An Optimization to Multi-Reservoir Operation Based on Integrated Water Resources Management

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Introduction
Programme operation and policy for water distribution for several conditions are determining factors for both the water stored in and released from reservoirs. The type of reservoir operation involves various significant steps and regulations in decision making.

Based on the type of system, there are single and multi-reservoir systems. Multi-reservoir systems can be organized and connected both in series or as parallel units. In this paper, we focus on multi-reservoir systems that are in series, forming a cascade. Furthermore, reservoirs can be classified according to their function and one distinguishes single purpose and multi purpose reservoirs. Single purpose reservoirs have a clear function and water may be used for, respectively, irrigation, power supply and flood management. Multi purpose reservoirs though serve a combination of functions, including irrigation, hydropower, flood management, fisheries, recreation and tourism. The operation of multi purpose reservoirs also involves various interactions between these different functions that can lead to conflicting interests.

The operation of multi reservoir systems from different points of view and with various objectives as well as by different organizers easily results in conflicts. For example, in the Saguling and Cirata Reservoirs, both single purpose reservoirs, generation of hydropower is the main issue and the main objective is to maintain head in order to produce maximum power. However, the Djuanda Reservoir is a multi purpose reservoir and it needs release of water from the reservoir in its upper course to comply with the needs in the lower course of the reservoir. This might cause a decrease in power production in the two reservoirs on their upper course. Since the Saguling, Cirata, and Djuanda Reservoirs have been operated in a cascade type manner since 1988, technical-operational problems started to develop for each of these reservoirs. This problem was caused by the different perspectives of the reservoir organizers. The first problem that appeared was a technical problem related to determining the rule curve for the reservoir that required integration for the reservoirs in order to be beneficial for the system.

According to Syariman (2005), in order to reduce the conflict, in 1998, due to the running of JWRMP Project (Jatiluhur Water Resources Management Project), Puslitbang Sumber Daya Air together with Nedeco, had made an optimization ("spreadsheet") model called the Resop Model (Reservoir Operation). The philosophy of this model is to make use of the water balance in the reservoirs by applying proportional/equal sharing of water that is based on the effective volume for each reservoir.

The Resop Model though - used for the time being – has still not been able to fully prevent a conflict of interests between user functions. By applying a trade-off analysis, it is expected that a more balanced approach is possible that takes care of both the needs of power supply and simultaneously satisfies fixed water demands the lower course of Djuranda Reservoir.

There are many optimization techniques being used to operate a cascade-type reservoir system; they include Linear Programming, Non Linear Programming, Stochastic and Deterministic Dynamic Programming. Hadihardaja (2002) carried out a study to optimize cascade reservoir operation using Chance-Constrained Linear Programming and Hadihardaja (2004) investigated an optimal trade-off between water demand and electrical energy in Saguling-Cirata-Jatiluhur in Indonesia (Cascade Reservoir) using Non-Linar Programming. Azmeri et al., (2006) investigated an optimal operation of single reservoirs to increase the potential for energy supply. In order to obtain the appropriate solution for the operation of Citarum Cascade Reservoir, the so-called Genetic Algorithm (GA) is utilized for the purpose. In addition, Azmeri et al (2007) observed and carried out research on cascade reservoir operation using GA; furthermore Azmeri (2007) observed trade off analysis between energy and downstream water demand for cascade reservoir operation using GA. The GA optimization model is an appropriate tool for problems related to multireservoir systems; it can deal with complex functions whereas the other optimization techniques often use a simplified approach. Furthermore, GA may overcome the difficult problems to obtain optimum global solution (Gen et.al., 2000).

The (relatively simple) GA optimization model can be applied for the complex operation of a reservoir, whether in the number of the type of functions or the number of release from the reservoir.
The simplicity/ease of this GA application is expected to reduce the unwillingness of reservoir operators (decision maker) in utilizing this optimization model to carry out their duties.

Development the operating model of cascade reservoir by applying GA optimization for cascade reservoir Saguling-Cirata-Djuanda in Indonesia. Long section of development Citarum River is presented in Figure 1.

**Figure 1:** Long section of development Citarum River n (Source: Perum Otorita Jatiluhur:1990)

**Results and Discussion**

The method used in this research is quantitative experimental and is a method of searching for optimum values from the cascade reservoir operation system by studying several constraints in achieving the optimum goal. From the modeling, it is expected that the optimum recommended advantages of water reservoir operation can be deduced. The concept of this model is presented in the form of flowchart in Figure 2.
In this model, the purpose of modelling is to maximize the firm-energy, that is maximizing the total amount of produced energy in a year of operation. Firm-energy is the minimum amount of energy that has to be produced during a certain time. Total firm-energy produced and based on the various types of optimization show that the model with the parameters probability of crossover, \( P_c = 0.75 \), probability of mutation, \( P_m = 0.20 \), popsize, \( P_s = 30 \), and number of generation=300 provides the greatest firm-energy. This type produces 4663.90 GWh total energy and the total firm-energy produced is 3347.16 GWh.

**Influence of increasing Water Demand on Production of Energy**

Production of energy is influenced by various percentages of water demand. Table 1 and Table 2 below show results for reservoir operation by using the GA model and the influence of increasing water demand on production of energy in the year 2005 and 2006.

**Table 1. Production of Energy and Percentage of Demand Year 2005**

<table>
<thead>
<tr>
<th>Percentage of Demand</th>
<th>Demand (MCM)</th>
<th>Production of Energy (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry Year</td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>847.69</td>
<td>2931.76</td>
</tr>
<tr>
<td>40%</td>
<td>1695.38</td>
<td>2931.29</td>
</tr>
<tr>
<td>60%</td>
<td>2543.07</td>
<td>2931.24</td>
</tr>
<tr>
<td>80%</td>
<td>3390.76</td>
<td>2931.11</td>
</tr>
<tr>
<td>100%</td>
<td>4238.45</td>
<td>2930.84</td>
</tr>
<tr>
<td>120%</td>
<td>5086.14</td>
<td>2930.84</td>
</tr>
</tbody>
</table>

**Table 2. Production of Energy and Percentage of Demand Year 2006**

<table>
<thead>
<tr>
<th>Percentage of Demand</th>
<th>Demand (MCM)</th>
<th>Production of Energy (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Normal</td>
</tr>
<tr>
<td>20%</td>
<td>841.59</td>
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</tr>
<tr>
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<td>100%</td>
<td>4207.95</td>
<td>2930.93</td>
</tr>
<tr>
<td>120%</td>
<td>5049.54</td>
<td>2930.93</td>
</tr>
</tbody>
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**Trade Off Analysis**

The amount of power production and demand of water percentage obtained from the optimization procedure of reservoir operation is divided by its fulfillment target. Then the curve is generated and lines (curves) representing both of the objectives will be crossing in one point that shows the optimal condition for trade off based on the service level. Graphs of trade off analysis for operating the cascade reservoir in the dry years 2005 and 2006 are illustrated in Figure 3 and Figure 4, respectively.

![Figure 3. Trade Off Analysis Based on Equal Priority Between Demand and Energy (Dry Year 2005)](image-url)
Figure 4. Trade Off Analysis Based on Equal Priority Between Demand and Energy (Dry Year 2006)

Conclusions
1. From the GA parameter analysis, one can determine that a GA parameter selection that produces optimum solution is that one with a probability crossover 0.75, mutation probability 0.20, number of populations 30, and the optimum global solution is obtained by the number of generations of 700.

2. Trade off analysis based on service level for the two objectives above is calculated in the dry year (season) in 2005 and 2006. It produced different service percentages for each year. In detail: in the year 2005 of 62% with priority level: 2897.24 GWh service to electrical and 2627.84 MCM service to downstream demand. In the year 2006 of 63% with priority level these numbers are: 2911.51 GWh service to electrical and 2651.01 MCM service to downstream demand.

3. By studying the results of the trade off analysis for the operation of reservoirs, based on service levels in 2005 and 2006, one may derive an illustration of reservoir rule curve based on service level from time to time. Since the optimum service level can established for the two objectives with the same priority, trade off analysis can be a proper tool for mediation to avoid conflicts of interest for multi-purpose reservoir systems.

4. The target of electric power production and fixed water supply are important elements in trade off analysis that is based on service level. The target for Citarum Cascade is determined in the agreement of Citarum Cascade Reservoir Operation. This rule curve is thoroughly monitored every month according to inflow realization of Citarum River. Every change that occurs for the rule curve is agreed upon and further checked for oncoming obstacles in every reservoir so that the optimum exploitation of Citarum River can be obtained.

REFERENCES