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MANAGEMENT OPTIMIZATION OF CIPANUNJANG-CILEUNCA RESERVOIR IN BANDUNG REGENCY USING DISCRETE MARKOV METHODS

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ABSTRACT

This research discusses about intake Cikalong as water resource infrastructure supplying water for PDAM Bandung City and PDAM Bandung Regency that depend on the operational of Cipanunjang Dam-Cileunca Dam, Plengan Hydropower, Lamajan Hydropower, Cikalong Hydropower and water from Cisangkuy River. Nowdays, capacity of PDAM Bandung city is 1800 L/sec and capacity of PDAM Bandung Regency is 500 L/sec. However, the amount of water that could be provided by PDAM Bandung City is 1400 L/sec while PDAM Bandung Regency is 200 L/sec. **Aim:** Optimization on upstream infrastructure is needed to make sure the quantity of water being supplied sufficient. **Methodology and Result:** There are some methods that can be used to fulfill that aim, on this research use Stochastic Markov Method. The optimization of the reservoir is achieved by the condition of the guideline track and the actual trajectory approaching 1, which means the absence of wasted water through the spillway but through the reservoir utility function for turbine demand, irrigation raw water and raw drinking water in the downstream. The comparison between trajectory and actual trajectory of Cipanunjang Reservoir is 0.861 while for optimization of Cileunca Reservoir is 0.827. **Conclusion, significance and impact study:** The correlation between the actual (historical) discharge and the Markov estimation discharge on the Cipanunjang-Cileunca Reservoir is closed to 1, so it can be show that the discharge estimation is conceptual because it corresponds to the actual condition (actual discharge).

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- Cileunca reservoir
- Cipanunjang reservoir
- Optimization
- Stokastic markov
- PDAM Bandung

1. INTRODUCTION

Drinking Water Supply System (SPAM) in the city consists of three components; there is water source, water treatment, and water service or distribution. Water service must meet the standard: the quality is in accordance with health requirements from Regulations of Health Minister or PERMENKES Number 462 Year 2010. Meanwhile the quantity meets the minimum needs of human (basic need) based on the regulations of the Minister of Public Work or PERMEN PU Number 14 Year 2010 which is 60 L/person/day, it must available throughout the day, and the price is competitive as well. The well-functioning of clean water services is highly dependent on the reliability of raw water sources, both the quality and continuity of water resources.

The issue of raw water for drinking water has become one of the problems in drinking water supply system in terms of both quality and quantity (BAPPENAS, 2005). The rapid growth of today's population and industry are affecting directly the need for clean water. The management of water resources should be directed to the synergy between regions and between sectors. According to the data obtained from Drinking Water Local Company (PDAM) Tirtawening Bandung on 2014, it able to serve 69.30% of population of Bandung city that is 2,486,457 people (April 2014). Data obtained from PDAM Bandung Regency, Tirta Raharja Bandung Regency, it able to serve 3 (three) areas, namely Bandung Regency as much as 348,132 people (19.75%) from 1,762,572 people, Cimahi City 133,170 people (24.11%) from 552,325 people, and West Bandung Regency 88,190 people (12.79%) from 692,036 people. While the national target of drinking water services for big cities is 80% (target Year 2015).

Water Supply System (SPAM) South Bandung Regional consists of Bandung PDAM and Bandung Regency PDAM. Bandung City and Regency PDAM take raw drinking water from Cisangkuy River. Currently, the Water Utilization Permit (SIPA) of Cisangkuy River for PDAM Bandung is 1800 L/sec but the realization is only 1400 L/sec. Meanwhile for SIPA PDAM Bandung Regency is equal to 500 L/sec but in realization is only 200 L/sec. Intake Cikalong taking water directly from Cisangkuy River, as well as from Cikalong Hydropower outlet. One of the reasons for using water from Cikalong Hydropower outlet is that the water has through the deposition process of the Tandon Daily Water Pond Unit before. Therefore, the water coming out of the outlet has better quality than water of the Cisangkuy River directly. The discharge of Cikalong Hydropower is more stable than the discharge of Cisangkuy River water, which is fluctuating. Another problem in the fulfilment of raw water is that the operation of the reservoir depends on

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the operation of the hydropower plant, where the hydropower has peak hour at 18:00 to 22:00. Therefore, to meet the needs of peak hour, raw water often detained. Such conditions affect the infrastructure in the downstream, that one of them is as raw water supply for drinking water that has to be fulfilled continuously.

Water resources are renewable natural resources through a hydrological cycle influenced by climate forming a hydrological regime where the components are random and stochastic. Stochastic components have a stationary and time-dependent nature. The Discrete Markov Stochastic model is a model that studies the properties of a variable in the present based on the properties of that variable in the past to predict the nature of the variable in the future.

According to the Government Regulation No.16 Year 2005, the implementation of SPAM development is planning, executing the construction, managing, maintaining, rehabilitating, monitoring and/or evaluating physical (technical) and non-physical systems of drinking water supply. In this research, optimization will be conducted on Cipanunjang Reservoir and Cileunca Reservoir utilization, using Discrete Markov model as discrete disposal model. Optimizing the reservoir pattern is said to be conceptual if the actual trajectory approaches the guideline. Optimization is done in order to maximize water utilization fulfill the water requirement in downstream infrastructure and no wasted water through spillway. The downstream infrastructures to be fulfilled are three hydroelectric power plant (PLTA), namely Plunder, Lamajan, Cikalong, and Intake Cikalong as well as raw water supply for PDAM Bandung and PDAM Bandung Regency.

2. RESEARCH METHODOLOGY

2.1 Water Discharge Estimation

The study of incidence between rainfall and discharge is based on the correlation between two random variables (rain and discharge observation stations) to predict future uncertainties through the discharge forecast model. The Markov process is a special case of a more general stochastic process.

Before going into the Chain Markov's rising model, a reliable discharge analysis is needed to analyze the reliability of the discharge by using the Hazen Method. The calculated reliability will result in three discharge classes, dry, normal, and wet as stated in Equation 1.

$$P\ (Xm) = \frac{2m-1}{2N} \quad (1)$$

P (Xm) = Hazen reliability (%)

m = data ranking x

N = amount of data after Hazen analysis done.

The stochastic process can be seen as a row of random variables over time. If the Markov process with n-occurrence of the transition probability from condition I on Xn-1 to condition j at Xn and assumed this probability stays all the time, then the transition will be more easily arranged in the form of a matrix. The matrix value is obtained by calculating the pair of years characterized by the discharge state (0, 1, 2). If a series of meteorological (N + 1) years is owned, a separate N-pair N_{01} and N_{10} will present the sum of consecutive changes of circumstance from the dry discharge (0) to the normal discharge state (1), or from the normal discharge (1) to dry discharge (0) and so on. If P_i is called the marginal probability of the discharge state *i*, the data of the correlation can be illustrated with Equation 2.

$$A_{ij} = \frac{N_{ij}}{N_i}\ dan\ P_i = \frac{N_i}{N} \quad (2)$$

Table 1 Matrix transition of one order three classes

Discharge condition t_{n-1}	Conditions of water discharge t_n			Total discharge condition t_{n-1}
	0	1	2	
0	N_{00}	N_{01}	N_{02}	$N_0 = N_{00} + N_{01} + N_{02}$
1	N_{10}	N_{11}	N_{12}	$N_1 = N_{10} + N_{11} + N_{12}$
2	N_{20}	N_{21}	N_{22}	$N_2 = N_{20} + N_{21} + N_{22}$

Flow chart of Chain Markov discharge flow shown in Figure 1 (Arwin, 2001).

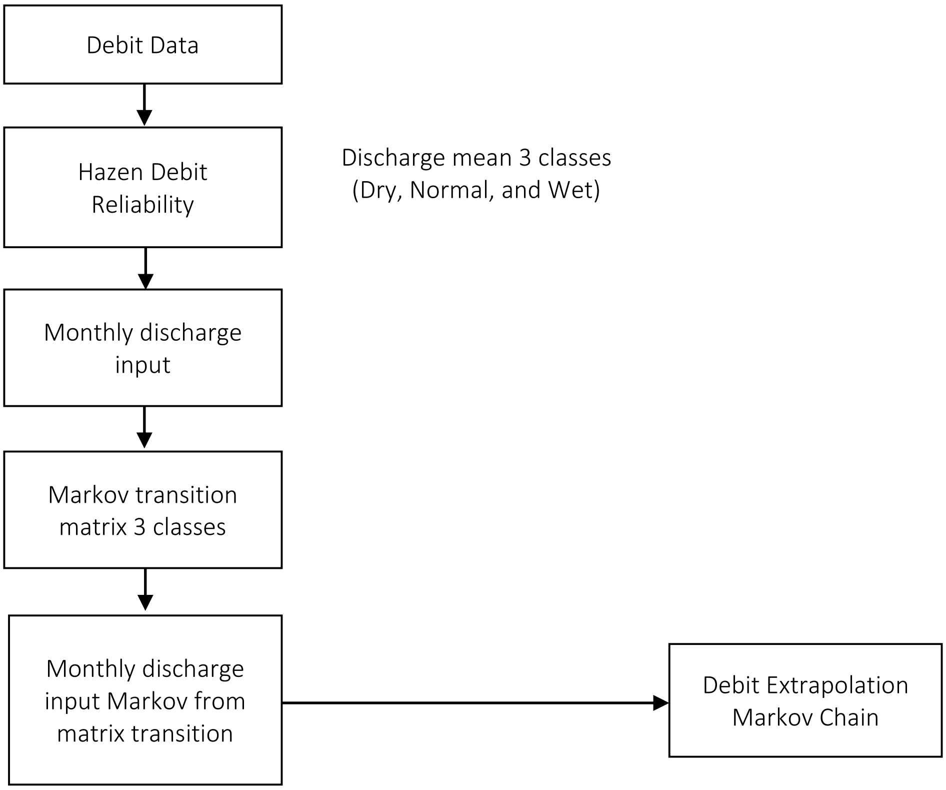

Figure 1 Chain Markov flow diagram model

To make a transition matrix, it is necessary to do the following:

a. Sort the discharge data from small to large.

b. Calculates the probability value of each data using the Weibull method where the probability of each sequence of data (P*i*) is determined by the equation P*i* = mi/(N+1).

c. Determine the cumulative probability for a series of data (series data) each month and divide it into three classes. The three classes are each with the following interval:

- Class 0 = dry → P= 0 – 1/3
- Class 1 = normal → P = 1/3– 2/3
- Class 2 = wet → P = 2/3 – 1

2.2 Determination of the year of Wet, Normal, and Dry

For the determination of dry, normal, and wet year trajectory using the discrete Markov method, the first step is to compile the complete discharge data from the biggest to the smallest, then the

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next step is to divide the discharge data into three classes, namely dry, normal, and wet. Later, Transition matrix of three order classes in one year is made to practice the wet, normal, and dry year.

2.3 Reservoir Operation Pattern

Based on the operating guidance of electric-electric multipurpose cascade reservoir No. 360 Year 2004, the operation pattern of the reservoir is critical in the operation of cascade reservoir with multipurpose electric pattern because each reservoir has attachment to each other. To create the pattern of cascade reservoir operation, the following data are required (Zhou, 2013):

a) Main inflow and local inflow to each reservoir.
   We need the data to calculate the volume of flow directly into the reservoir, either from the main river or from the local stream, for instance the flow that comes from the tributaries. If the data is not available, the amount of flow volume that enters the reservoir is calculated by the water balance method of the reservoir.
b) Initial TMA data (initial condition) of each reservoir
   Initial TMA data is actual TMA data on January 1st. Based on data of the correlation data between TMA with reservoir volume, reservoir volume at initial TMA is found. Furthermore, the initial TMA data is used as a reference to see the condition of TMA at the end of the year.
c) Data on the needs for irrigation water, industry and drinking water.
   The amount of water demand for irrigation, industry, drinking water varies every month. It has to be known in order to prevent the excess or shortage of water supply.
d) The data of the correlation between the TMA reservoir with the storage volume and the TMA reservoir data with the surface area of the labeled reservoir are the absolute data that must be available in reservoir.
e) Turbine data
   Turbine data is necessary to design the limits on cascade reservoirs operational.
f) Data on reservoir characteristic
   Data on reservoir characteristics, such as height of spillway buildings, normal height, and minimum operational height are necessary in establishing the operational limitation of a reservoir.

Based on these guidelines, it is necessary to define the economic environment of Cipanunjang

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Reservoir and Cileunca Reservoir to know the operation pattern of each reservoir for the interest of fulfilling the needs in the downstream.

2.4 Simulation and Reliability of Reservoir

The simulation model is used to evaluate what will happen inside the system if certain inputs are given. Thus, the pattern of system management can be evaluated by studying the behavior of the system to input various scenarios on the system to determine the level of reliability or failure of the operating behavior. The simulation method used in mathematical equations.

The mass conservation formula:

$$S_{t+1} = St + Qin - Qout - Evaporasi \tag{3}$$

S_{t+1} = reservoir at the beginning of the period or the upcoming period (m^3)
St = Dam capacity on t period (m^3)
Q_{in} = discharge Inflow on t period (m^3)
Q_{out} = Discharge need on t period (m^3)
E = Evaporation on t period
t = Month on the period
t+1 = Month on the upcoming period

3. RESULTS AND DISCUSSION

Cipanunjang Reservoir Flow and Cileunca Reservoir Scheme can be seen in Figure 2.

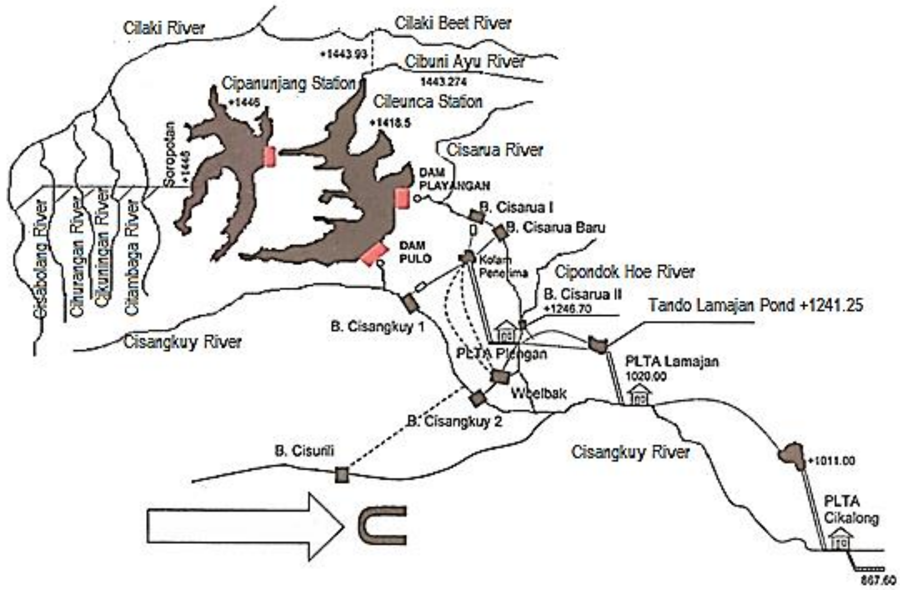

Figure 2 Water nets of Cipanunjang Reservoir and Cileunca Reservoir

3.1 Optimization of Cipanunjang - Cileunca Reservoir using Discrete Markov Method

The prediction of water volume or inlet discharge entering the reservoir are the determinants of the water volume to be stored in the reservoir as reserves or stock and how much water volume can be removed from the reservoir through the utility function (Yin, 2014). The discharge estimation model used in this study is the Markov Discrete Stochastic Method. The model will be correlated with historical discharge and will be the prove that if the conditions of the guideline and actual conditions are close to 1, then the method is conceptual or the method is appropriate in order to optimize the reservoir.

The approach with the Discrete Markov model uses a transition matrix that explains the occurrence probability value of a certain amount of discharge. In order to create three classes transition matrixes, the steps to be done are: sort the data from the biggest to the smallest, calculate the probability using Hazen method in order to divide the data into three classes: Wet (2), Normal (1), and Dry (0). Then in every class interval specified discharge mean representing each class. The three classes intervals are: Class 0 (Dry) = $0 < P \leq 1/3$, class 1 (Normal) = $1/3 < P \leq 2/3$, and class 2 (Wet) = $2/3 < P \leq 1$. The analysis result of the monthly class determination whether it is Wet, Normal, or Dry for Cipanunjang and Cileunca Reservoir using Three Discrete Markov Method

Class in Table 2 until Table 5. Distribution of discharge class intervals based on Cipanunjang Reservoir and local Cileunca's historical data from 2000 to 2013. Three classes order one transition matrix is made from the division of classes.

Table 2 Monthly discharge classes' limit of Cipanunjang Reservoir based on the historical discharge

Month	Wet	Normal	Dry
	(2)	(1)	(0)
Jan	3.43-5.27	2.68-3.12	1.36-2.63
Feb	4.37-5.33	3.35-4.19	1.40-3.21
Mar	3.81-5.14	2.58-3.79	1.24-2.56
Apr	3.28-5.43	2.83-2.95	1.00-2.03
May	1.89-3.64	1.34-1.86	0.53-1.08
June	1.40-2.93	0.74-0.77	0.19-0.44
July	1.00-2.27	0.38-0.75	0.04-0.37
Aug	1.21-1.90	0.53-1.19	0.00-0.30
Sep	1.38-3.52	0.47-1.36	0.02-0.47
Oct	1.48-3.00	0.53-1.36	0.02-0.47
Nov	2.03-6.10	1.27-1.91	0.22-1.06
Dec	2.79-5.72	2.14-2.38	0.15-2.09

Table 3 Monthly average limit of Cipanunjang Reservoir based on the historical discharge from 2000 until 2013

Month	Wet	Normal	Dry
	(2)	(1)	(0)
Jan	4.49	2.86	1.92
Feb	4.87	3.79	2.28
Mar	4.31	3.40	2.02
Apr	4.28	2.88	1.57
May	2.51	1.60	0.89
June	1.86	0.75	0.31
July	1.40	0.58	0.17
Aug	1.55	0.80	0.10
Sep	2.22	0.96	0.18
Oct	2.14	0.94	0.23
Nov	3.41	1.45	0.58
Dec	3.90	2.31	1.53

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Table 4 Monthly discharge classes' limit of Cipanunjang Reservoir based on the historical discharge from 2000 until 2013

Month	Wet	Normal	Dry
	(2)	(1)	(0)
Jan	1.86-2.90	1.45-1.73	0.59-1.38
Feb	1.90-3.42	1.50-1.72	0.24-1.27
Mar	2.59-3.21	1.81-2.42	1.43-1.77
Apr	2.59-3.11	2.00-2.59	0.00-1.77
May	2.03-3.21	1.60-1.87	0.00-1.49
June	1.81-3.11	1.29-1.41	0.00-1.25
July	1.34-2.14	0.92-1.34	0.27-0.89
Aug	1.30-2.14	0.82-1.21	0.27-0.70
Sep	1.17-2.07	0.52-1.04	0.13-0.42
Oct	1.34-2.04	0.54-1.26	0.24-0.54
Nov	1.30-1.92	0.78-1.17	0.00-0.62
Dec	1.42-2.64	1.34-1.40	0.05-1.21

Table 5 Monthly discharge average limit of Cileunca Reservoir based on the historical discharge from 2000 until 2013

Month	Wet	Normal	Dry
	(2)	(1)	(0)
Jan	2.32	1.60	1.11
Feb	2.50	1.64	0.98
Mar	2.83	2.09	1.54
Apr	2.81	2.23	1.23
May	2.49	1.71	1.06
June	2.19	1.32	0.84
July	1.59	1.20	0.60
Aug	1.52	1.02	0.42
Sep	1.57	0.67	0.29
Oct	1.56	1.02	0.37
Nov	1.45	0.95	0.40
Dec	1.74	1.35	0.56

The stochastic process has been done based on a random variable series of discharges over time. If the Markov process with n-occurrence of the transition probability from condition i on

Xn-1 to condition j on Xn and assumed this probability remains all the time, then the transition will be more easily arranged in the matrix form. The matrix value is obtained by calculating the pair of years characterized by the discharge state (0, 1, 2). If a meteorological series (N + 1) year is owned, then N will have separate pairs. N_{01} and N_{10} present the sum of circumstance's successive changes from the dry discharge (0) to the normal discharge state (1), or from the normal discharge (1) to dry discharge (0), and so on. Example of December - January order 1 matrix transition in Cipanunjang Reservoir - reservoir is shown in Table 6 and Table 7.

Table 6 December - January order 1 matrix transition in Cipanunjang Reservoir

December (t-1)	January Conditions (t)				
	0	1	2		
0	0.60	0.20	0.20	1.00	P0N
1	0.25	0.50	0.25	1.00	P1N
2	0.20	0.20	0.60	1.00	P2N
	1.05	0.90	1.05	3.00	
	P0N	P1N	P2N		

Tabel 7 December - January order 1 matrix transition in local Cileunca Reservoir

December (t-1)	January Conditions (t)				
	0	1	2		
0	0.20	0.40	0.40	1.00	P0N
1	0.50	0.25	0.25	1.00	P1N
2	0.40	0.20	0.40	1.00	P2N
	1.10	0.85	1.05	3.00	
	P0N	P1N	P2N		

The 1st order transition matrix in each of the Month conditions from January to December then the amount is determined according to the average limit of the discharge class as shown in Table 3 and Table 5. After the discharge of Markov Estimation is obtained from each Cipanunjang and local Cileunca Reservoir then correlated with historical discharge. Correlation between historical and estimation discharge at Cipanunjang Reservoir is 0,906, while the local Cileunca

Reservoir is 0.875 as can be seen in Figures 3 and 4.

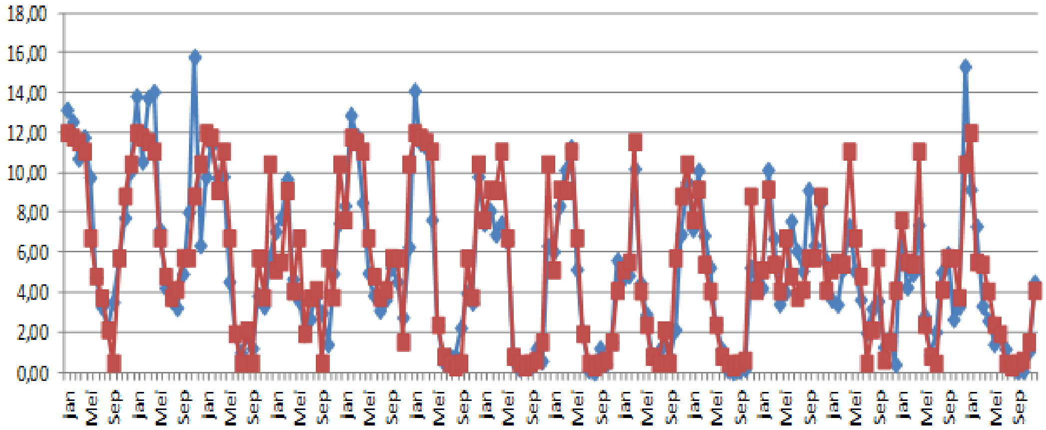


Figure 3 Correlation between historical discharge in Cipanunjang Reservoir and Discrete Markov discharge estimation

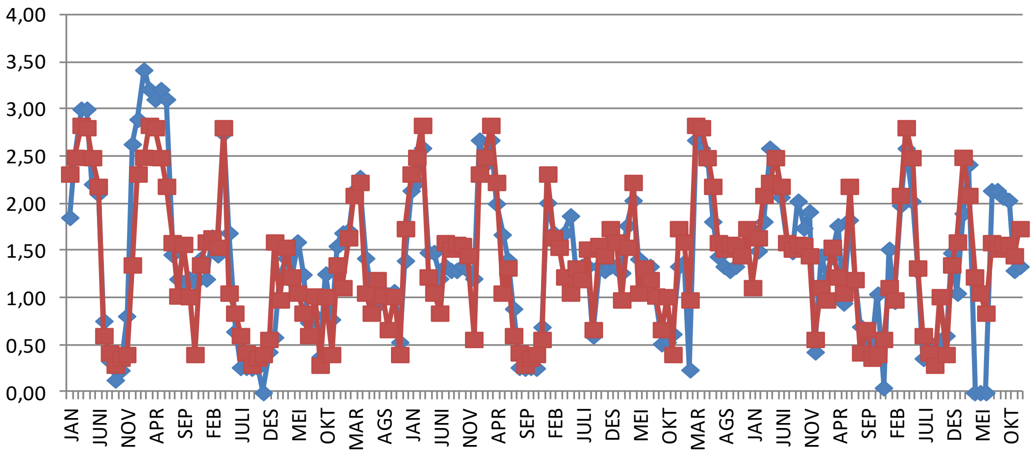


Figure 4 Correlation between historical discharge in local Cileunca Reservoir and Discrete Markov discharge estimation

There are two approaches used in this research to determine the reservoir trajectory guidelines. The first one is using Cipanunjang – Cileunca Reservoir Watershed Series as one hydrology system from the upstream to downstream (each reservoir has three trajectory guidelines, namely dry, normal, and wet). Second, an approach where the Cipanunjang–Cileunca Reservoir Watershed Series is a hydrologic dynamic system that has two sub system of hydrological unit. Therefore the sum of trajectory guidelines is divided into cascade sub-system 1

(Cipanunjang Reservoir), cascade sub-system 2 (Cileunca Reservoir). The sum of trajectory guidelines on each reservoir sub-system (PM_iN_j) is determined by this equation (Arwin and Lieza, 2015):

$$PMiNj = Mi^{Nj} \tag{4}$$

where N_j = 1 for the 1st cascade (Cipanunjang Reservoir); N_j = 2 is for the 2nd cascade (Cileunca Reservoir); M_i = Number of trajectories (i = 3).

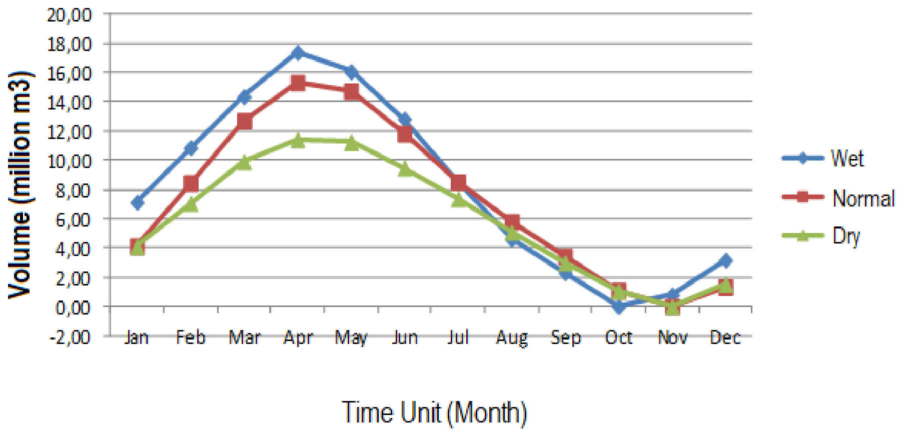
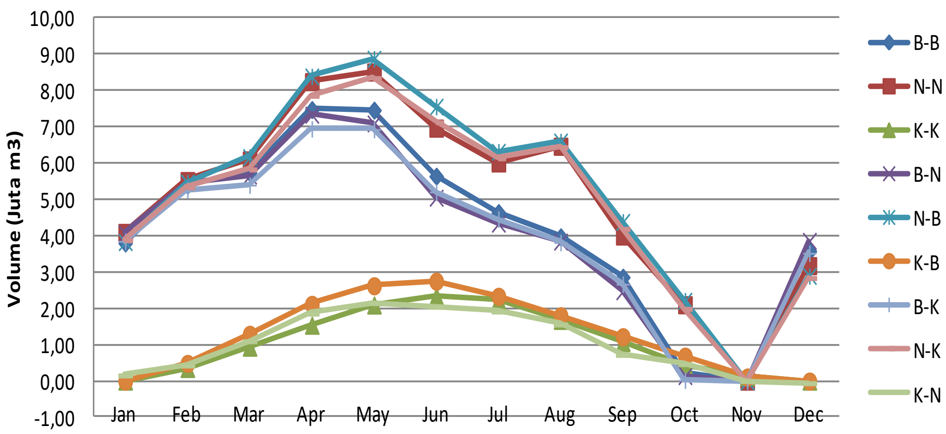


Figure 5 Trajectory guidelines based on the discharge plan three class discrete Cipanunjang Reservoir



**) Information:*
K = dry-dry, NN = normal-normal, BB = wet, KB = dry-wet, KN = dry-normal, NK = Normal-dry, NB = normal-wet, BK = wet-dry, BN = Wet-normal

Figure 6 Trajectory guidelines based on the discharge plan three class discrete Cileunca Reservoir with nine trajectories combination

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The calculation result from Cipanunjang Reservoir is three tracks, namely Dry, Normal and Wet Path as shown in Figure 5, while for Cileunca Reservoir is nine paths that is a combination of dry, normal and wet path as shown in Figure 6.

In the optimization of this series of reservoirs, the reservoir trajectory pattern has been described in the discussion of deterministic patterns. The actual inlet discharge is historical discharge data, while discharge estimation is discrete data of Markov Discrete estimation. The minimum output in Cipanunjang Reservoir is the R5 discharge plan R5, while the minimum output in Cileunca Reservoir is the minimum operational discharge one turbine on PLTA Plengan. The trajectory guidance on Cipanunjang Reservoir can be seen in Table 8. While in order to obtain the pattern of trajectory guidance on Cileunca Reservoir is to sum up the monthly discharge at Cipanunjang Reservoir and local Cileunca Reservoir, the guideline trajectory is used as the basis for predicting the annual class types in Dry, Normal, and Wet categories. Recapitulation of year class types in Cileunca Reservoir showed in Table 9.

Table 8 The determination of year class type based on the annual volume in Cipanunjang reservoir

Year	Trajectory Pattern
2000	Wet
2001	Wet
2002	Normal
2003	Normal
2004	Wet
2005	Wet
2006	Dry
2007	Normal
2008	Dry
2009	Dry
2010	Wet
2011	Dry
2012	Normal
2013	Dry

Table 9 Determination of year class type based on annual volume in reservoir Cipanunjang-Cileunca series

Year	Cipanunjang	Cilaki Beet	Trajectory Pattern
2000	Wet	Wet	W – W
2001	Wet	Wet	W – W
2002	Normal	Dry	N – D
2003	Normal	Dry	N – D
2004	Wet	Normal	W – N
2005	Wet	Wet	W – W
2006	Dry	Normal	D – N
2007	Normal	Normal	N – N
2008	Dry	Dry	D – D
2009	Dry	Wet	D – W
2010	Wet	Wet	W – W
2011	Dry	Dry	D – D
2012	Normal	Dry	N – D
2013	Dry	Normal	D – N

When determining actual Q_{out} and St + 1, the turbine reserve and minimum operational turbine discharge must be considered. If the allocation of R5 is less than the minimum operational turbine discharge allocation, a minimum turbine value is used. Excess water stock is the amount of water stored in a reservoir declared as stock (St). If the stock value exceeds the maximum capacity of the reservoir then excess water stock is flown as an additional discharge through the turbine. If it still exceeds the maximum capacity of the turbine then the water passes through the spillway. In this research for optimization of Cipanunjang Reservoir, minimum Q_{out} is discharge plan of R5 Dry. Optimal Management Simulation of Cipanunjang Reservoir Year 2000-2013 with three trajectory guidelines can be seen in Figure 7.

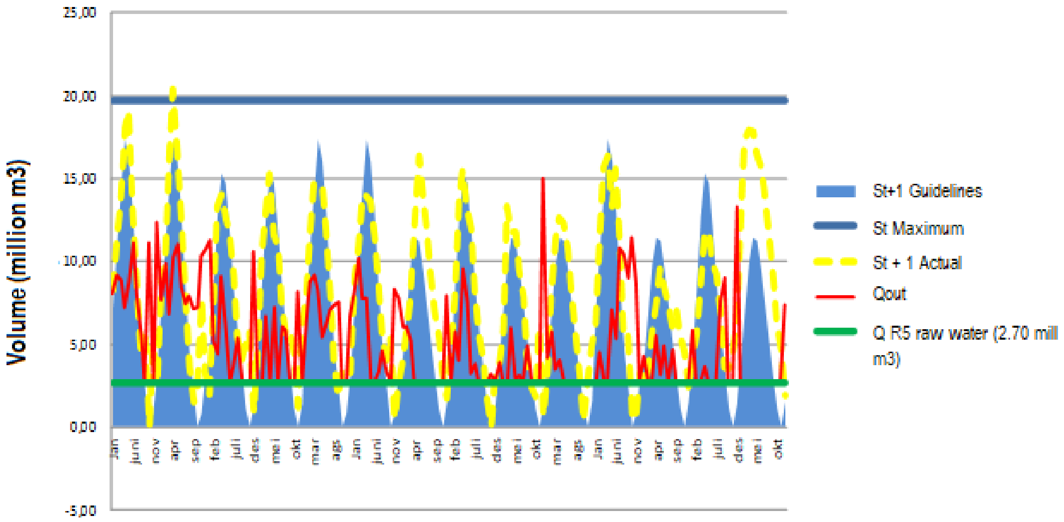

Figure 7 Optimal management simulation of Cipanunjang Reservoir year 2000-2013

Meanwhile, the optimization of the minimum Cileunca Reservoir, Q out is the minimum operational discharge of the PLTA turbine. It is due to the R5 dry discharge plan is smaller than the minimum turbine discharge. With this adjustment all of the facility in the downstream, irrigation and drinking water included, can meet the needs. Therefore, it can be said that this method is conceptual or the water utilization is function optimally to fulfill the minimum turbine on PLTA Plengan, irrigation, and drinking water. Optimal Management Simulation of Cipanunjang Reservoir Year 2000-2013 with nine trajectories guidelines can be seen on Figure 8.

For comparison, calculation simulation has also done for optimizing Cileunca Reservoir using three trajectories guidelines that is Dry, Normal and Wet. This simulation has done only to prove that the management of reservoir with cascade system will be better when using Equation 4 because of the difference of Sub hydrological system. Then Simulation of Cileunca Reservoir management using trajectories guidelines can be seen in Figure 9.

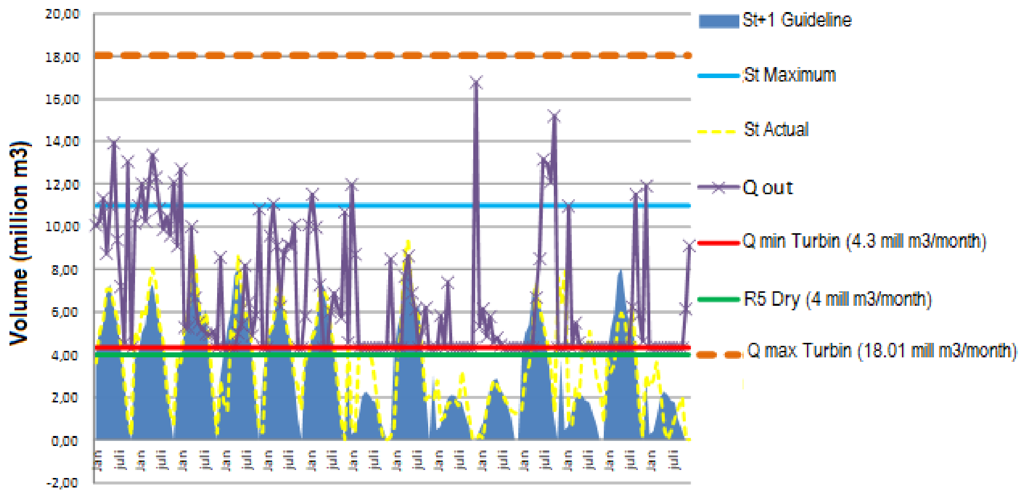

Figure 8 Optimal management simulation of Cileunca Reservoir year 2000-2013 with nine trajectories

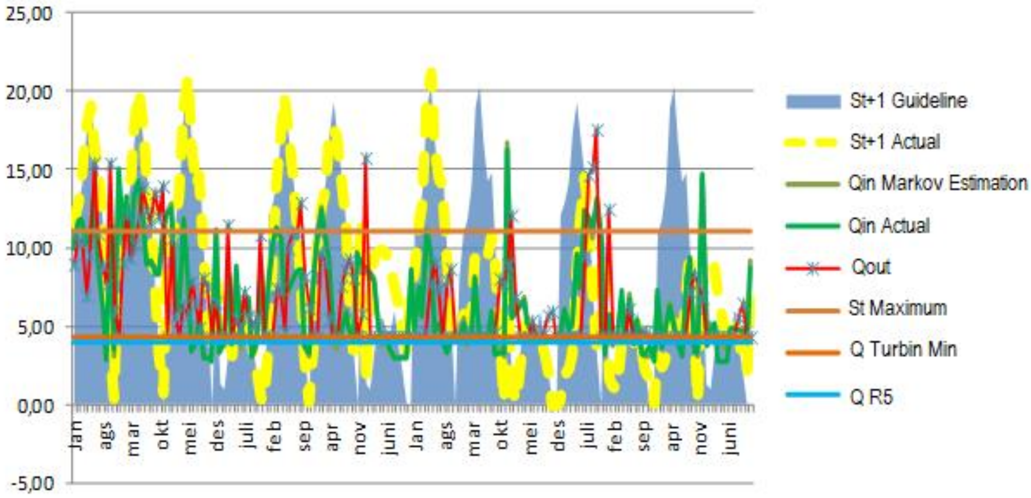

Figure 9 Optimal management simulation of Cileunca Reservoir year 2000-2013 with three trajectories

It can see that when only three trajectories used, Wet, Normal, and Dry are used, the actual trajectory correlation value with trajectory guidelines are not as good when using the nine trajectory guidelines are based on the combination of Dry, Normal, and Wet.

4. CONCLUSION

The conclusions obtained from this research are as follows:

Discharge plan for SPAM Requirement (R20) at Cipanunjang Reservoir of 570 L/sec and for Cileunca Reservoir is 1216.84 L/sec. The allocation of drinking water has to be fulfilled at all times even at the peak operational hour of the hydropower plant. Trajectory guidelines for cascade reservoirs will be more optimized after referring to the equations developed by Arwin and Lieza, where the first Reservoir has three trajectories and the second reservoir has nine trajectories. The optimization of the reservoir is achieved by the condition of the guideline and the actual trajectory approaching 1, which means the absence of water through the spillway but through the function of reservoir utilities for the Turbine, Irrigation water and raw water supply in the downstream. The comparison between Trajectory Guidance and actual trajectory of Cipanunjang Reservoir is 0.861 while for optimization of Cileunca Reservoir is 0.827. The correlation between the actual (historical) discharge and the Markov Estimation discharge on the Cipanunjang-Cileunca Reservoir is closed to 1, so it can be show that the discharge estimation is conceptual because it corresponds to the actual condition (actual discharge).

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