The analysis of water balanced in Bendo Reservoir using Dynamic System

N F Margini1*, N Anwar2, and W Wardoyo2
1 Doctoral Student in Department of Civil Engineering, Institute Technology of Sepuluh Nopember, Indonesia
2 Lecturer in Department of Civil Engineering, Institute Technology of Sepuluh Nopember, Indonesia.

*Corresponding author's e-mail: nastasia@ce.its.ac.id

Abstract. This research was conducted to analyze balancing the storage capacity of the Bendo Reservoir with the quantity of water needed. Bendo Reservoir located in Nginden Sawo Village, Ponorogo Regency is one of the multipurpose reservoirs in Indonesia designed for irrigation, water supply, and simultaneously hydroelectric power. The water available is observed to be decreasing along with climate change, thereby, requiring an appropriate reservoir operational system. Several methods have been designed to achieve this purpose through the use of vast and complex variables but this study used a Dynamic Systems approach for analysis. However, involved the use of two scenarios in the simulation model to obtain the most optimum results. A period of 5 years was simulated and the result showed water shortage started in the 54th month for scenario 2, 49th month for scenario 1, and 46th month for the base model. Therefore, means scenario 2 has the most optimum conditions and recommended as the appropriate solution for Bendo Reservoir water distribution.

1. Introduction
Nowadays water resources are becoming very limited due to rapid changes in population, and urbanization. [1]. Then, optimization of water resources has been developed through mathematical models to maximize the benefits of clean water. Because land and clean water are key factors for sustainable agricultural development in a country. Significant hydrological change is indicated by the magnitude and duration of rainfall that has changed from the previous year. As we are concerned, the amount of rain will significantly affect the inflow discharge and the amount of the existing storage volume [2]. Changes in the amount of water availability will result in changes in reservoir management and operational systems.

The reservoir management system is usually planned to have the ability of releasing water according to demand in the downstream. This, therefore, means its purpose is to balance the quantity of water available with the demanded quantity but this is mostly affected by an increase in population and rapid economic growth, thereby, causing an imbalance. Meanwhile, inappropriate planning of water management systems threatens agricultural sustainability due to the need for water by several users.

A number of areas in Ponorogo Regency, East Java Province have various water management problems, including flooding and drought [3]. This reservoir will later contain and accommodate Nginden River water precisely in Bendo Hamlet, Nginden Sawo Village, Ponorogo Regency, as shown in figure 1. The Bendo Reservoir project began in 2013 and is planned for completion in 2020. This
reservoir is a multipurpose reservoir operated as a supplier of water supply, hydropower, and irrigation. Because it is multipurpose, the availability of water in reservoirs has an important role. Whereas the current hydrological change dramatically affects the amount of water available in the reservoir.

A reservoir is ideally expected to function optimally and due to the fact that Bendo reservoir is designed to meet irrigation, domestic, and non-domestic raw water needs, there is the need for a system to regulate the volume of water to be expended to ensure optimal utilization of water discharge in the reservoir. This involves having a mechanism to analyze each intake and available discharge and for the purpose of this study, a dynamic system approach was used to solve the water distribution problem in the Bendo Reservoir.

Figure 1. Location of Bendo Reservoir.

2. Literature Review

Most of the study on reservoir optimization focus on creating operational strategies that can help overcome the difficulties of water variability. The difficulties of various stakeholders in dealing with water variability were also raised by [4] Haimes and Hall in 1977 and have extensively studied the optimization of reservoir operations since 1977.

The development of research on reservoir operations from the sciencedirect.com for keyword: operational optimization reservoir is increasing rapidly. In 2010 there were around 350 articles and then sharply increased to 1200 articles in 2019. From the many studies that have been developed various methods to optimize the amount of water availability and reservoir operation as in writings of [5] Yeh (1985). In this article, Yeh review about Linear Programming (LP) and Dynamic Programming (DP). Then, [6] writing about Nonlinear Programming and Simulation. In 2014, [7] which uses a dynamic system in the analysis process. The difference with this research is the influence of climate hydrological change and the function of the multipurpose reservoir.

The water stored in reservoirs serves multiple objectives such as irrigation which is usually influenced by climate change as well as the increase in population and food needs due to population growth. This research, therefore, used a dynamic system approach to offer a new method to optimize available water.

S. Ahmad & Simonovic in 2000 study about dynamic systems have systems and tools to represent complex systems in analyzing dynamic behaviour [7]. The most important feature of a dynamic system that facilitates the experiment of relationships in a system that is changed to produce different decisions. The dynamic system used in this study has four criteria, namely blocks, stock, flow, connectors, and converters. Stock (level) is used to represent something that has accumulated, for example, is the storage capacity in the reservoir. Then, flows (exchange rates) represent activities that fill and reduce stock.
Next, connectors (arrows) are used to establish relationships between variables in the Dynamic System that show causal/causal relationships [7]. Variable definitions, mathematical formulations, and units are provided in table 1.

The modeling, planning, and management of water resources systems were carried out years ago. The dynamic system approach has also resulted in a system of management, planning, policy, and sustainability of water resources [7], [8], and includes in the management of environmental water resources [9]. Some topics in water resources systems for flood management, hydrological systems and decision support systems for water operations [9]–[12]. [13] implemented the rice management in Central Taiwan using VENSIM Model. Whereas [10] present a new approach to optimizing irrigation management by developing a dynamics system model using VENSIM software. The VENSIM system is considered suitable for modeling and simulation involving significant components [14].

3. Methodology
This research was conducted through several stages including:

a. Define the purpose of the model
System dynamics models are developed to understand the relationships between components in a system in order to complex problems. They require a fundamental problem to be solved after which a modeler is used to determine the purpose of the model and gather relevant data both in the form of statistical data and knowledge from experts in the field.

This study aimed to balance the quantity of water available with those required in a Bendo Reservoir operation. This involved dividing the inflow discharge data into outflows in the form of irrigation and clean water requirements.

b. Define the identify variables
The dynamic system is a simulation which focuses on the interaction between variable and feedback loop within the structure [15]. The constituent variables in this system have been identified as having a causal relationship as arranged in a table to facilitate the identification process. In the table, write the name of a variable, a definition in the field of water resources management using International Unit System, and an explanation of its position in the system, as shown in table 1.
Table 1. Dynamic system model variable.

| No. | Variable                          | Definition                                                                 | Unit           | Information |
|-----|-----------------------------------|---------------------------------------------------------------------------|----------------|-------------|
| 1   | Storage Capacity                  | The amount of water that has the power and potential to be used in human life | m³             | Level       |
| 2   | Discharge Inflow                  | River minimum input discharge which can be utilized for people needs       | m³ / detik     | Auxiliarly  |
| 3   | Runoff Coefficient (C)            | Surface flow rate to the ability of the soil to absorb water              |                | Constanta   |
| 4   | Rainfall Intensity (I)            | The amount of rain expressed in each unit of time                         | mm / jam       | Auxiliarly  |
| 5   | Average daily rainfall max (R24)  | Maximum rainfall averages 24 hours                                        | mm             | Constanta   |
| 6   | Catchment Area (A)                | Wide catchment area for certain rivers                                    | Km²            | Constanta   |
| 7   | Irrigation                        | the amount of water needed to irrigation needs                             | m³ / s         | Auxiliarly  |
| 8   | Irrigation area                   | Unity of land that gets water from an irrigation network                  | Ha             | Constanta   |
| 9   | Discharge Intake (Dr)             | The amount of water volume tapped at the intake to irrigation needs       | m³ / s / Ha    | Auxiliarly  |
| 10  | Irrigation Efficiency             | Comparison of the amount of water supplied minus water loss with the amount given |                | Constanta   |
| 11  | NFR                               | The amount of water level tapped to meet the needs of irrigation in the fields | mm / day       | Auxiliarly  |
| 12  | WLR                               | The amount of water level for preparing paddy fields                       | mm / day       | Constanta   |
| 13  | (P)                               | The amount of volume of water that can seep into the ground               | mm / day       | Constanta   |
| 14  | Paddy consumptive water needs     | Amount of water volume needed by paddy plants                             | mm / day       | Auxiliarly  |
| 15  | Eto                               | Value of environmental needs, a collection of vegetation to conduct evapotranspiration | mm / day       | Constanta   |
| 16  | Paddy crop coefficient            | The coefficient of rice plants depends on the type of variety and its growth stage |                | Constanta   |
| 17  | Water Supply                      | The amount of water needed for domestic and urban households               | m³             | Auxiliarly  |
| 18  | Domestic total needs              | The amount of total consumptive water for households in an area            | l / day        | Auxiliarly  |
| 19  | per capita domestic water demand  | The large amount of water consumption for each individual                 | l / people / day | Constanta |
| 20  | Total population                  | The number of inhabitants who occupy an area and its growth                | people         | Auxiliarly  |
| 21  | Percentage of Population Increase | The rate of population growth in an area                                  | %              | Auxiliarly  |
| 22  | Non-domestic total needs          | The amount of total consumptive water for public buildings in an area     | l / day        | Constanta   |
| 23  | Number of public buildings        | the number of public buildings in an area                                  | buildings      | Auxiliarly  |
| 24  | Percentage of public building increase | the rate of increase in the number of public buildings in an area        | %              | Auxiliarly  |
| 25  | Non-domestic water needs          | The large amount of water consumption for each individual in a building   | l / people / buildings | Constanta |

Diagram the underlying mechanisms and feedback loops diagram
The main components affecting the balance of water available in the Bendo Reservoir include large inflow discharges, outflow for clean water, and for irrigation which are interrelated and influenced by sub-components. For example, the inflow discharge which is considered absolute is influenced by the drainage coefficient of rainfall intensity, catchment area, and maximum daily average rainfall. The quantity of inflow discharge can, therefore, be increased by increasing the water supply using another river nearby.

The need for irrigation and clean water also has its constituent components. For example, the clean water required is influenced by the increase in population and number of public buildings in the region while irrigation water needed is affected by the area to be irrigated, irrigation efficiency, DR (discharge ratio at intake), NFR (Net Field Requirements), WLR (Water Level Requirements), Percolation, Potential Evapotranspiration (Eto), and the coefficient of the plant. There is, therefore, the need to model the water quantity for these
variables in line with the region's development and growth. All the interrelated components were used to make Causal Loop Diagrams (CLD) and stock-flow diagrams (SFD) as shown in figures 2 and 3.

Figure 2. Causal loop diagram of the Bendo Reservoir reservoir water operating system model.

Figure 3. Stock flow diagram of storage capacity in Bendo Reservoir.
Figure 4 shows the initial water in the reservoir amounted to 45,415,000 m$^3$ and the value was observed to have decreased after been used as the source for irrigation and clean water for one year. This is due to the fact that the inflow discharge and initial reservoir quantity is smaller than the quantity needed as well as the irrigation plants using ordinary seeds. These results were later validated using available data.

d. Testing the model

The conceptual model was validated to determine the correctness and accuracy of the theories and assumptions used as well as their compatibility with the purpose of the model. This validation process was intended to ascertain the ability of the model to effectively describe the real system conditions using two methods which are statistical approach involving the Mean Comparison Test and Amplitudinal Variation Comparison Test (% error variance) [15] formulated as follows:

$$E_1 = \frac{\bar{S} - \bar{A}}{A}$$

(1)

Where,

$\bar{S}$ = average of the data model
$\bar{A}$ = average of existing data

$$E_2 = \frac{S_s - S_a}{S_a}$$

(2)

Where,

$S_s$ = standard deviation of model
$S_a$ = standard deviation of existing data

Each test is explained as follows:

- Mean comparison test
  The model is considered valid if $E_1 < 5\%$. Based on the average comparison test in the water distribution system in this reservoir, as in table 2 below shows that the value of $E_1$ on the validation of water availability is 2.911\%. The value of $E_1$ on validation of total population is 3.905\%. Then the model is considered valid because the $E_1$ value produced is less than 5\%.
• Amplitude Variation Comparison Test (% Error Variance)
The water availability was recorded to have a validation of 2.911% as shown in table 2 and graphically illustrated in figure 5 while the population number variable had 0.504%, therefore, the model is considered valid because the E2 value is less than 30%. The model and actual data are also shown in the figure to have a small difference and share the same trend.

|                     | Mean Comparison test | Amplitude Variation Comparison Test |
|---------------------|----------------------|-------------------------------------|
| Water availability  | 2.911 %              | 0.098 %                             |
| Total Population    | 3.905 %              | 0.504%                              |

Figure 5. Comparison graph for the model and actual data.

c. Testing the model’s response to different policies
Several scenarios were formulated after the model has passed the validation test to provide more optimum conditions and possibilities for the future. The process involved indicating how the structure of the system from the base model can be changed using new parameters through the concept of structural scenario. Moreover, the model parameters were not also changed to determine the impact of other variables in the system through parameter scenarios. The scenarios drafted include:

- Mean comparison test
- Scenario 2 adds the possibility of supervision from the Sawoo River close to the reservoir site and increases the percentage of population growth and public buildings in the Ponorogo Regency area as the study location.

The simulation was conducted using these scenarios for 5 years or sixty (60) months because changes in hydrological climate conditions generally occur once every five years.

f. Conclusion
A conclusion was made after the two proposed scenarios have been completely analyzed.
4. Results and discussion

- Scenario 1
  Scenario 1 adds a superior paddy crop coefficient with 0.9 compared with the estimated 1.1 for average common varieties [13] which are intended to reduce the amount of irrigation water needed. The SFD for the first scenario is presented in figure 6 while the result is in figure 7:

![Figure 6. SFD of scenario 1.](image)

![Figure 7. Simulation results of water availability in scenario 1.](image)

- Scenario 2
  This second scenario was developed by adding the Sawo’s irrigation area up to 1,000 Ha as an alternative variable, Sawoo River water supply averaging 4.4 m³/second, and increasing the percentage of population growth and public buildings [16]. The SFD for scenario 2 is shown in figure 8 while the result is presented in figure 9.
The results showed the quantity of water available for the base model, Scenario 1, and Scenario 2 experiences some differences starting from the 13th to the 60th month. Moreover, Scenario 2 was observed to be more positioned at saving reservoir water usage compared to the others. Meanwhile, water availability deficit was reported to have occurred in the base model, Scenario 1, and Scenario 2 in the 42nd, 46th, and 54th month respectively. The option selected to add more water supply to the Bendo Reservoir is clearly illustrated to have the ability of supplying to 1000 ha of irrigated rice fields.

5. Conclusion
A Dynamic System was developed and implemented in this research to produce water resource solutions due to uncertain inflow by allocating the resources for different uses and in several areas. Bendo Reservoir was used as a case study due to the government’s effort towards implementing an initiative to overcome the water crisis in Indonesia. The results provided are better in minimizing the quantity of water shortages and ensure the reservoir satisfies water outflows for the next five (5) years.
Several further studies are required to improve methodology and analysis because this research only considers the uncertainty associated with the reservoir flow and demand even though it can be extended to others such as the operational dates of different water-saving scenarios. Meanwhile, the uncertainty and variability in reservoir flow for case studies are based on limited historical data and may not illustrate long-term trends such as drought and hydrological change, therefore, further research is required.

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