THE APPLICATION OF STOCHASTIC MODEL IN CASCADE RESERVOIR OF SAGULING, CIRATA, AND JATILUHUR DAM FOR RESERVOIR STANDARD OPERATION PROCEDURE

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ABSTRACT

West Java has three cascade reservoirs namely Saguling, Cirata, and Ir. H. Juanda (Jatiluhur). This research was conducted to describe water availability using the stochastic method (ARIMA with RStudio) and to simulate future reservoir operating guidelines. The operating guidelines used for these three reservoirs are based on the modified SNI Pd T-21-2004-A for three conditions, dry, normal, and wet. The 1974 – 2018 Nanjung Station historical discharge data are used. From the preliminary test results, the possible model is ARIMA (1,0,0) (1,0,1) (12) and obtained correlation value of 0.51 and NSE value of 0.084. Forecasting is done for the next 5 years. The equation $Yt = 6.4368 + 0.5593.\ Yt{-}1 + 0.999.\ Yt{-}12 + at - 0.9723at{-}12$ is obtained and the results have not been able to describe the peak discharge. Dependable discharge is calculated for each condition. From the results of the calculation of the operating guidelines, there is a shortage in November 2020, but the available discharge is still sufficient for PJT II needs. The Jatiluhur Reservoir is hard to be full in June, so it is designed so that the reservoir will be closer to full in May. The water shortage in the calculation of the reservoir operating guidelines happens due to forecasted result that has not been able to describe the peak discharge. Although there are differences, in general the energy produced increases because the water elevation is maintained stable, and the discharge flow is not that different from data in the operating guidelines plan.

Keywords: Stochastic Model, Cascade, Reservoir

1. INTRODUCTION

In West Java, there are three cascade reservoirs located in the Citarum river, namely Saguling, Cirata, and Ir. H. Juanda (Jatiluhur). In 2019, there was a drought that affected the operations of the three reservoirs. It is noted that the water level in the Saguling Reservoir is -1.09 meters below the normal operating limit, the Cirata Reservoir is -0.26 meters below the normal operating limit, and the Jatiluhur Reservoir is -1.84 meters below

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DOI: https://doi.org/10.20885/icsbe.vol2.art20

the normal operating limit (Tempo.co, 2019). Jatiluhur Reservoir, in the 2019 dry season electricity production was only able to reach 110 MW by turning on four turbines (Firmansyah, 2019).

To calculate and estimate the discharge that will occur, one approach method that can be done mathematically is the stochastic method. By using the stochastic method, it is possible to predict the pattern of discharge/rainfall that will be searched based on existing data that has the same pattern. Then the data can be processed to obtain a calculation of the operating pattern which is expected to be more appropriate to have a positive impact on the practice of operating the reservoir in the future.

The model used will be made according to the condition of the series reservoir based on the data obtained from the reservoir manager to predict the Reservoir Operational Pattern (ROP) based on synthetic discharge data that has been generated by the stochastic method. With the existence of ROP based on synthetic discharge data, it is hoped that it can be one of the bases for decision making for anticipating drought or flood programs that may occur in the future. With these problems, the researchers took the title "The application of stochastic model in cascade reservoir of Saguling, Cirata, And Jatiluhur Dam for reservoir standard operation procedure". In general, this study aims to:

- Get an overview of the availability of discharge in the future by using the stochastic method.
- Simulates future series reservoir operation patterns based on the resulting stochastic discharge. The reservoir operation pattern will be made under several conditions, including wet conditions, normal conditions, and dry conditions.

With this research, it is expected to be able to produce appropriate ROP and be able to know the use of water in each reservoir in the future. Not only that, but the researcher also hopes that the development of this research can be used as a basis for making decisions to anticipate droughts or floods that may occur in the future.

2. STUDY LOCATIONS

This research was conducted in three series reservoirs, namely Saguling, Cirata, and Jatiluhur reservoirs. These three reservoirs are in West Bandung Regency, Cianjur Regency, and Purwakarta Regency. These three reservoirs are in the Citarum River Basin. Saguling Reservoir is a 99 m high embankment type reservoir which has a capacity of 560 million m3 at a normal water level at an elevation of + 643 m. These reservoirs have an electric generator engine capacity of 4 x 175 MW with the discharge capacity of each generator is approximately 54 m3/ s. The management is at PT. Indonesian Power. Cirata Reservoir is a reservoir in the middle between Saguling Reservoir and Jatiluhur Reservoir. This reservoir has a height of 125 m and has a capacity of about 1,784 million m3 at normal water levels at an elevation of 220 m and equipped with a generator engine with a capacity of 8 x 125 MW with the discharge capacity of each generator is approximately 135 m3/ s or a total of 1,080 m3/ s. This reservoir is managed by PT. PBJ BPWC. Jatiluhur Reservoir is a reservoir that has 4 saddle dams. The height of the main reservoir is about 96 m from the river body or about 105 m from the deepest foundation. Based on the survey in 2013, its capacity reached 2,685 million m3/ s at normal water level conditions at an elevation of 107 m. This reservoir has a generator engine with a capacity of 187.5 MW. This reservoir is managed by PJT II.

Table 1. Water catchment area (Associated Consulting Engineering ACE (PVT) LTD, 2015)

Reservoir	Local Catchment Area (Km^2)	Total Catchment Area (Km^2)
Saguling	2.283	2.283
Cirata	1.794	4.077
Juanda	460	4.537

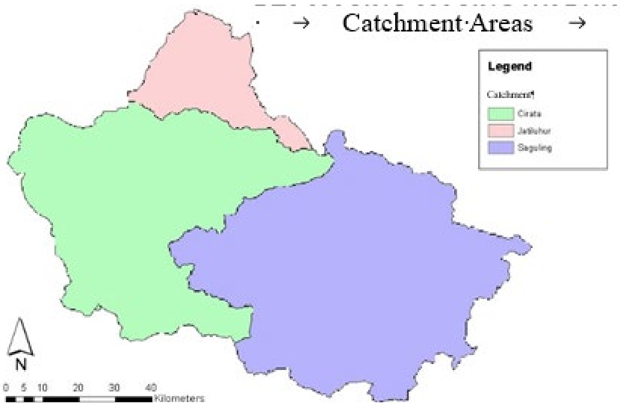

Figure 1. Catchment Areas of Each Reservoir

3. HISTORICAL DISCHARGE

Historical discharge data is available from 1919 – 2018, but in 1937 – 1973 the available data have twice the value of the other data. Because the data used must be stationary, one of the first steps that can be done is to choose data that has similar pattern. So that the data that used in the modeling are the data from 1974 – 2018.

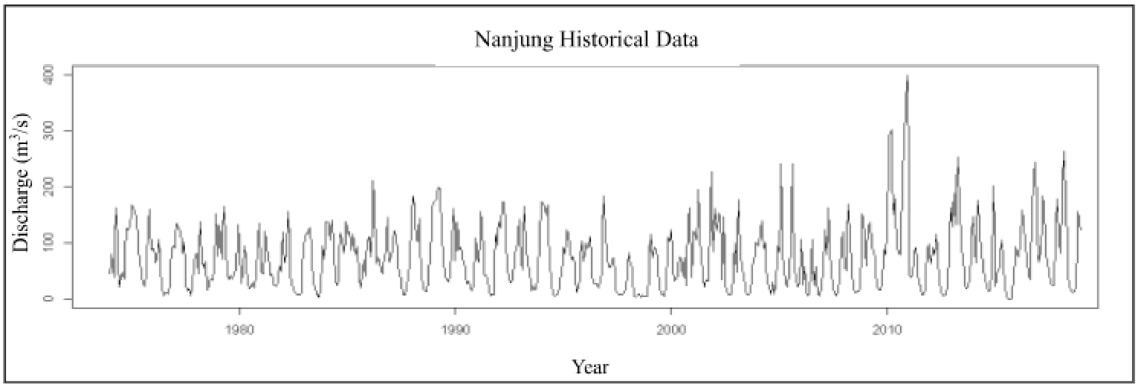

Figure 2. Nanjung Historical Data 1974 – 2018 (Pusair, 2019)

Mokoagow (2012) performs discharge calculations using the rational method and the NRECA method for regional discharges in the Saguling Reservoir. Calculation with the rational method with C = 0.62 shows a correlation between observation discharge and observation discharge of 76.48% while the NRECA method shows a correlation value of 62.33%. To simplify the calculation process, the regional discharge calculation in this study will be calculated based on the comparison of the rational debit formula. The runoff coefficient for each reservoir is Saguling = 0.62 (Mokoagow, 2012), Cirata = 0.75 (Physical and Spatial Conditions, 2014), Jatiluhur = 0.38 (RPMJD West Java 2018 - 2023, 2019).

4. ARIMA

ARIMA stands for Auto-Regressive Integrated Moving Average, where the function used is part of the data forecasting function with the Auto-Regressive (AR), Moving Average (MA) method, and the differencing method (which is denoted by I and describes a differencing process to produce a stationary input data). ARIMA is also often referred to as the Box-Jenkins model. The non-seasonal ARIMA model is classified as "ARIMA (p, d, q)" while the Seasonal ARIMA model is classified as "ARIMA (P, D, Q)".

Table 2. Determining the Forecast Model with ACF based on PACF.

Type of Model	ACF	Pattern PACF Pattern
AR	Decreasing Exponentially	Decreasing Drastically at Certain Lags
MA	Declining Drastically at Certain Lags	Declines Exponentially
ARMA	Decreasing Exponentially	Decreasing Exponentially

Source: Widarjono (2013) in Wellyanti (2019).

In the forecasting process, data are divided into 2 parts, training data and testing/validation data. The distribution of training and validation data is usually random, in this study the comparison of training data and testing data is 8:2 because the data is quite long. Training data from 1974 – December 2009 (432 monthly data) and testing data from January 2010 – December 2018 (108 monthly data).

4.1 Preliminary Test

To determine the ARIMA parameter, training data is used. The data are plotted, and it is seen that the data has a seasonal effect. This is also evidenced by the ACF value which has an up and down form with significant numbers at lag 12 and its multiples.

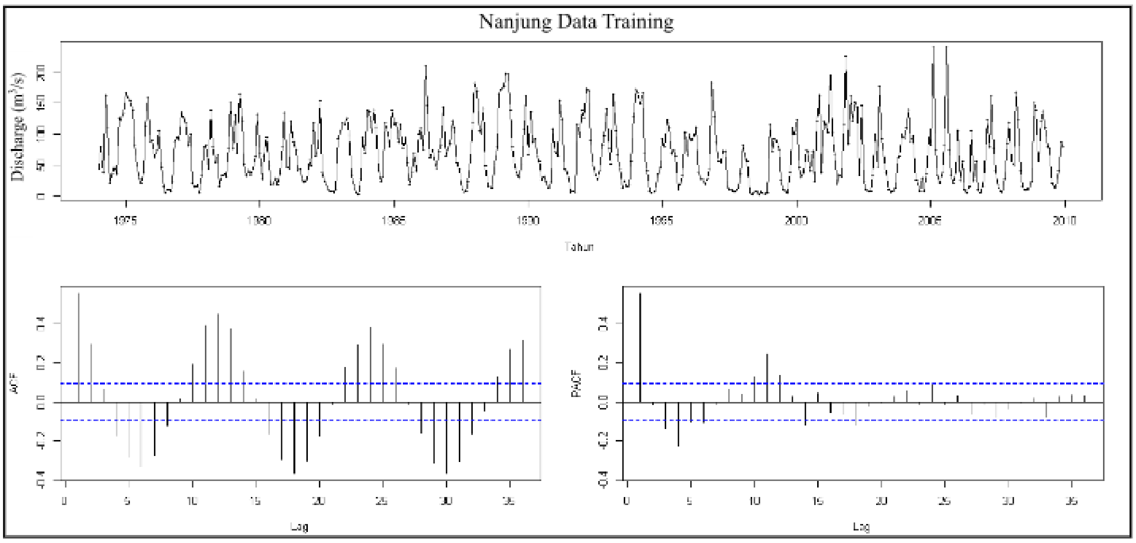

Figure 3. Plot of Nanjung Data Training

Data training was then tested in preliminary tests, namely the Box-Cox Transformation test, Augmented Dickey-Fuller Test, observations on the Plot Auto Correlation Function and Partial Auto Correlation Function, coefficient tests, Ljung-Box Test and Kolmogorov - Smirnov Test. Stationarity testing in variance is carried out using the Box-Cox transformation, the data is said to be stationary if the value is one.

From the calculation using the BoxCox method, it is known that the data is not stationary in the variance (lamda 0.49) for that the data is transformed first until the data is stationary in the variance. The data that is stationary in the variance and which is used in the calculation is named train.t2. Furthermore, the stationary data in the variant was checked for stationary against the trend using the Augmented Dicker-Fuller (ADF) test and it was found that the data was stationary, $p < 0.05$.

The next step is to identify the model based on the transformation data (train.t2) by using the ACF and PACF plots.

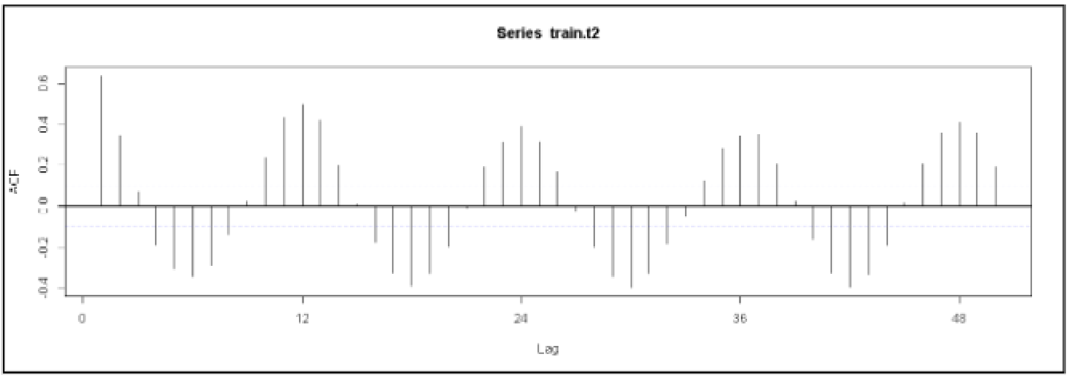

Figure 4. Plot of ACF on Data train.t2.

The ACF plot is presented in Figure 4, based on the figure it is known that the lag is interrupted (not significant) after the second lag, so that the order of $q = 2$. It is also seen that the lag is very significant in every multiple of 12 so it is identified that there is a seasonal pattern in every 12 period. Furthermore, it is necessary to do a differentiation with order 12 on the transformation data to get the seasonal order.

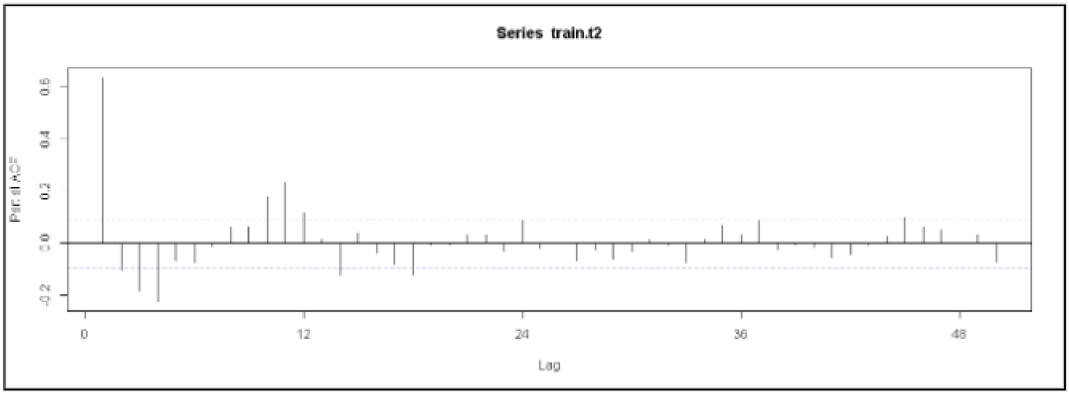

Figure 5. Plot of PACF on data train.t2.

The PACF plot is presented in Figure 5, based on the figure it is known that the lag breaks (changes direction) after the first lag, so that the order $p = 1$.

4.2 Identification of Seasonal Effects

Since the data has seasonal effects, seasonal differentiation is performed on the transformed data (d12.train .t2) and repeated ADF testing was carried out to check for stationary data.

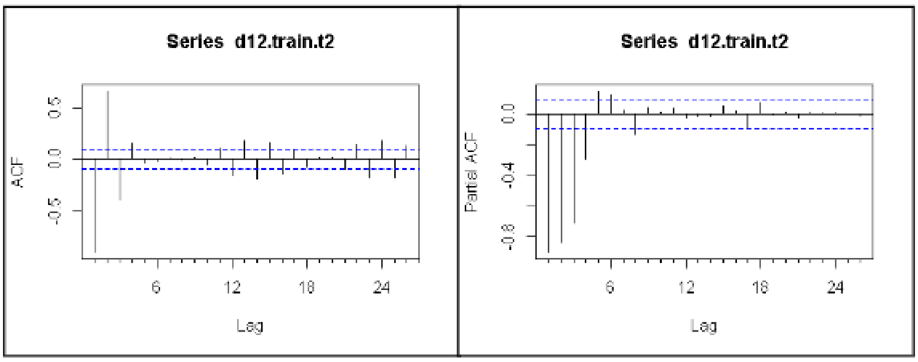

Figure 6. Plots of ACF and PACF on Data d12.train.t2.

The ACF plot is presented in Figure 6, based on the figure it is known that the lag is interrupted (changes direction) after the first lag, so that the MA order for the seasonal component is obtained, namely Q = 1. Based on the PACF plot it is known that the lag is interrupted (changes direction) after the fourth lag, so that the order of AR for the seasonal component is P = 4. Furthermore, the ADF-test was carried out and it was found that the data was stationary.

4.3 Results of Training Data Identification

The Transformed data (train.t2) is stationary so that the order of d = 0 is obtained. Based on the analysis of the ACF and PACF plots of the transformation data, the values of p = 1 and q = 2. While in seasonal differencing because the data is stationary, it is obtained D = 0 and based on the plots of ACF and PACF obtained P = 4 and Q = 1. So, if these values are combined there are 45 models to be estimated.

Based on the estimation results of the model above, a model with all significant parameters was selected. The significance of the parameter is indicated by the P Value or in the output P(>|z|) less than 5%. After obtaining significant ARIMA models, the next step is to test the assumptions of normality and residual independence. To determine the independence and normality of the residuals, the Ljung- Box Test, and the Kolmogorov – Smirnov Test were used.

In the Ljung – Box test, the p value > 0.05, it means that the residual is independent. In the Kolmogorov – Smirnov p value > 0.05, it means that the residual has no significant difference in distribution from the normal distribution. From the results of the residual test, only the ARIMA model (1,0,0) (1,0,1) (12) meets the requirements.

4.4 Validation of Nanjung Discharge Data

Nanjung discharge was forecasted based on data training, and obtained results as shown in Figure 7. Forecasting with R produces a forecast range with a 95% confidence level. In the figure, the mean value of the forecast are plotted. The data are still in the form of “data transform” so that the retransform process needed.

ISSN 2541-223X
Volume 4 2022

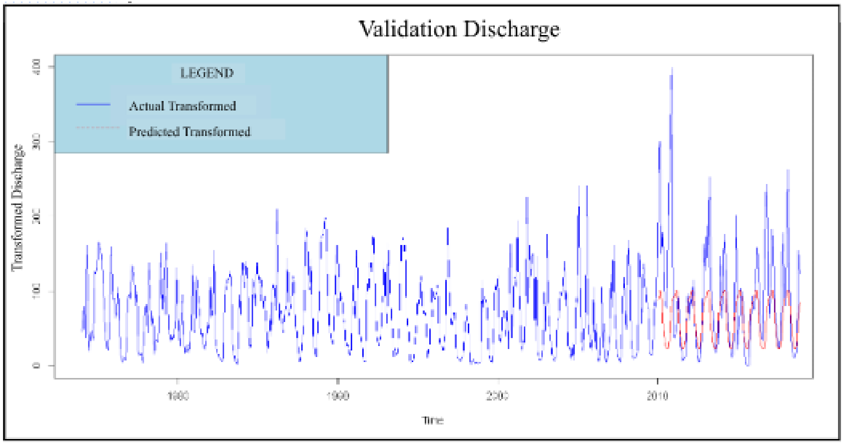

Figure 7. Nanjung Validation Discharge in m3/sec.

In general, the forecast still does not show the peak of the discharge in a period. However, statistically the results of this forecast are forecasts that meet the requirements and have a correlation value of 0.51 and have an NSE value of 0.084 or close to 0 which means that the value generated by the modeling has the same accuracy as the historical data.

4.5 Nanjung Discharge Forecasting Nanjung

Forecasting procedure is done in the same way. First, the data is transformed to be stationary in variance and mean (train.t3). Then do the calculations with the ARIMA model (1,0,0)(1,0,1)(12). From the results of the ACF and PACF plots, it is known that the data will have an order of p=4 and q=1. Because the resulting ARIMA order is still the same as train.t2, the data is directly forecasted using ARIMA (1,0,0)(1,0,1)(12). From the results of model testing, it is known that the ARIMA (1,0,0)(1,0,1)(12) model still meets the requirements for modeling. The next stage is to do the forecasting. Based on the test, the equation for the model is $Yt = 6.4368 + 0.5593. Yt-1 + 0.999. Yt-12 + at - 0.9723at-12$. After doing the forecasting with the following results obtained.

Table 3. Nanjung Forecasted Discharge (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	91.25	93.34	105.12	102.60	64.82	42.27	26.56	19.93	21.99	35.38	74.19	92.58
2020	80.85	87.35	101.49	100.57	63.94	41.90	26.41	19.87	21.96	35.36	74.15	92.53
2021	80.81	87.31	101.44	100.52	63.94	41.91	26.43	19.90	21.99	35.38	74.13	92.49
2022	80.79	87.28	101.39	100.47	63.93	41.92	26.46	19.92	22.01	35.40	74.12	92.46
2023	80.77	87.25	101.34	100.43	63.92	41.94	26.48	19.95	22.04	35.42	74.10	92.42

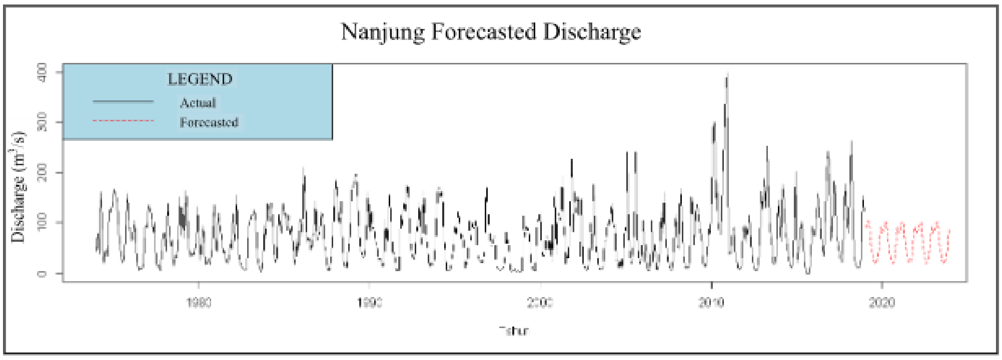

Figure 8. Nanjung Forecasted Discharge

5. RELIABLE DISCHARGE

Calculation for reliable discharge is carried out using the Weibull probability calculation. After getting the forecasted discharge results, the next step is to calculate the reliable discharge that will be used in each condition.

Table 4. Nanjung Reliable Discharge Design (m^3/s) Upper Limit, Q35.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	105.23	120.90	136.35	142.30	82.68	56.45	32.51	24.57	27.60	43.84	96.75	127.52
2020	104.75	120.33	134.53	141.41	82.14	54.53	31.15	24.48	26.20	42.59	95.88	125.85
2021	104.27	119.76	132.72	140.51	81.61	52.60	29.78	24.39	24.80	41.35	95.00	124.18
2022	103.72	119.22	130.98	139.70	81.14	51.28	28.85	24.13	23.87	40.14	93.48	122.90
2023	103.06	118.72	129.34	139.00	80.78	50.75	28.50	23.67	23.58	38.98	91.10	122.16

Table 5. Nanjung Reliable Discharge Design (m^3/s) Normal Limit, Q50.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	89.10	89.50	116.00	115.00	74.10	42.00	23.10	18.10	17.48	31.80	80.40	100.00
2020	89.70	90.58	111.00	114.75	73.76	42.14	23.66	18.55	17.74	31.81	80.35	99.71
2021	89.10	89.50	106.00	114.49	73.41	42.00	24.22	19.00	18.00	31.82	80.30	99.42
2022	88.55	89.25	105.56	112.75	72.71	41.96	24.33	19.12	18.50	31.91	79.60	99.10
2023	88.00	89.00	105.12	111.00	72.00	41.92	24.45	19.24	19.00	32.00	78.90	98.79

Table 6. Nanjung Reliable Discharge Design (m^3/s) Lower Limit, Q65.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	76.37	72.95	87.53	105.10	62.10	30.30	16.61	10.63	11.35	22.10	58.99	93.35
2020	76.62	73.51	89.39	104.36	62.45	31.12	17.70	10.68	11.47	22.43	61.06	92.91
2021	76.86	74.08	91.24	103.59	62.80	31.93	18.78	10.74	11.58	22.77	63.12	92.57
2022	77.56	74.58	92.39	102.79	63.14	33.45	19.41	10.80	11.76	23.12	64.31	92.54
2023	78.85	75.02	92.59	101.80	63.47	35.88	19.42	10.88	12.02	23.48	64.32	92.51

6. REGIONAL DISCHARGE

Regional discharges are obtained based on the equation resulting from the calculation of Nanjung regional discharge with runoff coefficients (C) that have been mentioned before.

6.1 Saguling Regional Discharge

Table 7. Saguling Regional Discharge (m^3/s) Upper Limit, Q35.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	137.76	158.26	178.49	186.28	108.23	73.90	42.56	32.17	36.13	57.39	126.65	166.93
2020	137.13	157.52	176.11	185.11	107.53	71.38	40.77	32.05	34.30	55.76	125.51	164.74
2021	136.50	156.78	173.74	183.94	106.83	68.86	38.98	31.92	32.46	54.12	124.36	162.55
2022	135.77	156.07	171.46	182.88	106.22	67.12	37.77	31.59	31.25	52.54	122.37	160.89
2023	134.91	155.41	169.31	181.96	105.75	66.43	37.31	30.98	30.87	51.03	119.26	159.91

Table 8. Saguling Regional Discharge (m^3/s) Normal Limit, Q50.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

2019	116.64	117.15	151.85	150.54	97.00	54.98	30.24	23.69	22.88	41.63	105.25	130.91
2020	117.42	118.57	145.31	150.21	96.55	55.16	30.97	24.28	23.22	41.64	105.18	130.52
2021	116.64	117.15	138.76	149.87	96.10	54.98	31.70	24.87	23.56	41.65	105.12	130.14
2022	115.92	116.83	138.18	147.59	95.18	54.92	31.85	25.03	24.22	41.77	104.20	129.73
2023	115.20	116.51	137.61	145.31	94.25	54.88	32.01	25.18	24.87	41.89	103.28	129.32

Table 9. Saguling Regional Discharge (m^3/s) Lower Limit, Q65.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	99.98	95.50	114.58	137.58	81.29	39.67	21.74	13.91	14.86	28.92	77.22	122.20
2020	100.30	96.23	117.01	136.62	81.75	40.73	23.16	13.99	15.01	29.36	79.92	121.63
2021	100.62	96.97	119.44	135.61	82.21	41.80	24.58	14.06	15.16	29.80	82.63	121.18
2022	101.52	97.64	120.94	134.55	82.65	43.78	25.41	14.14	15.40	30.26	84.18	121.14
2023	103.22	98.20	121.21	133.26	83.08	46.97	25.43	14.25	15.74	30.74	84.20	121.10

6.2 Cirata Regional Discharge

Table 10. Cirata Regional Discharge (m^3/s) Upper Limit, Q35.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	130.95	150.44	169.67	177.08	102.88	70.24	40.45	30.58	34.34	54.56	120.39	158.68
2020	130.35	149.73	167.41	175.96	102.21	67.85	38.76	30.46	32.60	53.00	119.30	156.60
2021	129.75	149.03	165.15	174.85	101.55	65.45	37.06	30.35	30.86	51.45	118.21	154.52
2022	129.06	148.36	162.98	173.84	100.97	63.80	35.90	30.03	29.71	49.94	116.32	152.93
2023	128.24	147.73	160.95	172.97	100.52	63.15	35.46	29.45	29.35	48.51	113.36	152.01

Table 11. Cirata Regional Discharge (m^3/s) Normal Limit, Q50.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	110.87	111.36	144.35	143.10	92.21	52.26	28.74	22.52	21.75	39.57	100.05	124.44
2020	111.62	112.71	138.12	142.78	91.78	52.43	29.44	23.08	22.07	39.58	99.98	124.07
2021	110.87	111.36	131.90	142.47	91.35	52.26	30.13	23.64	22.40	39.59	99.92	123.71
2022	110.19	111.06	131.35	140.30	90.47	52.21	30.28	23.79	23.02	39.70	99.05	123.32
2023	109.50	110.75	130.81	138.12	89.59	52.17	30.42	23.94	23.64	39.82	98.18	122.93

Table 12. Cirata Regional Discharge (m3/s) Lower Limit, Q65.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	95.04	90.78	108.92	130.78	77.27	37.71	20.67	13.23	14.12	27.50	73.40	116.16
2020	95.34	91.48	111.23	129.86	77.71	38.72	22.02	13.29	14.27	27.91	75.97	115.62
2021	95.64	92.18	113.54	128.91	78.15	39.74	23.37	13.36	14.41	28.33	78.54	115.19
2022	96.51	92.81	114.96	127.90	78.57	41.62	24.15	13.44	14.63	28.76	80.02	115.15
2023	98.12	93.35	115.22	126.68	78.97	44.65	24.17	13.54	14.96	29.22	80.04	115.12

6.3 Jatiluhur Regional Discharge

Table 13. Jatiluhur Regional Discharge (m3/s) Upper Limit, Q35.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	17.01	19.54	22.04	23.00	13.37	9.13	5.26	3.97	4.46	7.09	15.64	20.62
2020	16.93	19.45	21.75	22.86	13.28	8.81	5.03	3.96	4.24	6.89	15.50	20.34
2021	16.86	19.36	21.46	22.72	13.19	8.50	4.81	3.94	4.01	6.68	15.36	20.07
2022	16.77	19.27	21.17	22.58	13.12	8.29	4.66	3.90	3.86	6.49	15.11	19.87
2023	16.66	19.19	20.91	22.47	13.06	8.20	4.61	3.83	3.81	6.30	14.73	19.75

Table 14. Jatiluhur Regional Discharge (m3/s) Normal Limit, Q50.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	14.40	14.47	18.75	18.59	11.98	6.79	3.73	2.93	2.83	5.14	13.00	16.17
2020	14.50	14.64	17.94	18.55	11.92	6.81	3.82	3.00	2.87	5.14	12.99	16.12
2021	14.40	14.47	17.14	18.51	11.87	6.79	3.91	3.07	2.91	5.14	12.98	16.07
2022	14.32	14.43	17.06	18.23	11.75	6.78	3.93	3.09	2.99	5.16	12.87	16.02
2023	14.23	14.39	16.99	17.94	11.64	6.78	3.95	3.11	3.07	5.17	12.75	15.97

Table 15. Jatiluhur Regional Discharge (m^3/s) Lower Limit, Q65.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	12.35	11.79	14.15	16.99	10.04	4.90	2.69	1.72	1.83	3.57	9.54	15.09
2020	12.39	11.88	14.45	16.87	10.10	5.03	2.86	1.73	1.85	3.63	9.87	15.02
2021	12.43	11.98	14.75	16.75	10.15	5.16	3.04	1.74	1.87	3.68	10.20	14.97
2022	12.54	12.06	14.94	16.62	10.21	5.41	3.14	1.75	1.90	3.74	10.40	14.96
2023	12.75	12.13	14.97	16.46	10.26	5.80	3.14	1.76	1.94	3.80	10.40	14.96

7. RESOP Model Operational Procedure

RESOP Model Guidelines are made by the Water Resources Research and Development Center and are compiled based on the exchange of experiences in the creation of Reservoir Operations Citarum Cascade since 1992 with related agencies such as PT. PLN (Persero) Distribution and Load Management Center (P3B) – Bidding Unit and System Operation (UBOS). In this study, the RESOP model was used as the basis, which modified its appearance to display some other data that was deemed necessary.

In general, the normal operating patterns of the three reservoirs have similar conditions. Reservoir filling occurs in December to June and then the water level will shrink from July to November.

7.1 Relationship between Elevation, Reservoir Volume, and Reservoir Surface Area Reservoir

NEWJEC Characteristic Equation (1988) used to calculate reservoir surface area and head, namely:

$$A = a.\,(V)^b \tag{1}$$

$$H = (c * (V)^b) + e \tag{2}$$

Where:

a, b, c, d, e are constants obtained through calibration

A is Reservoir Surface Area (ha)

V is Reservoir Storage Volume (m3)

H is Reservoir Elevation (m)

After comparing the relationship between elevation value, reservoir volume and reservoir surface area based on reservoir coefficients made by NEWJEC in 1988 and Mokogaow in 2012, with the 2019 and 2020 Operational Pattern Plans, it is known that the results are irrelevant. For this reason, calculations are carried out based on data from the 2019 - 2020 Operational Pattern Plan. By testing, using data from NEWJEC as a basis, it is found that by changing the coefficients c and e have the smallest average error value compared to changing the other coefficients.

Table 16. Coefficient Calculation Results

Coefficient	Saguling	Cirata	Jatiluhur
a	289,70	17,46	2,15
b	0,90400466	1,0738287	0,42742471
c	0,113	0,3963	0,9605
d	0,6667	0,5546	0,8939
e	164,3402	38,968934	617,4648
Elevation Min	625	206	106,5
Max Elevation	642,5	219,5	87,5
A Average Error	5,247	3,547	8,429
H Average Error	0,504	0,235	1,387

Maximum average error produced is 8.4% for the calculation of the area of the Jatiluhur reservoir. However, after comparing the data in the 2019 Operational Pattern Plan and 2020 Operational Pattern Plan Draft, in general the correlation of data generated from calculations using these coefficients is close to 1. For this reason, these coefficients are used in this study.

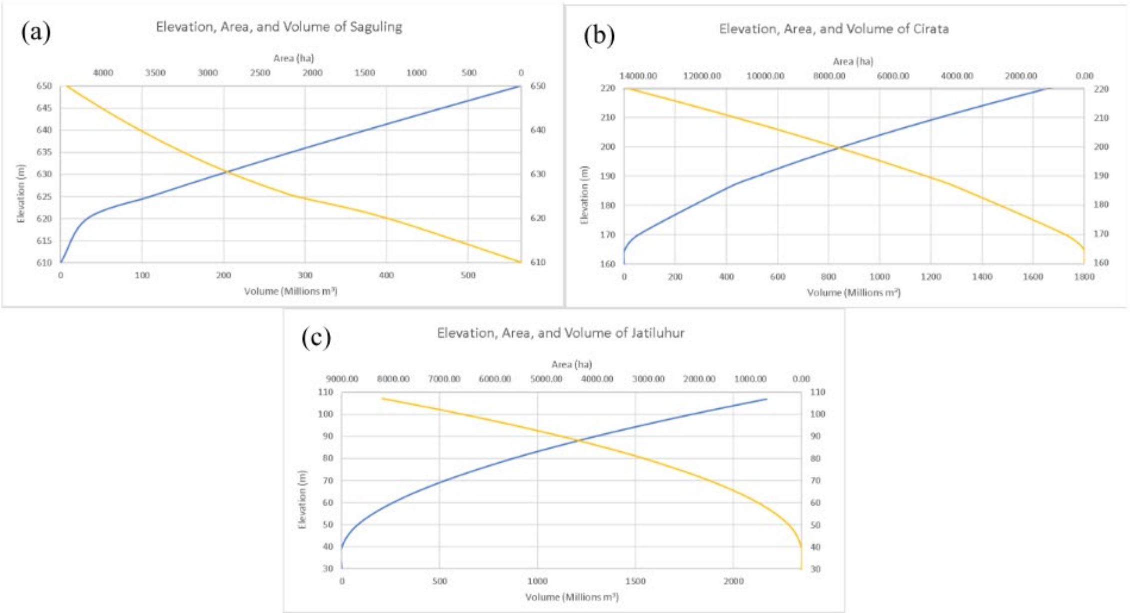

Figure 9. Graph of the Relationship of Elevation, Area, and Volume of the Saguling (a), Cirata(b), and Jatiluhur (c) Reservoir based on Equations with Generated Coefficients a, b, c, d, and e.

7.2 Equal Sharing

In operation, cascade reservoirs operate proportionally based on the effective volume of each reservoir to its total effective volume (all reservoirs). In other words, the percentage of effective volume each month for each reservoir is always the same. In the 2020 draft of the Saguling, Cirata and Djuanda/Jatiluhur Cascade Dam Operation Plan, the percentage of the effective storage capacity of the Saguling Dam is 20.27%, Cirata 27.90%, and Jatiluhur51.83%. In the calculations, there are differences regarding the principle of equal sharing. The calculation can be seen as in Table 17.

Table 17. Comparison of Effective Volume

Reservoir	**(%)**				
	RESOP		Calculation		
	2019	2020	Upper	Normal	Lower
Saguling	21,56	20,27	4 - 12	2 – 10	1,5 – 9
Cirata	27,45	27,9	36,5 – 46,5	37,5 – 46,5	38 – 46,5
Jatiluhur	50,99	51,83	50 - 53	50 - 53	50 - 53

7.3 Calculation of Electricity Production

The calculation of electricity production in each reservoir is based on the formula in SNI Pd T-21-2004-A. Where the calculation is based on the following equation:

- Saguling Reservoir

$$P = 9.81\ x\ et\ x\ eg\ x\ Q\ (\ H_{eff} -\ H_0) \qquad (3)$$

$$E = \frac{9.81\ x\ et\ x\ eg\ x\ V\ x\ (H1 - H0)}{3600} \qquad (4)$$

with:

P	is power, in kilowatts (kW).
et	is turbine efficiency = 0.915
eg	is generator efficiency = 0.98
Q	is turbine discharge water, in m3/sec.
H1	is the water level of the reservoir, in meters.
Ho	is the tail water level = 287.3 meters.
E	is the energy produced, in Kilo Watt Hours (kWh)

- Cirata Reservoir

$$P = 9.81\ x\ eg\ x\ Q\ x\ Heff \qquad (5)$$

$$\mathrm{E} = \frac{9.81\ X\ eg\ x\ Q\ x\ Heff}{3600} \qquad (6)$$

with:

eg is generator efficiency = 0 .94
Heff is the effective head fall, in meters.
if H1>205 then Heff = (0.955 x H1) – 98.325
H1>215 then Heff = (1.09 x H1) – 127.55
E is the energy produced, in Kilo Watt Hours (kWh)

- Jatiluhur

$$Q = \frac{MW}{0.009671\ X\ H\ X\left(0.896 - \frac{1.483}{MW}\right) x\ (0.00255\ x\ H + 0.8233} \quad (7)$$

$$E = P\ x\ n\ x\ 24 \quad (8)$$

MW is the power, in megawatts (MW).
Q is the flow of water out of the turbine, in m3/sec.
H is the reservoir TDC in meters.
E is the energy produced, in Mega Watt Hours (MWh)
n is the number of days in the month.

7.4 Reservoir Operation Simulation

Although the comparison of the effective volume of the reservoir is not in accordance with the written percentage, the quantities in ROP 2019 and Draft ROP 2020 are in range the same. In addition, for the Reservoir Standard Procedure for cascade reservoir, if there is an agreement between the three reservoir stakeholders, changes are allowed. For this reason, in this study, the limits on the principle of equal sharing will be based on calculations as shown in Table 17 and the total volume ratio remains 100%.

Calculation of Reservoir ROP in 2019 is carried out using the modified RESOP Model. The operating pattern is made by making the Maximum elevation in June at the RESOP as a reference. From the operation pattern calculated in this study, it is attempted in such a way that the elevation in June of the following year has the same value.

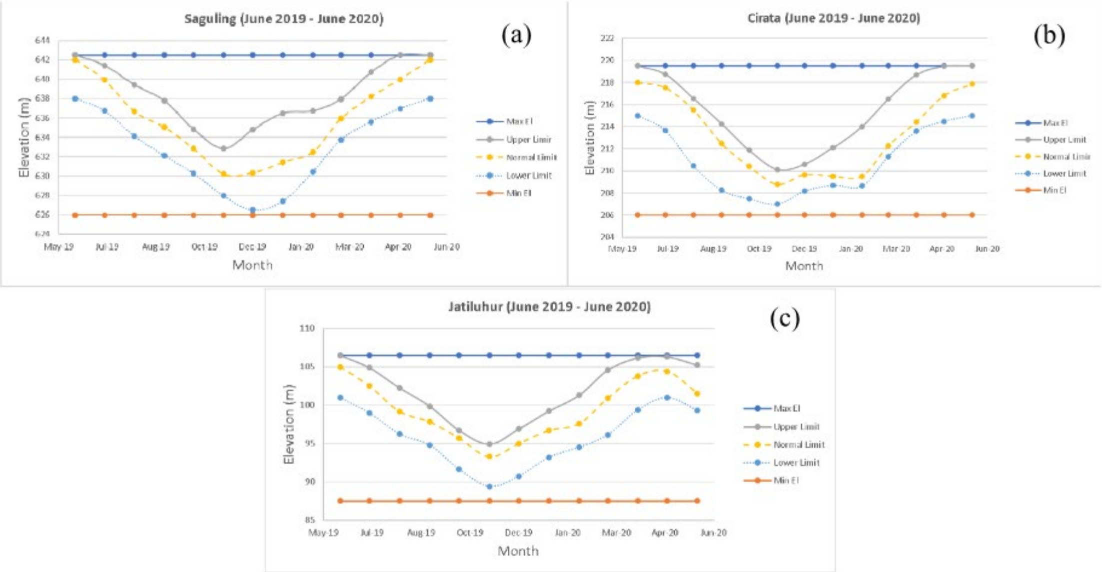

Figure 10. Saguling (a), Cirata(b), and Jatiluhur (c) Reservoir Operation Pattern (June 2019 – June 2020)

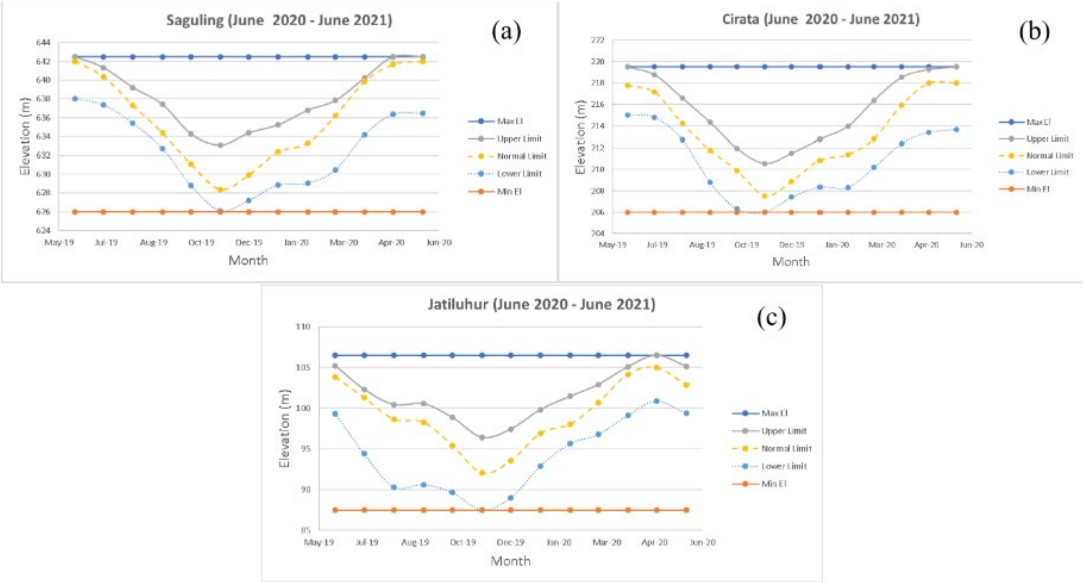

Figure 11. Saguling (a), Cirata(b), and Jatiluhur (c) Reservoir Operation Pattern (June 2020 – June 2021)

There is a difference in the energy produced. In general, the energy produced has increased. This is probably because the reservoir reservoir is kept relatively stable, and the discharge is not so different from the pattern contained in the data in the operation plan.

Table 18. Comparison of Energy Produced in June 2019 – June 2020 Pattern.

Operation	**Reservoir**	**Total Energy (GWh)**		**Delta** C- H
		Histories (H)	Calculated (C)	(GWh)
Upper	Saguling	3157.3	2929.86	-227.44
	Cirata	1786.5	1845.68	59.18
	Jatiluhur	1280.6	1935.99	655.39
Normal	Saguling	2259.5	2316.86	57.36
	Cirata	1304.2	1429.38	125.18
	Jatiluhur	930.2	1538.94	608.74
Lower	Saguling	1667.9	1877.73	209.83
	Cirata	936.2	1142.92	206.72
	Jatiluhur	636.2	1155.40	519.20

Table 19. Comparison of Energy Produced in June 2020 – December 2021 Pattern.

Operation	**Reservoir**	**Total Energy (GWh)**		**Delta** C - H
		Histories (H)	Calculated (C)	(GWh)
Upper	Saguling	1339,2	1147,32	-191,88
	Cirata	831,6	778,80	-52,80
	Jatiluhur	724	847,90	123,90
Normal	Saguling	889,8	942,94	53,14
	Cirata	549,1	611,49	62,39
	Jatiluhur	477	710,09	233,09

Lower	Saguling	623,4	765,59	142,19
	Cirata	381,4	481,90	100,50
	Jatiluhur	336,6	611,05	274,45

8. CONCLUSION

- The correct ARIMA model for data calculation is the ARIMA model (1,0, 0)(1,0,1)(12) with the equation Yt = 6.4368 + 0.5593. $Yt - 1 + 0.999.\ Yt - 12 + at - 0.9723at - 12.$
- From the validation, the resulted value is still not able to describe the peak discharge in each year.
- The correlation value between the data in the validation period and the calculation results is 0.51 and the NSE value is 0.084 or close to 0 which means that the value generated by the modeling has the same accuracy as the historical data.
- The pattern of operation using the RESOP Model starts from January to January and each reservoir will be at full condition in June.
- In the RESOP Model there is no spill column because the operation pattern designed without spill.
- Based on calculations, there is a shortage in November 2020. However, the value is smaller than the river needs. As the water used by PJT II will return to the river, and this operating pattern is still able to flow the needs of PJT II, the results are still considered as valid.
- In general, the water level of each reservoir in the generated operating pattern approaches full in May and will return to full condition in June of the following year. However, in Jatiluhur Reservoir, this condition is difficult to fulfill. So, in this study, the Jatiluhur reservoir is designed to be as close to full as possible in May. This is because the water demand is greater than the amount of incoming water obtained from the calculation.
- The shortage of water generated in the calculation of the reservoir operating pattern is due to the prediction of the amount of water entering more than not being able to describe the peak amount of incoming water.
- There is a difference in the energy produced. This difference is due to differences in inflow, elevation, and outflow calculated with the 2019 and 2020 ROP Plans. In general, the total power generated from this calculation has increased. The increase occurs because although the inflow, elevation, and outflow values are different, in general the values are close to each other.
- The use of an application to determine the optimization of the ARIMA method and the ROP modeling of the Cascade Reservoir is very necessary considering the large number of coefficients and constraints that would be difficult to calculate manually.
- Reservoir optimization calculations in series reservoirs cannot be treated as a single reservoir considering that there is a limit to the reservoir storage volume capacity.

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