WATER RESOURCES MANAGEMENT FOR THREE SERIES RESERVOIR OPERATION ON CITARUM RIVER BASIN WEST JAVA INDONESIA

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Indonesia today face a new paradigm in water management where aim to apply integrated water resources management has become an unavoidable task in purpose of achieving greater level of effectiveness and efficiency. One of most interesting case study is the case of Citarum river, one of the most potential river for water supply in West Java, Indonesia, with river basin area of 6,080 Km$^2$. The river flows from Mt. Wayang of 1,700 m above mean sea level and empties into Java Ocean with the annual rainfall between 2,000 up to 5,000 mm per year and the temperature between 18$^0$C up to 24$^0$C.

Alongside the river, Saguling, Cirata and Juanda Reservoirs had been constructed in series. The first and second reservoirs are particularly operated for hydro electrics power and the third one is multipurpose reservoir mainly operated for irrigating the 225,000 Ha paddy field and contribute domestic water supply for Jakarta the capital city of Indonesia, Saguling Reservoir (982 x 10$^3$ m$^3$, 1986) and Cirata Reservoir (2,165 x 10$^3$ m$^3$, 1988) are managed by the PT. Perusahaan Listrik Negara (PT. PLN), while Juanda Reservoir (3,000 x 10$^3$ m$^3$, 1963) is managed by PT. Jasa Tirta II.

Basically all reservoirs are relying on same resources, therefore this condition has considered addressing management and operational problem. Therefore, an approach toward new management and operation system are urgently required in order to achieve the effective and efficient output and to avoid conflicts of water used. This paper will elaborate, describes and discusses the concept and principle of the integrated water management as well the aspect of the reservoir operation.

Hopefully this paper will be useful for scientists and researchers with the aim of exchange information and transfer of knowledge in Asia Pacific region.

INTRODUCTION

In purpose of Indonesian government to improve the quality of peoples life, one of the important strategy and target to be achieved is developing the water resources in order to fulfill the vary needs of society, among any are supporting food production development, energy, and drinking water. One of most strategic and potential river for supporting food and energy supply for capital of Republic of Indonesia and the welfare improvement of
West Java provinces is by developing the Citarum’s river water resources conservation development. To serve that purpose, Juanda Reservoir has been established by year 1967 followed by the development of Cirata and Saguling reservoir on 1988 and 1996 respectively. These two last reservoirs were built with main purpose to produce the hydroelectric power. Juanda Reservoir was meant to irrigate rice field, hydroelectric power and drinking water supply for Jakarta. Hydroelectric power Saguling, Cirata, and Juanda are the supplier for electricity distribution along Java-Bali with investment values not less than US$ 1.7 billion (based on assumption of US$ 1000/Kwh).

The management of Juanda Reservoir, a multipurpose reservoir and play a very important role for food and electric supply, is highly dependent on the management of Cirata and Saguling Reservoir that is regarding the topographic location of both reservoirs which are located on the upstream of Citarum river. Besides, the management of those reservoirs is handled by two different institutions that is Departemen Pertambangan dan Energi (Department of Mining and Energy) and Departemen KIMPRASWIL (Department of Settlement and Regional Infrastructure). Therefore, it is understandable that some conflicts are occurred in the operation of the reservoirs. In order to overcome the problems, a coordination institution are established where the method of reservoir operation may be discussed in the operation planning following certain criteria.

Another factor influencing reservoir operation pattern is the two seasons climate condition regarding Indonesia located on the monsoon area, with principle of reserving the rainfalls in the three reservoirs to be used on the dry season. Since the duration of each rainy and dry season always changing from time to time in a monthly period, hence the reservoir operation pattern should be adjusted monthly.

The increase of population and economic growth resulted in the growing need for water supply from the reservoirs mainly for irrigation, drinking water and electric power. In the other side, the changes of catchments characteristic are causing changes in hydrograph inflow pattern of the three reservoirs. Therefore, it needs comprehensive study upon the reservoir operation pattern of the three reservoirs and further be developed to fulfill the demands of these 21st century.

DATA

As mentioned above, three reservoirs are built alongside the Citarum river for vary of purposes. The two reservoirs located on the upstream of Saguling and Cirata are meant for hydroelectric power while the third one, located on the downstream, is meant for multipurpose use, especially to irrigate 225,000 Ha rice field. The comparison of the three reservoirs characteristic can be show on Table 1.

Beside the usage to irrigate the rice field, Juanda Reservoir is also utilized for hydroelectric power with installed capacity of 175 MW and able to provide domestic water supply for the capital city Jakarta of 10 m$^3$/sec.

Saguling and Cirata Reservoir are operated and managed by Electric Enterprises PT Indonesia Power and PT.PJB where Juanda Reservoir by PT. Jasa Tirta II. The two government institutions are under different department, where PT PLN is under the supervision of Department Pertambangan and Energi while PT Jasa Tirta II is under the supervision of Department KIMPRASWIL.
Table 1. Reservoir Characteristics

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>SAGULING RESERVOIR 1996</th>
<th>CIRATA RESERVOIR 1988</th>
<th>JUANDA RESERVOIR 1967</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchments Area - Km²</td>
<td>2.283</td>
<td>4.061</td>
<td>4.500</td>
</tr>
<tr>
<td>Dam Height - m</td>
<td>99.0</td>
<td>125</td>
<td>96</td>
</tr>
<tr>
<td>Volume - mi. m³</td>
<td>603</td>
<td>1.927</td>
<td>2.448</td>
</tr>
<tr>
<td>Purpose</td>
<td>Electricity</td>
<td>Electricity</td>
<td>Multi/ Irrigation</td>
</tr>
<tr>
<td>Yearly Rainfall – mm</td>
<td>3.222</td>
<td>-</td>
<td>2.200</td>
</tr>
<tr>
<td>Design Discharge/ 100years – m³/sec</td>
<td>500</td>
<td>2.600</td>
<td>1.500</td>
</tr>
<tr>
<td>Surface Area – Ha.</td>
<td>4.869</td>
<td>6.200</td>
<td>8.200</td>
</tr>
<tr>
<td>Effective Volume – mi.m³</td>
<td>598.4</td>
<td>784.9</td>
<td>1.869</td>
</tr>
<tr>
<td>Design Flood / 10.000years - m³/sec.</td>
<td>6.600</td>
<td>5.682</td>
<td>8.000</td>
</tr>
<tr>
<td>Install Capacity – MW</td>
<td>4 x 175</td>
<td>8 x 125</td>
<td>6 x 30</td>
</tr>
<tr>
<td>Management</td>
<td>PT. Indonesia Power</td>
<td>PT. PJB</td>
<td>PT. Jasa Tirta II</td>
</tr>
</tbody>
</table>

Initially, the discharge inflow for each reservoir is predicted applying the combined data resulted from observation and generated data. However, along the operational of Citarum Reservoir Cascade, the generate data are no longer can be used since the speedy degradation of the forest and land use alongside the upper course of every catchments area. Therefore, since 1998 the prediction of the discharge inflow is obtained only derived from actual data recorded since that year.

RESEVOIR OPERATION

Reservoir operation pattern are made on three alternatives assuming normal climate condition (normal year), longer rain season climate (wet year) and longer dry season climate (dry year) for each pattern respectively. Since 1988, Saguling, Cirata and Juanda reservoir are operated in cascade, so-called The Citarum Reservoir Cascade.

Table 2. Flow discharge prediction for saguling reservoir year 2003 with log normal frequency analysis type III

<table>
<thead>
<tr>
<th>Probability</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>81.2</td>
<td>89.5</td>
<td>88.0</td>
<td>110.0</td>
<td>61.0</td>
<td>26.4</td>
<td>17.4</td>
<td>9.9</td>
<td>7.9</td>
<td>9.0</td>
<td>27.8</td>
<td>58.2</td>
</tr>
<tr>
<td>40%</td>
<td>124.9</td>
<td>116.4</td>
<td>145.4</td>
<td>156.7</td>
<td>89.9</td>
<td>52.0</td>
<td>31.0</td>
<td>19.2</td>
<td>16.8</td>
<td>32.4</td>
<td>87.1</td>
<td>99.8</td>
</tr>
<tr>
<td>Normal (50%)</td>
<td>137.2</td>
<td>125.5</td>
<td>159.6</td>
<td>168.7</td>
<td>97.6</td>
<td>59.2</td>
<td>35.9</td>
<td>22.7</td>
<td>20.3</td>
<td>40.8</td>
<td>104.0</td>
<td>110.6</td>
</tr>
<tr>
<td>60%</td>
<td>150.2</td>
<td>135.9</td>
<td>173.8</td>
<td>180.8</td>
<td>105.6</td>
<td>66.7</td>
<td>41.5</td>
<td>27.0</td>
<td>24.6</td>
<td>50.7</td>
<td>121.8</td>
<td>121.8</td>
</tr>
<tr>
<td>90%</td>
<td>210.7</td>
<td>195.6</td>
<td>231.7</td>
<td>232.1</td>
<td>140.7</td>
<td>101.7</td>
<td>75.8</td>
<td>55.3</td>
<td>53.6</td>
<td>111.0</td>
<td>205.7</td>
<td>169.8</td>
</tr>
<tr>
<td>Dry</td>
<td>180.5</td>
<td>165.8</td>
<td>202.8</td>
<td>206.4</td>
<td>123.1</td>
<td>84.2</td>
<td>58.7</td>
<td>41.1</td>
<td>39.1</td>
<td>80.8</td>
<td>163.8</td>
<td>145.8</td>
</tr>
<tr>
<td>Wet</td>
<td>103.0</td>
<td>102.9</td>
<td>116.7</td>
<td>133.3</td>
<td>75.5</td>
<td>39.2</td>
<td>24.2</td>
<td>14.6</td>
<td>12.4</td>
<td>20.7</td>
<td>57.5</td>
<td>79.0</td>
</tr>
</tbody>
</table>
Normal year discharge is the inflow discharge with highest probability P 60% while the lowest P 40%. Therefore, the normal year discharge probability lay on the range of P 40% - P 60% or equal with probability of P 50%.

The wet year discharge highest probability is P 90% while the lowest is P 60%. Therefore, the average of wet year discharge lay on the range of P 60% - P 90%.

The lowest probability of dry year discharge is P 10% while the highest is P 40%. Therefore, the average of dry year discharge lay on the range of P 10% - P 40%. For instance, the discharge predicted flow to Saguling reservoir on 2003 could be observed on Table 2 and graphically on Figure 1.

![Figure 1. Flow Discharge for Saguling Reservoir Year 2003](image)

Frequency analysis Log Normal Type III (LN3) and stochastic method are applied for discharge inflow prediction, the basic formula as follows:

$$X = \overline{X} + k.S$$

where:

- **X** = Discharge prediction in m$^3$/s
- **$\overline{X}$** = Average discharge inflow from time series X in m$^3$/s
- **k** = Characteristics and distribution log-normal type 3 as a function of skewness coefficient, CS
- **S** = standard deviation

ARIMA method only applied to predict discharge inflow on the normal year.
The principle of reservoir operation should be applied with to keep net system storage proportionally distributed (shared), water supply demands and ending water level same as or better than starting water levels. Beside, other principle should be paid attention e.g. max combine Saguling and Cirata firm output. For Standard Solver: The starting solution MUST be feasible, well within the constraint limits to ensure a good "warming-up" of the solver. Use smooth function (e.g. Nprob instead of MIN).

The Citarum Reservoir Cascade are operated based on equal sharing principle with several constraints are agreed among the reservoir management where several water supply needs such irrigation, drinking water on the downstream (of the Juanda Reservoir) become first priority while electricity production become other second priority. Constraints applied for The Citarum Reservoir Cascade are as follows:

1. Monthly water level $\geq$ Operational minimum water level
2. Monthly water level $\leq$ Operational maximum water level
3. Percentage monthly effective capacity equal with determined maximum capacity
4. Final water level for each reservoir $\geq$ Initial water level
5. Discharge outflow from Juanda reservoir (upstream) $\geq$ irrigation water demand

By using reservoir operation calculation method and principle described above, then can be obtained the reservoir operation pattern plan for year 2003 as shown in the Figure 2.

RESULT

On Figure 2, the rule curve of reservoir operation is presented for year 2003 with alternatives for dry and normal session. In purpose of maintaining the principle of the reservoirs effective volume of the water level condition should always be above the water level on the dry session. Water usage either for Saguling and Cirata Reservoir hydroelectric power and water usage in Juanda Reservoir for one-year period. Toward end of the year, water level condition should be restored to water level before the operation of the reservoirs. By applying two principles above, the water level prediction for year 2003 period may be obtained in order to achieve optimum product out of the three reservoirs.

DISCUSSION

As been described previously, technically there are many problems occurred in operating the rule curve of reservoir operation. The main problem is the hardly predicted climate condition, for instance, though the rule curve of reservoir operation to enter the wet and dry sessions has already obtained, either the wet and the dry session happened are not fit in with the actual climate by the time of operating the reservoir in order to fill the water needs. Discharge inflow into the three reservoirs is almost difficult to be predicted, where theoretically happen as effect of the land use change. In reality, there is land use change in the Citarum river basin along with the population and economic growth. Land use change clearly will affect the Citarum river hydrograph pattern. Although the total water
Figure 2. Operational Pattern of the Citarum Reservoir Cascade Year 2003
inflow into the three reservoirs is same for the total one year period, there are different for their each monthly distribution.

The prior usage of Juanda Reservoir is to irrigate the 225,000 Ha rice field, where each rice field are under the different control by Bupati (decision maker), therefore bring different planting pattern policy. The policy changes bring adjustment to the previous reservoir operation rule curve cause crisis to the water volume condition in the reservoir. Based on that condition, it needs more dynamic and flexible reservoir operation rule curve which able to be adjusted by any time. However, it should be deeply considered that reservoir operation rule curve of Juanda reservoir cannot be change easily since the inflow into this reservoir is so much dependent on the outflow of Cirata reservoir, as well inflow into Cirata reservoir is so much dependent on the outflow of Saguling reservoir. Inflow to Saguling reservoir is flow discharge from upper Citarum River basin, this catchment area having significant land use change toward the Citarum river discharge hydrograph.

Besides being technically evaluated and upgraded, problems faced on the three reservoirs are hardly solved from year to year. This is since the problem is essentially a non-technical problem as the change of decision maker. Therefore an institution with member of stakeholder institutions related with the operation of the three reservoirs head by Governor of the West Java provinces. This institution held monthly formal meeting to give direction to the Management of the reservoirs.

CONCLUSION

Electricity production from the three reservoir for Java-Bali electricity network have a very dominant contribution, therefore the operation of the three reservoirs is very essential to maintain the sustainability of energy supply in Java-Bali.

Reservoir operation pattern for the three reservoirs in Citarum River have different rules curve for each year, adjusted with the output product expected by decision maker. However, this condition frequently brings conflict of interest where cause crisis to the reservoir condition.

With the existence of coordination institution among stakeholder, the occurred problem may be overcome by the planned rules curve socialization therefore decision maker may understand the condition.

The prediction methods applied in determining discharge inflow into Saguling, Cirata and Juanda reservoir are merely a temporary approach. These two methods have disadvantage as follow:

- Frequency analysis method is not able to predict the discharge inflow for period of more than one month, however able to determined the corridor of discharge inflow for normal, dry and wet year. Meanwhile, ARIMA method is only able to determine inflow discharge or normal year.

The Citarum Cascade reservoir is operated integrally on the equal sharing principle. By this way, conflict of interest among reservoir management may be avoided though the three reservoirs cannot get operated in optimum.

In order to optimize the output product of each reservoir therefore constraint applied in the operation should be agreed among the reservoir management.
RECOMMENDATION

The optimum output product from reservoir operation rule curve from the three reservoirs depends on the discharge inflow into the reservoirs. Therefore it is recommended to observe and study the discharge inflow prediction into the reservoirs and maintain the preservation of Citarum River Basin.

It is also recommended to develop integral and flexible rules curve reservoir operation software therefore the hydrology condition may be adjusted with the expected output product by the decision maker.

The existing institution is temporary and has not cover all management aspect related with the usage of Citarum River. Therefore it is recommended to establish a permanent institution in order to implement an integrated management for operation and development while paying intention to sustainable water resources Citarum river basin as a whole.

REFERENCES


