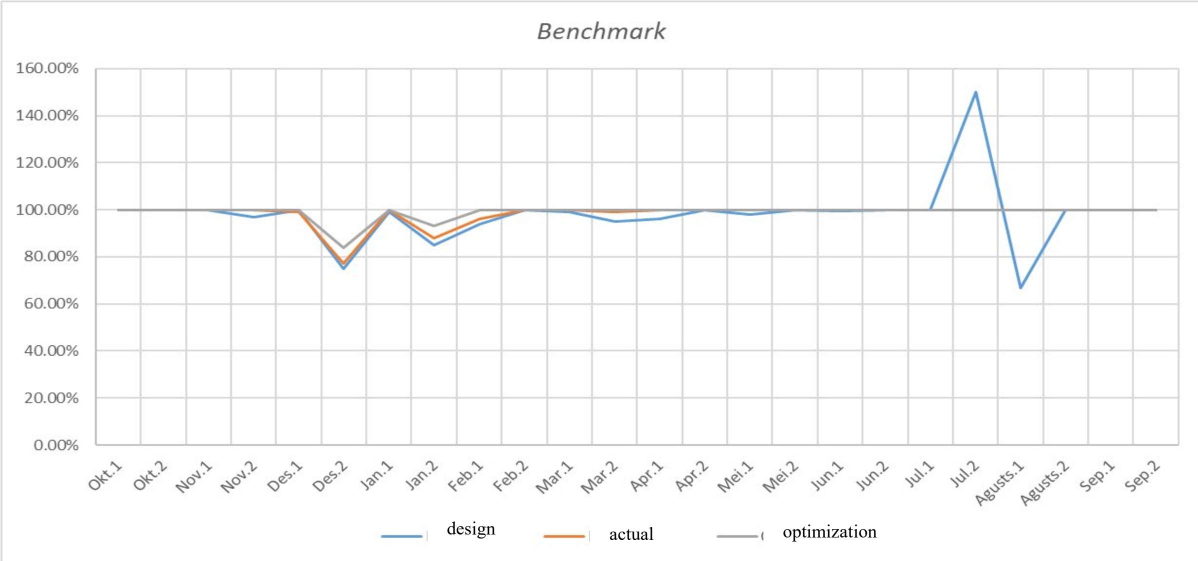


Figure 7. Performance Benchmarking Comparison Results Curve

Based on Figure 5, the optimization result of the reservoir operation rules is more optimal than the actual and planned reservoir operation pattern. The designed reservoir operation rule cannot operate the Mrica Reservoir optimally because the operating rule is below the actual operating plan. In contrast, the ability of the reservoir operating rules in actual conditions to meet the reservoir release needs is almost the same as the optimization result of the reservoir operation rules. After the benchmarking process, the Mrica reservoir simulation process was carried out.

The Mrica Reservoir Operation Rules Simulation is multipurpose, so the input and output data are used to determine the release for irrigation and hydropower needs. The simulation is carried out in 2 stages, consisting of simulation with 2017 inflow-outflow input data to check St-1 and Simulation with the actual 2017 release data compared to three scenarios resulting from the release optimization.

- **Simulation with 2017 inflow-outflow input data to check St-1**
  The simulation with 2017 inflow-outflow data input aims to determine whether the operating pattern between the optimization and actual results can run well with the 2017 inflow-outflow conditions. To see the comparison, see Table 2 and Table 3. Comparison of st-1 check results and performance between results The optimization in the actual condition shows that applying the optimization result of reservoir operation rules is more optimal than the actual of reservoir operation rules.

Table 2. Simulation results for optimization results of reservoir operation rules

Bulan	i	Jumlah Hari	Inflow MCM	ST MCM		Cek Elevasi m	A km2	Evaporasi Et0 mm/hr	Et MCM	QPembangkit (MCM)	Q IR (MCM)	RI(S) (MCM)	*Performace (%)*	cek St-1	Status
Okt.1	24	15	204.53	45.83	28.03	231.00	8.05	3.70	0.45	197.34	6.57	203.91	100.00%	28.03	overflow
Okt.2	23	16	143.37	45.35	28.03	231.00	8.14	3.83	0.50	142.42	7.01	149.43	100.00%	21.47	overflow
Nov.1	22	15	226.11	44.56	28.03	231.00	8.29	2.92	0.36	181.19	17.56	198.75	100.00%	28.03	overflow
Nov.2	21	15	228.30	41.92	28.03	231.00	8.69	3.39	0.44	221.32	17.36	238.68	100.00%	17.22	overflow
Des.1	20	15	216.72	36.75	28.03	231.00	9.02	3.43	0.46	202.99	17.36	220.35	100.00%	23.94	overflow
Des.2	19	16	127.13	36.43	28.03	231.00	9.02	3.56	0.51	156.26	18.51	146.81	84.00%	7.85	Feasible
Jan.1	18	15	153.85	33.87	28.03	231.00	8.95	1.42	0.19	136.69	17.36	154.04	100.00%	27.65	overflow
Jan.2	17	16	172.45	28.29	28.03	231.00	8.29	1.45	0.19	175.47	30.29	191.36	93.00%	8.93	Feasible
Feb.1	16	15	186.51	33.57	28.03	231.00	8.93	2.67	0.36	164.64	28.40	193.04	100.00%	21.15	Feasible
Feb.2	15	13	210.38	29.40	28.03	231.00	8.47	2.42	0.27	195.58	17.18	212.76	100.00%	25.38	Feasible
Mar.1	14	15	217.57	31.90	28.03	231.00	8.79	2.77	0.36	202.62	19.59	222.21	100.00%	23.02	Feasible
Mar.2	13	16	157.59	31.68	28.03	231.00	8.77	2.92	0.41	141.48	20.65	162.13	100.00%	23.08	Feasible
Apr.1	12	15	165.59	27.84	27.8426	231.94	8.21	2.93	0.36	157.22	19.37	176.59	100.00%	16.48	Feasible
Apr.2	11	15	168.43	22.39	22.38908	230.80	6.85	2.32	0.24	147.11	19.37	166.48	100.00%	24.10	Feasible
Mei.1	10	15	134.98	23.20	23.19874	230.96	7.09	3.37	0.36	126.24	19.37	145.61	100.00%	12.21	Feasible
Mei.2	9	16	85.62	23.85	23.85471	231.10	7.28	3.19	0.37	68.53	20.67	89.20	100.00%	19.90	Feasible
Jun.1	8	15	87.46	23.47	23.47303	231.02	7.17	3.03	0.33	75.05	19.38	94.43	100.00%	16.18	Feasible
Jun.2	7	15	76.29	20.83	20.83252	230.48	6.34	2.98	0.28	59.35	20.24	79.59	100.00%	17.25	Feasible
Jul.1	6	15	51.42	22.57	22.57076	230.84	6.91	2.84	0.29	17.09	20.24	37.33	100.00%	28.03	overflow
Jul.2	5	16	41.93	26.26	26.25629	231.59	7.88	2.07	0.26	20.19	1.13	21.32	100.00%	28.03	overflow
Agusts.1	4	15	37.70	39.99	28.03	231.00	8.88	3.20	0.43	25.39	6.57	31.96	100.00%	28.03	overflow
Agusts.2	3	16	26.45	42.22	28.03	231.00	8.65	3.38	0.47	15.67	7.01	22.68	100.00%	28.03	overflow
Sep.1	2	15	21.36	42.89	28.03	231.00	8.56	3.21	0.41	10.07	6.53	16.60	100.00%	28.03	overflow
Sep.2	1	15	47.61	40.61	28.03	231.00	8.83	2.81	0.37	42.59	6.53	49.12	100.00%	26.15	overflow
													99.04%		

Table 3. Simulation results of reservoir operation rules in actual condition

Bulan	i	Jumlah Hari	Inflow MCM	Actual Elv m	Cek St MCM	A km^2	Evaporasi Et0 mm/hr	Et MCM	QPembangkit aktual	Q IR (MCM) aktual	Q IR (MCM) rencana	RI(S) (MCM) aktual	Performace (%) dengan $Q_{irigasi\ aktual}$	Performace (%) dengan $Q_{irigasi\ rencana}$	cek St-1	Status	
Okt.1	24	15	204.53	230.49	23.98	8.05	3.70	0.45	197.34	1.17	6.57	198.51	100.00%	97.35%	28.0	overflow	29.55
Okt.2	23	16	143.37	230.04	21.01	8.14	3.83	0.50	142.42	2.59	7.01	145.01	100.00%	97.04%	18.9	Feasible	18.87
Nov.1	22	15	226.11	230.20	22.03	8.29	2.92	0.36	181.19	11.94	17.56	193.13	100.00%	97.17%	28.0	overflow	54.64
Nov.2	21	15	228.30	230.28	22.53	8.69	3.39	0.44	221.32	12.59	17.36	233.91	100.00%	98.00%	16.5	Feasible	16.48
Des.1	20	15	216.72	229.38	17.22	9.02	3.43	0.46	202.99	11.37	17.36	214.35	100.00%	97.28%	19.1	Feasible	19.12
Des.2	19	16	127.13	228.98	15.33	9.02	3.56	0.51	156.26	13.13	18.51	169.38	100.00%	96.92%	0	unfeasible	-27.43
Jan.1	18	15	153.85	228.90	14.98	8.95	1.42	0.19	136.69	11.61	17.36	148.30	100.00%	96.27%	20.3	Feasible	20.34
Jan.2	17	16	172.45	229.19	16.27	8.29	1.45	0.19	175.47	12.26	30.29	187.73	100.00%	91.24%	0	unfeasible	0.80
Feb.1	16	15	186.51	229.17	16.21	8.93	2.67	0.36	164.64	11.92	28.40	176.55	100.00%	91.46%	25.8	Feasible	25.82
Feb.2	15	13	210.38	229.83	19.70	8.47	2.42	0.27	195.58	9.14	17.18	204.72	100.00%	96.22%	25.1	Feasible	25.08
Mar.1	14	15	217.57	229.58	18.29	8.79	2.77	0.36	202.62	10.46	19.59	213.09	100.00%	95.89%	22.4	Feasible	22.42
Mar.2	13	16	157.59	228.98	15.34	8.77	2.92	0.41	141.48	10.90	20.65	152.38	100.00%	93.99%	20.1	Feasible	20.14
Apr.1	12	15	165.59	229.53	18.00	8.21	2.93	0.36	157.22	9.62	19.37	166.83	100.00%	94.48%	16.4	Feasible	16.39
Apr.2	11	15	168.43	229.44	17.55	6.85	2.32	0.24	147.11	12.16	19.37	159.27	100.00%	95.67%	26.5	Feasible	26.47
Mei.1	10	15	134.98	229.89	20.05	7.09	3.37	0.36	126.24	12.78	19.37	139.02	100.00%	95.47%	15.6	Feasible	15.64
Mei.2	9	16	85.62	230.39	23.29	7.28	3.19	0.37	68.53	16.35	20.67	84.88	100.00%	95.16%	23.6	Feasible	23.64
Jun.1	8	15	87.46	230.07	21.19	7.17	3.03	0.33	75.05	15.19	19.38	90.24	100.00%	95.56%	18.1	Feasible	18.08
Jun.2	7	15	76.29	228.79	14.55	6.34	2.98	0.28	59.35	14.26	20.24	73.61	100.00%	92.49%	16.9	Feasible	16.95
Jul.1	6	15	51.42	229.92	20.22	6.91	2.84	0.29	17.09	14.43	20.24	31.52	100.00%	84.44%	28.0	overflow	39.82
Jul.2	5	16	41.93	230.89	26.98	7.88	2.07	0.26	20.19	15.58	1.13	35.77	100.00%	100.00%	28.0	overflow	32.88
Agusts.1	4	15	37.70	230.83	26.53	8.88	3.20	0.43	25.39	7.58	6.57	32.97	100.00%	100.00%	28.0	overflow	30.83
Agusts.2	3	16	26.45	230.28	22.57	8.65	3.38	0.47	15.67	9.40	7.01	25.07	100.00%	100.00%	23.5	Feasible	23.48
Sep.1	2	15	21.36	230.36	23.09	8.56	3.21	0.41	10.07	8.91	6.53	18.99	100.00%	100.00%	25.1	Feasible	25.05
Sep.2	1	15	47.61	230.50	24.07	8.83	2.81	0.37	42.59	6.63	6.53	49.22	100.00%	100.00%	22.1	Feasible	22.08
													100.00%	95.92%			

- **Simulation with the actual 2017 release data compared to the three release optimization result scenarios.**
  The results of the simulation calculation of the Mrica Reservoir Operation Rules are classified into three scenarios, including:
  The results of the simulation calculation of the Mrica Reservoir Operation Rules are classified into three scenarios, including:

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1. Scenario 1 (Q IR Optimization=Actual)
   In scenario 1, the reservoir release is calculated by equating the irrigation and actual release rates.
2. Scenario 2 (Q IR Optimization=demand)
   In scenario 2, reservoir release is calculated by equating the amount of irrigation release with the design irrigation water requirement.
3. Scenario 3 (Q optimization generator = demand)
   In scenario 3, reservoir release is analyzed by equating the amount of generator release and actual demand. Generator discharge (Q generator) is the discharge used for power generation.

The results of the three scenarios above will be compared with the actual release conditions to obtain the difference in the results. In the comparison process, the quantity data used consists of the data from BPP PT. PLN and data on farmers' income per hectare from BPS. The results of the Scenario-1 simulation can be seen in Figure 8. Next, the results of the Scenario-2 simulation are shown in Figure 9. Then, the results of the scenario three simulations are depicted in Figure 10.

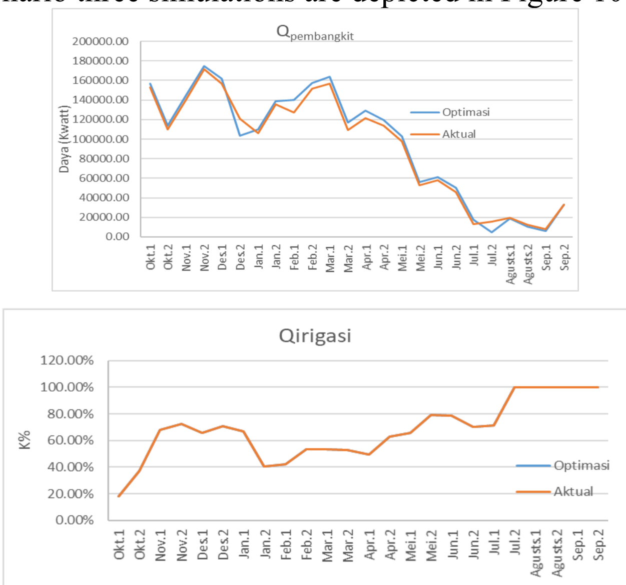

Figure 8. Reservoir Operating Rules Scenario 1

Figure 8 illustrate the comparison of the optimization discharge for electricity generation and the discharge for irrigation against the actual discharge using Scenario 1. Scenario 1 is intended to increase electrical power so that the irrigation discharge resulting from the optimization is equated with the actual irrigation discharge so that the excess discharge release irrigation results from the optimization can be diverted for electricity generation purposes. The electric power generated by Scenario-1 optimization increases to 102.77%.

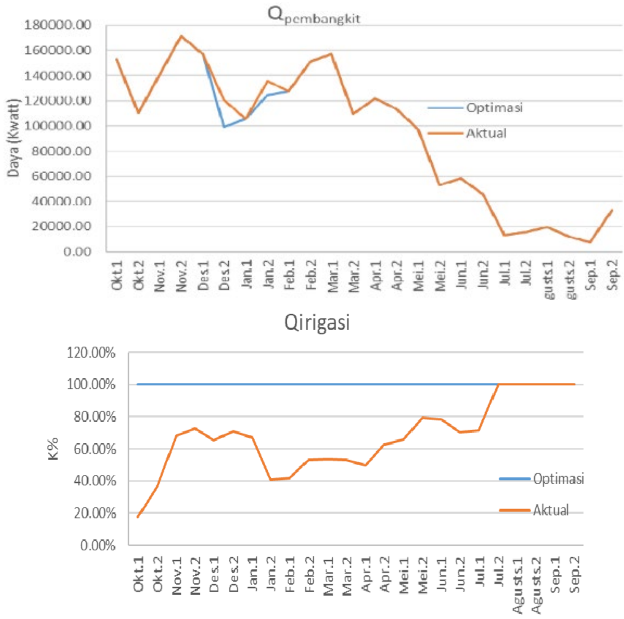

Figure 9. Reservoir Operating Rules Scenario 2

Scenario 2 aims to optimize the reservoir discharge for irrigation so that it impacts decreasing the hydropower release. Therefore, the irrigation release from the optimization results can reach 100% fulfillment. In contrast, the generator discharge in the optimal reservoir operation rules is a slight decrease in electric power production, as shown in Figure 9 above.

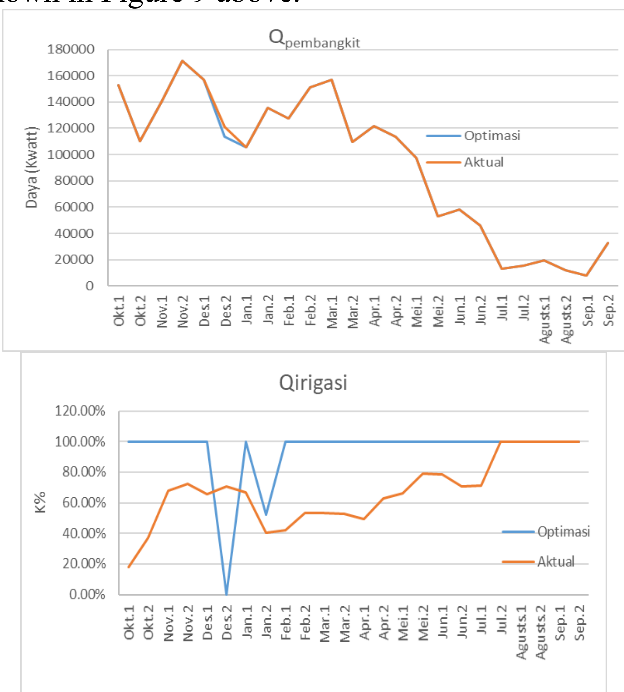

Figure 10. Reservoir Operating Rules Scenario 3

Figure 10 shows that Scenario 3 was at a time to optimize the release of the generator discharge on the optimization result of the reservoir operation pattern so that the fulfillment of the generator discharge needs to reach 99.67%, so it dramatically affects the reduction of irrigation distribution in the reservoir operation pattern in the optimization section. In addition, this study calculated the profit for each scenario besides performance efficiency analysis. The results of the performance and profit obtained for each scenario of the reservoir operation rules are shown in Table 4.

Table 4. Comparison of performance and profit obtained for each scenario of the reservoir operation rules

	Description	Actual Condition	Scenario 1	Scenario 2	Scenario 3
Irrigation	Farmers income	IDR 50,748,116,115	IDR 50,748,116,115	IDR 74,347,966,620	IDR 70,285,096,707
	Precentage of efficiency performance	67.42%	67.42%	100.00%	93.85%
Electricity	Electricity production income	IDR 2,032,432,759	IDR 2,088,776,760	IDR 2,002,560,561	IDR 2,025,769,865
	Precentage of efficiency performance	100.00%	102.77%	98.53%	99.67%
Total of profit		IDR 52,780,548,874	IDR 52,836,892,875	IDR 76,350,527,181	IDR 72,310,866,572
Average efficiency Performance		83.71%	85.10%	99.27%	96.76%

Overall, based on Table 6, the results of the performance efficiency analysis of each scenario of the reservoir operation pattern show that the optimized reservoir operation pattern is superior to the reservoir operating pattern under actual conditions. However, based on the profit value obtained in each reservoir operating pattern scenario, it can be concluded that the Scenario 2 reservoir operation pattern shows the maximum profit compared to the others, which is IDR. 76,350,527,181,-. So that the three scenarios of the reservoir operation rules above can be operated optimally in real conditions, it is necessary to coordinate with relevant agencies so that the right release can be realized under the planned scenario. The following are several explanation options that can be considered in implementing the scenario, including:

a. Scenario 1 is suitable to be applied if there is a policy regarding the need to increase the supply of energy to meet the shortage of electricity supply.
b. Scenario 2 is suitable to apply if there is a policy regarding food self-sufficiency; scenario 2 is the most appropriate option.
c. Scenario 3 is applied if the hydropower plant is only sufficient to meet the needs of electric power in actual conditions, and the rest is optimized to meet irrigation needs.

Referring to the three options, the most suitable to be applied is scenario 2. The primary consideration in the selection is the maximum profit value and the priority of benefit in the irrigation sector. It follows Article 29 paragraph 3 No. 7 of 2004 concerning water resources which reads, "The provision of water to meet daily basic needs and irrigation for smallholder agriculture in the existing irrigation system is the main priority for the provision of water resources above all needs." Therefore, reservoir operation rules Scenario 2 was carried out by optimizing the utilization of the available discharge for irrigation release so that irrigation water needs can be fulfilled as a whole and directly increase farmers' income by 46.5% compared to the actual condition of the reservoir operating pattern. On the other hand, the release of the hydropower plant in the Scenario 2 reservoir operation pattern only utilizes the remaining release of the existing release. Therefore, the release of hydroelectric power plants experienced a slight decrease in the middle of the month due to a slight reduction in discharge and would indirectly affect the income from electricity sales, which decreased by 1.47% compared to the reservoir operating pattern in actual conditions.

5. CONCLUSION

From the optimization research of the Mrica Reservoir using the deterministic method can be concluded that referring to the results of the comparison of reservoir operating patterns, the selected reservoir operation pattern is Scenario 2 because it can produce the most optimal profit and the priority of benefit in the irrigation sector. It follows Law No. 7 of 2004 concerning water resources, prioritizing meeting irrigation water needs. The total profit of Scenario 2 is IDR. 76,350,527,181. It becomes the scenario with the highest profit compared to other scenarios of reservoir operation rules. For future research, this research can be developed by considering aspects of raw water needs, flood storage, and sedimentation. Furthermore, this research can be re-analyzed by applying the probabilistic dynamic programming method.

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