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A Study on Continuous and Divided Flows for Optimal and Sustainable Dam Discharge Considering Dead Storage

Eddy Priyanto[1,2], Siti Nazahiyah Rahmat[1]*

[1] *Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA*
[2] *Faculty of Engineering, Gresik University, East Java 6111, INDONESIA*

*Corresponding Author: nazahiya@uthm.edu.my
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Abstract

This study focuses on discharge optimisation for the Gredek reservoir in Gresik. East Java, Indonesia, with a specific focus on the discharge at dead storage. The primary goal was to design and analyse a suitable model for optimising the final discharge. The methodology employed simple linear equations using general variables, namely inflow (Q_{in}) and outflow (Q_{out}), within a discharge balance equation, supplemented by the discharge at dead storage (Q_{DS}). This approach aimed to achieve an optimal and sustainable remaining monthly discharge (Q_{diff}). Based on the analysis, it was concluded that for determining Q_{diff} by considering inflow, outflow, and Q_{DS}, optimisation models using Continuous Flow (CF) and Divided Average (DA) approaches were successfully developed. In simulations using a 5 cm level (Q_{DS5}) at Dead Storage, the CF model yielded Q_{diff} values ranging from 767 m^3 to 66,649 m^3 at the end of each month, while the DA model yielded Q_{diff} values ranging from 2,568 m^3 to 46,242 m^3 throughout the 2021-2035 period. A comparative analysis of the CF and DA models reveals that both have distinct advantages. While the CF model achieved the highest Q_{diff} at 66,649 m^3, the DA model's highest Q_{diff} was 46,242 m^3. However, for comprehensive reservoir equilibrium management, a combination of both models is highly effective. The CF model is well-suited for long-term planning. While the DA model is ideal for day-to-day or monthly reservoir operational management, the CF model, in essence, estimates the potential magnitude of available water, whereas the DA model details how that water interacts with other operational components. These two models are complementary; their applicability depends entirely on the required level of detail and the scale of planning or operations.

1. Introduction

The development of water resource infrastructure, particularly reservoirs, has become a strategic priority for the Indonesian government. The main objective is to support food security and meet the continuously increasing domestic water demand. Reservoirs serve as multifunctional systems that not only store water but also play a crucial role in flood control and mitigating the impacts of climate change. In line with this initiative, the reservoir in Gredek Village, Gresik, underwent substantial reconstruction at the end of 2019. This reconstruction successfully increased its capacity from approximately 100 m^3 to about 350 m^3, with a depth of 4 meters and a surface area of 101,129.38 m^2. This enhancement represents a crucial effort to ensure future water availability, considering that water supply remains a major issue in the village.

Although the reservoir capacity has been increased, operational issues related to water release (outflow) still pose a major challenge. The Gredek reservoir currently lacks standardised operational guidelines, resulting in water releases being conducted without adequate control. This condition can disrupt the hydrological balance of the reservoir and potentially cause droughts, as evidenced by instances when the reservoir floor became exposed. This issue highlights the importance of evaluating and updating the reservoir operation model to align with the physical conditions of the reconstructed reservoir. Research on reservoir operations to meet water demand has been previously conducted [1]-[6], primarily aimed at developing operational strategies that enhance performance.

The study of reservoir operations is a crucial component of ongoing water resource development. This is understandable as there are always differences in objects and cases oriented towards sustainable benefits. The use of models in analysing reservoir performance systems is a reassessment study of reservoir water availability and existing operational performance. This periodic evaluation may be necessary to assess the system's performance against existing conditions and demands, driven by the ever-changing water usage [7]. Recent studies have further advanced reservoir operation modelling and optimisation methods. For example, storage-based operation schemes for global reservoirs have been optimised to improve inflow–outflow balance and ensure sustainability [8]. Other works have developed risk-averse and multi-objective frameworks to enhance flexibility in the face of extreme events and data uncertainties [9]. Real-time and adaptive operation approaches have also been proposed to manage flood and drought conditions dynamically [10], [11]. Despite these advances, most studies focus on large-scale, data-rich systems, whereas small, community-managed reservoirs such as Gredek remain underexplored. This highlights the need for simple yet effective modelling approaches that can be applied under data-limited conditions.

Generally, the simulation rules for reservoir release state that the reservoir water level must remain above the lower limit of effective storage capacity or be restricted by the outlet hole. Usually, the upper limit of effective storage capacity is bounded by the spillway, so when overflow occurs, the water will spill over the spillway [12]. In cases where water is extracted without using the outlet, a suction pump is typically employed, and withdrawal limits are defined by the Deep Level (DL) flow line installed on the reservoir embankment. In the Gredek reservoir, however, the absence of operational guidelines has led to uncontrolled water release, disrupting the balance of inflows and outflows. These challenges underscore the need for scientific solutions that ensure both water availability and long-term system sustainability.

Although the Gredek reservoir was substantially reconstructed in 2019/2020 to increase its capacity, no studies have yet modelled its operation under post-reconstruction conditions. This represents a significant knowledge gap, as the reservoir's expanded capacity requires updated operational strategies to maintain equilibrium and meet community water needs effectively [13], [14]. Unlike previous studies that rely on complex optimisation techniques such as stochastic programming, artificial neural networks, or genetic algorithms, this study introduces a simplified dual-model framework suitable for data-limited, village-managed reservoirs. The novelty lies in two aspects: (i) It represents the first attempt to optimise the post-reconstruction operation of the Gredek reservoir, and (ii) It demonstrates the effectiveness of combining CF for long-term planning with Divided Average (DA) for short-term operational management. This dual perspective provides both strategic and operational insights, making the approach practical, transparent, and easily replicable in similar contexts.

Similar research has also been conducted by other researchers [13], [15]-[28], emphasising that optimisation should always respect the physical and operational constraints of the reservoir to maintain its integrity and ensure sustainable water supply. This approach enables informed decision-making, balancing human and environmental needs with the inherent physical constraints of the reservoir system. This study specifically focuses on analysing the water balance of the post-reconstruction reservoir, developing an optimisation model for monthly water releases considering the minimum intake limits at Dead Storage (DS) starting from a height of 5 cm (Q_{DS5}), and evaluating the resulting operation patterns. The results of this study are expected to provide concrete solutions to operational problems, maintain the integrity of the reservoir and support sustainable water resource management in Gredek Village.

2. Methodology

2.1 Study Area and Data

The Gredek reservoir is fully owned and managed by the Gredek Village government and its residents. The location and dimensions of the reservoir are shown in Fig. 1. Following its renovation, which was completed in 2020, the residents have anticipated its immediate use to meet domestic clean water demands. The reservoir has a total surface area of approximately 101,120.26 m^2, with the eastern and southern sides measuring 303.92 m and 332.75 m in length, respectively, and an average depth of 4 m. Since the residential area of Gredek Village is located

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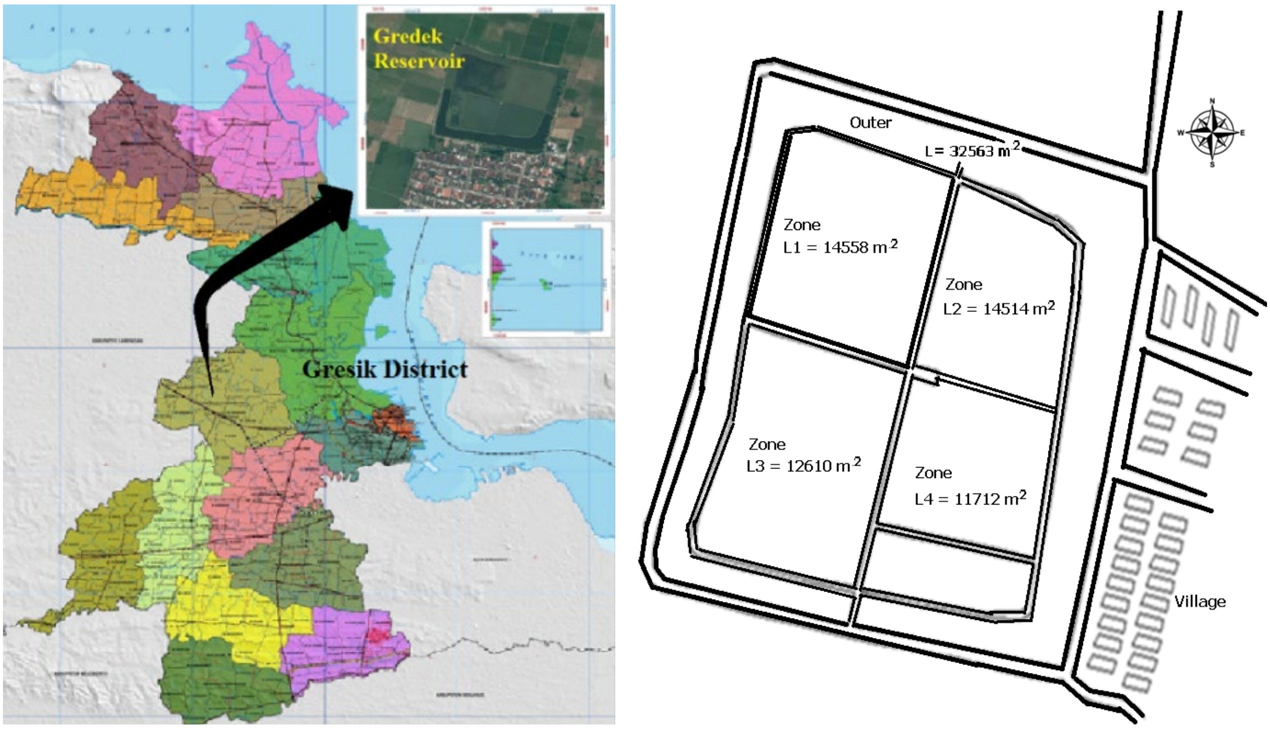
at a higher elevation than the reservoir's water surface, water abstraction must be carried out using a pumping system.



(a) **(b)**

Fig. 1 *(a) Location of Gredek reservoir on the map; and (b) Reservoir layout plan*

2.2 Data Collection Techniques

This study utilised both primary and secondary data. Primary data were obtained from direct field measurements, while secondary data were sourced from libraries, the internet, local government agencies, and individuals involved in reservoir management. Rainfall data 2005-2020 from the Duduksampeyan station were acquired from the Sub-Department of Public Works Water Resources of the Bengawan Solo River Basin Sub-Office. Furthermore, reservoir profile data, historical reservoir operation data, population figures, and land cover information were obtained from the Gredek Village Office. Site surveys and measurements were conducted to supplement missing data and ensure consistency with field conditions. All climatological data, except rainfall, were obtained from the Global Summary of the Day dataset managed by the National Oceanic and Atmospheric Administration (NOAA).

2.3 Data Analysis Techniques

2.3.1 Inflow Analysis

The initial stage involved acquiring rainfall data from the nearest rain gauge station for the period 2005-2020. This data was then used to forecast future rainfall magnitudes up to 2035. Data forecasting was performed using RStudio software to identify trends in rainfall magnitudes. Following this. the next step was to calculate the reservoir inflow originating from direct rainfall into the reservoir, using the equation established in the 2009 Minister of Public Works Regulation [29].

$$V = R \times A \times k \qquad (1)$$

where V is the volume of captured water (m^3/month), R is the rainfall (m/month), A is the area of catchment (m^2), and k is the runoff coefficient (0.3-0.5).

2.3.2 Outflow Analysis

The initial step in calculating reservoir outflow is to determine the evaporation occurring in the reservoir using the Penman equation. Analysing evaporation requires data on temperature, relative humidity, and wind speed. All these data were grouped by monthly averages, and then the monthly evaporation value was determined using the following equations.

$$H = \left(\frac{e}{E}\right).100 \quad (2)$$

where H is the relative humidity (%), e is the vapour pressure at the time of measurement (mb or mmHg), and E is the saturated vapour pressure (mb or mmHg). Subsequently, evaporation is calculated using Eq. (3).

$$E = 0.35(e_a - e_d)\left(1 + \frac{V}{100}\right) \quad (3)$$

where E is the evaporation (mm/day), e_a is the saturated vapour pressure at daily average temperature (mmHg), e_d is the actual vapour pressure (mmHg), and V is the wind speed at 2 m height above ground surface (km/hour). To simplify calculations, a summary of saturated vapour pressure (E) as a function of temperature (°C) [30] is provided in Table 1.

Table 1 *Vapour pressure values*

0°	*p* (mmHg)
-10	1.96
-1	4.22
0	4.58
10	9.21
20	17.55
30	31.86
40	55.4
50	93.6
60	149.6
80	355.4

The subsequent stage within this outflow sub-section involves analysing and estimating the magnitude of seepage occurring in the reservoir. In this analysis, seepage is calculated using the following equation:

$$(I + R) - (O + S_p + E) = S - S_o \quad (4)$$

where I is the inflow, R is rainfall, S_p is seepage, O is outflow through the reservoir gate, E is evaporation, S is current storage, and S_o is initial storage. Note that $S - S_o$ represents the change in storage volume over the period, which implicitly accounts for seepage if the other terms are known precisely. Another approach to estimate seepage is through field investigations to determine the physical properties of the reservoir body. In some situations, seepage from small reservoirs is omitted in the water balance calculation because there is no simple method to measure it [31]. The next phase of outflow analysis involves determining the village water demand. For this purpose, the initial step is to forecast the population of Gredek Village up to 2035 using the mathematical method. This method is suitable for areas with consistently increasing population trends over a short period [32].

$$P_n = P_o + r\,(d_n) \quad (5)$$

where P_n is the total population at the end of the projection period (people), P_o is the total population at the start of the projection (people), r is the average annual population growth rate (%), and d_n is the projection period (year). After obtaining these calculation results, the next step is to compute the total annual water demand for the village population for the years 2021-2035. The per capita water demand is calculated by multiplying the basic daily water requirement per person by the total population of the village. The individual water requirement standard refers to the National Standardisation Agency Specifically, specifically the 2002 standard from the Directorate General of Human Settlements, Ministry of Public Works [33].

The DA model is quite similar to the CF model, as it is also linked to the amount of discharge that must remain at the 5 cm water level (Q_{DS5}) below the Dead Level (DL). The reason for using a 5 cm water level was that it represented the minimum abstraction from the reservoir floor. For example, the DA model calculation was applied to the existing discharge data from 2021 to 2024, as shown in Table 5. It employs a simple mathematical equation that describes the relationship between the variables in the table.

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$$Q_{\text{diff}} = (Q_{\text{in}} - Q_{\text{out}} + Q_{\text{DS5}}) \tag{6}$$

The subsequent step in developing the discharge optimisation model is to formulate linear mathematical equations. The following variables are defined: $Q_{\text{in, m, y}}$ represents the inflow in month m and year y; $Q_{\text{out, m, y}}$ denotes the outflow; $Q_{\text{DS5, m, y}}$ is the discharge at station 5; and $Q_{\text{diff, m, y}}$ is the difference in discharge. To develop the discharge optimisation model using the DA, the first step is to sum the monthly Q_{in} values for a year. The equation is written as:

$$\Sigma Q_{\text{in.y}} = \sum_{m=1}^{12} Q_{\text{in.m,y}} \tag{7}$$

The above equation explains that $\sum Q_{\text{in}}$ represents the total inflow for one year, obtained by summing the monthly Q_{in} values. The next step is to distribute this $\sum Q_{\text{in}}$ evenly across the 12 months of that year, resulting in $Q_{\text{in, ave, y}}$. This equation can be expressed as follows:

$$Q_{in.ave.y} = \frac{\sum_{m=1}^{12}}{12} Q_{in.m,y} \tag{8}$$

From this equation, the average monthly Q_{in} is obtained. To calculate the monthly Q_{diff}, the next step is to subtract Q_{out} and Q_{DS5} from $Q_{\text{in, ave, y}}$ for each month within the same year. The equation for calculating the monthly Q_{diff} is as follows:

$$Q_{\text{diff,m,y}} = Q_{\text{in,ave,y}} - Q_{\text{out,m,y}} - Q_{\text{DS5,m,y}} \tag{9}$$

After obtaining the Q_{diff} results, the next step is to calculate the annual Q_{diff}. This Q_{diff} is then added to the $\sum Q_{\text{in}}$ of the following year using the following equation:

$$\Sigma Q_{\text{in,y+1}} = \Sigma Q_{\text{in,y}} + \Delta Q_{\text{diff,1}} \tag{10}$$

The above equation explains that, at the end of the year, the accumulated value is carried over to the following year ($_{\text{y+1}}$). Thus, it is important to note that the new $Q_{\text{in, y+1}}$ is obtained by adding the accumulated inflow from the previous year. The next step is to evenly distribute the result of $Q_{\text{in, y+1}}$ across the 12 months of that year to obtain the new monthly inflow $Q_{\text{in, ave, y}}$. The same procedure is then performed as before, which $Q_{\text{in, ave, y}}$ subtracted from the existing monthly Q_{out} and Q_{DS5} to obtain the monthly Q_{diff} ($Q_{\text{diff, m, y}}$). If $Q_{\text{in, ave, y}}$ substituted into the $Q_{\text{diff, m, y}}$ equation, the combined equation can be written as follows:

$$Q_{\text{diff, m,y}} = (\frac{1}{12}\sum_{k=1}^{12} Q_{\text{in.k,y}}) - Q_{\text{out,m,y}} - Q_{\text{DS5,m,y}} \tag{11}$$

The use of the index k in the summation within the parentheses is to avoid overlap with the index m, which refers to a specific month for the Q_{diff} calculation. This ensures that $Q_{\text{in, ave, y}}$ is calculated from the annual $\sum Q_{\text{in}}$, while $Q_{\text{out, m, y}}$ and $Q_{\text{DS5, m, y}}$ remain specific to month m.

2.4 Basic Data for Model

The optimal reservoir operation model was determined through simulation. The data used for this simulation were derived from the total water availability, including inflow (Q_{in}). outflow (Q_{out}), and the reservoir's differential discharge (Q_{diff}) for each year. Fig. 2 illustrates the Dead Storage Discharge (Q_{DS}) and can be calculated using Eq. (6). The simulation was performed using a trial-and-error approach for predetermined Q_{DS} values, starting with a dead storage level of 5 cm (Q_{DS5}). The Q_{DS} calculation is based on the water volume from the reservoir bottom area up to the DL flow line. From Fig. 2, the equation used to determine Q_{DS5} can be obtained as follows:

$$Q_{\text{DS5}} = \frac{(B1 + B2)}{2} \times h \tag{12}$$

where Q_{DS5} is the volume of Dead Storage discharge (m^3). *B1* is the low area (m^2), *B2* is the upper area (at *DL*) (m^2), and h is the height (m). This equation explains the measurement of the area from the bottom of the reservoir up to the *DL* at a height of 5 cm. To find Q_{DS5}, the initial step is to determine the upper surface area of the Dead Storage (DS). Subsequently, the following assumptions are made: the reservoir bottom area is 14.56 m², the uppermost storage surface area is 16.54 m², *H* is the total reservoir depth is 4 m, and *DL* surface height, *h* is 5 cm.

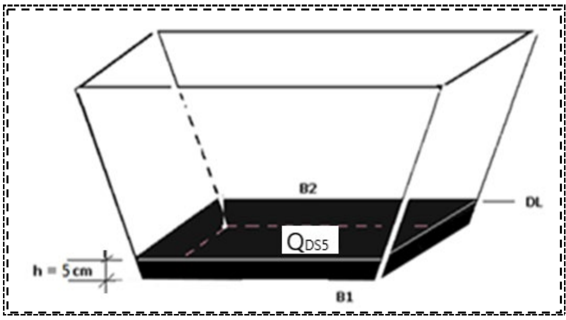

Fig. 2 *Q_{DS5} position in the reservoir*

Table 2 *Q_{DS5} at each reservoir zone*

Zone	Upper (m²)	Lower (m²)	ΔA (m²)	ΔH (m)	Volume ΔA/ΔH (m²)	h (m)	Ah (m²)	Q_{DS5} (m³)
L1	16542	14556	1986	4	496.5	0.05	14580.83	729.04
L2	14879	14514	365	4	91.25	0.05	14518.56	725.93
L3	14943	12610	2333	4	583.25	0.05	12639.16	631.96
L4	11712	10674	1038	4	259.5	0.05	10686.98	534.35
Outer	32563	28676	3887	4	971.75	0.05	28724.59	1436.23
							Total	4058

The value of h = 5 cm represents the water level in the reservoir, which serves as the threshold for water abstraction to meet various needs. The previous calculation yielded a Q_{DS5} value of 4,058 m³. This value serves as the basis for developing the optimisation model simulation. In the optimisation model planning, the CF model uses monthly data for Q_{in}, Q_{out}, and Q_{DS5}. These monthly results are then continuously accumulated until the target year. In contrast, the DA model is performed by summing the monthly Q_{in} data over a year to obtain an annual ΔQ_{in}. This ΔQ_{in} is then redistributed as a new monthly Q_{in} after being reduced by the corresponding monthly Q_{out} and Q_{DS5}. The result is a monthly Q_{diff}, which, when totalled over a year, becomes ΔQ_{diff}. Once ΔQ_{diff} is obtained, it is accumulated with the ΔQ_{in} of the following year. This process is repeated until the target year is reached. The use of *DS* data in this model remains consistent, namely Q_{DS5}. All relevant data, such as inflow, outflow, and Q_{DS5} were obtained from the initial calculations, allowing the model development and processing to proceed.

To achieve optimal results, the application of the CF and DA models requires simulating the discharge data from the initial calculations. The simulation results are then analysed and described based on the outcomes and conditions obtained. The model that yields the most optimal remaining discharge was selected as the reference for future reservoir operations. The suitability of the reservoir renovation objective, namely increasing its capacity from 100 m³ to approximately 350 m³, needs to be verified in terms of fulfilling the village's water needs and maintaining reservoir stability.

3. Result and Discussion

The prediction of monthly reservoir discharge for the period 2021-2035 is based on the average monthly rainfall data obtained from forecasting results. In this analysis, the calculations were performed using Eq. (1). Generally, the volume of rainfall inflow to the reservoir is defined as the rainfall value (mm) multiplied by the reservoir's surface area (m²). The results of the predicted discharge calculation for the Gredek reservoir from 2021 to 2035 are presented in Table 3.

Based on Table 3, the highest monthly inflow occurred in January 2021 at 27.088 m³. However, when considering the total annual inflow, the year 2021 recorded the highest total of 143.8 m³ for the 2021-2035 period. Conversely, the lowest monthly inflow was observed in September 2029 at 1,936 m³. Several other months also showed very low inflows around this value, including September 2028 (1.940 m³), September 2030 (1.933 m³), September 2031 (1.929 m³), September 2032 (1.928 m³), September 2033 (1.927 m³), September 2034 (1.926 m³), and September 2035 (1.926 m³). When examining the lowest total annual inflow, the year 2035 recorded the

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lowest value at 135.014 m^3 within the 2021-2035 period. The projected annual water demand for the population is presented in Table 4. Columns 2 and 3 in Table 4 outline the predicted population for the years 2021-2035 and the corresponding daily water requirements, while columns 4, 5, and 6 provide an explanation of water needs on a daily, monthly, and annual basis. After determining all projected reservoir outflow components, including evaporation, seepage, and water demand for the population, the subsequent step involved developing the Gredek reservoir operation model.

Table 3 *Predicted inflow of the Gredek reservoir (2021-2035)*

	Inflow (m^3)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2021	27.088	23.088	21.000	16.495	8.403	7.166	2.867	2.581	2.040	3.817	9.260	19.985	143.790
2022	26.636	22.712	20.665	16.237	8.275	7.059	2.825	2.544	2.011	3.764	9.137	19.724	141.589
2023	26.296	22.428	20.412	16.043	8.179	6.978	2.793	2.516	1.990	3.725	9.043	19.527	139.930
2024	26.039	22.214	20.222	15.897	8.106	6.917	2.769	2.495	1.973	3.695	8.973	19.378	138.678
2025	25.845	22.052	20.078	15.786	8.051	6.871	2.751	2.479	1.961	3.673	8.920	19.266	137.733
2026	25.699	21.931	19.970	15.703	8.009	6.837	2.738	2.467	1.952	3.656	8.880	19.182	137.024
2027	25.589	21.839	19.888	15.640	7.978	6.811	2.728	2.458	1.945	3.643	8.850	19.118	136.487
2028	25.506	21.770	19.826	15.593	7.954	6.791	2.720	2.452	1.940	3.634	8.827	19.070	136.083
2029	25.443	21.717	19.780	15.557	7.936	6.776	2.714	2.447	1.936	3.627	8.810	19.033	135.776
2030	25.396	21.678	19.745	15.530	7.923	6.765	2.710	2.443	1.933	3.621	8.797	19.006	135.547
2031	25.360	21.648	19.718	15.510	7.913	6.757	2.706	2.440	1.931	3.617	8.787	18.986	135.373
2032	25.334	21.626	19.698	15.495	7.905	6.750	2.704	2.438	1.929	3.614	8.780	18.970	135.243
2033	25.313	21.609	19.683	15.483	7.899	6.745	2.702	2.436	1.928	3.612	8.774	18.958	135.142
2034	25.298	21.596	19.672	15.474	7.895	6.742	2.701	2.435	1.927	3.610	8.770	18.949	135.069
2035	25.287	21.586	19.663	15.468	7.892	6.739	2.700	2.434	1.926	3.609	8.767	18.943	135.014

Table 4 *Projected water demand for Gredek Village (2021-2035)*

Years	Population (people) (a)	Standard Daily Water Usage (litre/people/day) (b)	Water Demand (day/litre) (c) = (a) × (b)	Annual Water Demand (m^3/month) (d) = (c) × 30	Annual Water Demand per Year(m^3/year) (e) = (d) × 12
2021	2582	60	154920	4647.6	55771.2
2022	2584	60	155040	4651.2	55814.4
2023	2586	60	155160	4654.8	55857.6
2024	2588	60	155280	4658..4	55900.8
2025	2590	60	155400	46620	55944
2026	2592	60	155520	4665.6	55987.2
2027	2594	60	155640	4669.2	56030.4
2028	2596	60	155760	4672.8	56073.6
2029	2598	60	155880	4676.4	56116.8
2030	2600	60	156000	46800	56160
2031	2602	60	156120	4683.6	56203.2
2032	2604	60	156240	4687.2	56246.4
2033	2606	60	156360	4690.8	56289.6
2034	2608	60	156480	4694.4	56332.8
2035	2610	60	156600	46980	56376

3.1 Continuous Flow (CF) Model Design

The water discharge in the Gredek reservoir serves two primary objectives. First, to meet the water demand of the population, and second, to maintain reservoir equilibrium. To achieve these two objectives, sufficient rainfall is essential as the source of inflow. For the first objective, the required variable is the monthly Q_{out}. For the second objective, Q_{DS5} (the discharge for equilibrium at a 5 cm height), derived from Q_{in} is necessary. Both objectives were analysed and optimised to obtain the best monthly remaining discharge (Q_{diff}).

The solution sought in this case was how to optimally determine the water demand for the population (Q_{out}) and the water discharge required to maintain reservoir equilibrium (Q_{DS}). This optimisation problem for the Gredek reservoir's discharge was analysed on a monthly basis. For instance, in January 2021, the discharge was categorised by only two variables, known as total Q_{in}. total Q_{out}. and discharge for equilibrium. This allows the data to be analysed and formulated into a linear equation. For each month, m (where m represents the month number from 1 to 12), an equation can be written to relate the water discharge at the end of that month ($Q_{\text{diff, m}}$). The basic equation can be expressed as:

$$Q_{\text{diff,m}} = \left(Q_{\text{in,m}}\right) - \left(Q_{\text{out,m}} + Q_{\text{DS5,m}}\right) \tag{13}$$

Using the 2021 data presented in Table 5 and a Q_{DS} height of 5 cm (Q_{DS5}), the calculation results for $Q_{\text{diff, m}}$ for each month in 2021 were obtained using Eq. (13).

Table 5 *Qdiff for 2021*

Year	Q(m^3)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2021	Qin	27088	23088	21000	16495	8403	7166	2867	2581	2040	3817	9260	19985
	Qout	7013	7013	7013	7013	7013	7013	7013	7013	7013	7013	7013	7013
	QDS_5	4058	4058	4058	4058	4058	4058	4058	4058	4058	4058	4058	4058
	Q_{diff}	16017	28034	37963	43387	40719	36814	28610	20120	11089	3835	2024	10938

Table 5 shows that the Q_{diff} (remaining discharge) is generally calculated by subtracting Q_{out} and Q_{DS5} (discharge for equilibrium at a 5 cm height) from Q_{in}. When using the CF model to calculate Q_{diff} in subsequent years, the Q_{diff} from the initial month (January) was added to the Q_{in} of the following month (February), and the Q_{diff} from February was added to the Q_{in} for March, and so on. Thus, the CF equation can be written as:

$$Q_{\text{diff,m}} = Q_{\text{diff,m-1}} + \left(Q_{\text{in,m}} - Q_{\text{out,m}} + Q_{\text{DS5,m}}\right) \tag{14}$$

For the initial calculation, an initial value of $Q_{\text{diff, m-1}}$ is required for January (m = 1). Since no prior information is available, $Q_{\text{diff, m-1}}$ was assumed to be zero ($Q_{\text{diff, 0}} = 0$). From this equation, the $Q_{\text{diff, m}}$ value for each month was obtained. The calculation of reservoir water discharge below the Dead Level (DL) yielded a Q_{DS5} value of 4058 m^3. Based on the CF model, the resulting Q_{diff} values are presented in Fig. 3. A general observation is the highly variable nature of the Q_{diff} values, which range from 66.65 m^3 to 767 m^3. The cumulative pattern for each year's Q_{diff} begins with a specific value in January and continues to increase significantly until June, then decreases slightly from July to November.

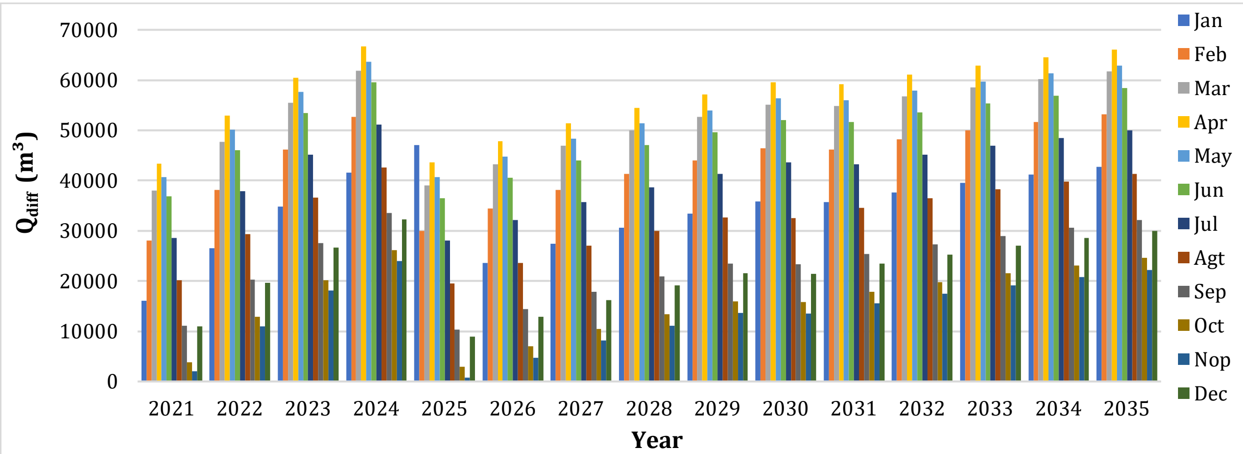

Fig. 3 *Qdiff with CF model*

Fig. 5 clearly shows the dynamics of water discharge accumulation that are very positive and progressive in the system over time. This figure demonstrates that the stored water volume is represented by the Q_{diff} value at the end of each month (which is the total water discharge that has accumulated or been stored in the system until the end of that month), and the monthly increase in Q_{diff} indicating that each month the system receives more water than is released or consumed by Q_{DS}, leading to continuous growth in water storage. The positive system performance is further evidenced by the fact that Q_{diff} continues to increase to very large values year by year, demonstrating the system's effectiveness in collecting and maintaining substantial water flow over time, as well as its success in water resource management, where inflow consistently exceeds outflow and other demands.

The implications for the CF discharge optimization model are as follows: (i) The model appears to successfully optimize water accumulation to a very high level, (ii) The optimization objective successfully maximizes storage discharge, ensuring that the system maintains abundant water reserves, (iii) Significant surges in Q_{diff} in certain years (2024, 2025, 2034, and 2035) could indicate major changes in input parameters, such as a drastic increase in Q_{in}, significant constancy in Q_{out}, or policy changes related to a decrease in Q_{DS} values that allow faster accumulation, and (iv) This model could represent either a prolonged wet year scenario or an aggressive strategy for building water reserves.

3.2 Divided Average (DA) Model Design

The Divided Average (DA) model is formulated based on Eq. (6) to Eq. (11), which are also derived from the remaining discharge at a water level of 5 cm (Q_{DS5}) below the Dead Level (DL). The same reason for using a water level of 5 cm is that this measurement is considered the minimum from the reservoir floor. For example, the DA model calculation is applied to the existing discharge (Q) data from 2021 to 2024 as in Table 5. Furthermore, by applying Eq. (6) to Eq. (11) to the discharge data in Table 3, the calculation results using these equations are shown in Fig. 6.

Fig. 6 illustrates that the monthly Q_{diff} results, calculated using the DA model through accumulation and averaging, appear stable throughout 2021-2035. As shown, the Q_{diff} value for each month within a given year is consistent, but this value gradually increases annually due to the accumulation of the previous year's Q_{diff} into the following year's Q_{in} into the following years Q_{in}, which subsequently influences the average Q_{in} for that year. Preliminary analysis and calculation yielded Q_{DS10} = 8127 m^3 and Q_{out} values rangin between 7013 m^3 and 7071 m^3 per month during 2021-2035. These results are considered satisfactory and acceptable.

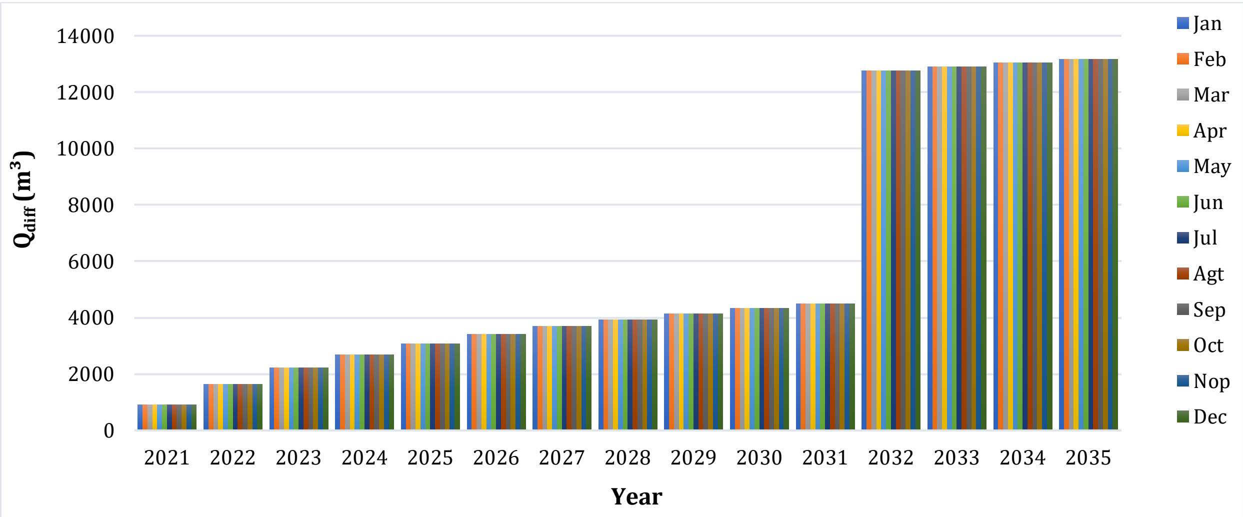

Fig. 6 *Q_{diff} result using DA model*

The discharge optimisation results also present monthly data for the variables (Q_{in}, $Q_{in/12}$, Q_{out}, Q_{DS5}, Q_{diff}) from 2021 to 2035. The highest Q_{in} during this period occurs at the beginning of each year, for example, 27.088 m^3 in January 2021. Conversely, the lowest Q_{in} values recorded were 1.926 m^3 in September 2035. In terms of Q_{diff}, the highest value was 13.160 m^3 in 2035, while the lowest was 912 m^3 in 2021. The Q_{out} values range from 7,013 to 7,071 m^3 during 2021-2035, and Q_{DS5} remains constant at 4,058 m^3. The DA model can also be optimised by adjusting Q_{DS} and Q_{out} according to the Q_{in} obtained each year in the future. To find the desired Q_{DS}, one only needs to know the original equation.

$$Q_{diff.m,y} = \left(\frac{1}{12}\sum_{k=1}^{12} Q_{in.k,y}\right) - Q_{out,m,y} - Q_{DS5,m\ y} \quad (15)$$

Thus, to find the desired $Q_{DS,\ m,\ y}$, the above equation only needs to be rearranged as:

$$Q_{DS,m,y} = \left(\frac{1}{12}\sum_{k=1}^{12} Q_{in.k,y}\right) - Q_{out,m,y} - Q_{diff,m,y} \quad (16)$$

where is the $Q_{DS,\ m,\ y}$ = desired discharge to be left in DS (m^3), $Q_{in,\ ave,\ y}$ is the average monthly discharge throughout the year derived from $Q_{in,\ y}$ (m^3), $Q_{out,\ m,\ y}$ is the monthly outflow discharge, $Q_{diff,\ m,\ y}$ is the remaining monthly discharge derived from $Q_{in,\ ave,\ y} - Q_{out,\ m,\ y}$ (m^3). The next activity is to apply all the above equations to the discharge data.

3.3 Feasibility and Reliability of the CF and DA Model

When analysing both models using the Q_{diff} benchmark, it is essential to understand that Q_{diff} represents the flow difference (Q_{in}, Q_{out}, Q_{DS5}). When discussing the feasibility of use, the preferred model is the one that provides the most relevant information for a specific purpose. To determine which model produces a higher Q_{diff}, it is necessary to compare the Q_{diff} values obtained from both models. In the CF model, Q_{diff} reached up to 66,649 m^3. The highest Q_{diff} values, especially in March and April, exceeded 60,000 m^3. Meanwhile, in the DA model, the highest Q_{diff} value was approximately 46,242 m^3. Preliminary findings indicated that the CF model consistently produces higher Q_{diff} values than the DA model, suggesting that the CF model projects a greater flow surplus.

The determination of which model is more suitable for application largely depends on the intended scenario. If the model is used for large capacity planning or long-term flood risk assessment, the CF model is more suitable. This is because the model shows very high Q_{diff} values, reflecting a significant surplus in discharge. When planning major infrastructure, such as dams or main waterways, or evaluating potential flood risks due to excess discharge, the CF model provides more relevant data. These higher values emphasise the need for greater capacity design and stronger risk mitigation strategies. Moreover, the seasonal peak patterns observed in March and April highlight critical periods of surplus discharge that require close monitoring or can be strategically utilized. In addition, the CF Model has benefits such as: (i) Allowing the tracking of how water volume in the reservoir system changes over time, (ii) Assisting in predicting future needs or capacities based on inflow and outflow trends, (iii) Being used to simulate various scenarios, for example, the impact of drought or increased water demand on water volume, and (iv) Providing critical insights for decision-making related to water resources management, such as when to release water from the reservoir or when to implement water use restrictions.

Meanwhile, the DA model has a crucial function in discharge optimisation, namely: (i) Calculating the monthly Qdiff, based on the annual average inflow, rather than actual inflow. This is very useful for smoothing the impact of extreme monthly Q_{in} fluctuations, enabling more stable operational planning that is not overly affected by months with very high or very low inflow. Thus, the model aims to achieve a more stable and sustainable flow optimisation throughout the year, assuming that the total annual water supply will be evenly distributed, (ii) This equation is highly relevant during the design and long-term planning stages of water infrastructure, such as reservoir capacity and irrigation networks. By utilising the annual average inflow, managers can design a system capable of handling average or normal conditions throughout the year, not just seasonal peaks or troughs. This helps in determining an optimal flow that can be maintained sustainably, (iii) This model explicitly reduces $Q_{\text{DS, m, y}}$, treating it as a deduction from the net water balance. If Q_{DS} represents the basic maintenance quantity for the reservoir, this formula calculates Q_{diff} after meeting those needs. This aspect is crucial for flow optimisation models, because there is often an obligation to release a certain amount of water regardless of inflow conditions, or there is a basic requirement that must be met, and (iv) Unlike the cumulative formula $Q_{\text{diff, m}} = Q_{\text{diff, m-1}} + \ldots$, the DA model calculates monthly Q_{diff} as discrete data points. This Q_{diff} can be part of a larger model where it is accumulated, or it can be used as a monthly performance measure that is independent of the previous month.

In the optimisation model, there may be two types of Q_{diff}, one that reflects the cumulative status (stock), and another that reflects the monthly surplus/deficit based on targets or average assumptions. The dynamics of Q_{diff} in the DA model can be interpreted in several scenarios as follows:

- Q_{diff} as an annual optimisation target or result distributed evenly, which is the most likely interpretation. In the discharge optimisation model, Q_{diff} represents the residual flow or the final target flow optimised for one year, which is then evenly distributed across each month. An increase in Q_{diff}, from year to year (for example, from 2568 in 2021 to 46242 in 2035), indicates that the maintainable flow or positive balance remaining in the system progressively increases.
- Q_{diff}, as an accumulation of a continuously improving system. If Q_{diff}, represents water stock (as in the cumulative equation), then the data shows that the system as a whole continuously accumulates more water from year to year. This accumulation is expressed as a constant average value (or target) for each month within a year. This can occur if the annual average Q_{in} increases, the annual average Q_{out} decreases, or Q_{DS}, as the requirement significantly decreases from year to year.

If the model is intended for daily/monthly operations, flow allocation, or comparison of flow components, then the DA Model is more suitable. The reason is that although its Q_{diff}, value is lower, this model provides more detailed and integrated information. In addition to Q_{diff}, it also allows you to view the main flow components (Q_{in}, Q_{out}, Q_{DS5}, $Q_{\text{in}}/12$) simultaneously for each month and year. This is very useful if you need to understand: (i) How Q_{diff}, is formed, which can be seen from the contribution of each Q_{in}, Q_{out}, and $Q_{\text{DS,5}}$ to Q_{diff}, (ii) In operational management, where a smaller Q_{diff} value may be more relevant for everyday or monthly operational decisions, for example, how much water can be allocated for irrigation without depleting reserves, and (iii) In water balance analysis, this model is more suitable for comprehensive water balance analysis. In terms of patterns, it also shows seasonal patterns that are important for scheduling.

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4. Conclusions

Based on the analysis of the Continuous Flow (CF) and Divided Average (DA) models with simulations using a 5 cm level (Q_{DS5}) in Dead Storage, the CF model produced Q_{diff} values ranging from 767 m^3 to 66,649 m^3 at the end of each month. Meanwhile, the DA model produced Q_{diff} values ranging from 2,568 m^3 to 46,242 m^3 throughout the 2021-2035 period. The general conclusion regarding the feasibility of both models asserts that neither model is absolutely superior. The choice of model is highly dependent on the specific objective and the scale of the planning being implemented. If the primary focus is on the large discharge surplus and its implications for extreme capacity planning and flood risk mitigation, then the CF model is the appropriate choice. This model provides an overview of the maximum water potential and the accompanying challenges. However, if the requirement is to obtain more detailed information on the discharge components that constitute Q_{diff}, or if operations are conducted at a more moderate Q_{diff} scale, the DA Model becomes more relevant for day-to-day operational management.

On the other hand, to achieve optimal reservoir management balance, the most feasible approach is a synergistic combination of both models. The CF Model is ideal for long-term strategic planning. It is used to understand the magnitude of the extreme potential surplus and to design the capacity of major infrastructure, like the reservoir itself, spillways, and long-term flood mitigation strategies. This model offers the "big picture" perspective regarding surplus challenges or opportunities. The DA Model is crucial for daily or monthly reservoir operational management, as it provides a more detailed view of the water balance components (Q_{in}, Q_{out}, Q_{DS}) that form Q_{diff}. This detail enables reservoir operators to make more precise decisions regarding water release, irrigation allocation, or gate adjustments based on projected inflow and outflow, thereby allowing the surplus/deficit to be measured more accurately on an operational scale.

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Conflict of Interest

The author declares that they have no financial or non-financial conflicts of interest relevant to the content or results of this research.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design:*** *Eddy Priyanto, Siti Nazahiyah;* ***Data collection:*** *Eddy Priyanto;* ***Analysis and interpretation of results:*** *Eddy Priyanto, Siti Nazahiyah;* ***Draft manuscript preparation:*** *Eddy Priyanto, Siti Nazahiyah. All authors reviewed the results and approved the final version of the manuscript.*

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