Impounding Duration Model Development at the Jlantah Dam, Karanganyar Regency, Central Java Province, Indonesia

Harimukti Rosita Rahmawati
Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Malang, Indonesia
alwaysrosita@student.ub.ac.id

Pitojo Tri Juwono
Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Malang, Indonesia
pitojo_tj@ub.ac.id

Lily Montarcih Limantara
Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Malang, Indonesia
lilymont2001@ub.ac.id (corresponding author)

Emma Yuliani
Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Malang, Indonesia
e_yuliani@ub.ac.id

Received: 15 May 2025 | Revised: 15 July 2025 and 22 July 2025 | Accepted: 27 July 2025

 DOI: https://doi.org/10.48084/etasr.12161

ABSTRACT

Upon the completion of dam construction and before its operation, an initial impounding phase of the reservoir takes place. The latter requires careful planning and observation. A predictive model for impounding duration has been developed to provide more accurate predictions, facilitating more effective monitoring and the control of the increasing water level elevation rate. Its application requires an implementation phase that involves applying a reservoir impounding model by formulating a parabolic equation that describes the relationship between the time and daily water elevation. This research investigated the development of the prediction model of impounding duration. The deployed methodological approach involves statistical analysis to test the conformity of the model results with the field data, utilizing statistical conformity criteria. This research was conducted at the Jlantah Dam located in Karanganyar Regency, Central Java Province, Indonesia, which was chosen as the site for the model development. A coefficient of determination (R^2) close to 0.98 was obtained between the planned curve of the time–elevation relationship and the observed daily elevation data during the impounding process at the Jlantah Dam. Therefore, the developmental stages of this study's findings can serve as a reference for a better application of the initial reservoir impounding duration model.

Keywords-model; initial impounding; formulation

I. INTRODUCTION

Initial impounding, or the first filling of a dam reservoir, represents a critical transition phase between the completion of the dam construction and the beginning of its operational life. This stage involves the controlled accumulation of water behind the dam once all major structural components, such as the dam body, spillway, intake structures, and outlet works, have been completed and the river diversion system has been closed or rerouted. The initial impounding not only initiates the formation of the reservoir, but also serves to evaluate the dam's structural integrity, hydraulic performance, and geotechnical behavior under increasing hydrostatic pressure. It provides an essential opportunity to monitor seepage, deformation, instrumentation data, and other safety indicators in real time. Given the potential risks associated with this phase, such as unexpected leakage, slope instability, or inadequate discharge capacity, it is crucial that the process follows a detailed impounding plan, supported by emergency preparedness protocols, and overseen by experienced dam safety professionals. Recently, AI models have surpassed traditional hydrological methods in making precise predictions of the water levels and inflows [1], which has led to further research in developing prediction models for impounding duration. The impounding duration prediction model aims to provide more precise estimates [2], facilitating more effective monitoring [3, 4] and regulating the rate of the reservoir water level rise.

The most severe effects of climate change are experienced in tropical and subtropical areas, where these regions encounter a higher frequency and greater intensity of climate phenomena than temperate zones [5]. This underscores the importance of accurate prediction of the impounding duration for dam monitoring and safety during the initial operation. In practice, this involves applying the model through a relation that incorporates a parabolic equation illustrating the connection between time (duration) and daily water elevation [6]. A statistical approach is used to analyze the variables influencing the impounding duration, such as inflow, outflow [7, 8], and the ratio between the storage volume and inflow. For example, authors in [7] proposed an analytical framework for estimating the reservoir inflow and outflow from water level observations using hydrological models and reasoning, which allows for more accurate estimation of the key variables during the dam filling. In addition, the estimation of the storage volume capacity is performed using the Gould-Dincer formulation [8], which is reinforced by the probability theory [9]. This method offers more accurate estimates of the storage capacity in the context of reservoir initial impounding. Authors in [10] studied how reservoirs significantly alter the flow regimes in watershed systems, affecting the streamflow magnitude and timing. This study introduces a parametric reservoir operation model using piecewise-linear relationships between the storage, inflow, and release.

The dam was completed at the end of 2024, making it the chosen site for model development. It is hoped that the findings will contribute to further studies in developing prediction models for impounding duration. Additionally, this research aims to enhance the modeling applications by forecasting the impounding duration in similar reservoir construction locations.

II. MATERIALS AND METHODS

A. Research Location

Jlantah Dam, located in Karanganyar Regency, Central Java Province, Indonesia, was selected as the study site for developing a reservoir initial impounding duration model. The dam completed its first impounding cycle at the end of 2024, and the data from this process have been well documented. As shown in Figure 1, the dam is situated on the Jlantah River, within the villages of Tlobo and Karangsari in Jatiyoso District. Its geographical coordinates are 7°42′44.05″ S and 111°4′47.51″ E.

Fig. 1. Location of the Jlantah Dam.

- Benefits:

1. Supply of raw water demand of 150 L/s for Jumapolo District, Jumantono District, Jatipuro District, and Karangnyar Regency.
2. Supply of water irrigation in the Jlantah irrigation area of 1494 ha in Karanganyar Regency, the 806 ha is existing irrigation, and 688 ha is new irrigation.
3. Reduction of the flood of 70.33 m^3/s or 51.26% of $Q_{50years}$ (the volume is 1436000 m^3).
4. The potency as Micro Hydro Electric Power with a capacity is 625 kW.
5. There is a chance to develop tourism and agro-tourism.

The general layout of Jlantah Dam is presented in Figure 2.

The Jlantah Dam is a gravel random rock fill dam with a vertical core zonal structure. It has a dam peak length of 404 m and a height of 70 m from the deepest foundation, or 65 m from the riverbed. The elevation at the dam peak is EL. +690, while the deepest foundation lies at EL. +620. The width of the dam peak is 12 m, with slope ratios of 1:3.2 on the upstream side and 1:2.4 on the downstream side. The cofferdam, which supports the construction during river diversion, has a height of 28 m and a peak elevation of EL. +653, with a width of 6 m at the top. Figure 3 illustrates the cross section of the Jlantah Dam.

The Jlantah Reservoir has a catchment area of 22.47 km². Its flood discharge levels are EL. +688.75 for the probable maximum flood (Q-PMF) and EL. +687.46 for the 1000-year flood (Q1000). The Normal Water Level (NWL) is set at EL. +685, while the minimum water level is EL. +661. During flood conditions, the reservoir covers an area of 53.5 Ha, which reduces to 50.5 Ha under normal conditions and further to 27.38 Ha during low water levels. Correspondingly, the storage volumes are 11.96 million m³ during flood, 10.97 million m³ at normal level, and 2.67 million m³ during low water level, with an effective storage capacity of 8.3 million m³. Figure 4 and Table I display the reservoir capacity curve of the Jlantah Reservoir.

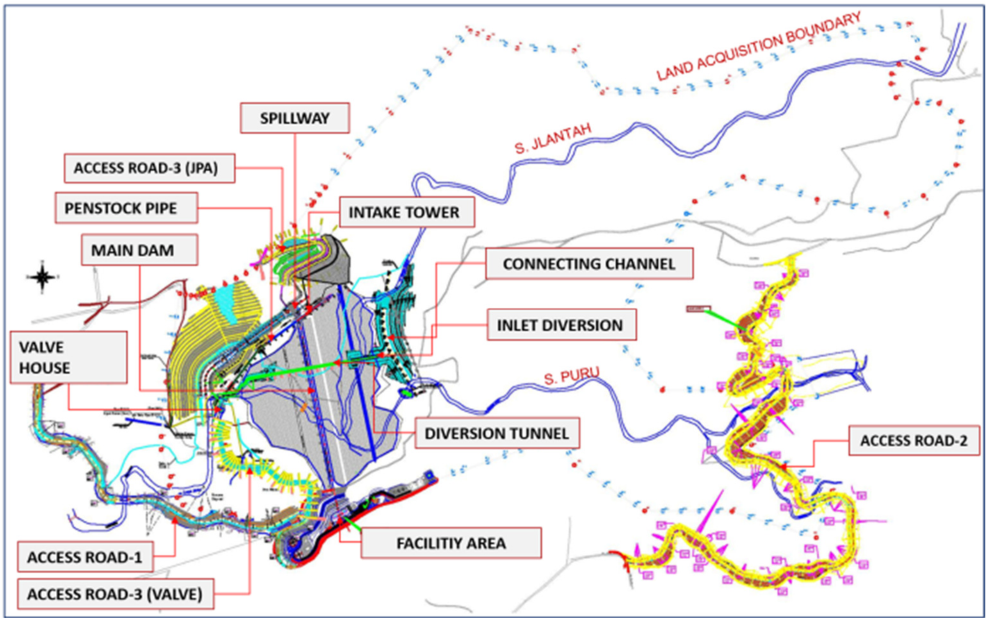
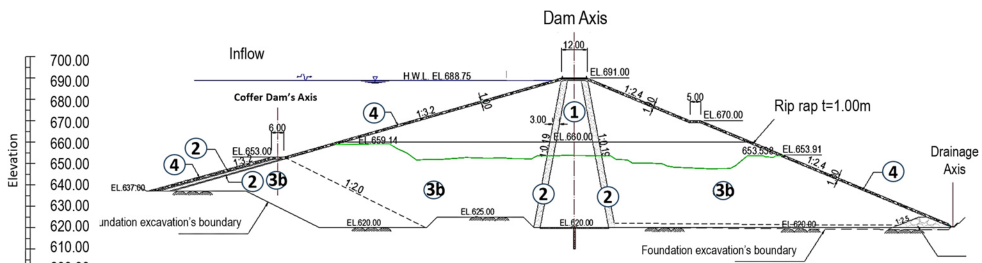


Fig. 2. General layout of the Jlantah Dam.



SYMBOL	ZONE	MATERIAL SPESIFICATION
①	CORE	Diameter 10 mm, thickness 25 cm/layer
②	FILTER	Diameter 30 mm, thickness 60 cm/layer
③	RANDOM MATERIAL	Diameter 40 mm, thickness 60 cm/layer
④	RIP RAP	Diameter 70 mm, thickness 100 cm/layer

Fig. 3. Cross section of the Jlantah Dam.

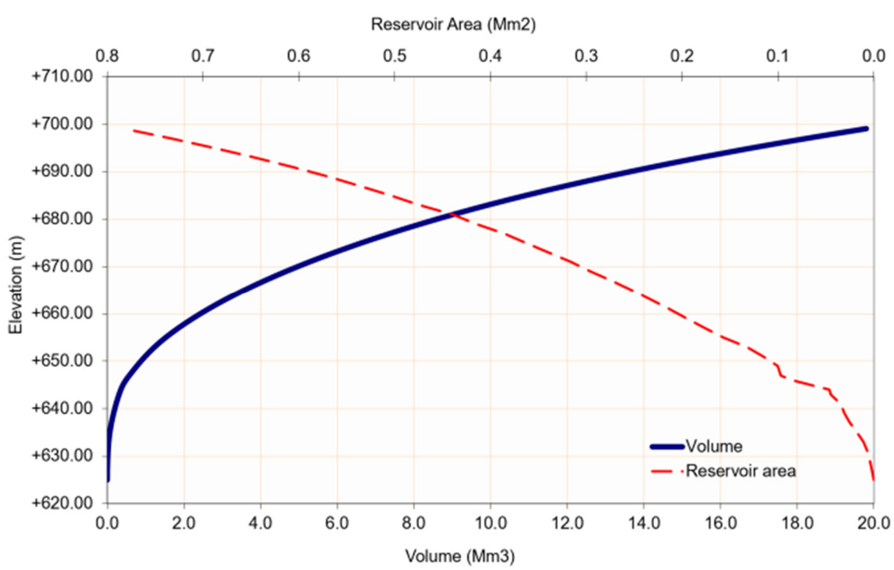


Fig. 4. Reservoir capacity curve of Jlantah reservoir.

TABLE I. TABLE OF RESERVOIR CAPACITY CURVE OF JLANTAH RESERVOIR

No	Elevation	Reservoir area	Storage volume	Information
	(m)	(Ha)	(million m^3)	
1	+635	1.7	0.06	Inlet diversion
2	+662	22.34	2.9	Intake
3	+682	45.71	9.53	Apron of spillway
4	+685	50.5	10.97	Spillway crest
5	+688.75	56.58	12.98	PMF elevation

The Jlantah Dam is equipped with an overflow ogee-type spillway, with a crest elevation at EL. +685 m and an apron elevation at EL. +682 m. The spillway has a width of 25 m, a 15 m long transition channel, a 166 m long approach channel, and a 40 m long stilling pool of USBR Type II. It is designed to handle an inflow of 477.69 m^3/s and an outflow of 389.58 m^3/s. Figure 5 portrays the long section of the spillway. The diversion structure of the Jlantah Dam consists of a conduit and concrete tunnel with a horseshoe-shaped cross-section. The total length of the channel is 508.34 m, comprising a 223.7 m tunnel, a 167.04 m conduit, and a 117.6 m open channel. The tunnel has a diameter of 4.2 m. The elevation of the upstream channel bed is EL. +635, while the downstream channel bed is at EL. +618, with a bed slope of 0.047. The structure is designed to accommodate a 25-year design flood (Q25) of 125.57 m^3/s. It includes one sliding steel gate, measuring 4.2 m in width and 4.2 m in height. Figure 6 shows the long and cross section of the diversion tunnel, Figure 7 illustrates the inlet of the diversion tunnel, and Figure 8 presents the long section of the intake tunnel.

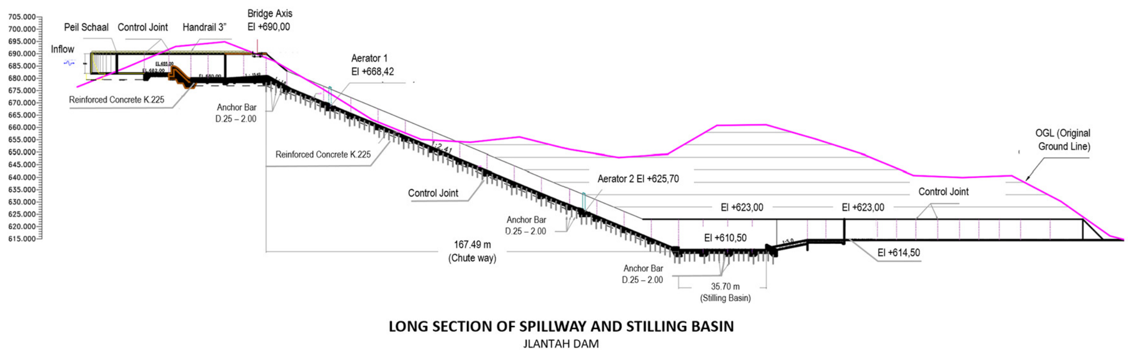


Fig. 5. Long section of spillway and stilling basin.

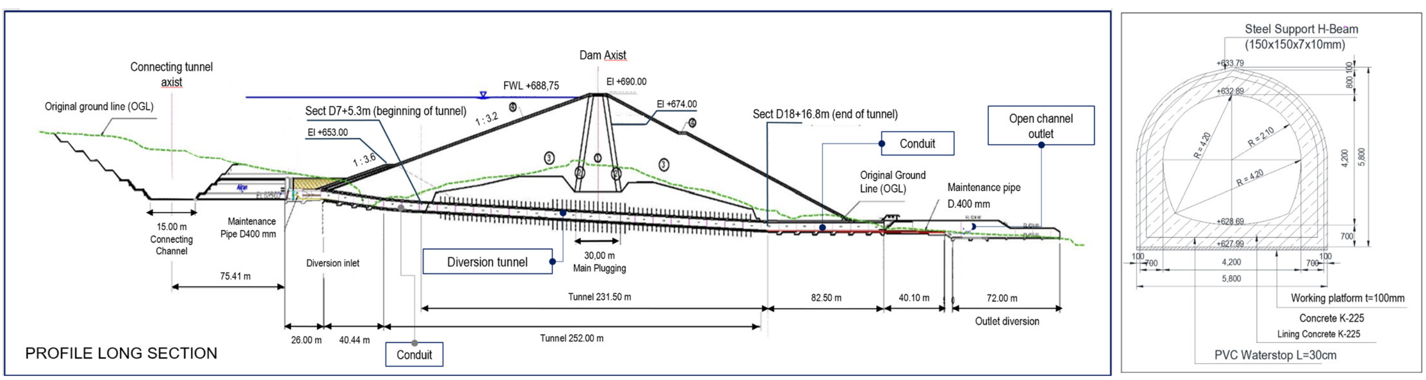


Fig. 6. Long and cross section of diversion tunnel.

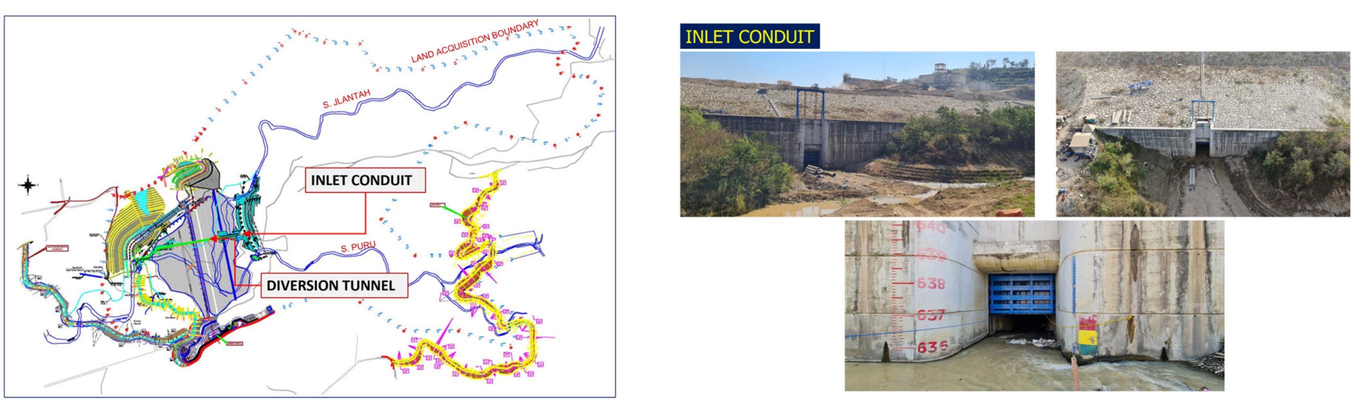


Fig. 7. Inlet diversion tunnel.

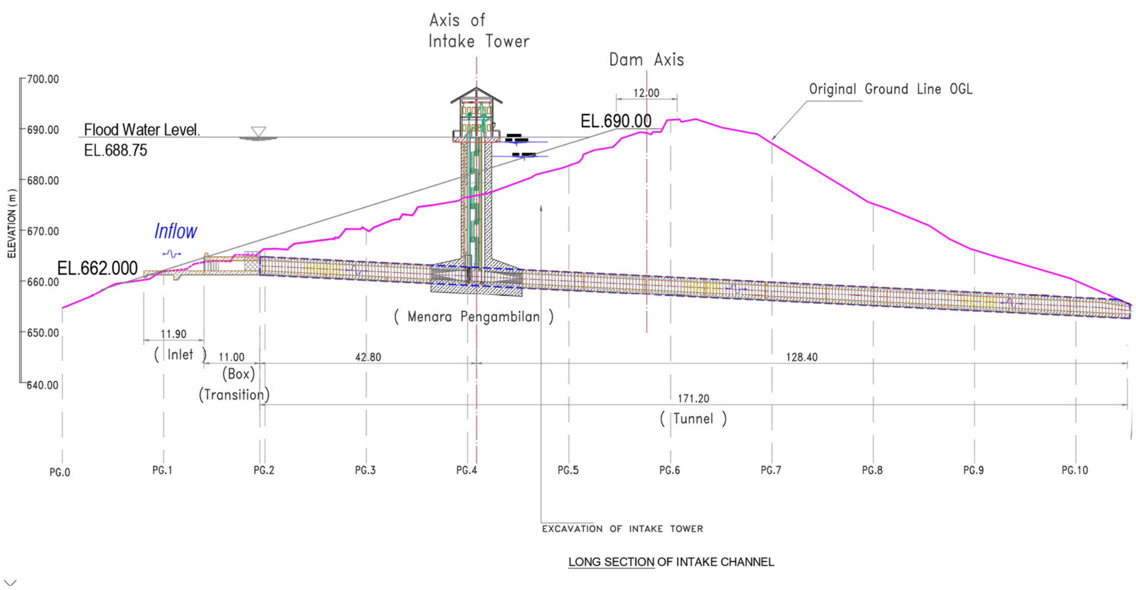
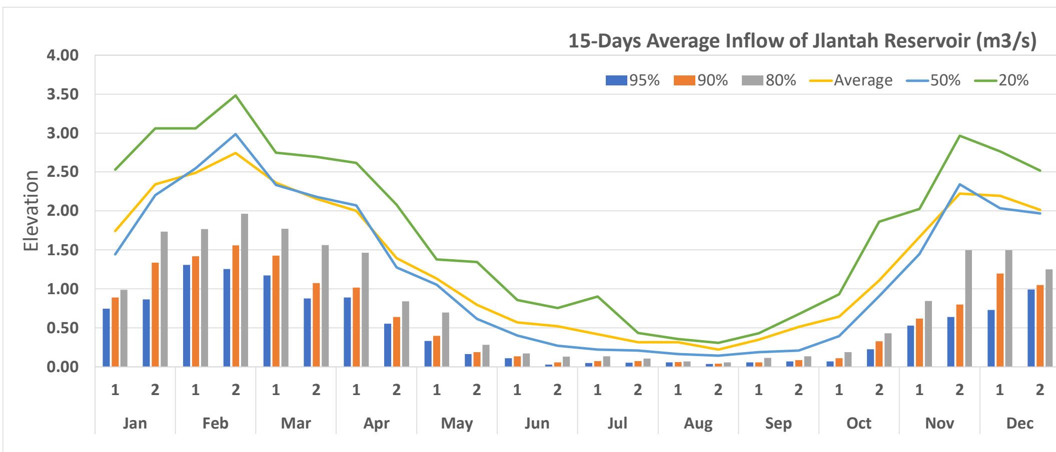


Fig. 8. Long section of intake tunnel.



Probability	January		February		March		April		May		June	
	1	2	1	2	1	2	1	2	1	2	1	2
95%	0.74	0.87	1.31	1.25	1.17	0.87	0.89	0.55	0.33	0.16	0.11	0.03
90%	0.89	1.34	1.42	1.56	1.42	1.07	1.02	0.64	0.40	0.19	0.13	0.06
80%	0.99	1.74	1.77	1.96	1.77	1.56	1.46	0.84	0.70	0.28	0.17	0.13
Average	1.74	2.34	2.49	2.75	2.36	2.16	2.00	1.39	1.13	0.79	0.57	0.52
50%	1.44	2.20	2.55	2.98	2.33	2.18	2.07	1.27	1.05	0.61	0.40	0.27
20%	2.53	3.06	3.06	3.48	2.75	2.69	2.62	2.08	1.38	1.34	0.86	0.75

Probability	July		August		September		October		November		December		Average discharge(m3/sec)	Average Volume (Mm3)
	1	2	1	2	1	2	1	2	1	2	1	2		
95%	0.05	0.05	0.05	0.03	0.05	0.07	0.07	0.22	0.53	0.64	0.73	0.99	0.490	15.466
90%	0.07	0.07	0.06	0.04	0.05	0.08	0.11	0.32	0.62	0.80	1.20	1.05	0.608	19.178
80%	0.13	0.11	0.07	0.06	0.11	0.13	0.19	0.43	0.84	1.50	1.50	1.25	0.819	25.838
Average	0.42	0.31	0.31	0.22	0.35	0.51	0.64	1.11	1.67	2.22	2.19	2.01	1.342	42.321
50%	0.22	0.21	0.16	0.14	0.19	0.21	0.39	0.91	1.45	2.34	2.03	1.97	1.232	38.864
20%	0.90	0.43	0.35	0.31	0.43	0.67	0.93	1.86	2.02	2.97	2.77	2.52	1.782	56.184

Inflow into Jlantah reservoir.

The intake structure and outlet of the Jlantah Dam are located on the right bank of the dam abutment and utilize a shaft-type intake design. The intake bed is positioned at an elevation of EL. +661 m. The intake tunnel is semi-circular in shape, with a diameter of 3.7 m and a length of 175 m. The intake pipe system consists of a steel pipe with two segments: an embedded section with a diameter of 2 m and a length of 175 m, and an exposed section with a diameter of 1.4 m and a length of 219.7 m.

B. *Inflow*

To apply the model [11, 12], the analysis of impounding duration uses the daily inflow data. Figure 9 presents the inflow simulation data of the Jlantah reservoir.

The catchment area of the Jlantah Dam covers 22.47 km². Due to the absence of an upstream gauging station, the average inflow into the Jlantah Reservoir was estimated at 1,342 m³/s using rainfall–runoff analysis. Annual rainfall was determined using Global Precipitation Measurement (GPM) data, which were calibrated against ground-based rainfall station measurements, resulting in an estimated annual rainfall of 2,818.93 mm.

C. *Observed Impounding Data of the Jlantah Dam*

The initial impounding of the Jlantah Dam began on December 20, 2024, and reached the NWL elevation of +685 m on March 30, 2025, taking a total of 101 days. During this period, the average water level rise was 0.5 m per day, with the highest daily increase recorded at 4.378 m on December 22, 2024. The impounding occurred during the rainy season, resulting in a daily average inflow of 1.86 m³/s, which is higher than the annual average discharge of 1.35 m³/s. During the spill-out phase, the spillway discharge ranged between 1.4 and 3.9 m³/s. The downstream river channel has a sufficient capacity of over 102.7 m³/s, which corresponds to the peak discharge for a 50-year return period (Q50). The observed impounding data from the Jlantah Reservoir include measurements of the water elevation and outflow, as shown in Figure 10.

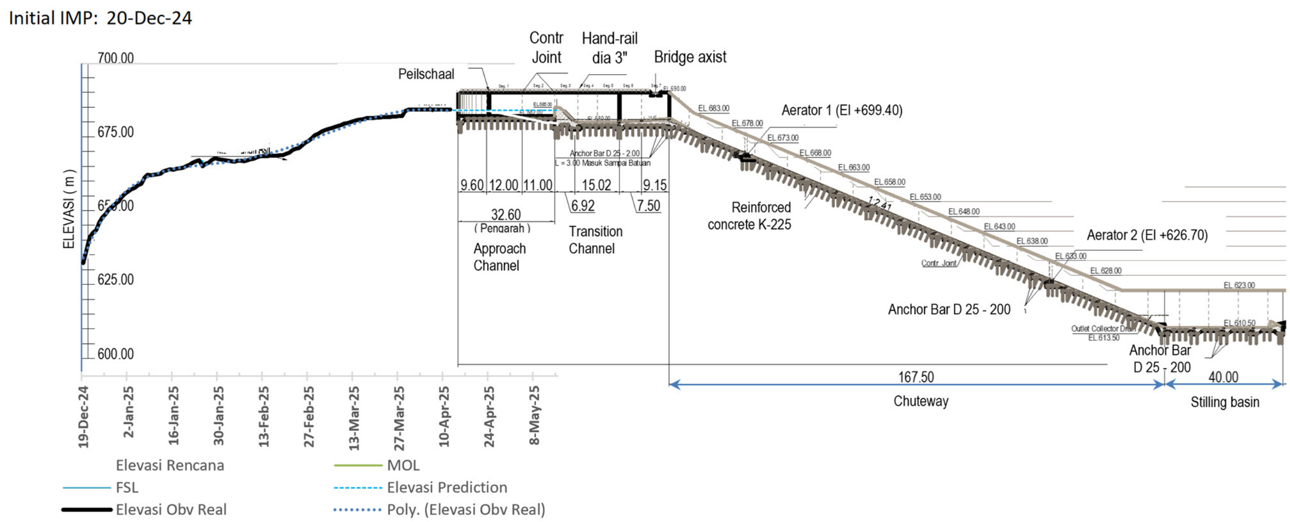


Fig. 9. 10 Schematic impounding of Jlantah reservoir.

By analyzing the reservoir equation it is observed that the inflow into the reservoir from the beginning of the impounding (20th December 2024) until the first day of the spill out (30th March 2025) can be calculated as shown in Figure 11 and in [13]. Then the average number is taken for the model input.

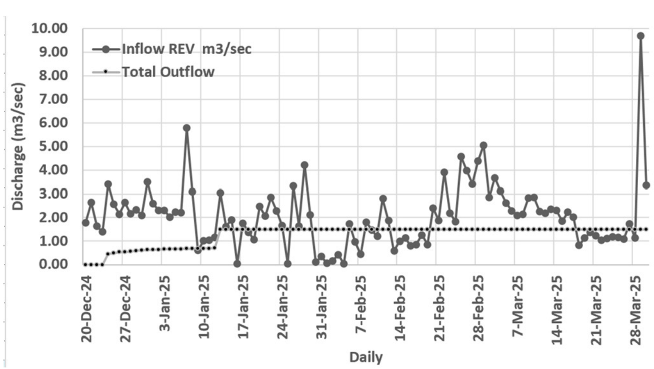


Fig. 10. Daily calculated inflow and observed outflow of Jlantah Dam during impounding (December 20, 2024 – March 30, 2025).

D. *Method: Reservoir Simulation Theory*

Reservoir simulation is an essential approach in the planning, management, and operation of dams. It is a vital tool for understanding the dynamic response of the water levels to the inflows and for managing the initial impounding process of reservoirs, particularly in earth-fill dams. The simulation model aims to predict the water storage behavior during the impoundment, including the potential changes in the over time water elevation.

At the core of the reservoir simulation lies the mass balance equation, expressed as:

$$\frac{dV}{dt} = I(t) - O(t) \tag{1}$$

where $\frac{dV}{dt}$ is the rate of change in the reservoir storage volume (m^3/day), $I(t)$ is the inflow discharge (m^3/day), $O(t)$ is the outflow discharge (m^3/day). Additionally, the relationship between the storage volume and water surface elevation H is typically represented by a parabolic equation as:

$$V(H) = aH^2 + bH + c \tag{2}$$

where $V(H)$ is the storage volume based on the height of H, H is the height of elevation, and a, b, c are coefficients. The effectiveness of these models requires accurate calibration and validation. Authors in [13] highlighted the sensitivity of the slope deformation to water elevation during the impoundment phase, reinforcing the need for precise predictions. Authors in [11] demonstrated the application of integrated simulation tools like SWAT+ for managing the water allocation in highly regulated basins, offering valuable insights for operational planning.

E. Method: Impounding Duration Model

This analysis demonstrates the application of the initial impounding duration model for the Jlantah Dam, supported by statistical validation using the methods proposed in [14, 15]. The regression equation derived from the analysis and identified as the most suitable model is [13]:

$$\left(D_{regression}\right) = (S^{1.047}) \times (I_{net})^{-1.08807} \qquad (3)$$

where *D* is the duration based on the impounding model (day), S is the volume of storage (1000 m^3), I_{net} is the net inflow = (*I*-*O*) (1000 m^3/ day), where *I* is the inflow to the reservoir (1000 m^3/ day), and *O* is the outflow from the reservoir (1000 m^3/ day). The steps involved in applying the initial impounding prediction model to the Jlantah Reservoir are outlined in a simplified flow chart shown in Figure 12.

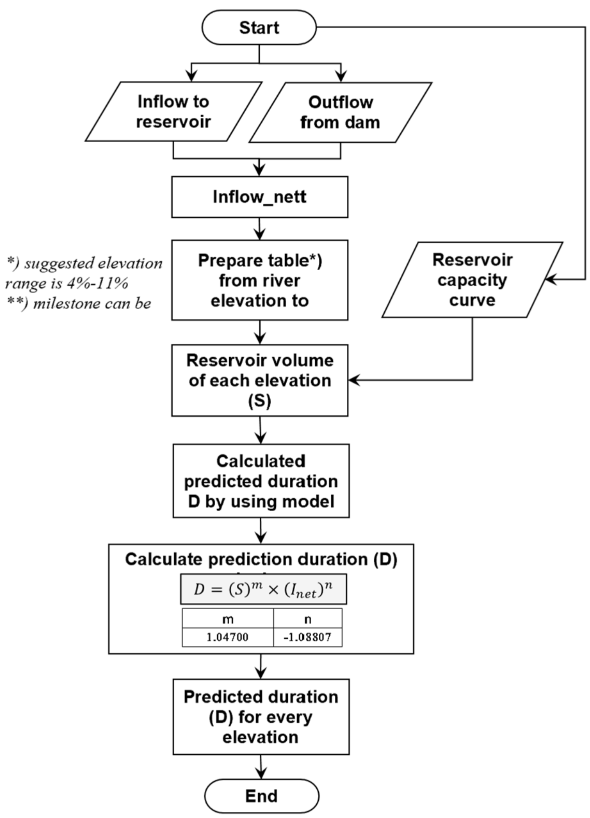


Fig. 11. Flow chart of the predicting impounding duration model.

III. RESULTS AND DISCUSSION

A. Statistics Approach

The performance of the model was quantitatively assessed using a set of statistical indicators, including R^2, Nash–Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), Root Mean Square Error (RMSE), and the ratio of RMSE to the standard deviation of the observed data (RSR). The interpretation of these metrics follows the criteria established in [16], which provide a structured classification of the model performance into four categories: "very good," "good," "satisfactory," and "unsatisfactory," as summarized in Table II. Although RMSE is not explicitly categorized in the guideline, a lower RMSE value, when considered relative to the range of the observed data, generally indicates a higher level of predictive accuracy.

TABLE II. STATISTICAL MODEL PERFORMANCE EVALUATION CRITERIA

Indicator	Criteria	Value
R^2	Very good	> 0.85
	Good	0.7 – 0.85
	Satisfactory	0.5 – 0.7
	Unsatisfactory	< 0.5
NSE	Very good	> 0.75
	Good	0.65 – 0.75
	Satisfactory	0.5 – 0.65
	Unsatisfactory	< 0.5
PBIAS (%)	Very good	< ±10
	Good	±10 – ±15
	Satisfactory	±15 – ±25
	Unsatisfactory	> ±25
RSR	Very good	< 0.50
	Good	0.5 – 0.60
	Satisfactory	0.6 – 0.7
	Unsatisfactory	> 0.7
RMSE		
	Very good	RMSE < 10% of the average observed data
	Good	10% ≤ RMSE < 20% of the average observed data
	Satisfactory	20% ≤ RMSE < 30% of the average observed data
	Unsatisfactory	30% ≤ RMSE < 50% of the average observed data
	Need improvement	RMSE ≥ 50% of the average observed data

IV. ANALYSIS

Table III presents the summary of the observed data of initial impounding.

TABLE III. SUMMARY OF THE OBSERVED DATA OF INITIAL IMPOUNDING

	Elevation	Volume		Date achieved	Duration days
Elev NWL	+ 685	10.95	Mm^3	30 Mar'25	101.0 days
	+ 682	9.52	Mm^3	23 Feb'25	66.0 days
Elev MOL	+ 664	2.88	Mm^3	9 Jan 2025	21.0 days
Intake level	+ 662	2.88	Mm^3	4 Jan 2025	16.0 days
	+ 661	2.65	Mm^3	3 Jan 2025	15.0 days
	+ 660	2.45	Mm^3	2 Jan 2025	14.0 days
	+ 646	0.49	Mm^3	24 Dec'24	5.0 days
	+ 640	0.21	Mm^3	22 Dec'24	3.0 days
	+ 635	0.07	Mm^3	20 Dec'24	1.0 days
	+ 635	0.07	Mm^3	20 Dec '24	1.0 days

The first step in the analysis involves determining the inflow and outflow rates, along with listing the reservoir elevations in ascending order from the riverbed elevation to the spillway crest elevation. The inflow discharge is selected based on user preferences, whether representing the dry season, wet season, or monthly average values. The outflow discharge varies depending on the dam characteristics, but during initial impounding in most Indonesian dams, a minimum maintenance flow release defined by the government regulations is commonly used. To calculate the storage volume, the elevations must be arranged in increasing order, and the capacity curve is used to convert these elevations into the corresponding storage volumes. An elevation range between 4% and 11% is generally proposed, though milestones can be adjusted depending on the site conditions. For the Jlantah Dam, the analysis considers milestones from the riverbed elevation of +639.85 m up to the spillway crest elevation of +685 m. The prediction of impounding duration is based on the equation $D_{prediction} = (S)^{1.047} \times (I_{net})^{-1.08807}$, where D is the predicted duration (days), S is the storage volume (1000 m³), and Inet is the net inflow, calculated as inflow minus outflow (1000 m³/day). Table IV outlines the predicted impounding durations, while Figure 13 compares the observed and predicted durations for the Jlantah Dam.

TABLE IV. SUMMARY OF THE PREDICTED IMPOUNDING DURATION (P) IN DAYS

El	Volume (1000 m³)	In-flow (m³/s)	Out-flow (m³/s)	I_{net} (1000 m³/day)	S^m	$(I_{net})^n$	Predicted duration *D* (days)
+639.85	202.27	1.86	0	160.56	259.61	0.004	1.034
+640	208.33	1.86	0	160.56	267.74	0.004	1.066
+645	418.93	1.86	0	160.56	556.4	0.004	2.216
+650	891.53	1.86	0	160.56	1,226.85	0.004	4.885
+655	1538.06	1.86	0	160.56	2171.48	0.004	8.647
+660	2448.11	1.86	0	160.56	3532.66	0.004	14.067
+665	3585.77	1.86	0.57	111.17	5267.99	0.006	31.294
+670	4988.95	1.86	0.57	111.17	7444.09	0.006	44.222
+675	6653.68	1.86	0.57	111.17	10063.3	0.006	59.781
+680	8630.68	1.86	0.57	111.17	13214	0.006	78.498
+685	10951.4	1.86	0.57	111.17	16955.9	0.006	100.727

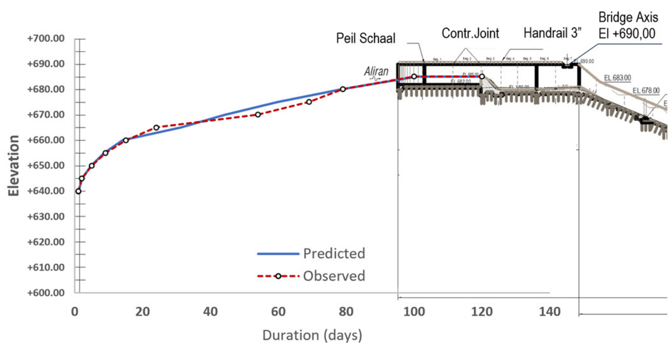


Fig. 12. Comparison of observed and predicted impounding duration in Jlantah Dam.

Table V provides a statistical analysis to evaluate the model performance against the impounding observed data of the Jlantah dam.

The statistical evaluation of the model's performance shows that it has strong predictive reliability. The R² is 0.972, indicating that 97.2% of the variation in the observed data is accurately explained by the model, a sign of a strong correlation between the predicted and actual values. The RMSE is 5.68, which is low relative to the observed data range (1–100 days), reflecting high prediction accuracy. The NSE value of 0.972 also indicates an excellent model performance, nearly matching the accuracy of using the observed mean. The PBIAS of 4.74% suggests a slight overestimation, but it remains well within the acceptable range (PBIAS < ±10%) for high-performing models. The RSR is 0.164, categorizing the model's performance as "very good" according to the evaluation standards in [16]. These results support the model's suitability for hydrological monitoring, planning, and water resource management. To strengthen the contribution of this paper, it is proposed to emphasize the novelty of the introduced approach and to compare the obtained results with those of recent studies in the same field.

TABLE V. SUMMARY OF THE STATISTICAL ANALYSIS: OBSERVED AND PREDICTED IMPOUNDING DURATION OF THE JLANTAH DAM

El.	Observed Duration (O)	Prediction duration (P)	R2	RMSE	NSE	PBIAS	RSR=RMSE /STDEV
	(days)	(days)					
+639.85	1	1					
+640	1	1.1					
+645	2	2.2					
+650	5	4.9					
+655	9	8.6					
+660	15	14.1					
+665	24	31.3					
+670	54	44.2					
+675	69	59.8					
+680	79	78.5					
+685	100	100.7					
			99.19%	4.63	98.20%	3.51%	0.128
				14.18%			
			> 0.85	< 10% O	> 0.75	< ±10	< 0.50
			Very Good	Good	Very Good	Very Good	Very Good

V. CONCLUSIONS

This study develops a predictive model to estimate the duration of initial reservoir impounding, with a focus on the Jlantah Dam in Central Java, Indonesia. The model aims to improve the accuracy of monitoring and managing the water level rise during the impounding phase of newly built dams. The novelty of this research lies in the use of a parabolic predictive model, specifically designed for multipurpose dams in Indonesia. Unlike traditional methods, this model allows for precise control of the water elevation by combining statistical validation with the dam's unique site characteristics. The approach involves formulating a parabolic equation that describes the relationship between the time and daily water surface elevation, based on an analysis of the reservoir storage capacity, hydrological conditions, and field observations. To evaluate the model's performance, several statistical indicators were used: the coefficient of determination (R^2), Nash–Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), Root Mean Square Error (RMSE), and the ratio of RMSE to the standard deviation of the observed data (RSR). The model achieved an R² of approximately 0.99, indicating excellent agreement between the predicted and observed data. The Jlantah Dam, which completed its initial impoundment in late 2024, served as the validation site. The model, defined by the equation $D_{prediction} = (S)^{1.047} \times (I_{net})^{-1.08807}$ demonstrates strong predictive capability. Presented through a simple flowchart and calculation tables, it offers a practical tool for planning construction schedules and reservoir operations in similar dam projects.

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