Joint operation of parallel reservoir with interconnected tunnel

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Abstract. Reservoir operation is strongly influenced by water balance conditions in the catchment area. The amount of inflow, reservoir capacity, and water requirement are major factors in arranging the reservoir operation rules. The purpose of this research is to obtain the extent of the parallel reservoir operation reliability that performed simultaneously by utilizing water transfer from wet to dry watershed. Simulation method used to operate the parallel reservoir with interconnecting tunnel between. From simulated results on three seasons, there are obtained that the water potential to be transferred to the dry watershed. By utilizing this water potential, further simulation for 25 years will come to see the reliability of the joint operating rule in this location.

1. Introduction
Management of Water Resources requires a comprehensive study indeed. The involvement of all sectors in the Watershed area is needed. Problems that often occur in management are flood prevention, water supply for irrigation, raw water availability, and energy. In its implementation, social problems also often arise related to the water allocation process. The solution to overcoming problems in management is by managing the water resources such as constructed dams. The practical application scenarios of reservoir operation are extremely complex and involve multiple time scales and multflow regimes, often accompanied by occasional emergencies [1].

Multireservoir operating policies are usually defined by rules that specify either individual reservoir desired (target) storage volumes or desired (target) releases based on the time of year and the existing total storage volume in all reservoirs [2]. Reservoir Operation is largely determined by the function of the reservoir. Besides that, the management rule becomes a reference in decision making in the event of extreme conditions such as floods or droughts. Join operating rules are also proposed based on a water diversion rule, a hedging rule based on an aggregated reservoir, and a storage allocation rule [3].

To obtain the appropriate operating rule, a new set of release rules for each reservoir is made in the form of an analytical consideration of the optimal conditions of water balance and reservoir value in each reservoir [4]. Water Transfers between Watersheds are usually considered as one of the most effective facilities for balancing non-uniform temporal and spatial distributions between water resources and water requirements. This was done with the intention of diverting water from surplus areas to less
areas. Several methods of operating reservoirs with additional water from other watersheds have long been developed. The development of a multilevel model of the pattern of multi-reservoir operations with the aim of minimizing runoff and maximizing the pattern of water availability with the transfer of water between watersheds to minimize the risk of water shortages [3]. A set of water transfers optimization between watersheds modeled through three stages to maximize profits from agricultural products on land and minimize water transfer costs [2].

The purpose of this paper is to show the reliability of joint operation rules from parallel reservoir with interconnected tunnel. Potential discharge that could be transferred becoming one basis of the utilization of two reservoirs through the interconnected tunnel. The potential discharge volume simulated from three seasons wet, normal and dry. Furthermore, the level of reservoir reliability shown by simulation for the next 25 years.

2. Case study
This study took the case of Rukoh and Tiro Dam that located in Pidie Regency Aceh province Indonesia. Tiro Dam has a Catchment Area of 174.24 km² with the main river has 46 km length. While the Rukoh Dam has a Catchment Area of 19.63 km² with the main river length was 6.87 km. The purpose of each dam was to provide raw water requirement for irrigation and cities downstream. The location of these two reservoirs is shown in figure 1.

The Baro Irrigation area of 11,950 ha where the irrigation demand at Intake 14.50 m³/s taken from the Baro River. While the water demand of Tiro Irrigation area (6,330 ha) sourced from Tiro River. Dependable discharge of Baro River is 2.52 m³/s, Tiro River is 1.89 m³/s and Rukoh River 0.77 m³/s. The condition of dependable discharge the condition caused only 6417 hectares of Baro Irrigation land covered. Likewise, the area of Tiro irrigation can only be served 2463 hectares. The condition is decreasing in the dry season [5].

By considering the rules to minimize potential conflicts of interest between the raw water and irrigation water, it would require suppletion from Krueng Tiro amounted to 52.30% [6]. With the potential of Rukoh Reservoir and interconnected with the potential discharge from Tiro River obtained a reservoir system that has a large potential to be developed. Schematic of the system shown in figure 2. Hopefully as a supply of irrigation water Kr. Baro covering 11,950 ha and irrigation Kr. Tiro Area of 6,330 ha. are expected to supply the irrigation water requirement of the Baro Irrigation Area of 11,950 ha and Tiro Irrigation Area of 6,330 ha. In addition, to fulfill the needs of the raw water, river maintenance flows, and power plants.

![Figure 1. Maps of Rukoh and Tiro catchment area.](image-url)
3. Simulation model
Simulation in water resources is a modeling technique that used to simulate and move the behavior of a system into a model with the help of a computer, to spread all the characteristics of the system widely with mathematical or algebraic description [7]. The simulation model could predict and show what will happen to a system at a certain moment when the systems are given certain inputs. Thus, management rule system could decide and define by studying the reaction of various system management scenarios without needed to have the system itself in real.

Application of the simulation model in reservoir system is a problem-solving technique for complex systems, in addition to analyze the model, the simulation can also be used for decision making process. The modelling of the reservoir operation for conservation purposes is based on the water balance for the time interval [8].

\[ V_t = V_{t-1} + \text{Total Inflow} - \text{Total Outflow} \]  
\[ STr_t = STr_{t-1} + ITr_t - LTr_t - DivTr_t(x) - \sum DTr_t(y) - SpillTr_t(x,y) \]  
\[ SRk_t = SRk_{t-1} + IRk_t - LRk_t + DivTr_t(x) - \sum DRk_t(y) - SpillRk_t(x,y) \]

Where \( V_{t,i} \) is Reservoir volume in period \( t \) (m\(^3\)), \( V_t \) is Reservoir volume in period \( t \) (m\(^3\)), \( IR \) is irrigation water requirement, \( S_t \) is initial storage in period \( t \) (m\(^3\)) and \( S_{t,i} \) is storage in the end of period \( t \) (m\(^3\)), \( I_t \) is Inflow period \( t \) (m\(^3\)), \( L_t \) is water loses in period \( t \) (m\(^3\)), \( Div_t \) is volume of water transfer in period \( t \) (m\(^3\)), \( D_t \) is water demand in period \( t \) (m\(^3\)), \( Spill_t \) is Volume of Spillway in period \( t \) (m\(^3\)), \( Tr_t \) is Tiro and \( Rk_t \) is Rukoh.

3.1. Boundaries condition
The main boundary of reservoir simulation is the reservoir capacity. At each stage of operation, the reservoir capacity is limited by the maximum volume of operation and minimum operating volume. The water Transfer from Tiro Reservoir is an additional inflow to Rukoh Reservoir. While the constraints on water transfer from the Tiro reservoir can only be done after fulfilling the water requirements in the downstream [9].
3.1.1. Storage capacity. The reservoir volume corresponds to the technical data of the Tiro Reservoir and the Rukoh Reservoir. The lower limit is the dead storage while the upper limit is the cap on the normal water level.

\[ S_{i,min} \leq S_{i,t} \leq S_{i,max}; S_t = T \]  

(4)

Where \( S_{i,min} \) Dead Storage in Reservoir i and \( S_{i,max} \) Maximum Storage in Reservoir i.

In its application, the capacity of these two reservoirs is considered to be a system, so that the principle used as associated vessel. The minimum and optimum limit of the reservoir is the number of two reservoirs capacity. While the normal and maximum water level is equal. The volume of water that exceeds the maximum capacity will be released.

3.1.2. Water release. The amount of water released from the reservoir must meet the water demand in the downstream. The Volume of water requirement includes irrigation, raw water and river maintenance.

\[ Q_R \geq D_t \]  

(5)

Where \( Q_R \) is Release Debit from storage, \( D_t \) is Water demand

The volume of water requirement for irrigation is the total needs of both irrigation areas, Tiro irrigation area and Baro irrigation area. Land area of both irrigation areas that will be aggregated as a whole amount of water requirement.

3.1.3. Water Transfer in Joint Operation. Water transfer in joint operation connected with 120 meters long and 4.5 meters width tunnel. The maximum discharge value that can be transferred through a tunnel depends on the water elevation of the Tiro Reservoir.

\[ 0 \leq Div_{tr}(x) \leq Div_{max} \]  

(6)

Where \( Div_{tr} \) is Water Transfer and \( Div_{max} \) is Maximum Water Transfer Discharge.

3.2. Simulation operation

The simulation is done using Standard Operating Rule method [10]. In this simulation, the water requirement was divided into the needs of raw water and irrigation water demand. It is intended to be the need for raw water being the main priority to be fulfilled and the irrigation water demand to be the second priority of water release. Simulated conducted monthly on three conditions of the year wet (20%), normal year (50%), and dry year (80%). Figure 3 shows the simulated scheme performed.

4. Results and discussion

4.1. Potential of water transfer

To see the potential for the discharge of Kr Tiro that can be transferred to the Rukoh Reservoir, simulated the Tiro reservoir. The simulation is done in three seasons, dry year, normal year, and wet year. The simulation was conducted on a monthly basis by looking at the amount of discharge from the Tiro reservoir in all three seasons. The potential of transferred water based on simulation of three-season shown in figure 4.a to 4.c.
Figure 3. Simulation procedure.

Figure 4.a. Simulation of Tiro reservoir in dry season.

Figure 4.b. Simulation of Tiro reservoir in normal season.
The amount of potential discharge of Kr. Tiro can be transferred as a Rukoh Reservoir inflow can be seen from the simulation results of the Tiro Reservoir. Utilization of two potential of the dam of Rukoh Reservoir and Tiro Reservoir and inflow of both rivers is carried out as a joint operation rule. Then from the simulation, both reservoirs can be seen the reliability of fulfillment of the needs of irrigation water and raw water occurring. From the results of the simulation done on the reservoir of Tiro for all three conditions of the year, it appears that the water potential can be transferred very large. The greatest volume of water that can be utilized is in the wet season between July and November. In the dry year, the amount of water volume from the Tiro reservoir reaches 147.31 MCM. In the normal year, the water volume would reach 176.61 MCM. As for the wet year, the amount of water volume is 221.17 MCM. With a large amount of flow can be used as a limitation in subsequent simulations. The next simulation was done utilizing both the capacity of the Rukoh Reservoir and the Tiro Reservoir as a joint operation rule.

4.2. Joint operation reservoir simulation
In the simulating process of parallel reservoir with the interconnecting channels between the reservoir, the two reservoirs become a unified operating rule. Inflow reservoirs are sourced from both rivers. Reservoir capacity is the total of the two reservoirs. The capacity of Tiro Reservoir is 37.7 MCM while for Rukoh Reservoir of 124.4 MCM. The area of irrigation that must be served for Tiro irrigation area amounted to 6,330 ha and Baro irrigation area of 5,803 ha which cannot be served from the Bendung Keumala on the Baro River. The results of simulation in three season condition shown in figure 5.a to 5.c.

Figure 5.a shown that the joint operating rules of dry season. In May, July and December Outflow greater than inflow. This led to the water level being below the elevation of 150 meters in August and October. However, due to the high inflow in the wet months, the water surface at the end of the year returns above 150 meters. While in the figure 5.b and 5.c which is the result of simulated joint operation in the normal and wet season, there are no significant constrains.

From the simulation chart above, shows that by merging the operations of the two reservoirs through interconnection tunnel could reached high levels of service fulfillment. The lowest water reservoir in May in dry year is 143.42 MCM at 120.10 meters. While in other conditions the position of the water surface is almost always full.
Figure 5.a. Simulation of parallel reservoir in dry season.

Figure 5.b. Simulation of parallel reservoir in normal season.

Figure 5.c. Simulation of parallel reservoir in wet season.
4.3. Reservoir reliability
Reliability was measured by the probability of a system being in a satisfactory state [11]. Simulation was done in series for the next 25 years. Where it does not result in any failure of the 600-simulation period performed. Thus, simulated Rukoh-Tiro joint operating of parallel reservoirs with interconnecting channels can provide 100% reliability for the fulfillment of raw water and irrigation.

5. Conclusion
Based on the analysis above, it can be concluded that with operating the two reservoirs simultaneously with diversion tunnel between could increase the water requirement fulfillment services. Two reservoir capacity will be operating as one system. According to that, tunnel capacity being an important constraint on the reservoir operating model besides the reservoir capacity. With managing the diversion discharge, multi reservoir operation model could give optimize result. In addition, it can also be seen that the operation of two parallel reservoirs still has the potential to serve more extensive irrigation. Further optimization can be done to get a wide range of services that can be covered.

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