IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Multi-reservoirs with inter-reservoir water transfer operation rules

To cite this article: Khairul Iqbal *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **437** 012021

View the article online for updates and enhancements.

Multi-reservoirs with inter-reservoir water transfer operation rules

Khairul Iqbal[1], Lily M. Limantara[2], Widandi Soetopo[3], Ussy Andawayanti[4]

[1] Doctoral Program, Civil Department, Faculty of Engineering, University of Brawijaya, Malang, Indonesia
[2, 3, 4] Water Resources Engineering Department, Faculty of Engineering, Universitas Brawijaya, Malang, 65145, Indonesia

E-mail: khairuliqbal@gmail.com

Abstract. Reservoir operation is strongly influenced by water balance conditions in the catchment area. The amount of inflow, reservoir capacity, and water requirements are major factors in creating reservoir operation rules. The purpose of this research is to obtain the extent of the reliability of parallel reservoir operation with simultaneous execution by utilizing water transfer from wet to dry watersheds. Reservoir operation rules were derived by utilizing the storage capacity of the two reservoirs with two spillways and two separate water demands in the downstream parts. The various parameters applied for the operation rules are expected to optimize the operation of the reservoirs.

Keywords: Reservoir Operation, Water Transfer, Storage Capacity, Optimization.

1. Introduction

The management of water resources requires comprehensive studies. 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 in relation to the water allocation process. The solution to overcoming problems in management is by managing water resources such as constructed dams. The practical application scenarios of reservoir operation are extremely complex and involve multiple time scales and multi-flow regimes, often accompanied by occasional emergencies [1].

Multi-reservoir operation policies are usually defined by rules that specify either individual desired (target) reservoir storage volumes or desired (target) releases based on the time of year and the existing total storage volumes in all reservoirs [2]. Reservoir operation is largely determined by the function of the reservoirs. In addition, the management rules become a reference in decision-making in the event of extreme conditions such as floods or droughts. Joint 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 appropriate operating rules, 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 transfer between watersheds is usually considered as one of the most effective methods 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 areas of deficit (Gu, 2016). Several methods of operating reservoirs with additional water from other watersheds have long been developed. Guo (2012) developed a multilevel model of the pattern of multi-reservoir operations with the aim of minimizing runoff and maximizing the pattern of water availability. Gu (2017) developed a multi-reservoir operation model with the transfer of water between watersheds to minimize the risk of water shortages [5]. Rani (2015) modelled a set of water transfers optimization between watersheds through three stages to maximize profits from agricultural products on land and minimize water transfer costs [6].

The purpose of this study is to describe the main and important parameters from the joint operation of multi-reservoirs. The presented parameters are as objective factors and constraints for the optimization model.

2. Reservoir Operation

2.1. Reservoir Operation Rules

Reservoir operation rules are references or guidelines for water management for reservoir operations, which are mutually agreed upon by water users and managers through the Water Management Committee (PTPA) [7].

2.1.1. Purposes and Objectives

The operating rules of a reservoir are intended as guidelines for regulating water to meet various water needs and to control floods. The aim is to utilize water optimally by allocating it proportionally so that there are no conflicts of interests.

2.1.2. Types of Reservoir Operation Rules

Within one year of operation, the pattern of operation is usually executed according to two models:

1. Rainy season reservoir operation rules, which apply as reservoirs are filled (December to May)
2. Dry season reservoir operation rules, which apply as reservoirs are emptied (June to November)

2.1.3. Influential Factor

Efficient and optimal operation of reservoirs is a complex problem because this involves several factors, which include:

1. Reservoir operation rule policies
2. The inflow discharge that will enter the reservoir, which depends on the accuracy of the planned discharge that will enter the reservoir
3. Demand of water for irrigation, raw water, hydropower, environmental preservation, and flood control
4. Accuracy in estimating the amount of flood discharge that will occur
5. Reliability of the monitoring equipment for reservoir level, flow rate, and rainfall
6. Coordination between related agencies
7. Operator capabilities
8. Coordination of short-term, medium-term, long-term, and real-time operations

2.2. Water Transfer

Gurung (2015) explains that water transfers between watersheds have been performed as early as the Roman civilization [8] and now there are dozens of watershed water transfer infrastructures throughout the world. Most of these were created according to the economic development perspectives of each country [9]. The main purpose of water transfer between watersheds is for reduction of water scarcity (for household and agricultural consumption), hydropower generation, navigation, and improvement of water quality. Apart from these existing water transfer projects, several water transfer projects between watersheds are under construction and there are dozens of planned projects around the world. China plans to transfer 45 billion cubic meters (BCM) of water from the Yangtze River to the plains of North China.

Water transfer between watersheds is a structural technical procedure. The real problem is the division of water resources between the receiving watershed and the original watershed. The physical relationship between separate water systems (basins) can be an element in facilitating shared water management for the benefit of both watersheds. Co-management must promote sustainability, respond to common ethical values, produce mutual benefits, and be managed by appropriate institutions [10].

3. Materials and Methods

3.1. Description of the Study Location

This study involves the case of the Rukoh and Tiro Dams, located in Pidie Regency of the Province of Aceh, Indonesia. Tiro Dam has a catchment area of 174.24 km^2, and the main river (Krueng) has a length of 46 km. Meanwhile, Rukoh Dam has a catchment area of 19.63 km^2, and the main river has a length of 6.87 km. The purpose of each dam is to provide raw water for irrigation and downstream cities. The location of these two reservoirs are shown in Figure 1.

The Baro irrigation area has an area of 11,950 ha, and the irrigation demand with an intake of 14.50 m^3/s is taken from the Baro River. The water demand of the Tiro Irrigation area (6,330 ha) is taken from the Tiro River. The dependable discharge of Baro River is 2.52 m^3/s, Tiro River is 1.89 m^3/s, and Rukoh River is 0.77 m^3/s. The dependable discharge condition results in an irrigation coverage of only 6417 hectares in Baro. Likewise, the irrigation area coverage of Tiro is only 2463 hectares. The condition decreases in the dry season [11].

By considering the rules to minimize potential conflicts of interest between raw water and irrigation water, suppletion is required from Tiro River that amounts to 52.30% [12]. Rukoh Reservoir being interconnected with the potential discharge from Tiro River results in a reservoir system that has a large development potential. The schematic of the system is shown in Figure 2. It is expected that the irrigation water supply of Baro River will cover the required 11,950 ha and that of Tiro River will cover the required 6,330 ha. In addition, the system will fulfil the needs of raw water, river maintenance flows, and power plants.

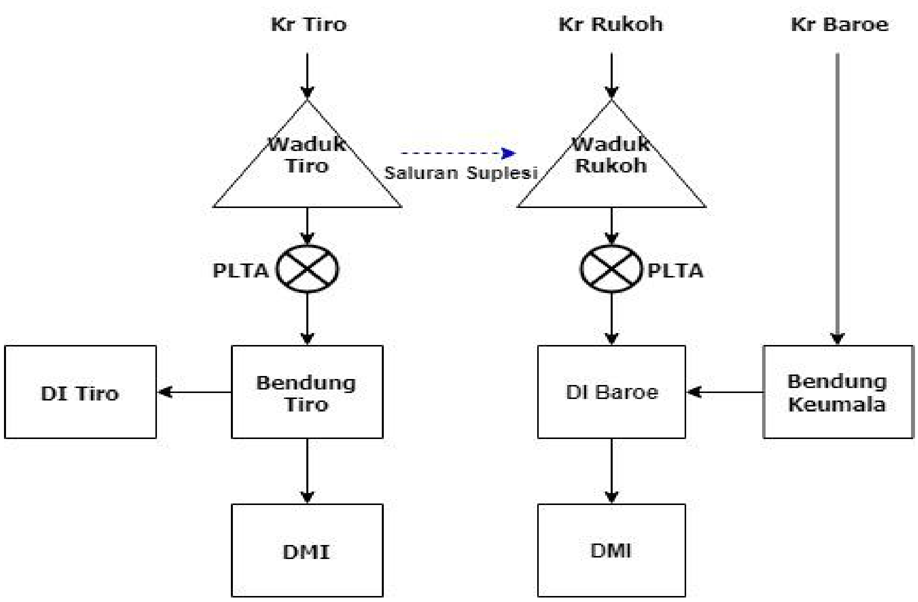

Figure 1. Scheme of Rukoh and Tiro Dams

3.2. Modelling Completion Method

3.2.1. Water Availability

Analysis of water availability was carried out using the F.J. Mock method. This method involves the process of generating discharge data from rainfall data, and then calibrating with AWLR data from Tiro River.

3.2.2. Water Requirement

a) Maintenance flow
In accordance with the 2016 Circular of the Directorate General of Water Resources, river protection is also carried out with river maintenance (QM); thus, the maintenance of river ecosystems is taken from the availability of 95% mainstay discharge.

b) Irrigation water requirement
The equation is used to determine the maximum irrigation water requirements (QDmax) and plant water requirements (NFR), according to KP-02 (2013: 123).

c) Urban water requirement
Urban water requirements are calculated based on the number of uses for the population, industry and livestock. In this case, water use for fisheries or ponds is not taken into account.

3.3. Model Optimization

In carrying out optimization and simulation, several things that must be considered. A constraint factor is the amount of discharge value needed, as the output from each reservoir. The volume of available water is taken from the volume of the reservoirs, which is the mainstay discharge value during the operating period. The area of land planted to the maximum is the available area of raw land [13].

The objective function, as the goal to be achieved from the optimization, involves the values to be maximized or minimized [14]. In this study, the objective function to be achieved is to maximize profits by allocating a certain volume of water for various planting seasons and ensuring the availability of clean water downstream. The determining of stages for the optimization of operations of the Rukoh Reservoir and Tiro Reservoir is formulated below.

3.3.1. Objective Function

The goal of optimization is to maximize revenue from meeting the needs of irrigation water and raw water by maximizing the capacity of both reservoirs.

$$\text{Max Z} = \max \sum_t^T C_1 IR_{rk,tr} + C_2 E_{rk,tr} + C_3 WD_{rk,tr} \quad (1)$$

The modelling of reservoir operations for conservation purposes is based on the water balance for the time interval [14].

$$V_t = V_{t-1} + Total\ Inflow - Total\ Outflow \quad (2)$$

$$STr_t = STr_{t-1} + ITr_t - LTr_t - DivTr_t(x) - \sum DTr_t(y) - SpillTr_t\ (x, y) \quad (3)$$

$$SRk_t = SRk_{t-1} + IRk_t - LRk_t + DivTr_t(x) - \sum DRk_t(y) - SpillRk_t\ (\text{x,y}) \quad (4)$$

Where:
IR : Irrigation
E : Energy
WD : Water demand
STr_t : Reservoir at the start of period t (m^3)
STr_{t-1} : Reservoir at the end of period t (m^3)
ITr_t : Inflow during period t (m^3)

LTr_t : Water losses during period (m^3)
$DivTr_t$: Volume of water transferred from Tiro Dam during period t (m^3)
DTr_t : Water demand during period t (m^3)
$SpillTr_t$: Spillway of Tiro Dam during period t (m^3)
Tr : Tiro Dam
Rk : Rukoh Dam
C_i : Coefficient of unit values

3.3.2. Formulation of the Limitation Functions

The constraint variable applies to storage reservoirs. At each stage of operation, the reservoir volume is limited by the maximum operating volume and minimum operating volume.
Water transfer from Tiro Reservoir is an additional inflow to the Rukoh Reservoir. The constraints on the transfer of water from the Tiro Reservoir can only be met after fulfilling downstream water needs.

Reservoir 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.

$$S_{i,min} \leq S_{i,t} \leq S_{i,max}; \; S_t = T \tag{5}$$

$S_{i,min}$: Minimum capacity of reservoir i
$S_{i,max}$: Maximum capacity of reservoir i
For the two reservoirs to be optimized, the following are the boundaries of the reservoir:

In its application, the capacity of the two reservoirs is considered to be a system, and thus the utilized principle is as an associated vessel. The minimum and optimal limit of the reservoir is the capacity of the two reservoirs. The normal and maximum water levels are equal. The volume of water that exceeds the maximum capacity will be released.

Irrigation Area:

The limit of land area is the Baro River Irrigation Area (Rukoh) and Tiro Irrigation Area. The maximum area value is the maximum land area of each irrigation area.

$$A_{planting} \leq A_{irrigation} \tag{6}$$

Where:
A : Area
A_{Tr} : Tiro Irrigation Area
A_{Rk} : Rukoh Irrigation Area
1, 2, 3 : Planting seasons

This constraint can also be regarded as the discharge requirement to irrigate each land area.

Water Release:

The amount of water released from the reservoir must meet the downstream water demand. The volume of water requirement includes irrigation, raw water, and river maintenance.

$$Q_R \geq Q_D \tag{7}$$

Where:
Q_R : Release discharge from storage
Q_D : Water demand

The volume of water demand for irrigation is the total needs of both the Tiro irrigation area and the Baro irrigation area. The land area of both irrigation areas are aggregated as the entire amount of water requirement. The volume of water requirement includes irrigation, raw water, and river maintenance. The following is the equation for the volume of the water requirement for each planting season:

$$Q_{Di} = DR_{Rki} + DR_{Tri} + Q_{MF} + Q_{DMI} \leq Q_{MTi} \quad (8)$$

Where:
Q_{Di} : Water requirement for season i
DR_{Rk} : Rukoh irrigation water requirement
DR_{Tr} : Tiro irrigation water requirement
Q_{MF} : Discharge for maintenance flow
Q_{DMI} : Discharge for raw water requirement
i : Planting seasons

Water Transfer:
Water transfer for joint operation involves a tunnel that is 120 meters long and 4.5 meters wide. The maximum discharge value that can be transferred through the tunnel depends on the water elevation of the Tiro Reservoir.

$$0 \leq Div_{tr}(x) \leq Div_{max} \quad (9)$$

Where:
Div_{Tr} : Water transfer
Div_{max} : Maximum water transfer

4. Conclusion
Based on the analysis above, it can be concluded that the simultaneous operation of the two reservoirs with a diversion tunnel between them can increase the passive intake of the system. The two reservoirs will operate with their capacities as one system. Accordingly, tunnel capacity becomes an important constraint on the reservoir operating model in addition to the reservoir capacity. The management of the diverted discharge leads to optimize results for the multi-reservoir operation model.

References
[1] Zhang *et al*. 2018; *Modeling and simulating of reservoir operation using the artificial neural network, support vector regression, deep learning algorithm; Journal of Hydrology*; **565**; 720–736
[2] Oliviera P, Loucks D P 1997; *Operating Rules for Multireservoir Systems*; *Water Resources Research*, **Vol. 33**, No. 4; 839-852
[3] Fang *et al*. 2014 *Simulation-optimization model of reservoir operation based on target storage curves; Water Science and Engineering* 7(4); 433-445
[4] Zeng *et al*. 2015 *Derivation of operation rules for reservoirs in Parallel with joint water demand*; Water Resour. Res., 51; 9539–9563
[5] Gu *et al*. 2017 Simulation and Optimization of Multi-Reservoir Operation in Inter-Basin Water Transfer System; Water Resources Management;
[6] Rani *et al*. 2015 *A Set of Linked Optimization Models for an Inter-Basin Water Transfer*; Hydrological Sciences Journal

[7] Anonymous 2013 *Irrigation Design Criteria*; The Ministry of Public Works

[8] Gurung, P 2015 *Inter-basin Water Transfer: Is this a Solution for Water Scarcity?*; http://www.researchgate.net/publication; doi.10.13140/RG.2.1.3592.5607

[9] Misra A K, Saxena A, Yaduvanshi M 2006 *Proposed river-linking project of India: a boon or bane to nature*. *Environ Geol* 51:1361–1376.

[10] Bogardi. J *et al*. 1999 International Workshop on Interbasin Water Transfer UNESCO Proceeding, Paris; 9 – 16

[11] Anonymous 2015 *Rukoh and Tiro Reservoir Technical Document*; Association of Sumatera Water Region I

[12] Azmeri *et al*. 2017 *Completion of Potential Conflicts of Interest through Optimization of Rukoh Reservoir Operation in Pidie District, Aceh Province, Indonesia*; AIP Conference Proceedings

[13] Sun *et al*. 2018 *Multi-Objective Optimization for Reservoir Operation Considering Water Diversion and Power Generation Objectives*; Water 10, 1540

[14] Montarcih L 2011 Manajemen Sumber Daya Air [*Water Resource Management*], Lubuk Agung, Bandung